ELECTRICAL WIRING:

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Electrical Terms

We are going to be talking a lot about volts, amperes and watts, so let's get a thorough understanding of what these terms mean.

Voltage. Voltage is a measure of the pressure under which electricity flows. The lower the pressure the slower the flow, and any voltage (V) under 50 V is regarded as low. Car batteries operate under a pressure of 12 V, truck batteries sometimes at 24 V, and both can give a mild shock. Higher voltages, such as the common line load of 120 V, can give a nasty shock, particularly if the skin surface is wet, and contact with 240 V lines, used for heavy appliances, is to be avoided.

No home wind energy system will ever need to use voltages higher than 120 V (240 V in the UK), which is just as well as contact with such high voltages often causes fatal shocks — what a way to begin a section on home energy! In truth, there is no danger of such an occurrence provided there is no human contact with any live wire — certainly not with anything over 50 volts.

Amperage. Whereas voltage is the pressure, amperes (or amps) indicate the flow rate of that electricity. Amperes can range from a fraction of an amp to the several hundred amps required to start a car's engine. The greater the flow of amps through a wire the wider its diameter should be — much the same as water flowing through a pipe. The cause of most electrical house fires is that an excess of current (amperes) is drawn through a wire too small to carry the load. The excess is frequently the result of multi-socket adaptors, for example two 25 amp heaters plugged into one 25 amp socket. The result is that the wire overheats and may cause fire.

It is to prevent this type of occurrence that fuses are used, for when an excess of current is drawn through a fuse, it will simply melt. Replacing a blown fuse with an over-rated one defeats the purpose and causes house fires, too. The golden rule: *Never draw more current through a wire or cable than it is rated for.*

Wattage. Watts are a measure of the amount of power used by an electrical appliance. Multiply the amps at which the appliance operates by the voltage and you have its wattage. So:

$$\text{Watts} = \text{Amps} \times \text{volts}$$

from which follows:

$$\text{Amps} = \frac{\text{watts}}{\text{volts}}$$

and

$$\text{Volts} = \frac{\text{Watts}}{\text{amps}}$$

Hence a 12 V car light bulb which draws two amps is a 24 watt bulb.

But take another 24 watt bulb, operating at a voltage of 120 and it will only draw 0.2 amps. At 0.2 amps a much lighter wire may be used to carry the same 24 watts of power under the high pressure of 120 volts as opposed to 12 volts. Running four 100-watt light bulbs at 120 volts would require only 3.3 amps, whereas the same wattage at 12 volts would draw a current of 33 amps, requiring a heavy wire.

If a 100-watt bulb is left on for one hour it will use 100 watt-hours, and if it is left on for 10 hours it will use one kilowatt-hour (1,000 watt-hours equals one kilowatt-hour). Batteries are usually rated in amp-hours. Hence a 100 amp-hour battery will give one amp for 100 hours, or 100 amps for one hour. The amp-hour rating by itself is not very informative unless the battery voltage is known. In other words a 100 amp-hour battery at *6 volts* will give only 600 watt-hours, whereas a bank of 100 amp-hour batteries rated at *120 volts* will give 12,000 watt-hours or 12 kilowatt-hours (kwh). A kwh is the standard electrical unit of measure.

Resistance. There is one other aspect of electricity which wind power workers must understand, and that is Ohm's Law. The ohm is a measure of any material's resistance to the flow of electricity. Materials with very high resistance, such as plastic, are used as insulation. On the other hand metals such as copper or aluminum have very low resistance to the flow of electricity and are used as electric conductors.

At low voltages, such as 12 or 36, a loss of power can easily occur where a wind generator is sited far from the house. Thick copper cable suitable for conducting 12 volt current is expensive, and very expensive if one has to buy more than 100 or 200 feet of it. But what is possibly worse than the cost is the loss of power due to resistance in the thick wire.

The resistance loss of copper and aluminum wire is shown in the accompanying table.

All electric circuits have two wires, one positive and the other negative. The voltage drop in a wire is equal to amps times the resistance of the wire: Voltage drop = Amps × Resistance.

Wire Gauge (A.W.G.)*	Resistance in ohms per 100 ft. (two wire) Copper	Aluminum
000	0.0124	0.0202
00	0.0156	0.0256
0	0.0196	0.0322
2	0.0312	0.0512
4	0.0498	0.0816
6	0.079	0.1296
8	0.1256	0.206
10	0.1998	0.328
12	0.3176	0.522

* American Wire Gauge.

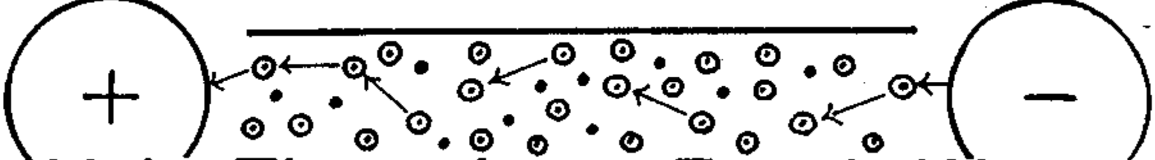
A drop in the voltage (due to resistance) will have a damaging effect on most electrical equipment. The power loss in watts in a wire is equal to amps squared times resistance: Power loss (watts) = $\text{Amps}^2 \times \text{Resistance}$.

And if that is as clear as mud to you, I am not surprised. It was the same to me for a long time. However, the following example may help clarify the matter:

Power produced by a wind generator is 600 watts, and 200 feet of No. 4 (AWG) copper wire is used to carry power to the battery bank. Wire resistance (see above), equals 0.1 ohm ($0.0498 \times 2 = 0.1$). The choice of generator voltages is 12, 24, 32, 120 or 240.

Power Generated	Generator Voltage	Generator Amps Output	Line Voltage Drop	Voltage at load	Power Loss in wire	Power at load
600 Watts	12 Volts	50 Amps	5 Volts	7 Volts	250 Watts	350 Watts
600	24	25	2.5	21.5	62.5	537.5
600	32	18.75	1.87	30.12	35.15	564.85
600	120	5	0.5	119.5	2.5	597.5
600	240	2.5	0.25	239.75	0.62	599.37

In this particular case it can be seen that doubling the generator voltage cuts to a quarter the power loss. There will always be some power loss in an electric line, but the object of understanding Ohm's Law is that the voltage and wire gauge may be chosen so as to minimize losses.



Volts Times Amps Equals Watts

Unfolding the mysteries of electricity

A great deal of our learning depends upon being able to observe and touch. In the early years of our life we do not get thoroughly acquainted with electricity the way we do with material objects because electricity cannot be inspected and dissected. In fact, for most of us it remains a total mystery. It actually seems quite magical or supernatural when it is demonstrated how it seems to be able to pass through a solid object such as lead or copper.

If we are living with our own Solar Electric system we need to at least have a basic understanding of what the difference is between volts, amps and watts.

Yes, magical it is! And the marvelous wonders that can be performed with it just go on ad infinitum. But don't let any of this mystical stuff deter you from getting some kind of a working grasp of it. We are not going to attempt to unfold the mysteries of the universe in this chapter but just enable you to be able to deal with the basic principles associated with a Solar Electric system.

Sunshine into Electricity

If the sun shines on your Solar Panel and the Panel is properly connected to the Battery you should have a current flowing between the Panel and the Battery. This current is measured in amps. When the current is flowing between the charging source and the battery to increase the voltage of the battery, we refer to it as a charging current.

Electrons are an integral part of atoms and molecules. Each atom must always have the same number of electrons near it. Not all atoms and molecules are happy about letting go of one electron in exchange for another, only those atoms and molecules known as electric conductors will readily do so. A conductor is a material within which there are "free" electrons. These electrons will move when a force is exerted upon them. The movement of these free electrons in a conductor (eg copper wire) creates an electric current. Some materials are better conductors than others.

If a free electron from a source of energy is forced into an atom at one end of a conductor, it upsets the balance between electrons and protons of that atom. This forces another free electron from that atom to shift to an adjacent atom, thus upsetting its balance. This shifting or drifting of free electrons towards the other end of the conductor is called electric current flow.

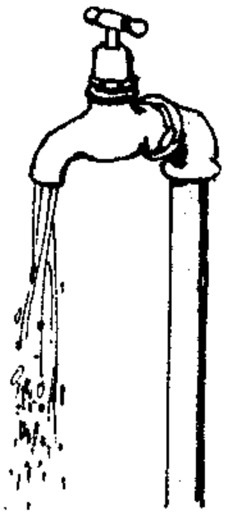
A Solar Electric Panel (Photo Voltaic Panel) will exert a force upon these free electrons in an electric conductor, but only if light falls upon it and the electric circuit is completed. You could, for example connect a piece of copper wire directly between the positive and negative terminals on the Solar Panel.

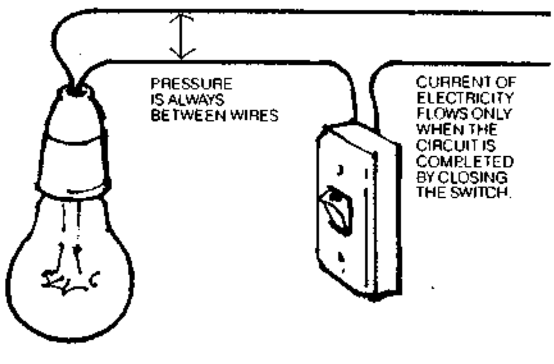
As a result of the force exerted upon them each electron just jumps from the outer electron shell of one atom to the next, causing that atom to shed an electron which is then passed on to the next atom and so on. But the other end of the conductor must also be connected to the energy source that is causing the electrons to flow.

The end of the conductor passes its free electron back to the Solar Panel to fill the gap by the first electron which started the process. To put this electric current to some use, you could cut the wire at some point and connect an appliance or light bulb to the cut ends. The electric current would then pass through the appliance or light bulb as it is pushed around the circuit by the Solar Panel.

Comparing electricity to water

To help your understanding of these fundamentals it makes it easier if we compare the principles of electric current to those of flowing water. If you pump water into a pipe and place a secure plug in the other end of the pipe, the water will cease to flow. Regardless of the amount of pressure you build up, the water will not flow.





However, if we construct a unit with a water pump forcing a current of water through a closed system of pipes that connects back to the inlet of the pump, we have made a path or circuit for the flow of water. We could now install and run an hydraulic motor somewhere in this circuit in the same way as we used the light bulb in the electrical circuit.

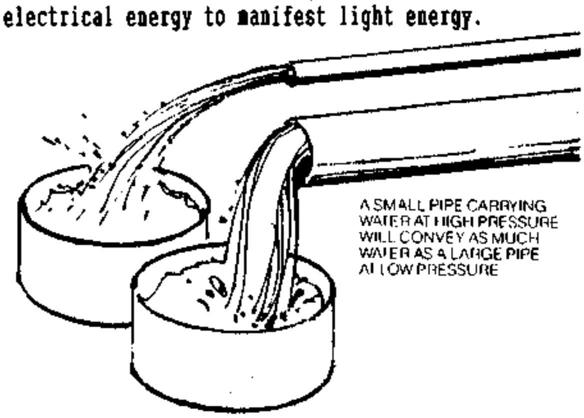
A Solar Panel or Electric Generator is like a pump. It creates pressure (voltage) which makes electrons move or flow in the wire. If a return path is not available to make a complete circuit (such as when a switch is off - ie not making contact) the flow is stopped. Regardless of the amount of pressure (voltage) generated, the electrons cannot flow.

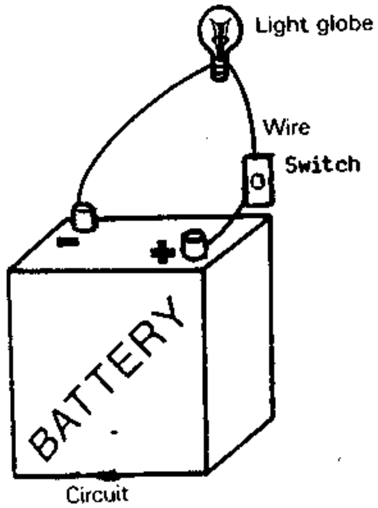
As you may have gathered by now, voltage is the term used for electrical pressure and may be compared with pressure under which water flows through a pipe. Current is the term used for the rate of flow of electricity in a conductor and corresponds to the rate of flow of water in a pipe.

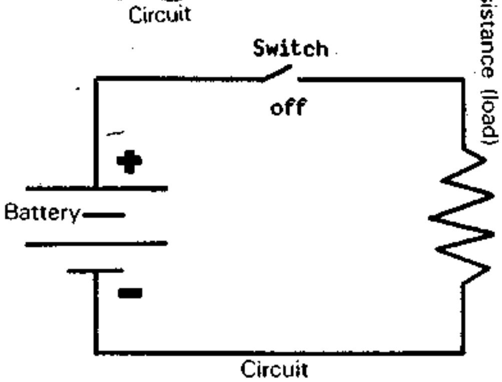
Battery Storage

When a battery is connected into circuit with a Solar Panel it does not actually store the electricity (moving electrons) produced by the Solar Panel but undergoes a chemical change as a result of the electric current passing through it. This chemical change when the battery is connected to an energy source such as a Solar Panel is referred to as charging. This process can be reversed by connecting the same battery to an appliance or light. When the chemically stored energy in a battery is changed into an electric current to power an appliance or a light, this process is referred to as discharging.

At night when the Solar Panel is not receiving any sunlight to cause electron flow then the battery must be able to take over this role when you want to use some electricity. So if you turn a light on the battery starts discharging and in so doing pushes the electrons around the circuit and through the light bulb which then uses the electrical energy to manifest light energy.







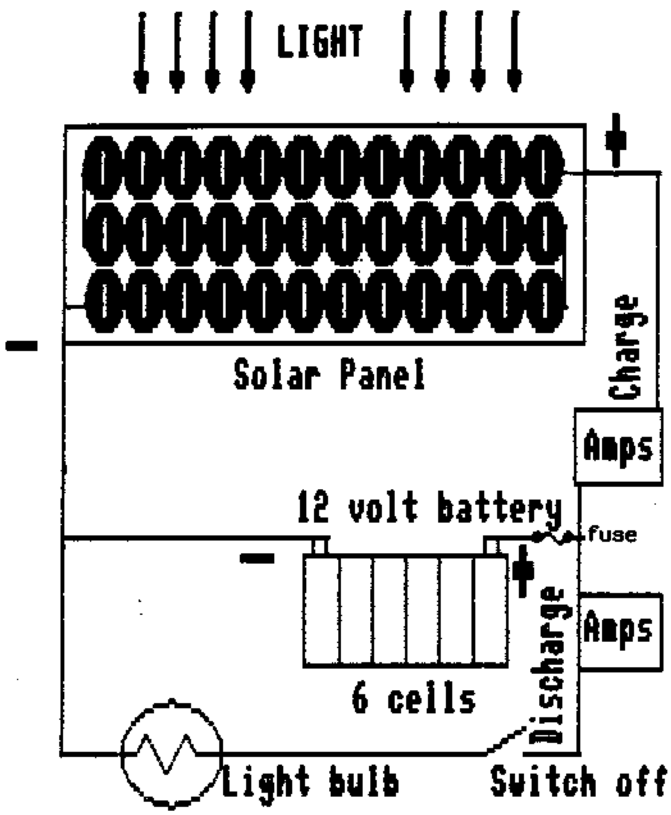
In the diagram you can see that when the light switch is turned off, the circuit is broken and hence the electrons cannot flow.

Voltage is pressure

A 12 volt Solar Panel will actually produce a voltage higher than 15 volts in order to charge a 12 volt battery. If the voltage of the Solar Panel was not greater than the voltage of the battery, the current would not flow and the battery would not charge. We need to have a difference in electrical pressure to induce a current to flow and the current will flow from the higher pressure to the lower pressure.

If you imagine a water tank on a hill with a water pipe coming out of it you may also visualize that the further down the hill you go with the hose, the more water pressure you will get. If you turned on a tap, without the use of pumps or any other way of artificially increasing the pressure, you will not get any water out of it if the tap is at the same level as the water in the tank. The further down the hill the tap is located the faster the water will flow out of it. In the same way you need a voltage higher than the battery voltage in order to charge a battery (so that the current can flow into it). The main difference between water and electricity in this analogy is that electricity flows just as easily uphill as downhill.

The average 12 volt Solar Panel has between 32 and 36 cells, each of which produces about 0.5 volts under direct sunlight. The number of cells connected in series determines the combined voltage potential of the cells and of the panel as a whole.



The size of the individual cells that make up the Solar Panel determines the amount of current flow that the panel can produce. The current would flow from the Solar Panel to the 12 volt battery and would flow at a rate that would be determined by the combination of the voltage difference between the Solar Panel and the battery and the size of the individual cells in the Solar Panel. If there is insufficient light to make all the cells in a Solar Panel produce a voltage greater than the battery voltage, the battery will not be getting any charge, regardless of the size of the individual cells.

The 12 volt lead-acid battery has 6 cells in series, each of which produces a voltage of about 2 volts. Actually, a fully charged cell of a lead acid battery not under charge will be about 2.1 volts and hence a 12 volt battery will have a voltage of 12.6 volts.

The sun shining on the Solar Panel may be equated to rain falling on the shed roof that fills the water tank where the rate at which the tank fills is dependent on how heavy the rain is, how big the shed roof is in comparison to the water tank, and how good the connections are between the shed roof and the water tank. Similarly, the connections between the Solar Panel and the battery and the size of the wire to carry the current are also important. Undersized wire and bad connections can impair the current flow or stop it entirely. A bad connection has the same effect as a resistance.

The flow rate, or amps, is largely determined by the size of the pipe (for water), or cable (for electricity), assuming that there are no other restrictions anywhere that are greater than the pipe or cable. If we go back to the example of the tap below the tank and we wish to determine how fast the water flows from the tap, we can do so by knowing two things.

Firstly we need to know the pressure, which is a function of the vertical distance between the tap and the tank (minus the resistance of the pipe).

Secondly we need to know the diameter of the outlet of the tap, assuming this is the main limiting factor for the flow rate. The rate at which the water flows is directly proportional to the pressure and is also directly proportional to the diameter of the outlet. If we call the pressure volts, we call the diameter of the outlet amps and the rate at which you could fill a bucket we call watts; we can say now that watts equals volts times amps.

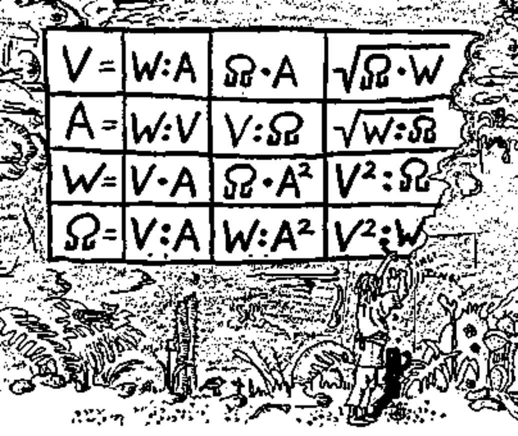
To make it easier to understand the significance of this, you can understand that there are two ways of filling a bucket faster, you can either increase the pressure (have a tap further downhill) or increase the size of the tap and the water-pipe. If you have no pressure, no matter how large the pipe and outlet is, there will be no flow.

Battery storage versus usage

If you fill a battery with a trickle charger charging at the rate of one amp for 100 hours, you can say that you have put 100 amp-hours into the battery. Similarly, if you charged the battery at a rate of 10 amps for 10 hours, you have again put 100 amp-hours into that battery. If you turn on a light that uses 2 amps and leave it on for 5 hours, you have taken 10 amp-hours out of the battery.

The overall state of charge of a battery is the amp-hours charge (including the initial charge in the battery) minus the amp-hours discharge. In this equation you must also take into account that the battery needs a little excess charge to maintain itself. The maximum amp-hour charge in a battery is limited to the amp-hour capacity rating of the battery which is to say that you cannot store more in a battery than it is capable of storing. All batteries have some degree of self discharge and transfer some electricity into other forms of energy other than electro-chemical (transferring electrical energy into chemical energy and vice-versa).

We have already determined that amps times volts equals watts. Watts is a rating of power. It stands to reason that amp-hours times volts would then equal watt-hours. Watt-hours is a rating of work. Battery capacity is usually given in amp-hours.

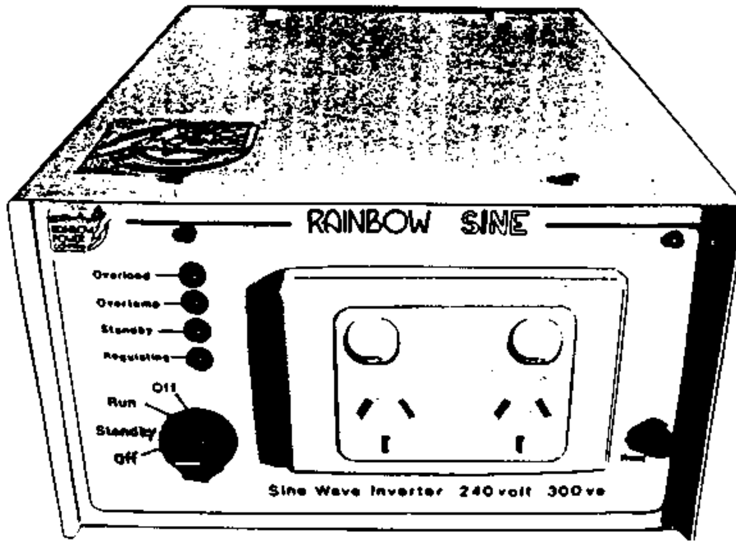

V = W:A Ω·A √Ω·W
A = W:V V:Ω √W:Ω
W = V·A Ω·A² V²:Ω
Ω = V:A W:A² V²:W

Volts Times Amps Equals Watts

Pressure Times Flow Rate Equals Power

The formula: volts times amps equals watts (V x I = W) tells us that there is a direct relationship between pressure (volts), flow rate (amps) and power (watts).

The same relationship holds true with water. It is possible to mechanically transfer the power of water with a low pressure and high flow rate to a high pressure and low flow rate. There is some power lost in the mechanical transfer. The total power of the output can never be greater than the power of the input. It is equally possible to do the reverse of going from a high pressure and low flow rate to a low pressure and high flow rate.



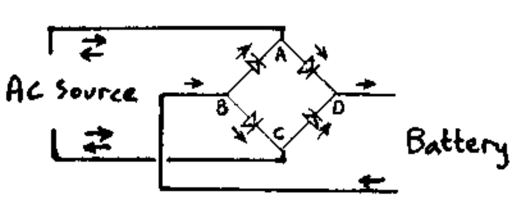
Inverters and transformers

This principle is the most basic clue as to how a 12 volt to 240 volt inverter works. Modern solid-state inverters however depend on AC or alternating current where both the pressure and the flow are rapidly alternating in direction (ie from positive to negative and back to positive, from forward to reverse and back to forward etc).

The reverse of changing from a high pressure (eg 240 volts AC) to a low pressure (eg 12 volts AC) is the function of most transformers).

Changing AC to DC

To change AC into DC you can use a full wave bridge rectifier. That sounds like a mouthful but it is simply four diodes placed in the following configuration:



If you imagine an AC power source connected to points A and C, the diodes only allow the current to flow in the direction of the arrows. When the current flows from point C through the power source to point A it can only ever flow on to point D and point B and back to point C. It cannot flow from point B to point D because it cannot flow through the diodes in reverse.

When the current flows in reverse from point A through the power source to point C it can again only ever flow on to point D and point B, and then back to point A.

An inverter does the reverse to change DC into AC but that is a lot more complicated process and can be done by a variety of methods often involving rapid switching of the current before it gets transformed to a higher voltage.

Maximizing Power

To continually gain the maximum charging rate to a battery or power to a pump from a variable energy source such as solar or wind it is possible to employ the concept of changing from a higher to a lower voltage (pressure) or vice versa in order to maximize the flow rate. It is the electrical flow rate that determines the rate at which a battery bank charges; keeping in mind that electricity will only flow from a point of higher voltage (pressure) to a point of lower voltage (pressure).

This principle is used in the RPC Pelton Wheel where, by adjusting two dials on the machine, you can achieve maximum charge to the battery bank given any AC voltage produced by the generator. The output voltage is varied by switching to different tappings on the transformer.

Maximum Power Point Tracking is used in a more sophisticated manner with a device known as a Maximizer. The battery charging version of the Maximizer modifies the source current and voltage to the optimum battery charging current and voltage and it does it totally automatically. The Solar Pump Maximizer again modifies the source current and voltage to that current and voltage that most suits the pump, and again totally automatically. Hence the Maximizer utilizes the incoming power (eg generated by the sun) to store the maximum possible amp-hours into the battery or to pump the maximum water volume.

Electrics
Amps equals watts divided by volts.

Cable/Current Requirements

Possible Item	**Current requirement in amps (approx)**	**Conductor specification in mm**		**Cable Ref. Numbers***	
		Single core	Twin Core	Single core	Twin core
Gauge lamps	6-8	14/0.30	2x14/0.30	PV2a76/1	PV2a 76/2
Interior lamps	9-12	21/0.30	2x21/0.30	PV2b76/1	PV2b 76/2
Larger lamps (such as search lights)	17.5	28/0.30	2x28/0.30	PV376/1	PV3 76/2
Battery supply	27.5	44/0.30	2x44/0.30	PV3a76/1	PV3a 76/2
Dynamo	42	84/0.30	-	PV3b12/1	-
Alternator	60	120/0.30	-	PV3c12/1	-
Starter motors		135	266/0.30	-	PV336/1
		170	37/0.90	-	PV436/1
Electric winch		300	61/0.90	-	PV536/1

*These are Ripaults reference numbers.

Nobility Table

	Material	Voltage potential
Least noble	Magnesium alloy	– 1.6
	Zinc	– 1.10
	Galvanised iron	– 1.05
	Aluminium	– 0.75
	Mild steel	– 0.70
	Cast iron	– 0.65
	Lead	– 0.55
	Brass*	– 0.27-0.29
	Magnese bronze	– 0.27
	Copper-Nickel	– 0.25
	Silicon bronze	– 0.18
	Monel*	– 0.08-0.20
Most noble	Stainless Steel*	– 0.05-0.20

**The actual nobility depends upon the exact alloy composition of the metal.*

To eliminate corrosion in sea-water it would be necessary to achieve a voltage difference of only 0.20 volts — so anodic protection is the answer.

**Boatowner's Mechanical & Electrical Manual. Calder.
Allard Coles Nautical Publishers. UK/USA. 1996. 0-7136-4291-2.**

Cable construction. Nothing but copper cable is suitable for use in the marine environment. Sometimes aluminum cable is found in household wiring, but this has a lower conductivity than copper and builds up a layer of aluminum oxide on the surface of the cable which creates resistance in connections and terminals—it is not suited to marine use (similarly, because of the corrosion problem, aluminum and unplated steel are not to be used for studs, nuts, washers, and cable terminations). An added measure of protection against corrosion can be gained by drawing the individual strands of a copper cable through a tin "bath" before assembling the cable, to form what is known as *tinned* cable. Tinned cable is more expensive than regular cable, but will provide troublefree service for much longer and is, in the long run, an excellent investment.

Cables in boat use are subjected to vibration and, at times, considerable shocks. Solid-cored cable of the kind used in household wiring is liable to fracture. Stranded cable must be used in boats. The ABYC lists three types, based upon the number of strands (column 6 of Table 3-6 on page 116). Recently the use of Type 1 cable (solid) has been discontinued for marine use; the more flexible Type 2 (19 strands) is recommended for use in general-purpose boat wiring, with Type 3 (many strands—the number varies with cable size) used if frequent flexing occurs.

Insulation is the other critical factor in cable construction. It must be able to withstand the ever present salt-laden atmosphere; contamination by various chemicals, particularly oil, diesel, and dirty bilge water; and exposure to ultraviolet rays from sunlight.

The most commonly available wire in the USA that may be suitable for general-purpose marine wiring is classified as THWN (Thermoplastic, Heat resistant, for Wet locations, and with a Nylon jacket—Table 3-1), or XHHW (cross-linked polyethylene, High-Heat resistant, for Wet locations). Other grades are MTW (Machine Tool Wire), which is rated for wet locations and is oil-, gasoline-, and diesel-resistant, and AWM (Appliance Wiring Material), which is similar to MTW but with a Higher Heat rating (up to 221°F; 105°C), making it suitable for engine rooms.

Wire insulation will frequently carry more than one designation, for example: THHN/THWN. In this instance the insulation has a higher heat (HH) rating in dry locations (up to 194°F/90°C) than it does in wet locations (up to 167°F/75°C).

The problem with Table 3-1 is that the requirements that have to be met for these designations are not rigorous enough to determine whether the cable is really suitable for marine use. A good-quality marine-rated cable will exceed all existing UL, Coast Guard, and ABYC standards. Consequently it is not possible simply to recommend buying a cable that meets a particular standard or has a certain designation, although in the USA it should at the least be labeled as meeting "BC5W2" or "UL1426." To be on the safe side, *tinned, multi-stranded* cable should always be bought from a recognized marine outlet. The cable will be more expensive than that bought from a local electrical wholesaler or retailer, but the added cost is insignificant when compared to the cost of troubleshooting and rectifying faulty circuits in the future.

No normal insulation is suitable for prolonged immersion in water. Sooner or later current leaks will develop. Even good-quality boat cable

Table 3-1 Common Electric Cables Acceptable to the ABYC and Their Designations (USA)

TW: *Th*ermoplastic insulation (usually PVC), suitable for *W*et locations (60°C/140°F heat- resistance rating).

THW: *Th*ermoplastic insulation (usually PVC), *H*eat resistant (75°C/167°F rating) suitable for *W*et locations.

HWN: *H*eat-resistant (75°C/167°F rating) suitable for *W*et locations, with a *N*ylon jacket for abrasion resistance.

THWN: Same as for HWN, but with *Th*ermoplastic insulation.

XHHW: Cross-linked synthetic polymer insulation, *H*igh *H*eat resistant (90°C/194°F rating) suitable for *W*et locations (but in this case de-rated to a 75°C/167°F rating).

MTW: *M*achine *T*ool *W*ire. Usually thermoplastic insulation (PVC) or thermoplastic with a nylon jacket. Moisture-, heat-, and oil-resistant. Most MTW is rated 60°C/140°F. *The ABYC requires it to be rated 90°C/194°F.*

AWM: *A*ppliance *W*iring *M*aterial. Usually thermoplastic insulation (PVC) or thermoplastic with nylon jacket. Thermosetting. 105°C/221°F rating.

BC5W2 and UL 1426 "Boat Cable": Any cable with this designation is good for general- purpose boat wiring. 5 = the heat rating in a dry environment (there are 5 ratings: 1 = 60°C; 2 = 75°C; 3 = 85°C; 4 = 95°C; and 5 = 105°C); 2 = the heat rating in a wet environment (there are two ratings: 1 = 60°C and 2 = 75°C). The insulation on UL 1426 cable is self-extinguishing, which is to say in a fire it will simply char down and drip rather than melt.

For shore-power cords:

SO: Hard *S*ervice cord, *O*il resistant compound.

ST: Hard *S*ervice cord, *Th*ermoplastic.

STO: Hard *S*ervice cord, *Th*ermoplastic with *O*il-resistant rating.

All are available with several temperature ratings (e.g., 60°C/140°F and 75°C/167°F)

Key: T = *Thermoplastic*, a plastic that can be softened by heating, as opposed to *Thermosetting*, a plastic that is heat-cured into an insoluble and infusible end product

W = Moisture-resistant

H = Heat-resistant (75°C/167°F rating)

HH = Higher-heat-resistant (90°C/194°F rating)

N = Nylon jacket

X = Cross-linked synthetic polymer, a plastic in which polymers are linked chemically by polymerization

BC = Boat Cable

should not be run through perpetually damp or wet areas of a boat. For this, special waterproof, oil-resistant insulation is required, and naturally this is more expensive.

Welding cable. Welding cable is sometimes used on boats for high-current DC circuits (notably for high-output alternator and DC/AC inverter installations), and in fact I recommended it for these purposes in the first edition of this book. The reason for using welding cable is its extreme flexibility, which is particularly useful when running heavy cables in tight quarters, and its tolerance of vibration (for example, when attached to the back of an alternator). The problem with welding cable is that its flexibility comes from its large number of very small strands and its soft insulation. These strands tend to wick up moisture, encouraging corrosion, and the insulation is not as moisture-resistant as other insulation and is easily damaged. For these reasons I am persuaded that welding cable should not be used on boats: It does not, in any case, meet the applicable ABYC standards.

Color coding. A standardized system of DC color coding has been adopted by the ABYC (Tables 3-2 and 3-3). However, in many instances it is not feasible to follow this entirely. The primary consideration (USA) is to use red leads on DC positive circuits, and black or yellow on DC negative. AC color coding is explained on page 103. (Note that black is also used for the "hot" leads on AC circuits in the USA, creating the possibility of dangerous confusion. When rewiring a boat I would strongly recommend the use of yellow for the DC negative).

Cable sizes. Selecting the proper wire size for a given application is critical, especially when electric motors are concerned. Undersized cables introduce unwanted resistance, resulting in voltage drop at appliances, reduced performance, and premature failure.

In the USA, two tables developed by the ABYC are commonly used to determine wire sizes in the marine field. The first assumes that a 10% voltage drop at the appliance is acceptable; the second is based on a 3% voltage drop (Tables 3-4 and 3-5). The tables are entered on

Table 3-2. ABYC DC Color Coding

Color	Use
Red	DC positive conductors
Black or Yellow	DC negative conductors
Green or Green with Yellow stripe(s)	DC grounding (bonding) conductors (see Chapter 4)

Table 3-3. ABYC Color Code for Engines and Accessory Wiring

Color	Item	Use
Yellow w/Red Stripe (YR)	Starting Circuit	Starting Switch to Solenoid
Brown/Yellow Stripe (BY) or Yellow (Y)—see note	Bilge Blowers	Fuse or Switch to Blowers
Dark Gray (Gy)	Navigation Lights	Fuse or Switch to Lights
	Tachometer	Tachometer Sender to Gauge
Brown (Br)	Generator Armature	Generator Armature to Regulator
	Alternator Charge Light	Generator Terminal/Alternator
		Auxiliary Terminal to Light and Regulator
	Pumps	Fuse or Switch to Pumps
Orange (O)	Accessory Feed	Ammeter to Alternator or Generator Output and Accessory Fuses or Switches
	Accessory Feeds	Distribution Panel to Accessory Switch
Purple (Pu)	Ignition	Ignition Switch to Coil and Electrical Instruments
	Instrument Feed	Distribution Panel to Electrical Instruments
Dark Blue	Cabin and Instrument Lights	Fuse or Switch to Lights
Light Blue (Lt Bl)	Oil Pressure	Oil Pressure Sender to Gauge
Tan	Water Temperature	Water Temperature Sender to Gauge
Pink (Pk)	Fuel Gauge	Fuel Gauge Sender to Gauge
Green/Stripe (G/x) (Except G/Y)	Tilt down and/or Trim in	Tilt and/or Trim Circuits
Blue/Stripe (Bl/x)	Tilt up and/or Trim out	Tilt and/or Trim Circuits

NOTE: *If yellow is used for DC negative, blower must be brown with a yellow stripe. (ABYC)*

one side by the total length of the wiring in a circuit (which includes both the hot and the ground wire) and on the other side by the maximum current draw (amps) of the appliance on the circuit. The required wire size, in American Wire Gauge (AWG), for the given voltage drop is then read in the body of the table. Note that the larger the AWG number, the smaller the wire size.

If more than one appliance is to be operated from common cables, *the cables must be rated for the total load of all the appliances. The ground cables to all fixtures must be sized the same as the hot cables, since they carry an equal load.*

Many appliances, particularly lights, will work with a 10% voltage drop, but nevertheless I recommend that you use the 3% voltage drop tables at all times. Given the harshness of the marine environment, it just does not pay to start out by trying to cut calculations as fine as possible.

Cable ampacity. All wire has some internal resistance, and so the passage of any current will generate heat. If this heat builds up faster than it dissipates, the cable will eventually pose a fire hazard. The extent to which this is so depends on the nature of the cable insulation and, in AC circuits, on how many cables are bundled together.

Table 3-8 has been developed by the ABYC to indicate the maximum allowable current (ampacity) of different types of cable, both inside and outside engine spaces. *The correction factors at the bottom are to be applied when bundling current-carrying AC cables.* (Note that in a 120-volt circuit [240-volt UK circuit] the hot and neutral conductors are both current-carrying; in a 240-volt circuit [USA] the two hot conductors are current-carrying. In other words, regardless of the system voltage, there are normally two current-carrying conductors in each circuit.)

Table 3-4. Conductor Sizes for 10% Drop in Voltage

(Length of conductor from source of current to device and back to source—feet)

(Total current on circuit in amps)	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
12 volts																			
5	18	18	18	18	18	16	16	14	14	14	12	12	12	12	12	10	10	10	10
10	18	18	16	16	14	14	12	12	10	10	10	10	8	8	8	8	8	8	6
15	18	16	14	14	12	12	10	10	8	8	8	8	8	6	6	6	6	6	6
20	16	14	14	12	12	10	10	8	8	8	6	6	6	6	6	6	4	4	4
25	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
30	14	12	12	10	10	8	8	6	6	6	6	4	4	4	4	2	2	2	2
40	14	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	2
50	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1
60	12	10	8	8	6	6	4	4	2	2	2	2	2	1	1	1	0	0	0
70	10	8	8	6	6	6	4	2	2	2	2	1	1	1	0	0	0	2/0	2/0
80	10	8	8	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	2/0
90	10	8	6	6	6	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0	3/0
100	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0	3/0	3/0
24 volts																			
5	18	18	18	18	18	18	18	18	16	16	16	16	14	14	14	14	14	14	12
10	18	18	18	18	18	16	16	14	14	14	12	12	12	12	12	10	10	10	10
15	18	18	18	16	16	14	14	12	12	12	10	10	10	10	10	8	8	8	8
20	18	18	16	16	14	14	12	12	10	10	10	10	8	8	8	8	8	8	6
25	18	16	16	14	14	12	12	10	10	10	8	8	8	8	8	6	6	6	6
30	18	16	14	14	12	12	10	10	8	8	8	8	8	6	6	6	6	6	6
40	16	14	14	12	12	10	10	8	8	8	6	6	6	6	6	6	4	4	4
50	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
60	14	12	12	10	10	8	8	6	6	6	6	4	4	4	4	2	2	2	2
70	14	12	10	10	8	8	6	6	6	6	4	4	4	2	2	2	2	2	2
80	14	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	2
90	12	10	10	8	8	6	6	6	4	4	4	2	2	2	2	2	2	1	1
100	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1

Table 3-5. Conductor Sizes for 3% Drop in Voltage

(Length of conductor from source of current to device and back to source—feet)

(Total current on circuit in amps)	10	15	20	25	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170
12 volts																			
5	18	16	14	12	12	10	10	10	8	8	8	6	6	6	6	6	6	6	6
10	14	12	10	10	10	8	6	6	6	6	4	4	4	4	2	2	2	2	2
15	12	10	10	8	8	6	6	6	4	4	2	2	2	2	2	1	1	1	1
20	10	10	8	6	6	6	4	4	2	2	2	2	1	1	1	0	0	0	2/0
25	10	8	6	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0
30	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	3/0	3/0	3/0	3/0
40	8	6	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	3/0	4/0	4/0	4/0	4/0
50	6	6	4	4	2	2	1	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0				
60	6	4	4	2	2	1	0	2/0	3/0	3/0	4/0	4/0	4/0						
70	6	4	2	2	1	0	2/0	3/0	3/0	4/0	4/0								
80	6	4	2	2	1	0	3/0	3/0	4/0	4/0									
90	4	2	2	1	0	2/0	3/0	4/0	4/0										
100	4	2	2	1	0	2/0	3/0	4/0											
24 volts																			
5	18	18	18	16	16	14	12	12	12	10	10	10	10	10	8	8	8	8	8
10	18	16	14	12	12	10	10	10	8	8	8	6	6	6	6	6	6	6	6
15	16	14	12	12	10	10	8	8	6	6	6	6	6	4	4	4	4	4	2
20	14	12	10	10	10	8	6	6	6	6	4	4	4	4	2	2	2	2	2
25	12	12	10	10	8	6	6	6	4	4	4	4	2	2	2	2	2	2	1
30	12	10	10	8	8	6	6	4	4	4	2	2	2	2	2	1	1	1	1
40	10	10	8	6	6	6	4	4	2	2	2	2	1	1	1	0	0	0	2/0
50	10	8	6	6	6	4	4	2	2	2	1	1	0	0	0	2/0	2/0	2/0	3/0
60	10	8	6	6	4	4	2	2	1	1	0	0	0	2/0	2/0	3/0	3/0	3/0	3/0
70	8	6	6	4	4	2	2	1	1	0	0	2/0	2/0	3/0	3/0	3/0	3/0	4/0	4/0
80	8	6	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	3/0	4/0	4/0	4/0	4/0
90	8	6	4	4	2	2	1	0	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0	4/0	4/0	
100	6	6	4	4	2	2	1	0	2/0	2/0	3/0	3/0	4/0	4/0	4/0				

Notes: These tables are based on SAE wiring sizes. SAE-rated cables are typically 10% to 12% smaller than AWG-rated cables of the same nominal size (see Table 3-6, columns 2 and 3). Consequently, if a cable is sized by reference to these tables, and then AWG-rated wire of the same nominal size is substituted for SAE, the cable will be somewhat oversized for the application, which is all to the good. Although SAE-rated wiring can be used in DC circuits, *AWG-rated wiring must be used in AC circuits* (If you find this confusing, blame the ABYC and not me!).

Table 3-6. Conversion of American Wire Sizes to European Standards

1 Conductor Size	2 Minimum Acceptable Circular Mil[1] (CM) Area (SAE specs and ABYC for DC Wiring)	3 Minimum Acceptable Circular Mil[1] (CM) Area (UL specs [AWG] and ABYC for AC Wiring)	4 Conductor Diameter (mm)	5 Conductor Cross-sectional Area (mm^2)	6 Minimum Number of Strands Type 1	Type 2	Type 3
25			0.455	0.163			
24			0.511	0.205			
23			0.573	0.259			
22			0.644	0.325			
21			0.723	0.412			
20			0.812	0.519			
19			0.992	0.653			
18	1537	1620	1.024	0.823	7	16	
17			1.15	1.04			
16	2336	2580	1.29	1.31	7	19	26
15			1.45	1.65			
14	3702	4110	1.63	2.08	7	19	41
13			1.83	2.63			
12	5833	6530	2.05	3.31	7	19	65
11			2.30	4.15			
10	9343	10380	2.59	5.27	7	19	105
9			2.91	6.62			
8	14810	16510	3.26	8.35	7	19	168
7			3.67	10.6			
6	25910	26240	4.11	13.3		37	266
5			4.62	16.8			
4	37360	41740	5.19	21.2		49	420
3			5.83	26.7			
2	62450	66360	6.54	33.6		127	665
1	77790	83690	7.35	42.4		127	836
0 (1/0)	98980	105600	8.25	53.4		127	1064
00 (2/0)	125100	133100	9.27	67.5		127	1323
000 (3/0)	158600	167800	10.40	85.0		259	1666
0000 (4/0)	205500	211600	11.68	107.2		418	2107
00000 (5/0)	250000		13.12	135.1			
000000 (6/0)	300000		14.73	170.3			

1. 1 circular mil (CM) = 0.0005067 mm^2, and 1 MCM = 1,000 CM = 0.5067 mm^2

NOTES:
Type 1 no longer accepted in boat wiring by ABYC.
The lesser ABYC requirements for DC circuits reflects the fact that much of the industry is using SAE-rated cable. Using the UL specs for both DC and AC is preferable.

USA Cable-Sizing Formula

The ABYC tables have been developed by the application of the following formula:

CM = (K × I × L) ÷ E where:

CM = Circular Mil area of the conductor (a measure of its cross-sectional area)

K = 10.75 (a constant representing the mil-foot resistance of copper)

I = the maximum current (amps) on the circuit

L = the length in feet of the conductors in the circuit

E = the maximum allowable voltage drop (in volts) at full load

Use the formula to calculate wire sizes for loads and voltage drops not covered by the tables. For example, if voltage drop is to be limited to 3%, what size cables would be required for a 12-volt electric windlass that pulls 200 amps at full load and which will be situated 25 feet from its battery?

3% of 12 volts is 0.36 volts.

CM = (10.75 × 200 × 50) ÷ 0.36 = 298611 Circular mils.

Table 3-6 converts Circular Mils to AWG. In our example a humongous, and totally impractical, 6/0 cable is required. Two 3/0 cables could be run in parallel, but in all probability we would settle for a 10% voltage drop at full load, which can be met with a 2/0 cable (still big!).

Column 2 of Table 3-6 gives minimum SAE (Society of Automotive Engineers) cable specifications, which the ABYC considers adequate for DC wiring, and column 3 gives minimum UL (Underwriters Laboratories) cable specifications (AWG), which the ABYC considers necessary for AC wiring. For a given cable size, UL cables (AWG) are larger than SAE (wiring is one of those confusing areas where there are several different standards). Using the UL standards (AWG) for both DC and AC wiring will ensure the best results.

Total current on circuit in amps	Length of conductor from source to device and back to source in feet									
	10	15	20	25	30	40	50	60	70	80
5	18	16	14	12	12	10	10	10	8	8
10	14	12	10	10	10	8	6	6	6	6
15	12	10	10	8	8	6	6	6	4	4
20	10	10	8	6	6	6	4	4	2	2
25	10	8	6	6	4	4	2	2	2	1
30	10	8	6	6	4	4	2	2	1	1
40	8	6	6	4	4	2	2	1	1	0
50	6	6	4	4	2	2	1	0	2/0	3/0

[Wire sizes in American Wire Gauge (AWG); for European conductor sizes, use Table 9-2.]

Table 9-1. Conductor size for 3 percent voltage drop.

Conductor Size in AWG	European Equivalent (diameter in mm)
18	1.024
16	1.290
14	1.630
12	2.050
10	2.590
8	3.260
6	4.110
4	5.190
2	6.540
1	7.350
1/0	8.250
2/0	9.270
3/0	10.400

Table 9-2. **AWG conductor sizes and their European equivalents.**

Copper Wire Table- AWG to Metric

American Wire Gauge Number (B&S)	*Diameter in mm at 20°C.*	*Meters per Ohm at 20°C.*
OOOO	11.6800	6219.0000
OOO	10.4000	4932.0000
OO	9.2660	3911.0000
O	8.2520	3102.0000
2	6.5440	1951.0000
4	5.1890	1227.0000
6	4.1150	771.5000
8	3.2640	485.2000
10	2.5880	305.1000
12	2.0530	191.9000
14	1.6280	120.7000
16	1.2910	75.9000
18	1.0240	47.7400
20	0.8118	30.0200
22	0.6438	18.8800
24	0.5106	11.8700
26	0.4049	7.4680
28	0.3211	4.6970
30	0.2546	2.9540

WIRE AMPACITY

The current output of the armature/stator is entirely dependent upon the current carrying capacity, or ampacity, of the wire used. Ampacity is related to wire size. Comparing relative wire sizes can be accomplished by comparing the wire's circular area (called circ. mils), unit weight, unit length, or unit resistance. The following chart

FIGURE 2: COPPER WIRE TABLE

Wire Guage	Circular Mils	Pounds/ 1000 feet	Feet/ Pound	Ohms/ 1000 feet
10	10380.0	31.430	31.82	0.9989
11	8234.0	24.920	40.13	1.2600
12	6530.0	19.770	50.58	1.5880
13	5178.0	15.680	63.77	2.0030
14	4107.0	12.430	80.45	2.5250
15	3257.0	9.858	101.40	3.1840
16	2583.0	7.818	127.90	4.0160
17	2048.0	6.200	161.30	5.0640
18	1624.0	4.917	203.40	6.3850
19	1288.0	3.899	256.50	8.0510
20	1022.0	3.092	323.40	10.1500
21	810.1	2.452	407.80	12.8000
22	642.4	1.945	514.10	16.1400
23	509.5	1.542	648.50	20.3600
24	404.0	1.223	817.70	25.6700

lists these relationships for wire sizes used in generators & alternators: Note that half sizes exist for most wire gauges but in the interest of clarity are not listed.

UK Cable-Sizing Procedures

In the UK a slightly more involved procedure is used to determine cable sizes. The allowable volt-drop-per-amp-per-meter must be calculated. Taking the windlass example, a 3% volt drop on a 12-volt circuit is 0.36 volts. At a maximum current of 200 amps, this gives an allowable volt-drop-per-amp of:

$0.36 \div 200 = 0.0018$ volts (1.8 millivolts [mV, thousandths of a volt]).

Now we have a hitch. Some UK volt-drop tables are based on the *total length of the circuit* (as in the ABYC tables), but other tables are constructed on the basis of the *meter run* of the circuit, which means it is necessary to measure only the distance *in one direction* in order to enter the table. Table 3-7 is a *meter-run* table. The circuit is 7.5 meters (25 feet) in one direction, so the allowable volt-drop-per-amp-per-*meter run* is:

$0.0018 \div 7.5 = 0.00024$ volts (0.24 mVolts).

Table 3-7 is entered in the DC millivolt (mV) column. Reading down we find 0.25mV, which is very close to the 0.24 mV we are looking for. Reading across to the left-hand side, we find we need a cable with a cross-sectional area of 185 mm^2 (which is pretty close to AWG 6/0—see Table 3-6). If we decide to accept a 10% volt drop on the circuit, the allowable volt-drop-per-amp-per-meter run is now:

$1.2 \div (200 \times 7.5) = 0.0008$ volts (0.8 mV).

Entering Table 3-7, we find the nearest mV readings are 0.67 and 0.96. When we cannot find an exact correlation, we always use the *larger* cable which in this case is 70 mm^2. This is pretty close to AWG 2/0—the formula worked again! (Unless precise electrical engineering is needed, UK readers can use the ABYC tables to determine an American Wire Gauge size for a cable, and then use Table 3-6 to convert this to mm^2, but remember that the American tables require measurements in *feet,* both *to and from* the load.)

Table 3-7. Continuous Current Ratings for Cables

Conductor nominal cross-sectional area	Current rating DC or single-phase AC or 3-phase AC	Volt-drop-per-ampere-per-meter		
		DC	Single-phase AC	3-phase AC
1	2	3	4	5
mm²	A	mV	mV	mV
1.0	17	53	53	46
1.5	21	34	34	29
2.5	30	18	18	16
4	40	12	12	10
6	51	7.6	7.6	6.6
10	71	4.5	4.5	3.9
16	95	2.7	2.7	2.3
25	125	1.7	1.7	1.5
35	155	1.2	1.2	1.2
50	190	0.96	0.98	0.87
70	240	0.67	0.69	0.63
95	290	0.48	0.52	0.49
120	340	0.38	0.42	0.43
150	385	0.31	0.36	0.38
185	440	0.25	0.32	0.34
240	520	0.19	0.27	0.31
300	590	0.15	0.24	0.29
	DC AC			
400	690 670	0.12	0.23	0.28
500	780 720	0.093	0.22	0.27
630	890 780	0.071	0.21	0.26

NOTES:

1. There are different tables for different types of cable in different ambient temperatures. This is a conservative table based on insulation rated for 60°C (140°F). A cable with insulation rated for higher temperatures will be able to carry higher currents. Since any good-quality boat cable should exceed the 60°C (140°F) temperature rating, this table can be safely used to size just about any cable.
2. This table is based upon distances measured in *meter-runs*—i.e., it is necessary to measure only the circuit *in one direction.* See the text for an explanation of how to use it.

Table 3-8. Allowable Ampacity of Conductors

CONDUCTOR SIZE AWG	Temperature Rating of Conductor Insulation: 60°C (140°F) OUTSIDE ENGINE SPACES	60°C (140°F) INSIDE ENGINE SPACES	75°C (167°F) OUTSIDE ENGINE SPACES	75°C (167°F) INSIDE ENGINE SPACES	80°C (176°F) OUTSIDE ENGINE SPACES	80°C (176°F) INSIDE ENGINE SPACES	90°C (194°F) OUTSIDE ENGINE SPACES	90°C (194°F) INSIDE ENGINE SPACES	105°C (221°F) OUTSIDE ENGINE SPACES	105°C (221°F) INSIDE ENGINE SPACES	125°C (257°F) OUTSIDE ENGINE SPACES	125°C (257°F) INSIDE ENGINE SPACES	200°C (392°F) OUTSIDE OR INSIDE ENGINE SPACES
18 (0.8)	10	5.8	10	7.5	15	11.7	20	16.4	20	17.0	25	22.3	25
16 (1)	15	8.7	15	11.3	20	15.6	25	20.5	25	21.3	30	26.7	35
14 (2)	20	11.6	20	15.0	25	19.5	30	24.6	35	29.8	40	35.6	45
12 (3)	25	14.5	25	18.8	35	27.3	40	32.8	45	38.3	50	44.5	55
10 (5)	40	23.2	40	30.0	50	39.0	55	45.1	60	51.0	70	62.3	70
8 (8)	55	31.9	65	48.8	70	54.6	70	57.4	80	68.0	90	80.1	100
6 (13)	80	46.4	95	71.3	100	78.0	100	82.0	120	102.0	125	111.3	135
4 (19)	105	60.9	125	93.8	130	101.4	135	110.7	160	136.0	170	151.3	180
2 (32)	140	81.2	170	127.5	175	136.5	180	147.6	210	178.5	225	200.3	240
1 (40)	165	95.7	195	146.3	210	163.8	210	172.2	245	208.3	265	235.9	280
0 (50)	195	113.1	230	172.5	245	191.1	245	200.9	285	242.3	305	271.5	325
00 (62)	225	130.5	265	198.8	285	222.3	285	233.7	330	280.5	355	316.0	370
000 (81)	260	150.8	310	232.5	330	257.4	330	270.6	385	327.3	410	364.9	430
0000 (103)	300	174.0	360	270.0	385	300.3	385	315.7	445	378.3	475	422.8	510

Maximum Allowable Amperage

Correction Factors for Bundling of AC Cables

No. of current-carrying conductors	Correction factor
3	0.70
4-6	0.60
7-24	0.50
25+	0.40

(ABYC)

This table, and these correction factors, are used to double-check the adequacy of cables selected by using the voltage-drop tables. For example, a 2/0 cable on a 200-amp circuit: If this is to be run through an engine space, Table 3-8 tells us the cable insulation must be rated for 167°F/75°C; if the only cable available has a 140°F/60°C rating, the 2/0 cable cannot be used to carry 200 amps in the engine room, but would be adequate outside it.

Table 3-9 converts American wire gauge sizes to European specifications.

Connections and Terminals

Poor connections are the bane of many an otherwise excellent electrical installation. The keys to success are using the proper terminals, installing them with the proper tools, and keeping moisture out of the terminal.

Proper terminals. Crimp-on connectors and terminals have gained almost universal acceptance in marine wiring. However, it should be noted that every one is a potential source of trouble: The exposed end of the cable core, protruding from the terminal, provides an entry path for moisture to wick up into the wiring, causing corrosion and resistance; the terminal forms a hard spot in the wiring so that any vibration will tend to cause the wire to fracture where it enters the terminal; and the terminal itself will be fastened to a terminal block or piece of equipment that may use a screw of a dissimilar metal, opening up the possibility of galvanic corrosion.

It makes sense to use the very best terminals available, and as usual there is more to this than meets the eye. A quality terminal will include the following features (none of which are likely to be found on the cheap terminals available at auto parts stores!):

- an *annealed, tin-plated*, copper terminal end. The annealing softens the copper so that the retaining screw will bite into it for maximum conductivity. The tin plating enhances conductivity and corrosion resistance.
- a *seamless* tin-plated brass or bronze sleeve to crimp onto the cable, preferably with a serrated inside surface to enhance its mechanical grip. A seamless sleeve can be crimped from any angle and will hold the wire better than a seamed sleeve.

Table 3-9. Comparison of Conductor Cross-Sections

AWG Ga.	AWG mm^2	ISO mm^2	Ampacity AWG	Ampacity ISO
18	0.82	0.75	20	12
		1.0		18
16	1.31		25	
		1.5		21
14	2.08		35	
		2.5		30
12	3.31		45	
		4.0		40
10	5.26		60	
		6.0		50
8	8.39		80	
		10.0		70
6	13.3		120	
		16.0		100
4	21.2		160	
3	26.6	25.0	180	140
2	33.6	35.0	210	185
1	42.4		245	
0	53.5	50.0	285	230
2/0	67.7	70.0	330	285
3/0	85.2		385	
		95.0		330
4/0	107		445	
250 kcm	127	120	500	400
300 kcm	152	150	550	430

ISO = International Standards Organization, the governing body for European standards.

(ABYC)

- *a long, nylon insulating sleeve,* extending up over the wire insulation. Nylon will not crack or punch through when crimping, and is UV-, diesel-, and oil-resistant (unlike the PVC found on cheap terminals). If the long sleeve contains an extra brass sleeve, a double crimp can be made—once on the terminal barrel, and once on the sleeve around the wire insulation—to provide maximum strain relief.

On wire sizes larger than 4 AWG, uninsulated *lugs* are used to terminate cables. Key features to look for in such lugs are once again an annealed terminal end, tin plating, and a seamless construction. In addition, *the lower end of the barrel should be closed to prevent water entry.* A long barrel will enable a double crimp to be made.

A terminal must be matched to both its cable and its retaining screw or stud. Terminals are given a simple color code: red for 22-18 gauge wire (0.5 to $1.0mm^2$); blue for 16-14 gauge (1.5 to $2.5mm^2$); and yellow for 12-10 gauge (3.0 to $6.0mm^2$).

Ring-type terminals are preferred to spade, since they cannot pull off a loose screw. Locking spades are preferred to straight spades (Figure 3-43).

Wire nuts are frequently used to make connections in household circuits in the USA, though not in the UK. They are not suitable for marine use since the threaded metal insert is made of steel and will rust; what is more, the lower end of the nut is open to the atmosphere. If used, wire nuts should always be installed with the open end down so that the nut does not become a water trap. It is a good practice then to seal the nut with polyurethane sealant (it is a better practice to "just say no").

Proper tools. *It is simply not possible to turn out successful crimps without the right tools.* This means a *properly sized* insulation stripper (not a pocket knife, see Figure 3-44), and a *properly sized* crimper.

There are two types of crimp: an indented crimp, in which a deep slot is made in the terminal, and an elliptical crimp, in which the terminal is compressed around its circumference.

WIRE SIZING CHART/FORMULA

We could give you some incomprehensible voltage drop charts (like we've done in the past), but this all-purpose formula works better.

This chart is useful for finding the correct wire size for any voltage, length, or amperage flow in any AC or DC circuit. For most DC circuits, particularly between the PV modules and the batteries, we try to keep the voltage drop to 3% or less. There's no sense using your expensive PV wattage to heat wires. You want that power in your batteries!

Note that this formula doesn't directly yield a wire gauge size, but rather a 'VDI' number which is then compared to the nearest number in the VDI column, and then read across to the wire gauge size column.

1. Calculate the Voltage Drop Index (VDI) using the following formula:

$$\text{VDI} = \text{AMPS} \times \text{FEET} \div \%\ \text{VOLT DROP} \times \text{VOLTAGE}$$

Amps = Watts × Volts
Feet = One way wire distance
% Volt Drop = Percentage of voltage drop acceptable for this circuit (typically 2% to 5%)

2. Determine the appropriate wire size from the chart below.

   A. Take your VDI number you just calculated and find the nearest number in the VDI column, then read to the left for AWG wire gauge size.
   B. Be sure that your circuit amperage does not exceed the figure in the Ampacity column for that wire size. (This is not usually a problem in low voltage circuits.)

Wire Size	Copper Wire		Aluminum Wire	
AWG	VDI	Ampacity	VDI	Ampacity
0000	99	260	62	205
000	78	225	49	175
00	62	195	39	150
0	49	170	31	135
2	31	130	20	100
4	20	95	12	75
6	12	75	•	•
8	8	55	•	•
10	5	30	•	•
12	3	20	•	•
14	2	15	•	•
16	1	•	•	•

APPENDIX B

CURRENT CARRYING CAPACITY OF COPPER WIRE

The ratings in the following tabulations are those permitted by the National Electrical Code for flexible cords and for interior wiring of houses, hotels, office buildings, industrial plants, and other buildings.

The values are for copper wire. For aluminum wire the allowable carrying capacities shall be taken as 84% of those given in the table for the respective sizes of copper wire with the same kind of covering.

Size A.W.G.	Area Circular (mils)	Diameter of Solid Wires (mils)	Rubber Insulation (amperes)	Varnished Cambric Insulation (amperes)	Other Insulations and Bare Conductors (amperes)
24	404	20.1	–	–	1.5
22	642	25.3	–	–	2.5
20	1,022	32.0	–	–	4
18	1,624	40.3	3*	–	6**
16	2,583	50.8	6*	–	10**
14	4,107	64.1	15	18	20
12	6,530	80.8	20	25	30
10	10,380	101.9	25	30	35
8	16,510	128.5	35	40	50
6	26,250	162.0	50	60	70
5	33,100	181.9	55	65	80
4	41,740	204.3	70	85	90
3	52,630	229.4	80	95	100
2	66,370	257.6	90	110	125

Note: 1 mil = 0.001 inch.

*The allowable carrying capacities of No. 18 and 16 are 5 and 7 amperes, respectively, when in flexible cords.

**The allowable carrying capacities of No. 18 and 16 are 10 and 15 amperes, respectively, when in cords for portable heaters. Types AFS, AFSI, HC, HPD, and HSJ.

Wire Sizing and Voltage Drop in Low Voltage Power Systems

Part 1

John Davey and Windy Dankoff

Properly sized wire can make the difference between inadequate and full charging of your energy system, between dim and bright lights, and between feeble and full blast performance of your tools and appliances. Even wiring that is slightly undersized can cheat you out of a major portion of your system's energy.

Designers of low voltage systems are often confused by the implications of voltage drop and wire size. In conventional home electrical systems (120/240 volts ac), wire is sized according to its safe amperage carrying capacity know as "ampacity". The overriding concern here is fire safety. However in low voltage (12/24/48 volts DC) systems, sizing for larger wire is usually necessary to minimize power loss due to voltage drop before increased wire size is required for amperage safety.

Typically, low voltage systems are seen in Alternative Energy (AE) home systems and Recreational Vehicle (RV) systems. The heart of these systems is DC power, because DC electrical power can be stored in batteries. With photovoltaic systems, the electrical power produced is also DC. DC systems are primarily low voltage because most of the DC lights and appliances have traditionally been built for the vehicular market, which is typically 12 or 24 volts. There is also increased fire danger with high voltage DC because of the high potential for arcing in switches and in poor electrical connections. DC at high voltage also has high shock hazard (more than at equivalent ac voltages).

Voltage Drop

Voltage Drop is caused by a conductor's electrical resistance (Ohms) and may be calculated according to Ohm's Law--

(1) Voltage Drop (Volts) = Electrical Resistance (Ohms) X Current (Amps)

Power Loss is calculated by--

(2) Power Loss (Watts) = Voltage Drop (Volts) X Current(Amps)

By substituting the Voltage Drop Equivalence from equation (1) into equation (2), we find--

Power Loss (Watts) = Ohms X Amps^2

If we have a 12V system with a 100 ft. wire run of 12 gauge wire (0.33 Ohms) and a 72 watt load, there will be a 6 amp current (Amps = Watts/Volts) and a power loss of 12 watts (0.33 Ohms X 6 Amps^2). If we converted this system to 24V, we would have a current of 3 amps and a power loss of 3 watts. The implication here is that by DOUBLING the system voltage, power loss is reduced by a FACTOR OF FOUR. Or for no increase in power loss, we can use ONE FOURTH the wire size by doubling the voltage. This is why the trend in AE full home systems with DC circuits is towards 24V instead 12V systems. It is also why it is important to reduce the current by using efficient loads and putting fewer loads on the same circuit. Likewise, reducing wire resistance by using large wire and shorter wire runs is important. All of these are particularly critical with AE systems, where cost per kilowatt of electrical power may be several times that of "Grid" supplied electrical power.

Wire Size Chart

Because of the significance of voltage drop in low voltage electrical systems, we have developed an easy-to-use wire sizing chart. Most such charts published assume a 2% or 5% voltage drop for 12 and 24 volt systems and result in pages of numbers. This new chart works for any voltage and accommodates your choice of percentage voltage drop. You'll find it the handiest chart available. The chart applies to typical DC circuits and to simple ac circuits (refer to footnote on Wire Size Chart).

We recommend sizing for a 2-3% voltage drop where efficiency is important. We shall discuss this as it applies to specific loads in greater detail in Part II of the article.

ac/DC Wire Size Chart

❶ Calculate Voltage Drop Index (VDI)

$$\text{VDI} = \frac{\text{AMPS X VOLTS}}{\text{\% VOLT DROP X VOLTAGE}}$$

where:
AMPS= Watts/Volts
FEET=One-way Wire distance
% VOLTAGE DROP= Percentage you are willing to accept (e.g. use 2 for 2%)
VOLTAGE=Line voltage

❷ Calculate Voltage Drop Index (VDI)

a. Compare the "calculated VDI" with the VDI values for the American Wire Gauge (AWG) sizes in the chart to determine the appropriate wire size.
b. Amperage must not exceed the indicated fire hazard AMPACITY for the wire gauge (set by the National Electric Code).

Wire Size	Copper Wire		Aluminum Wire	
AWG	VDI	Ampacity	VDI	Ampacity
OOOO	99	260	62	205
OOO	78	225	49	175
OO	62	195	39	150
O	49	170	31	135
2	31	130	20	100
4	20	95	12	75
6	12	75	•	•
8	8	55	•	•
10	5	30	•	•
12	3	20	•	•
14	2	15	•	•
16	1	•	•	•

Information applies to DC circuits and ac circuits where Power Factor =1.0 and line reactance is negligible.

For 2-wire circuits. For more complex circuits, refer to an electrical engineering handbook.

We recommend sizing for a 2% to 3% voltage drop where efficiency is important.

Sizing Example

We have a 12 volt system with a total one-way wire run of 40 ft. servicing three 13 watt fluorescent lights and one 20 watt quartz halogen light. Sizing for a 2% voltage drop, what wire size is needed for this circuit?

$$\text{AMPS} = \frac{\text{TOTAL WATTS ALL LOADS}}{\text{VOLTS}}$$

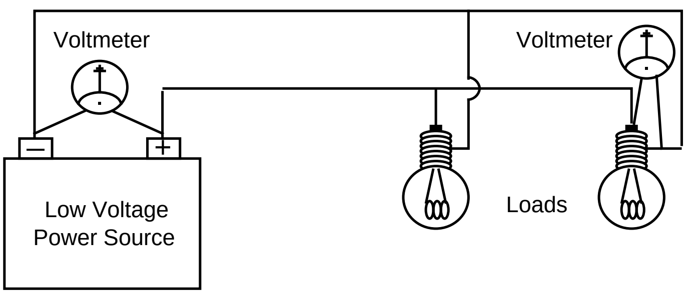
$$= \frac{3 \text{ X } 13 + 20}{12} = 4.9$$

$$\text{VDI} = \frac{4.9 \text{ X } 40}{2 \text{ X } 12} = 8.2$$

The "calculated VDI" 8.2 is between VDI values 8 and 12 on the Chart. This calls for #8 gauge wire (#12 gauge wire could be used in a 24V system). Since the "calculated VDI" is not much greater than 8, we may consider sizing-down and accepting a slightly greater voltage drop. This would be sensible because #8 gauge wire is expensive and difficult to work with. Or we might consider putting these loads on two circuits--compare wire and labor costs. If on the average only one of the fluorescents and the quartz halogen are on at the same time, we could size for this load, being sure not to exceed the wire ampacity for the total of all loads. In this case #12 gauge wire would be adequate. This is an example of some of the considerations and tradeoffs that will be discussed in Part II of the article.

Determining Voltage Drop In Existing Circuits

You may wish to know how efficient an already existing circuit is in terms of voltage drop. There is an easy way to measure this. With a "multi-tester" or voltmeter, measure the "source voltage" for the circuit and the "load Voltage" at the end of the line, then compare the difference. Do this while the circuit is powered and all the loads are on:



Now calculate the % voltage drop for the circuit by--

$$\text{\% VOLTAGE DROP} = \frac{\text{SOURCE VOLTAGE - LOAD VOLTAGE X 100}}{\text{SOURCE VOLTAGE}}$$

where:

$$\text{AMPS} = \frac{\text{TOTAL WATTS ALL LOADS}}{\text{VOLTS}}$$

FEET= One-way length of the circuit

VDI= VDI value from Wire Size Chart for the gauge of wire in the circuit

This method will total ALL voltage drops in the circuit caused by wire, connections, and switches. Because the amperage is diminished beyond each load in the circuit, the true % voltage drop will be somewhat less than is calculated in the above equation.

An easy way to calculate the wire voltage drop WITHOUT any measurements, if you have the information needed about the circuit, is to solve for % Voltage Drop using the VDI equation--

$$\text{\% VOLTAGE DROP} = \frac{\text{AMPS X FEET}}{\text{VDI X VOLTAGE}}$$

Look for Part II of the article in the next issue dealing with: PRACTICAL APPLICATIONS OF VOLTAGE DROP AND WIRE SIZE.

NERD'S CORNER

Wire Size Chart Derivation

Voltage drop is caused by the electrical resistance (Ohms) of a conductor. This in turn is determined by resistance of the conductor material and the cross sectional area and length of the conductor. The nominal resistance for copper wire is 10.7 Ohms (17.0 Ohms for aluminum wire) per foot of wire one circular mil in cross sectional area. Therefore the resistance of a copper wire run may be determined by--

$$\text{R (copper wire)} = \frac{\text{10.7 X Length of the wire in Feet}}{\text{cross sectional area in circular mils}} \quad \text{(a)}$$

From Ohm's Law, the voltage drop in a conductor is E = I X R. Upon substituting equation (a) for R, the voltage drop in a circuit may be calculated by--

$$\text{E} = \frac{\text{10.7 X Current in Amps X 2 X Oneway Wire Feet}}{\text{cross sectional area in circular mils}} \quad \text{(b)}$$

Percent voltage drop can be calculated by--

$$\text{\% Voltage Drop} = \frac{\text{10.7 X Current X 2 X Wire Feet X 100}}{\text{cross sectional area in circular mils X voltage}} \quad \text{(c)}$$

By rearranging this equation we can calculate the appropriate wire size (circular mils) for a given % voltage drop and current--

$$\text{c-mils} = \frac{\text{10.7 X Current X 2 X Wire Feet X 100}}{\text{\% Voltage Drop X Voltage}} \quad \text{(d)}$$

This equation may be reduced to--

$$\text{c-mils} = \frac{\text{2140 X Current X Wire Feet}}{\text{\% Voltage Drop X Voltage}} \quad \text{(e)}$$

We use the American Wire Gauge (AWG) system which has 40 gauges ranging from the largest gauge 0000 (0.4600 in. diameter) to the smallest #36 (0.005 in. diameter). The ratio of any gauge diameter to the diameter of the next smallest gauge is--

$$\sqrt[39]{\frac{0.4600}{0.0050}} = 1.1229322$$

Using this relationship we can calculate the diameter (inches) of every gauge.

The cross sectional area of the gauges in circular mils is calculated by--

$$\text{c-mils} = (\text{1000 X wire diameter in inches})^2$$

Now, recalling the equation--

$$\text{c-mils} = \frac{\text{2140 X Current X Wire Feet}}{\text{\% Voltage Drop X Voltage}}$$

and rearranging it we obtain--

$$\frac{\text{c-mils}}{2140} = \frac{\text{Current X One way wire length in feet}}{\text{\% Voltage Drop X Voltage}}$$

If we solve c-mils/2140 for each gauge we come up with a value, which we shall denote the Voltage Drop Index (VDI), for each gauge.

Now, to size wire for a particular circuit, we calculate VDI for this circuit using--

$$\text{VDI} = \frac{\text{Current X One way wire length in feet}}{\text{\% Voltage Drop X Voltage}}$$

and compare this "calculated VDI" to the VDI's for the standard gauges in the Chart and come up with the appropriate wire gauge for the acceptable % voltage drop.

END OF DERIVATION

Access

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Windy Dankoff is owner of Flowlight Solar Power. Flowlight supplies remote home PV systems and manufactures "Flowlight Solar Pumps". Windy began working with wind generators in 1975 and PV in 1979. He has contributed 12 articles to Home Power since issue #2.

Wire Sizing and Voltage Drop in Low Voltage Power Systems

John Davey & Windy Dankoff

Properly sized wire can make the difference between inadequate and full charging of your energy system, between dim and bright lights, and between feeble and full blast performance of your tools and appliances. Even wiring that is slightly undersized can cheat you out of a major portion of your system's energy.

Designers of low voltage systems are often confused by the implications of voltage drop and wire size. In conventional home electrical systems (120/240 volts ac), wire is sized according to its safe amperage carrying capacity know as "ampacity". The overriding concern here is fire safety. However in low voltage (12/24/48 volts DC) systems, sizing for larger wire is usually necessary to minimize power loss due to voltage drop before increased wire size is required for amperage safety.

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Voltage Drop is caused by a conductor's electrical resistance (Ohms) and may be calculated according to Ohm's Law--
(1) Voltage Drop (Volts) = Electrical Resistance (Ohms) X Current (Amps)

Power Loss is calculated by--
(2) Power Loss (Watts) = Voltage Drop (Volts) X Current(Amps)

By substituting the Voltage Drop Equivalence from equation (1) into equation (2), we find--

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If we have a 12V system with a 100 ft. wire run of 12 gauge wire (0.33 Ohms) and a 72 watt load, there will be a 6 amp current (Amps = Watts/Volts) and a power loss of 12 watts (0.33 Ohms X [6 Amps]^2). If we converted this system to 24V, we would have a current of 3 amps and a power loss of 3 watts. The significance here is that by DOUBLING the system voltage, power loss is reduced by a FACTOR OF FOUR. Or for no increase in power loss, we can use ONE FOURTH the wire size by doubling the voltage. This is why the trend in AE full home systems with DC circuits is towards 24V instead 12V systems. It is also why it is important to reduce the current by using efficient loads and putting fewer loads on the same circuit. Likewise, reducing wire resistance by using large wire and shorter wire runs is important. All of these are particularly critical with AE systems, where cost per kilowatt of electrical power may be several times that of "Grid" supplied electrical power.

Wire Size Chart
Because of the significance of voltage drop in low voltage electrical systems, we have developed an easy-to-use wire sizing chart. Most previous charts published assume a 2 or 5% voltage drop for 12 and 24 volt systems and result in pages of numbers. This new chart works for any voltage and accommodates your choice of % voltage drop. You'll find it the handiest chart available. The chart applies to typical DC circuits and simple ac circuits (refer to footnote on Wire Size Chart). We recommend sizing for a 2-3% voltage drop where efficiency is important.

ac/DC Wire Size Chart

① Calculate Voltage Drop Index (VDI)

$$VDI = \frac{AMPS \ X \ FEET}{\% \ VOLT \ DROP \ X \ VOLTAGE}$$

where:
AMPS = Watts/Volts
FEET = One-way wire distance
%VOLT DROP = Percentage Volatage Drop
e.g. use 2. for 2%

② Determine Appropriate Wire Size from Chart

a. Compare the "calculated VDI" with the VDIvalues for the American Wire Gauge (AWG) sizes in the chart to determine the appropriate wire size to use.
b. Circuit amperage must not exceed the indicated fire harzard AMPACITY rating for the wire gauge set by the National Electric Code.

Wire Size	Copper Wire		Aluminum Wire	
AWG	VDI	Ampacity	VDI	Ampacity
OOOO	99	260	62	205
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2	31	130	20	100
4	20	95	12	75
6	12	75	•	•
8	8	55	•	•
10	5	30	•	•
12	3	20	•	•
14	2	15	•	•
16	1	•	•	•

• Size for a 2% to 3% Voltage Drop where efficiency is important.
• Information here applies to DC and ac circuits where the Power Factor = 1.0 and the line reactance is negligible.
• For 2-wire circuits. For more complex circuits refer to an electrical engineering handbook.

Sizing Example

We have a 12 volt system with a total one-way wire run of 40 ft. servicing three 13 watt fluorescent lights and one 20 watt quartz halogen light. Sizing for a 2% voltage drop, what wire size is needed for this circuit?

$$\text{AMPS} = \frac{\text{TOTAL WATTS ALL LOADS}}{\text{VOLTS}}$$

$$\text{AMPS} = \frac{(3 \times 13) + 20}{12} = 4.9 \text{ AMPS}$$

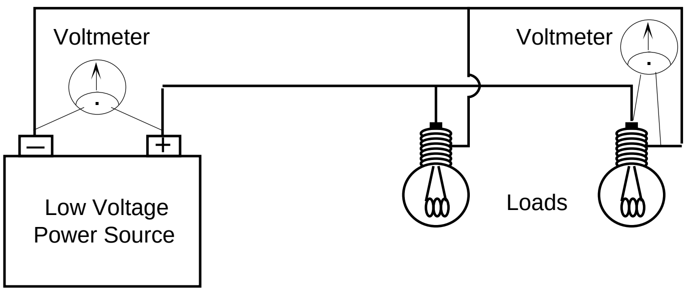
$$\text{VDI} = \frac{\text{AMPS} \times \text{FEET}}{\%\text{ VOLT DROP} \times \text{VOLTAGE}}$$

$$\text{VDI} = \frac{4.9 \times 40}{2 \times 12} = 8.2$$

The "calculated VDI" 8.2 is between VDI values 8 and 12 on the Chart. This calls for #8 gauge wire (#12 gauge wire could be used in a 24V system). Since the "calculated VDI" is not much greater than 8, we may consider sizing-down and accepting a slightly greater voltage drop. This would be sensible because #8 gauge wire is expensive and difficult to work with. Or we might consider putting these loads on two circuits--compare wire and labor costs. If typically only one of the fluorescents and the quartz halogen are operating at the same time, we could size for this typical load, being sure not to exceed the wire ampacity for the total of all loads. In this case #12 gauge wire could be used. This is an example of some of the considerations and tradeoffs that will be discussed later in this article.

Determining Voltage Drop In Existing Circuits

You may wish to know how efficient an already existing circuit is in terms of voltage drop. There is an easy way to measure this. With a "multi-tester" or voltmeter, measure the "source voltage" for the circuit and the "load Voltage" at the end of the line, then compare the difference. Do this while the circuit is powered and all the loads are on:



Now calculate the % voltage drop with the following equation--

$$\%\text{ VOLT DROP} = \frac{(\text{SOURCE VOLTS} - \text{LOAD VOLTS}) \times 100}{\text{SOURCE VOLTS}}$$

This method will total ALL voltage drops in the circuit caused by wire, connections, and switches. Because the amperage is less beyond each load in the circuit, the true % voltage drop will be somewhat less than that calculated in the above equation.

An easy way to calculate the wire voltage drop WITHOUT any measurements, if you have the information needed about the circuit, is to solve for % Voltage Drop using the VDI equation--

$$\%\text{ VOLTAGE DROP} = \frac{\text{AMPS} \times \text{FEET}}{\text{VDI} \times \text{VOLTAGE}}$$

where:

$$\text{AMPS} = \frac{\text{TOTAL WATTS ALL LOADS}}{\text{VOLTS}}$$

FEET = one-way wire length of the circuit.

VDI = VDI value, from Wire Size Chart for the gauge of wire in the circuit.

VOLTAGE = System Voltage.

Practical Applications and Considerations

Here, we will consider voltage drop and wire sizing for different types of electrical loads, alternatives to the use of large wire and long wire runs, and some recommended wiring techniques. Different electrical loads (power-consuming devices) have different tolerances for voltage drop. These guidelines will help you determine how much drop is acceptable.

Lighting Circuits

Incandescent and Quartz Halogen

A voltage drop below appropriate levels results in a disproportionate loss in performance. A 10% voltage drop causes an approximate 25% loss in light output. This is because the bulb not only receives less power, but the cooler filament drops from white-hot towards red-hot, emitting far less visible light.

Fluorescent

Voltage drop here is less critical, causing a proportional drop in light output. A 10% voltage drop results in an approximate 10% loss in light output. Because fluorescents are more efficient, they use 1/2 to 1/3 the current of incandescent or QH bulbs and therefore many be used with smaller wire (including most pre-existing ac wiring). We strongly advocate use of fluorescent lights. The unpleasant qualities of flicker and poor color rendition may be eliminated by using the more advanced 12, 24, and 120 volt fluorescents now available. See our "Efficient Lighting" article in HP#9 for details. We suggest using a 2-3% voltage drop for sizing wire in lighting circuits. If several lights are on the same circuit but are rarely all on at once, see the Part-Time Loads section for an economical approach.

Motor Circuits

DC Motors

DC motors operate at 10-15% higher efficiencies than ac motors and eliminate the costs and losses associated with DC/ac inverters. DC motors have minimal surge demands when starting, unlike ac induction motors. Voltage drop results in the motor running at a proportionally slower speed and starting more gradually. We suggest using a 2-5% voltage drop under normal operating conditions for DC wire sizing.

DC motors used for hard-starting loads, particularly deep-well piston pump jacks and compressors, may have high surge demands when starting. High power demands are also seen in DC power tools when overloaded. DC refrigerators (e.g. Sun Frost) with electronically controlled (brushless) motors will fail to start if the voltage drops to 10.5 volts, in a 12V system, during the starting surge. This is due to a low voltage shut-down device in the refrigerator intended to protect your batteries from damage. We suggest sizing wire here for a 5% voltage drop at surge current (use 3X operating current).

ac Motors

Alternating Current (ac) induction motors are commonly found in large power tools, appliances and well pumps. They exhibit very high surge when starting. Significant voltage drop in these circuits may cause failure to start and possible motor damage.

Universal Motors

Brush type ac motors ("Universal Motors") are found in smaller appliances and portable tools. As with DC motors, they do not have large surge demands when staring. However, wire should still be generously sized to allow for overload and hard-starting conditions. Consult an electrician or the *National Electrical Code* for wiring standards in ac tool and appliance circuits.

Photovoltaic Battery-Charging Circuits

In PV battery charging a voltage drop can cause a disproportionately higher loss in power transfer. To charge a battery, a generating device must apply a higher voltage than exists in the battery. That's why most PV modules are designed for 16 volts or more. A voltage drop of 1 or 2 volts in wiring will negate this necessary voltage difference, and greatly reduce charge current to the battery. A 10% voltage drop in a wire run may cause a power loss of as much as 50% in extreme cases. Our general recommendation here is to size for a 2-3% voltage drop.

PV array voltage also drops in response to high temperatures. Use high voltage modules (over 17 volts peak power) in very hot climates (where module temperatures commonly exceed 117°F./47°C.). In moderate climates, high voltage modules allow for more line voltage drop, but they cost more per Amp delivered to the battery bank. Therefore, size wire for a somewhat larger voltage drop, e.g. 5%, when high voltage modules in a moderate climate.

If you think you might expand your array in the future, install wire appropriately sized for your future needs NOW, while it is easier and less costly. It never does any harm to oversize your wire.

Number Of Circuits

If circuits are designed with numerous loads requiring large wire, overall wire cost may be adding additional circuits and putting fewer loads on each circuit. Fewer loads per circuit reduces circuit current which in turn allows for the use of smaller wire.

More Than One Size Of Wire In A DC Circuit

If you size wire for the loads on "End Branches" of a circuit, smaller wire may be used. For instance, voltage drop sizing may specify 10 gauge wire for a circuit but a light on an "End Branch" of the circuit, when sized separately, may allow for the use of 12 gauge wire from the switch to the light. Using smaller wire for "End Branches", may also make your electrical connections faster and easier because it is physically difficult to make connections to standard household switches, receptacles, and fixtures with wire larger than 12 gauge.

BE SURE THAT THE AMPACITY RATING OF ALL WIRE IN A CIRCUIT MEETS OR EXCEEDS THE FUSE PROTECTION RATING OF THE CIRCUIT.

Part-Time Loads

If a number of loads are on the same circuit but are rarely all operating at the same time, you can size the wire for voltage drop according to the TYPICAL load demand. AGAIN, BE CERTAIN THAT THE AMPACITY RATING OF ALL WIRE IN THE CIRCUIT MEETS OR EXCEEDS THE FUSE PROTECTION RATING OF THE CIRCUIT.

System Voltage

Consider 24 volt DC instead of 12 volt where feasible. Use 120 volt ac from inverter to loads where 10-20% conversion loss is not a major comprise. See our article "Selecting System Voltage" in HP#4.

Location Of System Components

Locate batteries, inverter, ac battery charger, and distribution panel near each other. Also, locate the distribution panel as close as possible to very large loads and as central as possible to all other loads. This will shorten wire runs and for some circuits, reduce the wire size required.

Water Well Pumps

Consider a slow-pumping, low power system with a storage tank to accumulate water. This reduces both wire and pipe sizes where long lifts or runs are involved. An ARRAY-DIRECT pumping system may eliminate a long wire run by using a separate PV array located close to the pump. (For more about water system design, see our article "Solar Powered Pumping", HP#11.)

Soldering vs. Mechanical Connections

Soldering is recommended around battery and inverter terminals (see "Build Your Own Battery/Inverter Cables" in HP#7) and in other corrosive, high-current environments OR at the discretion of the installer. Soldering requires skill and has numerous pitfalls--too much or too little heat, oxidized or dirty metal, the wrong solder or flux, or just lack of experience will GUARANTEE poor solder joints. Do not attempt to solder connections in your system unless you have learned do it properly. A tight mechanical joint is far safer than a questionable solder joint.

Grounding And Lightning Protection

We've seen thousands of dollars of damage to electrical equipment from lightning. In one PV home a lightning bolt entered the house via the PV wiring and exited the other side of the house, popping plaster and light bulbs, and burning wire along the way. Proper grounding PREVENTS nearly all such occurrences. For a more thorough discussion, see our article "Grounding and Lightning Protection", HP#6.

Audio Signal Wires

Wires that carry audio signals (telephones, intercom, speakers) may pick up buzzing noise if run alongside ac wiring. This is especially true when the ac power is from an inverter. Avoid this problem by running audio wires along a separate path (or in a separate trench) from the ac wires. Keep then as far apart as possible, especially on long runs. Proper grounding also helps. Audio wires will NOT pick up noise from DC lines.

Wiring Design And Installation Book

We recommend *The Solar Electrical Independent Home Book* to familiarize you and your PV installer/electrician with safe up-to-code installation procedure (available from Flowlight Solar Power).

About the Authors

Windy Dankoff is owner of Flowlight Solar Power. Flowlight supplies remote home PV systems and manufactures "Flowlight Solar Pumps". Windy began working with wind generators in 1975 and PV in 1979. He has contributed 12 articles to *Home Power* since issue #2.

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***Editor's Note**: I have reprinted the first section of this article which appeared in HP#13. This is because I introduced serious errors when typesetting the equations in this article for HP#13. My sincere apologies to John, Windy & any reader who tried to make sense of the hash I made of the data. This version contains the straight info. Richard Perez*

Courant nominal maximal de l'élément fusible, en A	Courant minimal admissible de court-circuit entre deux phases, en A	Sections minimales admissibles des conducteurs de câble, en mm²		Courants maximaux admissibles en service ininterrompu, en A	
		câbles souples isolés au caoutchouc, séries GRCh et GRChN	câbles armés, séries SB et SBG	câbles souples isolés au caoutchouc, séries GRCh et GRChN	câbles armés, séries SB et SBG
Tension nominale de 380 et 660 V					
20	140	2,5	—	25	—
25	175	2,5	—	25	—
35	245	4	2,5	34	28
60	420	6	4	43	37
80	560	10	6	55	45
100	700	16	10	70	60
125	800	25	16	95	80
160	800	35	25	115	105
200	800	50 (35)	35	145	125
—	—	—	50	—	155
—	—	—	70	—	200
—	—	—	95	—	245
Tension nominale de 127 V					
6	24	2,5	—	25	—
10	40	2,5	—	25	—
15	60	2,5	—	25	—
20	80	2,5	—	25	—
35	140	4	—	34	—
60	240	6	—	43	—

Nota : La section d'un conducteur de câble, de 35 mm², indiquée entre parenthèses admissible au point de vue d'échauffement par les courants de court-circuit, est à éviter du fait d'une chute de tension importante au démarrage.

Approximate full load currents of a.c. electric motors

Motor rating		*Single-phase*	*Three-phase*		
kW	*HP*	*240V*	*220V*	*380V*	*415V*
0.75	1.0	6.2	3.3	2.1	2.0
1.5	2.0	11.8	6.2	3.6	3.5
3.0	4.0	20	11.6	6.6	6.5
4.0	5.5	29	15.3	8.5	7.7
5.5	7.5	36	21	11.5	11
7.5	10	45	27	15.5	14
15	20	91	53	30	29
20	27		70	40	38
25	34		85	50	45
30	40		101	60	54

HBC fuse ratings for direct-on-line and assisted starting

Direct-on-line starting (to withstand 7 × full load current for 10 seconds)			*Assisted starting: Star-Delta, auto-transformer, rotor resistance starters (to withstand 3 × full load current for 20 seconds)*		
Motor full load current, A		*Standard fuse rating, A*	*Motor full load current, A*		*Standard fuse rating, A*
From	*To*		*From*	*To*	
0	0.7	2	5.5	10.0	16
0.8	1.1	4	10.1	14.3	20
1.2	1.6	6	14.4	18.3	25
1.7	2.6	10	18.4	22.6	32
2.7	5.2	16	22.7	29.2	35
5.3	7.5	20	29.3	35.0	40
7.6	9.9	25	35.1	42.8	50
10.0	11.6	32	42.9	55.0	63
11.7	15.7	35	55.1	74.2	80
15.8	19.3	40	74.3	97.3	100
19.4	22.9	50	97.4	125	125
23.0	28.6	63	125	160	160
28.7	41.4	80	160	180	200
41.5	54.3	100			
54.4	71.5	125			

Sizing cables for submersible pumps

3 × 415V, 50 Hz (4% voltage drop)

Motor kW	*Maximum cable length (metres) for cables of the following cross-sectional area*								
	1.5mm²	2.5mm²	4mm²	6mm²	10mm²	16mm²	25mm²	35mm²	50mm²
0.37	700								
0.55	530								
0.75	400								
1.1	285								
1.5	220								
2.2	150	260							
3.7	90	160	260						
5.5	70	130	200						
7.5		100	150	230	330				
11.0			100	150	260				
15.0				120	200				
18.5					160	250			
22.0					130	200			
30.0						160	250		
37.0						130	210	290	
45.0							170	240	
55.0								200	
75.0									200

1 × 240V, 50 Hz (4% voltage drop)

Motor kW	*Maximum cable length (metres) for cables of the following cross-sectional area*				
	1.5mm²	2.5mm²	4mm²	6mm²	10mm²
0.37	125	210	330		
0.55	90	155	235		
0.75	65	115	175		
1.1	50	85	135	205	310
1.5	35	60	95	140	235
2.2		45	70	110	175

Source: Grundfos Pumps Ltd

Cables should be protected from physical damage by burying in trenches, putting them overhead or running them through conduits, such as pipes.

G. Voltage Drop in Conductors

Where the permissible voltage drop is greater than 1 percent, multiply the distance values below by the total percentage of voltage drop. For example, if a 2 percent voltage drop is acceptable, double the distance values in the following table.

Table G

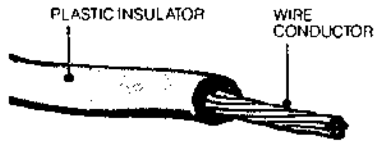
One-Way Distance (Feet) to Load for 1 Percent Voltage Drop in Copper and Aluminum Wire in the United States

Approx. Gen. Size (kW)	Max. Current (amps)	Wire Size (AWG) 10 (Cu)	10 (Al)	8 (Cu)	8 (Al)	6 (Cu)	6 (Al)	4 (Cu)	4 (Al)	3 (Cu)	3 (Al)	2 (Cu)	2 (Al)	1 (Cu)	1 (Al)	0 (Cu)	0 (Al)	00 (Cu)	00 (Al)	000 (Cu)	000 (Al)
12 volts																					
0.01	1	48	30	74	47	118	74	187	118	236	149	299	188	375	237	472	299	594	377	753	476
0.06	5	10	6	15	9	24	15	37	24	47	30	60	38	75	47	94	60	119	75	151	95
0.12	10	5	3	7	5	12	7	19	12	24	15	30	19	38	24	47	30	59	38	75	48
0.24	20	2	2	4	2	6	4	9	6	12	7	15	9	19	12	24	15	30	19	38	24
0.48	40	1	1	2	1	3	2	5	3	6	4	7	5	9	6	12	7	15	9	19	12
24 volts																					
0.24	10	10	6	15	9	24	15	37	24	47	30	60	38	75	47	94	60	119	75	151	95
0.48	20	5	3	7	5	12	7	19	12	24	15	30	19	38	24	47	30	59	38	75	48
0.7	30	3	2	5	3	8	5	12	8	16	10	20	13	25	16	31	20	40	25	50	32
1	40	2	2	4	2	6	4	9	6	12	7	15	9	19	12	24	15	30	19	38	24
1.4	60	2	1	2	2	4	2	6	4	8	5	10	6	13	8	16	10	20	13	25	16
1.9	80	1	1	2	1	3	2	5	3	6	4	7	5	9	6	12	7	15	9	19	12
2.4	100	1	1	1	1	2	1	4	2	5	3	6	4	8	5	9	6	12	8	15	10
2.9	120	1	1	1	1	2	1	3	2	4	2	5	3	6	4	8	5	10	6	13	8
3.4	140	1	0	1	1	2	1	3	2	3	2	4	3	5	3	7	4	8	5	11	7
36 volts																					
0.7	20	7	5	11	7	18	11	28	18	35	22	45	28	56	36	71	45	89	57	113	71
1.4	40	4	2	6	4	9	6	14	9	18	11	22	14	28	18	35	22	45	28	56	36
2.2	60	2	2	4	2	6	4	9	6	12	7	15	9	19	12	24	15	30	19	38	24
2.9	80	2	1	3	2	4	3	7	4	9	6	11	7	14	9	18	11	22	14	28	18
3.6	100	1	1	2	1	4	2	6	4	7	4	9	6	11	7	14	9	18	11	23	14
48 volts																					
1	20	10	6	15	9	24	15	37	24	47	30	60	38	75	47	94	60	119	75	151	95
1.4	30	6	4	10	6	16	10	25	16	31	20	40	25	50	32	63	40	79	50	100	63
1.9	40	5	3	7	5	12	7	19	12	24	15	30	19	38	24	47	30	59	38	75	48
2.4	50	4	2	6	4	9	6	15	9	19	12	24	15	30	19	38	24	48	30	60	38
2.9	60	3	2	5	3	8	5	12	8	16	10	20	13	25	16	31	20	40	25	50	32
3.4	70	3	2	4	3	7	4	11	7	13	9	17	11	21	14	27	17	34	22	43	27

One-Way Distance (Feet) to Load for 1 Percent Voltage Drop in Copper and Aluminum Wire, con't.

Approx. Gen. Size (kW)	Max. Current (amps)	Wire Size (AWG) 10 (Cu)	10 (Al)	8 (Cu)	8 (Al)	6 (Cu)	6 (Al)	4 (Cu)	4 (Al)		3 (Cu)	3 (Al)	2 (Cu)	2 (Al)	1 (Cu)	1 (Al)	0 (Cu)	0 (Al)	00 (Cu)	00 (Al)	000 (Cu)	000 (Al)
120 volts																						
1.2	10	48	30	74	47	118	74	187	118		236	149	299	188	375	237	472	299	594	377	753	476
1.8	15	32	20	49	31	78	50	125	79		157	99	199	125	250	158	315	199	396	252	502	317
2.4	20	24	15	37	23	59	37	93	59		118	74	149	94	188	119	236	149	297	189	376	238
3	25	19	12	30	19	47	30	75	47		94	60	119	75	150	95	189	119	238	151	301	190
3.6	30	16	10	25	16	39	25	62	39		79	50	100	63	125	79	157	100	198	126	251	159
4.2	35	14	9	21	13	34	21	53	34		67	43	85	54	107	68	135	85	170	108	215	136
4.8	40	12	8	19	12	29	19	47	30		59	37	75	47	94	59	118	75	149	94	188	119
7.2	60	8	5	12	8	20	12	31	20		39	25	50	31	63	40	79	50	99	63	125	79
10	80	6	4	9	6	15	9	23	15		30	19	37	24	47	30	59	37	74	47	94	60
12	100	5	3	7	5	12	7	19	12		24	15	30	19	38	24	47	30	59	38	75	48
240 volts																						
2	10	95	60	148	94	235	149	374	236		472	298	597	376	750	474	945	597	1188	755	1506	952
5	20	48	30	74	47	118	74	187	118		236	149	299	188	375	237	472	299	594	377	753	476
10	40	24	15	37	23	59	37	93	59		118	74	149	94	188	119	236	149	297	189	376	238
14	60	16	10	25	16	39	25	62	39	79	50	100	63	125	79	157	100	198	126	251	159	
19	80	12	8	19	12	29	19	47	30	59	37	75	47	94	59	118	75	149	94	188	119	
24	100	10	6	15	9	24	15	37	24	47	30	60	38	75	47	94	60	119	75	151	95	

Wire



Low voltage power systems often operate at rather high current levels. If the interconnecting cables are too small, a large proportion of the power available will be wasted in the cable itself. This loss can be reduced by using a larger cable, but this increases costs. The chart and the formula on this page are provided to help you in selecting the best cost / power loss compromise.

WIRE CHART

Voltage lost per 10 metres of route length of twin cable.

Amps	Wire Size .4	2	3.2	5	7.5	15
.5	.43	.09	.05	.03	.02	.01
1	.85	.17	.11	.07	.05	.02
1.5	1.3	.26	.16	.10	.07	.03
2	1.7	.34	.21	.14	.09	.05
2.5	2.1	.43	.27	.17	.11	.06
3	2.6	.51	.32	.20	.14	.07
4	3.4	.68	.43	.27	.18	.09
5	4.3	.85	.53	.34	.23	.11
7.5	6.4	1.3	.80	.51	.34	.17
10		1.7	1.1	.68	.45	.23
15		2.6	1.6	1.0	.68	.34
20		3.4	2.1	1.4	.91	.45
25		4.3	2.7	1.7	1.1	.57
30	DO NOT		3.2	2.0	1.4	.68
40	use cable			2.7	1.8	.91
50	sizes and currents				2.3	1.1
75	in this section as					1.7
100	overheating will occur					2.3

Power loss in watts per 10 m of route length of twin cable

Amps	Wire Size .4	2	3.2	5	7.5	15
.5	.21	.04	.03	.02	.01	.01
1	.85	.17	.11	.07	.05	.02
1.5	1.9	.38	.24	.15	.10	.05
2	3.4	.68	.43	.27	.18	.09
2.5	5.3	1.1	.66	.43	.28	.14
3	7.7	1.5	.96	.61	.41	.20
4	14	2.7	1.7	1.1	.73	.36
5	21	4.3	2.7	1.7	1.1	.57
7.5	48	9.6	6.0	3.8	2.6	1.3
10		17	11	6.8	4.5	2.3
15		38	24	15	10	5.1
20		68	43	27	18	9.1
25		106	66	43	28	14
30	DO NOT		96	61	41	20
40	use cable			109	73	36
50	sizes and currents				113	57
75	in this section as					128
100	overheating will occur.					227

NOTE: The above distances are route length. The table takes the total conductor length into account. If the positive and negative leads are different lengths an average must be taken.

Metric cables are specified by the copper area (in square millimetres), the number of strands of wire and the number of conductors or cores in each sheath. The voltage drop is the same regardless of voltage, assuming that amps, distance and cross sectional areas are the same. If the wattage remains the same for different voltages, the amps can be calculated by dividing watts by volts.

The Formula

To calculate amps for 0.5 volt drop, divide above figures by 2.

To calculate amps for a 2 volt drop, multiply above figures by 2.

If you need to calculate the voltage drop under a given set of circumstances, there is a formula by which it can be determined.

Let:

A = cross sectional area of cable in (mm^2)
L = length of cable in metres
(twice distance to complete circuit)
I = current measured in amps
R = resistance of cable (Ω)
resistance of copper = 0.017 Ω
aluminium = 0.028 Ω
steel = 0.18 Ω

Voltage Drop = LxIxR÷A

Example:

You have a power point connected to a power source. The distance of the positive wire is greater than the distance of the negative wire. The total distance that the current must flow is obtained by adding both these distances together. If the length of the positive cable is 6 metres and the negative is 4 metres, then the total distance that the current must flow is 10 metres. If the wire is 5 mm^2 multi-stranded copper cable and the expected current is expected to be 20 amps, we have:

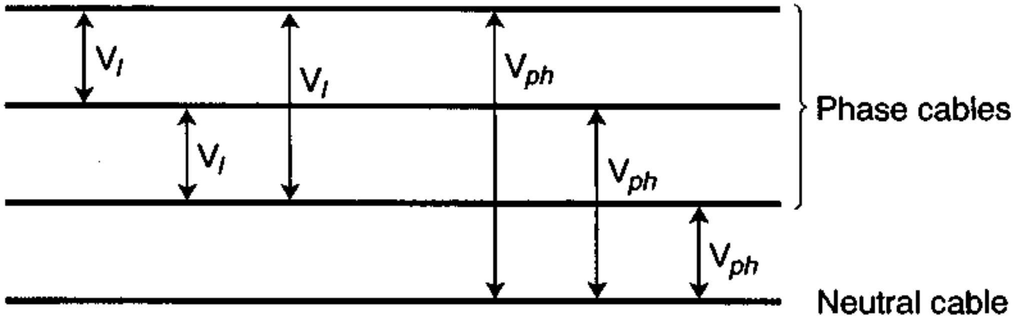
A = 5 L = 10 I = 20 R = 0.017

Voltage drop can then be calculated to be 0.68 volts. If this figure is considered to be acceptable it would avoid spending more money on larger wire.

Catalog Numbers

mm^2		per metre	30 m roll	100 m roll
0.4	twin	WIR-M01	WIR-301	WIR-101
2.0	twin	WIR-M03	WIR-303	WIR-103
2.0	double	WIR-M04	WIR-304	WIR-104
2.5	twin+earth	WIR-M12	WIR-312	WIR-112
3.2	double	WIR-M06	WIR-306	WIR-106
5.0	double	WIR-M05	WIR-305	WIR-105
7.5	single	WIR-M09	WIR-309	WIR-109
15.0	single	WIR-M10	WIR-310	WIR-110

Figure summarizes the terminology used when referring to a three-phase electricity supply.



V_l is the line voltage (also known as the system voltage)

V_{ph} is the phase voltage

$V_l = \sqrt{3} \times V_{ph}$

Example: If V_l = 415V, then V_{ph} = 240V and the system is designated 415/240V

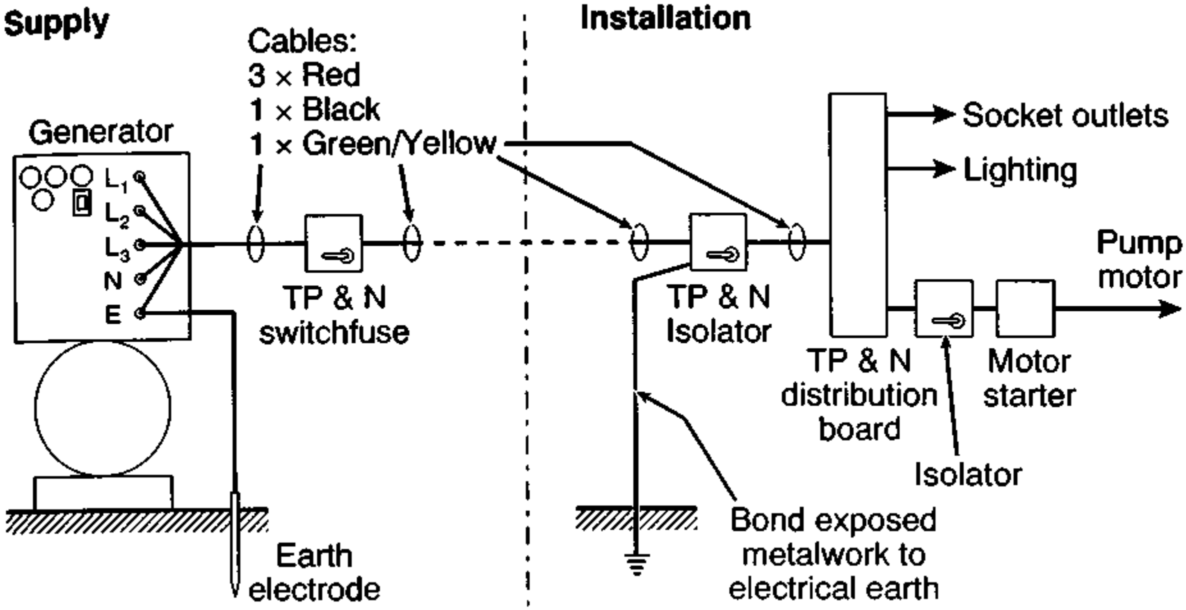
A typical three-phase electricity supply

Cable coding

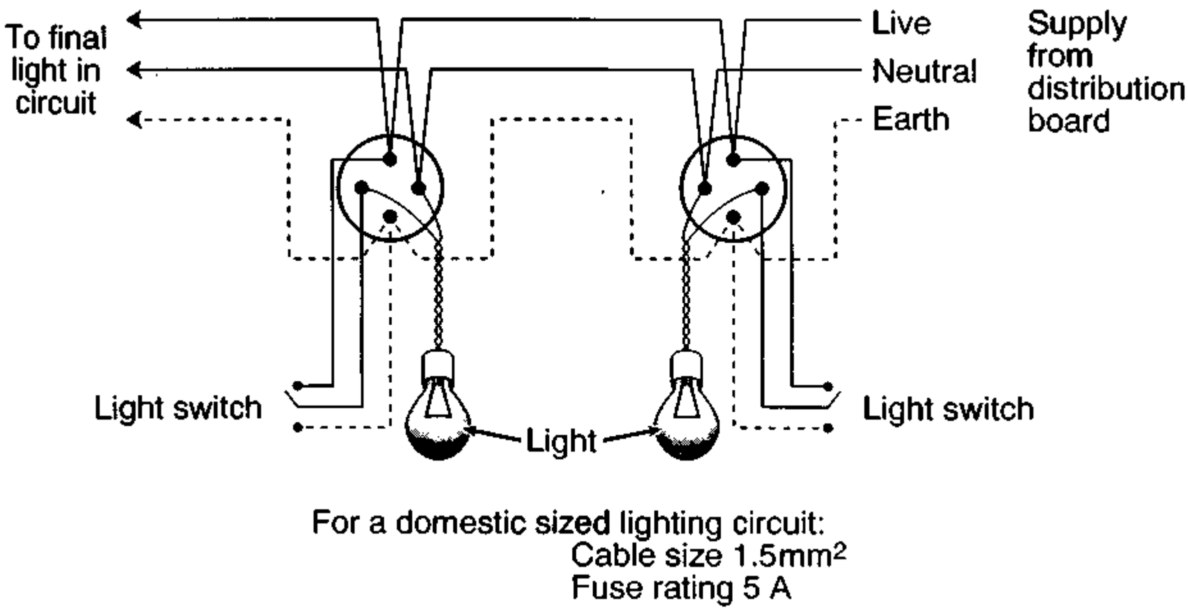
There are standard codings for cables used in three-phase, neutral and earth supply (see Box 14.1). Keeping to the standard colour codes makes subsequent fault-finding easier. Codes may be indicated by coloured core insulation, sleeving or tapes.

Box 14.1 Standard cable coding

Phases			Neutral	Earth
Red U R L_1	Blue V S L_2	Yellow W T L_3	Black N N N	Green/Yellow E E E

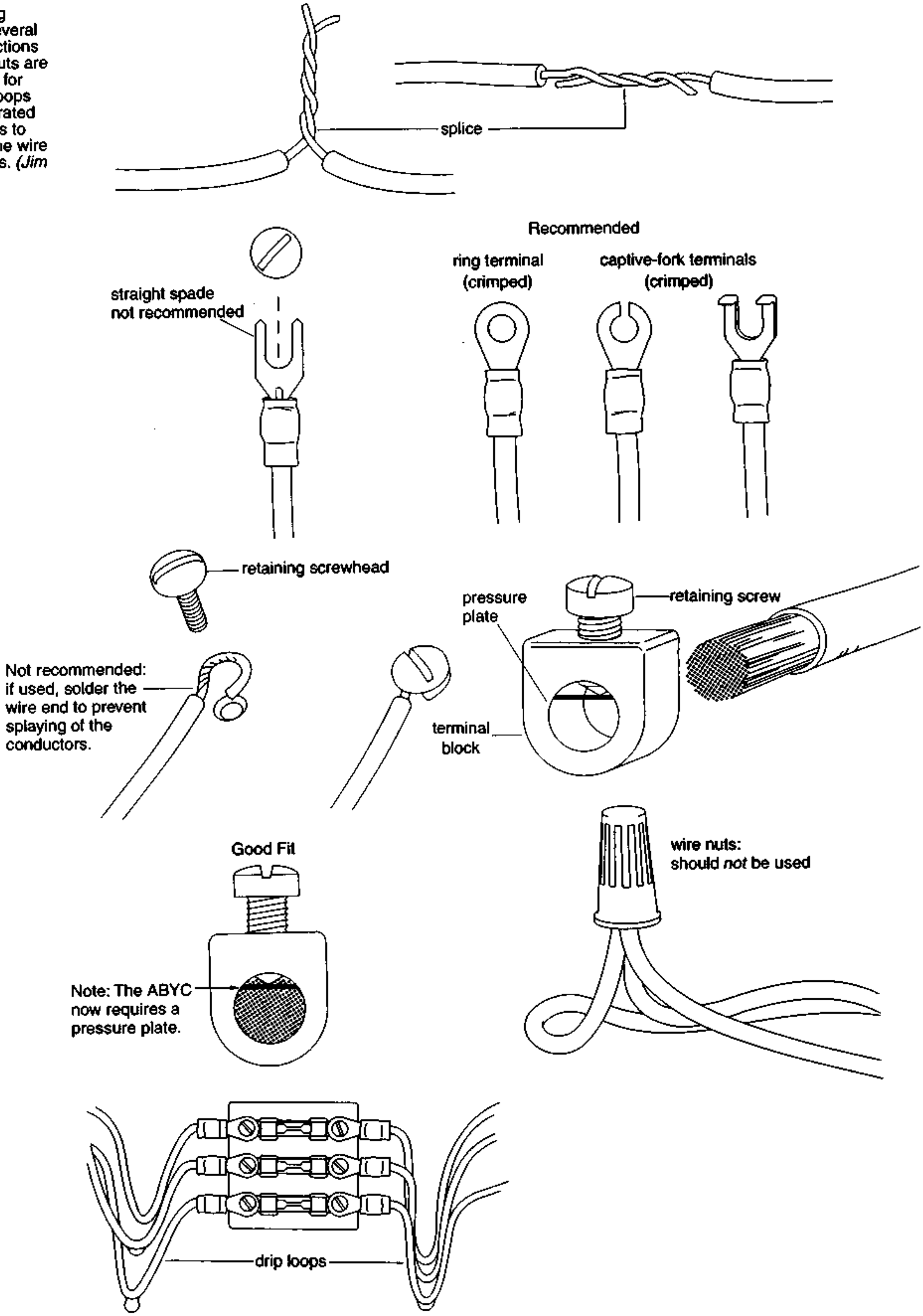


A typical electrical supply from generator to pump



A simple lighting circuit

Figure 3-43. Wiring installation tips. Several acceptable connections are shown. Wire nuts are *not* recommended for marine use. Drip loops should be incorporated into all connections to keep water from the wire ends and terminals. *(Jim Sollers)*



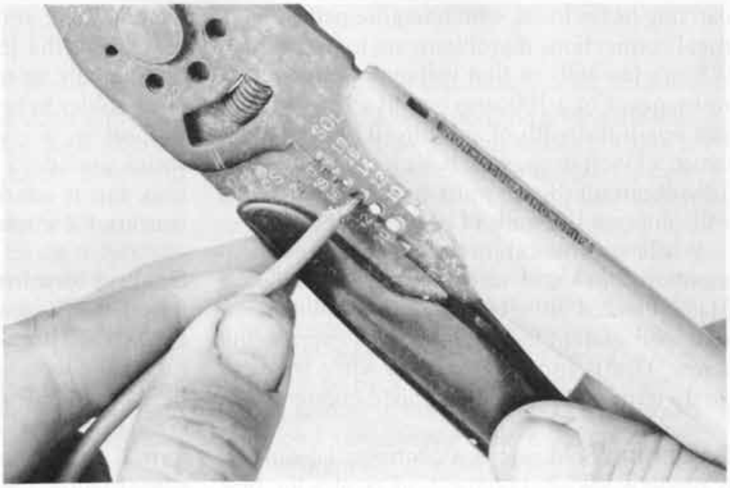


Figure 3-44. Wire stripper in use on a cheap multi-purpose crimping and stripping tool. Note that the stripping holes are numbered with their AWG sizes—the numbers on the left-hand side are for stranded cable; those on the right-hand side for solid cable. The threaded holes in the tool (top left) are for cutting terminal retaining screws to length. The screws are threaded in from the numbered side, cut to length, and backed out. This tool has both indent and elliptical crimping slots (not shown).

Figure 3-45. A ratcheting-type crimper that does a perfect job every time. This one makes a double crimp (see Figure 3-46).

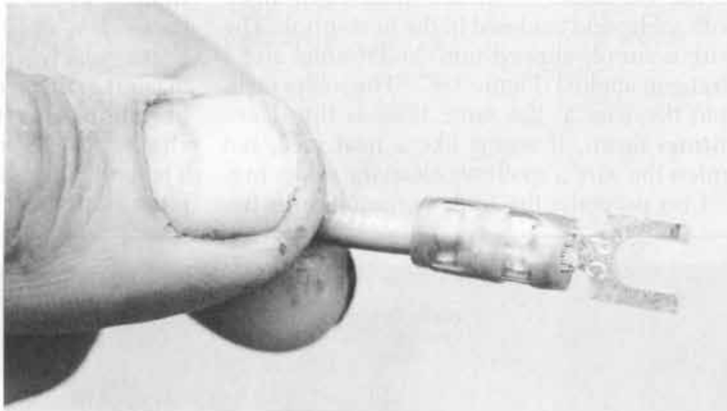


Figure 3-46. Double crimp, once on the terminal barrel and once on the insulated sleeve. Note that these are elliptical crimps, not indent crimps, because this is an insulated terminal (although in point of fact, an indent crimp could have been used in this case since this is a nylon sleeve).

To avoid the risk of cutting through any insulation, *an indent crimp is normally made only on an uninsulated terminal* (although it is permissible to use it on *nylon-sleeved* terminals, since the nylon resists cracking); for insulated terminals it is important to use an *elliptical* crimp (most cheap crimping tools will do both—its simply a matter of choosing the right slot).

But rather than use a cheap crimping tool, every maintenance-conscious boatowner should have a ratcheting-type crimper in the toolbox (Figures 3-45 and 3-46). These will assure a perfect crimp every time.

Special crimping tools are needed for larger cable sizes, but these need not be expensive (the Ancor catalog is an excellent source for marine-grade wiring products and installation tools: Ancor, Cotati, CA). These large cables will be carrying heavy loads, which require perfect electrical connections if problems are to be avoided. (Ohm's law tells us that voltage = amperage × resistance. On a 100-amp circuit a resistance of just one-hundredth of an ohm (0.01 ohm) will cause a 1-volt drop, which is close to 10% on a 12-volt circuit. Since watts = volts × amps, this will generate 100 watts of heat.)

While on the subject of tools, let me also mention *split-shank* screwdrivers. These have a blade divided into two sections that can be squeezed apart in the slot of a screw, gripping the screw. This is an invaluable tool when trying to do up terminal screws in cramped quarters.

Soldering. Soldering is a controversial subject. A properly soldered connection creates the best electrical connection, but all too often the soldering is not done properly. In any case, ABYC regulations require that every joint have a *mechanical* means of connection other than solder. The reason for this is that if the joint gets hot (through excessive resistance or a high current flow) the solder may melt and the joint fall apart. So soldering frequently becomes just an adjunct to a crimped connection, but in this case the solder wicking up the cable creates a hard spot, which is then liable to fail from vibration. *The consensus among professionals is that a properly made crimp, done with the proper tools, is frequently a more reliable termination than soldering.*

Recently low-temperature solder connections with a heat-shrink sleeve have been introduced to the US market. The terminals come lined with solder and enclosed in the heat shrink. The wire is simply slipped into the terminal and a heat-gun applied (Figure 3-47). The solder melts into the wire at the same time as the sleeve shrinks down. It seems like a neat idea, but unless the wire is spotlessly clean the solder may not tin properly; the solder penetration is frequently poor; and the solder melting point is so low that if the joint heats up it may well fail. Additionally, as mentioned, the ABYC does not allow solder to be the sole means of mechanical support in a connection. Although the heat shrink provides a degree of mechanical connection, this is not the same as a crimp. For these reasons, these terminals are not recommended.

Sealing terminals. In recent years heat-shrink tubing has become widely available. Heat shrink consists of a plastic tube that is slipped over a terminal and then heated, preferably with a proper heat gun, but a small propane torch or even a cigarette lighter will do. The tubing contracts to form a tight fit around the terminal barrel and wire (Figures 3-49A, 3-49B and 3-49C).

There are three types of heat shrink: *thin wall*; *dual wall* (which is thin wall lined with an adhesive); and *heavy wall with sealant*. The thin wall (which is commonly found at Radio Shack in the USA) provides insulation, but *not weatherproofing*; the adhesive in the dual wall and heavy wall is squeezed out of both ends of the tubing as it contracts, *forming an extremely effective barrier to moisture penetration*. The heavy wall provides an added margin of abrasion resistance over the dual wall. One or two companies now have a line of "waterproof" terminals that have a length of heat shrink tubing already built onto the terminal sleeve.

Some joints that need insulating are an awkward shape with protruding corners and screws. In these instances, electricians' putty comes in handy. It is a pliable substance, similar to plasticene, which is molded around the connection to fair it so that it can be wrapped smoothly with heat shrink tape (this can be bought in rolls; it is known as *self-amalgamating tape* in the UK). The putty itself has a high insulating value but is too soft to be left uncovered.

Figure 3-47. Low-temperature solder connection with built-in heat shrink tubing. The solder sleeve is just beginning to melt into the lay of the two cables. At the same time the heat shrink sleeve is starting to clamp down around the cables.

Soldering on Board

Most soldering aboard can be done with a 50- to 100-watt soldering iron; a few large jobs are best done with a propane torch. Soldering irons can be bought for use with 12-volt systems but are electrically greedy (a 50-watt iron will draw close to 5 amps). Since the iron is used intermittently and for short periods, this is not a great problem. Also available now are small, pocket-sized temperature-controllable butane soldering torches.

Solder is always used with a *flux*, an agent that helps to keep the metal surfaces clean while being soldered. Fluxes are either acid based or rosin based. Only rosin-based fluxes can be used in electrical work, acid fluxes will corrode copper wire.

There are numerous grades of solder, rated by their percentage of tin, lead, or silver. The best all-around solder for electrical work is 60/40 (60% tin; 40% lead). Avoid cheap solders with higher percentages of lead. Solder comes in rolls of either solid or rosin-cored wire, the latter having a hollow center with flux already in it whereas solid solder requires an external application of flux. The rosin-cored solder is suitable for most marine uses and is much more convenient.

The keys to successful soldering are having a well-tinned soldering iron and tinning the individual pieces to be bonded *before* the joint is made. To tin the iron, clean its tip down to bare metal with a file, heat it up, and then touch rosin-cored solder to it. The solder should flow over the whole tip to form a clean, shiny surface. If it will not adhere to areas of the tip, there are impurities. Sometimes scratching around with a knife and the solder (to lay on more rosin) will clean these areas, but it may be necessary to go back and start again with the file. During soldering, the tip of the hot iron should be wiped periodically with a damp rag to remove burnt flux and old solder.

To tin wire ends and terminals, clean them down to bare, shiny metal and then hold the iron to the part to heat it. Touch the solder *to the part*, not to the iron. When the part is hot enough, the solder will flow over and into it, at which point the iron can be withdrawn—the tinning is complete. Once again, if the solder will not adhere to certain areas, they are not clean enough. To speed the heating of the part, place a drop of solder on the iron itself where it is in contact with the part; the actual tinning should always be done by applying the solder as described above.

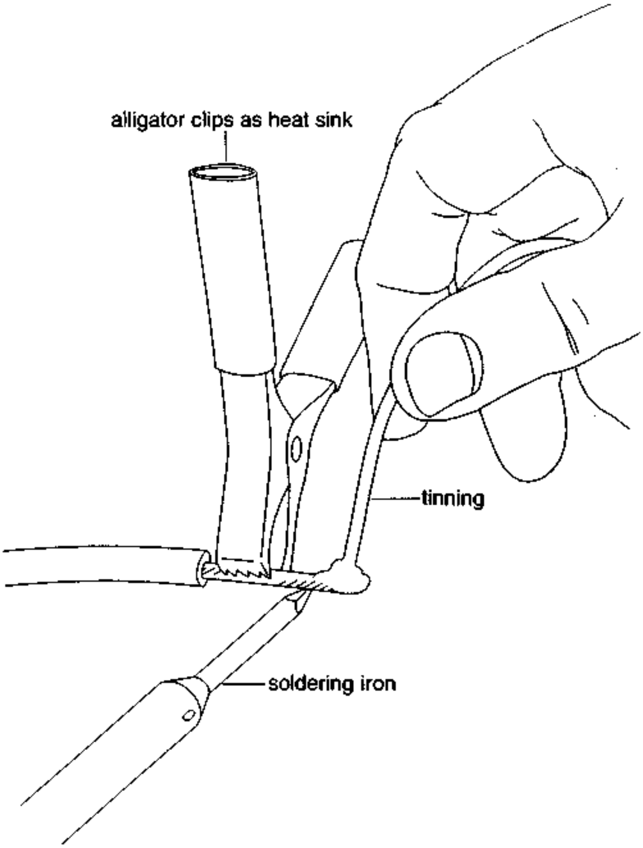
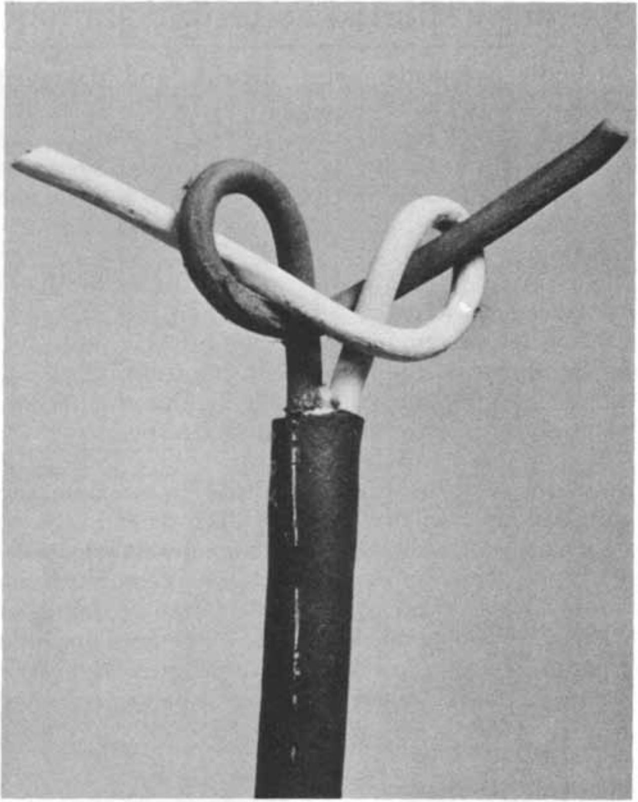


Figure 3-48. Soldering practices. Note that an alligator clip or a strip of aluminum used as a heat sink will protect the insulation from melting. When tinning (applying solder to the wire—not necessary on tinned wire), touch the solder to the wire, not to the iron. As a preparatory step, sandpaper or file the tip of the iron to a pyramid-shaped point of bright metal, then heat the iron, file it bright again, and, working fast, run on a little solder. Try to achieve a good coating of solder over the entire point and ½ inch or so down the tip. Before making a joint, scrape the wire clean and bright. Place the parts to be soldered in firm contact. Use enough heat, but don't overheat. Keep the joint and wire immobile while the solder cools. *(Jim Sollers)*



Form an Underwriters' Laboratory electrical knot like this. Purpose of the knot is to prevent undue strain on the plug when it's pulled out of an outlet by the cord—instead of by the plug. When you strip the wire, give yourself about 3 to 4 inches of wire for the knot. Thread the plug on the wire before you tie the knot. Then pull the knot as tight as possible and slip the plug down over the knot so it is seated snugly in the base of the plug.

Wiring Your Own Home

The Basics of 12 Volt Wiring

Many people living in rural areas will have discovered the high cost of connecting to the power grid. The only affordable option for you may be to have your own stand-alone power supply. Petrol and diesel generators may be seen as an immediate solution. But, per kilowatt hour of power, they are a more expensive way to meet your power requirements than being connected to the power grid.

In this kind of situation a Solar Electric power system becomes quite price competitive. The major costs of such a power system are primarily the capital expenses (ie purchase price of solar panels, batteries, wire, fittings etc.). One advantage with low voltage systems such as a 12 volt or 24 volt system is that it is considered not to be dangerous and hence a licenced electrician is not required.

If the walls of your house are not already lined, it makes good sense to design and install your electrical wiring before the walls are finished to avoid problems later on and unsightly wires being visible. Make sure the walls are vermin proof as rats chewing through insulation can cause serious problems. Attempt to plan for future expansion of your electrical system by using a larger size of wire where necessary and allowing for extra connections in accessible areas.

On the previous page we have a very basic circuit diagram for a typical small home, along with some useful hints. First of all we must stress the importance of using significantly larger wire than would be used in an equivalent 240 volt situation. With 12 volt wiring, the voltage drop resulting from resistance losses is comparatively twenty times higher than with 240 volt wiring. The voltage drop is actually much the same regardless of voltage, but a 2 volt drop at the appliance end of a 240 volt lead is quite insignificant (0.83%), whereas a 2 volt drop in a 12 volt situation is quite significant (16.67%).

The size of the wire should be increased when either the distance or the amps is increased. It is also important to make good solid connections everywhere and to guard against corrosion. In a low voltage installation it can save you a lot of annoyance and inconvenience to solder multi-stranded wire whenever the insulation is stripped back. The corroded surface on a strand of wire has an electrical resistance which could cause havoc in a low voltage installation.

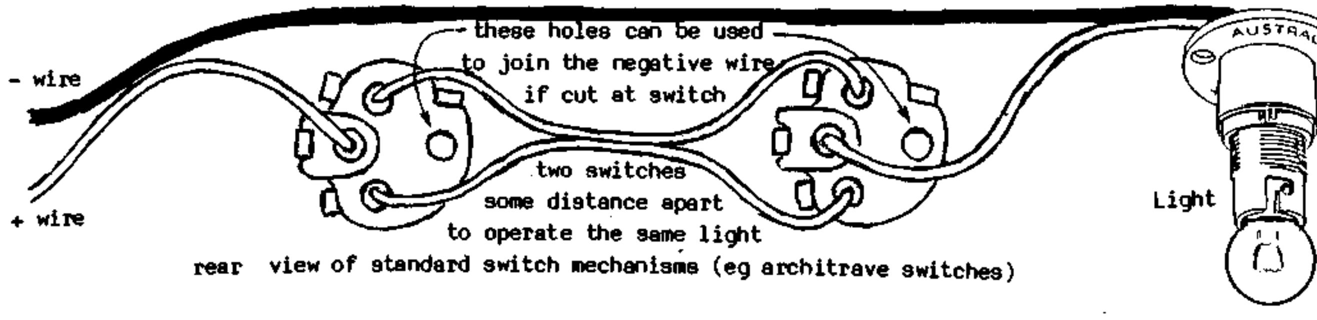
Tarnished metal cannot be soldered. All metal surfaces must be absolutely clean, shiny and untarnished before any soldering is attempted.

It is a good idea to use a soldering iron that can be heated over a clean gas flame and a fairly large tip to retain the heat. The tip must be 'tinned' over an area which is at least equivalent to the cross sectional area of the wire you intend to solder. 'Tinning' is the process of melting solder onto a metal surface so that the two metals bond to each other (ie the solder and the copper). If the tip looks black, flakey or generally dirty it may need to be cleaned up with a file so that a shiny metallic surface is exposed. Once the iron has built up enough heat over a clean flame, the solder should flow onto the tip very easily.

The solder that is normally used for electrical work is resin core solder, which means that it carries a special soldering flux mixture in the centre of the usually wire-like solder. For most of the work that we are going to describe we would recommend 1 mm diameter resin core solder, although for some of the larger cables a larger diameter solder may be desirable.

The insulation should be stripped away from the cable cleanly without damaging the wire strands underneath. The hot soldering iron is placed against the exposed wire whilst carefully melting the end of the solder against the iron in such a way as to transfer some of the molten solder and the heat of the iron onto the wire. The wire should then acquire enough heat to melt the solder directly. The solder should cover the exposed wire completely so that the separate copper strands are bonded together and the exposed copper surface no longer visible. The solder should flow into the multi-stranded wire so that all the strands are bound together.

If there is any corrosion on the copper, the solder will not take. You may then have to dip the end of the wire into hydrochloric acid in order to clean it up so that the solder will take. A flat copper surface can be cleaned with a file or sandpaper, but this approach cannot be used with multi-stranded cable. Ideally, the solder should have flowed back into the insulation without having heated it to the point that the insulation has expanded. You may need to put in a lot of practice before you do it well.



rear view of standard switch mechanisms (eg architrave switches)

You may now fasten the wire into screw connectors (in active and neutral links*, switches, power points etc.). Tighten the screw down, and be assured that you make a firm contact with the whole of that wire. The wire and connectors at the battery terminal and the battery itself, should be lightly coated with petroleum jelly (vaseline) for extra protection against the corrosive properties of battery acid. Do not connect onto both battery terminals until all other wires connected to the battery are safely secured and not likely to short (positive touching negative).

The control board should be fairly close to the battery using wire of at least 5 mm^2 connected between the two. Once connected, the control board now becomes the hub of the system, with all the wiring from here on connected back to the control board and not to the battery.

We must point out that a 12 volt power supply has as much potential to cause a fire as does a 240 volt supply. The fuse or circuit breaker is there to protect against such risk. While you are wiring up the house, leave the fuse out of the fuse holder or leave the circuit breaker off until you have finished the job. A danger still exists between the battery and the fuse holder or circuit breaker and steps should be taken to minimize this risk (eg fuse closer to the battery, positive and negative cables a distance apart from each other).

The control board should be connected before the cable is bolted onto the battery terminals. Whether you are putting in 12 volt lights or 12 volt power points, you will usually find it easier if you start at the light fitting, power point or control board and carefully lay and securely fix the wire until you get back to the active and neutral links.

You may want to install a whole lot of lights and power points in one area at a fair distance from the control board. What you can do here is to run a heavy duty twin cable (positive and negative) of say 5 mm^2 from the control board to another set of active and neutral links near where you want to do this extra wiring. Once connected, these links now become a distribution point for further expansion.

As you are running the wire from the light fitting back to the active and neutral links, you should take the wire past the point where you want the light switch. Cut through the positive wire only and the two exposed ends of this cut can now be stripped of insulation, soldered and connected into the switch. If the switch happens to be further away from the power source than the light, you can start wiring from the switch and take the wire past where you want the light to be and connect the light to the two exposed ends of the positive wire in the same way as we did the switch in the previous example. But if you do this, you must remember that the wire coming back from the switch to the light fitting is now negative (in case you are connecting a polarity conscious light fitting).

Incandescent lights are not polarity conscious, that is to say that it doesn't matter which way it is connected to the power source. Fluorescent lights designed for 12 volt systems are usually polarity conscious and you can damage the built in circuitry if you connect them the wrong way round. The same applies to TV's, radios, tape decks etc, so take care and check everything several times before plugging appliances in. You may find that there is a reverse polarity protection built-in, but you should always assume that there isn't, unless you know otherwise.

When wiring up switches and to avoid making mistakes, it makes it easier if you only cut through the positive wire coming past the switch and to leave the negative wire intact. The recommended wire to your lights should be 2 mm^2. 5 mm^2 may be used for long cable runs and high wattage lights.

You may want some 240 volt power points around the house, powered either by an inverter or by a petrol/diesel generator. It must be stressed that 240 volts can be lethal and it is required in Australia that all 240 volt wiring be done by a licenced electrician.

* Because active and neutral links were designed and rated for 240 volts AC, they are called active and neutral links, but in a low voltage DC application you can substitute the word 'positive' for 'active' and 'negative' for 'neutral'.

Low Voltage Wiring Techniques

by
Alex Mason

In many AE systems it is efficient and inexpensive to use the low voltage DC electricity directly from the batteries. Here is all the info you need to get this energy down the line, to the job, with a minimum of loss.

Resistance- The BIG Problem

Resistance is the impedance to electron flow within any material. All electrical wiring, connections, plugs, and switches have some electrical resistance. This resistance causes losses within the entire low voltage circuit. The idea with low voltage wiring is to minimize this resistance, and thereby the associated losses. The reasons for this are: 1) we don't want to waste power, and 2) 12 VDC from the batteries is already low enough in voltage, we can't afford to lose any more than necessary transferring this energy from the batteries to the load. Low voltage at a load causes substandard performance. It means slow motors, dim lights, and generally poor appliance operation.

The Entire Circuit

Every electrical appliance in a system must have a complete circuit to the batteries. Consider the lightbulb on the ceiling. The electrons that power this lightbulb follow a very specific path to accomplish their purpose. Every electron originates at the battery's negative pole. From this pole it makes a journey through the wiring, connections, and switch(es) to the lightbulb. After any given electron passes through the lightbulb it makes its way through the wiring, connections, and switch(es) back to the positive pole of the battery. This path is set. Every electron must make this entire journey in order to do work. Every electron must pass through each circuit element (piece of wire, connection, plug and/or switch) in order to complete the circuit. In technical terms, what we have here is a series circuit. A series circuit means that there is only one path available to the electrons.

A series circuit is like a chain: it is limited by its weakest element. The total resistance of a series circuit is the sum of all the resistances within that circuit. Each individual element within the circuit introduces losses based on its resistance. The primary lesson to be learned here is that ANY (and it only takes one) high resistance element within the circuit will make the ENTIRE circuit's resistance high enough to be unacceptable. Every element within the circuit must have low resistance for the entire circuit to have low resistance. It only takes one piece of undersized wire, one funky connection, or one wornout switch to make the loss of the entire circuit unacceptable. So, in low voltage circuits we must consider every element in the circuit. It is not good enough to use properly sized wire if it is connected improperly, or if the wire is connected to a switch (or any other single circuit element) with high resistance. Attention to the details of the circuit is essential. Let's look at the individual elements that make up the circuit.

Wiring

The size of the wire (or gauge) feeding the load is critical. Wire size is specified in any application by considering two factors: 1) the amount of current that the wire transmits, and 2) the total wire length (both conductors) from the battery to the load. Ohm's Law (see Home Power #1 if this is a new idea for you) gives us the relationship between voltage, current, and resistance in an electrical circuit.

$$E = IR$$

Wiring makes up many of the elements in a circuit. Larger sizes of wire have more copper in them, and hence lower resistance. Wire size is specified by a gauge number. The lower the gauge number, the larger the diameter of the copper wire, and thereby the lower its resistance. The actual resistance per 1,000 feet of various copper wire gauges is detailed in Table 1, the Copper Wire Table. We encourage you to use only copper wire in your AE system. Aluminum wire has greater resistance (about twice for the same cross sectional area) and is virtually impossible to interconnect without higher resistance connections. If you don't think so, then try soldering an aluminum wire sometime.

From the Copper Wire Table, we can calculate the resistance of any particular piece of wire. The resistance per foot times the number of feet gives us the total resistance of a length of wire. When estimating the resistance of wiring be sure to include BOTH conductors, i.e. if an appliance is 100 feet from the battery, then the total wiring length is 200 feet (there are two wires actually, each one 100 feet long).

If we know the amount of current being consumed, the resistance per foot of any given wire gauge, and the length of the total wire in the circuit, then how do we determine the actual gauge of wire we should use? The answer is determined by exactly how much loss we find acceptable. In general, consider a 5% loss to be the maximum acceptable (2.5% is better). If we are using 12 VDC, then 5% voltage loss is 0.6 volts (2.5% is 0.3 volts). Consider the following equation to specify exactly which wire gauge to use for any given application.

R = Resistance expressed in Ohms (Ω) per 1000 feet.
E = Maximum allowable voltage loss in the wiring, in Volts.
I = Amount of current flowing through the circuit, in Amperes.
L = The length of wire in the complete circuit, in feet.

This equation gives us a value in Ohms per 1,000 feet. Simply find the copper wire gauge size that has LESS than this amount of resistance per 1,000 feet, and you've found your wire gauge size.

$$R = \frac{E}{I\,L}\ (1000)$$

Consider a PV array that produces 12 amperes. This array is located 100 feet from the batteries. What gauge size of wire should be used to keep the voltage loss in the wiring to less than 0.6 volts? Well, there is 200 feet (two conductors, remember) of wire in the circuit, and a current of 12 amperes flowing. The equation above gives us a maximum resistance of the wire as 0.25Ω per 1,000 feet. By consulting the Copper Wire Table, we find that 4 gauge wire has a resistance of 0.2485Ω per 1,000 feet. Since this is less than the 0.25Ω/1,000 ft. the equation generated, 4 gauge wire is the size to use.

TABLE 1- THE COPPER WIRE TABLE

	RESISTANCE				DIAMETER	
WIRE GAUGE	OHMS PER 1000 FEET	FEET/ OHM	OHMS/ KM.	METERS PER Ω	MILS	MM.
0000	0.04091	20400	0.1608	6219	460.0	11.68
000	0.06180	16180	0.2028	4932	409.6	10.40
00	0.07793	12830	0.2557	3911	364.8	9.266
0	0.09827	10180	0.3224	3102	324.9	8.252
2	0.1563	6400	0.5127	1951	257.6	6.544
4	0.2485	4025	0.8152	1227	204.3	5.189
6	0.3951	2531	1.296	771.5	163.0	4.115
8	0.6282	1592	2.061	485.2	128.5	3.264
10	0.9989	1001	3.277	305.1	101.9	2.588
12	1.588	629.6	5.211	191.9	80.81	2.053
14	2.525	396.0	8.285	120.7	64.08	1.628
16	4.016	249.0	13.17	75.90	50.82	1.291
18	6.385	156.6	20.95	47.74	40.30	1.024
20	10.15	98.50	33.31	30.02	31.96	0.8118
22	16.14	61.95	52.96	18.88	25.35	0.6438
24	25.67	38.96	84.21	11.87	20.10	0.5106

Get on the Bus

In reality houses and systems contain many circuits. Some of these circuits are straight series types as mentioned above. Others are parallel circuits, where two or more loads are supplied electricity by the same piece of wire. The mathematical analysis of all these circuits can become very complex. A way around this complexity is to use a standard wiring technique that is very effective in low voltage systems--The Bus.

A bus is a heavy set of wires used to carry current to other smaller wires which eventually feed the loads. The battery's energy can be distributed by two heavy wires (usually 2 or 4 gauge) that run the entire length of a building. Smaller 8 or 12 gauge wires are soldered to this bus to supply the individual loads. This structure is similar to the skeleton of a fish, a heavy spine with smaller bones attached to it. This technique allows low voltage energy to be distributed with a minimum loss. Ideally, each load should have its own individual feeder wires soldered to the bus. All feeder wiring lengths should be as short as possible. This technique also allows the use of standard wiring components like switches, plugs and sockets, which will not accept the huge diameter of 2 or 4 gauge wire.

Solder Connections When Possible

In standard 120 VAC house wiring, it is very unusual to solder connections. In low voltage systems, soldered connections should be made wherever possible. All wire to wire connections should definitely be soldered. Mechanical connections using wire nuts are OK for higher voltage systems, but these connections have too much loss for low voltage systems. Soldering assures a permanent, low resistance connection. Mechanical connections gradually oxidize over a period of time. While copper is a very good conductor of electricity, copper oxide is not. Gradual oxidation in mechanical connections increases their resistance. Remember, a single high resistance connection within the circuit will make the resistance of the entire circuit high. So get into solder. Once you've made a good solder joint, it's good forever.

Switches, Sockets & Plugs

The switches, sockets and plugs in a low voltage systems must have low loss (i.e. low resistance) just like every other component in the system. We can assure low loss in these components by two techniques. The first is to purchase specialized low voltage switches, sockets and plugs. These components have more massive contacts, with higher contact pressures, to deliver low resistance. These components are expensive and hard to find.

Another technique is to use standard 120 VAC components and to derate them. Derating means that we run only a portion of the rated current through the component. Derate 120 VAC switches, sockets and plugs by at least a factor of three. Consider a plug or a switch that is rated to handle 15 amperes of current at 120 VAC. If we run 5 amperes or less (15/3) through the component, then its losses will be acceptable. Derating allows use of the more commonly available, higher resistance, components by reducing the current we run through them.

In any case, keep the use of switches, sockets, and plugs to a minimum in a low voltage system. If an appliance can be soldered to its power wiring, then this should be done. If you are using standard 120 VAC sockets and plugs in low voltage systems, be sure to use the 3 conductor types. The three-prong type of sockets and plugs are polarized. They will only connect in one fashion. If they are wired with proper polarity to start with, it is impossible to plug in a polarized low voltage appliance backwards. This can save electronics, fluorescent lights and other DC appliances from being connected backwards and destroyed. The third conductor on these plugs and sockets can also be used to carry current.

Simply wire this third connector (normally used for the ground in AC systems) in parallel with either of the power wires. This even further reduces the overall resistance of the plug and socket combination.

Low voltage wiring is not difficult. It only requires that you cozy up to Ohm's Law. If you can work with the concepts of resistance, voltage and current, then you can apply these concepts in your system. Low voltage wiring requires attention to detail. Consider every element in the circuit. If you keep the individual losses within components to a minimum, then the overall system will take care of itself.

the Wizard

So, are you interested in a FREE LUNCH? Will you go for it?

"What is anti-entropic?", you ask. Well, here's one definition: An anti-entropic process is one which creates more energy than it consumes. There are three basic strategies which may provide a path to the free lunch.

1) Create a feedback process to continually regenerate the source, using only a portion of the output. This is a source multiplier.
2) Create a process that is more than 100% efficient. This is a direct energy multiplier.
3) Find an infinite and undiminishable power source. This is equivalent to finding God in the physical universe.

These paths are possible and can be implemented through the proper understanding and use of leading edge physical theories in the following areas:

1) The basic structure of matter & energy.
2) The nature of gravity & magnetism: how they interrelate.
3) Space & time.

Even today the first short-term approaches to the free lunch are being taken. This will hopefully lead to an era of unparalleled abundance.

Go with the Wizard. Onward into the Future!

House Wiring, Standards & the Electrical Code

Windy Dankoff, with help from Mike Mooney

WARNING! "Cigarette lighter" type sockets are a de-facto standard for 12 Volts, only because there is not yet an official standard for DC home wiring. They are LIGHT DUTY, ALL of them, and are questionable even for the 15 Amps that SOME of them are rated for (the plugs only handle skimpy #18 lamp cord!). Use them at your "entertainment center" for your 12V stereo and TV that came with cig. lighter plugs (their current draw is very low). DO NOT USE THEM for DC lights and appliances in general! NEVER mount them within reach of children. A paper clip inserted into one of these sockets can turn red hot!

What To Use

It will probably be a long time before a true standard will emerge. Meanwhile, THERE IS A MUCH BETTER SYSTEM that many of us have been using for years. It is safe, child-resistant, easy to wire, locally available, and compatible with ordinary wiring hardware and cover plates! Go to your local electrical parts supplier and order "240 volt 15 amp horizontal-prong DUAL receptacles". They look like ordinary sockets except for the position of the prongs. Suppliers generally stock only single receptacles, but will get the duals if you order them. Plugs can be found in most hardware stores when you run out. Because these are 3-prong connectors, you can run 12 and 24 volts to the SAME receptacle.

Power Access for the AE Home

An important part of power distribution in any home is the method used to gain access to the system. The plugs and wall sockets to be used are critical.

• 120/240 vac: The standard of access for alternating current has long been established and should be used for the A.C. current developed by the inventor in the AE home. All established electrical codes should be strictly observed.

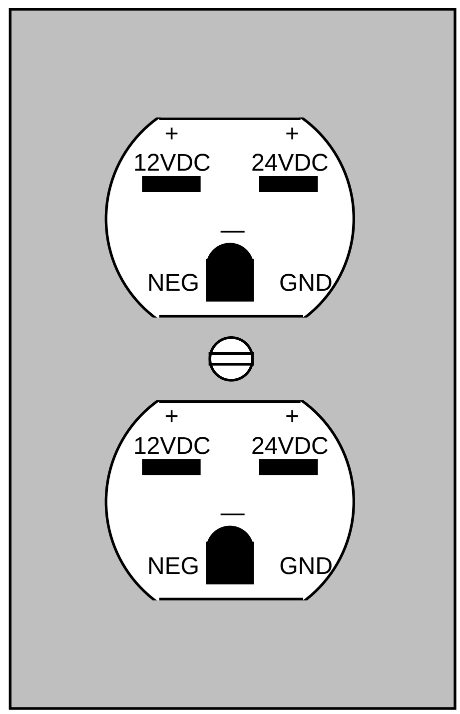
• 12/24 VDC: There is not yet a standard for low voltage D.C. power access, and it will probably be some time before one will emerge. Unfortunately, the automotive cigarette lighter type plug and socket are being used.

Sockets and plugs of this type have been adapted to conduit boxes for installation in motor homes and PV powered homes. THOSE NOW ON THE MARKET ARE FLIMSILY CONSTRUCTED, ELECTRICALLY UNSAFE, AND WE DON'T WANT ANY!

Described here, for your consideration, is an alternative method of access to the D.C. system which we have used for several years. It has proved to be both safe and child proof. As well as safety and convenience, we wanted a method which was durable, pleasing to the eye, and which would preclude any chance of cross-plugging an A.C. appliance into D.C., or vice versa. We also wanted the ability to access both 12 VDC and 24 VDC at each wall socket.

We have found the 250 volt/15 amp straight blade plug and receptacle shown below to be quite workable. The receptacles are manufactured by many in both single and duplex units, and are available in ivory, white and brown. We use the Leviton "Spec-Master" variety.

For the mating plug, we have found the 250 volt/15 amp Leviton "Spec-Master" to be a real jewel! It is very durable, looks good, provides excellent strain relief for the cord, and is very easy to assemble. Since we do use cigarette lighter plugs on occasion, we have made up a few "pigtail" pendants using



the Leviton plug and Safeco automotive adaptors (Radio Shack #RS270-1535A).

Power access is JUST ONE LINK in the chain of power distribution. In the near future we will cover THE POWER BUS, WIRE SIZE vs. LOAD and LENGTH, SPLICES and CONNECTION, CIRCUIT BREAKERS and FUSES, GROUND FAULT ANALYSIS, and SWITCHING.

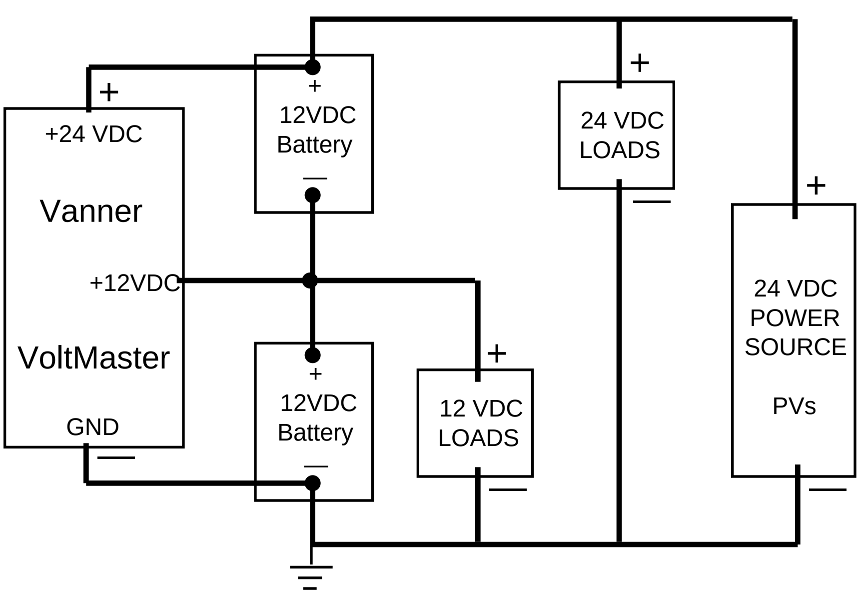
Now if you have a 12V TV to plug in, you wire it to the negative (ground) prong and the +12. If you have a 24V lamp to wire, connect it to negative (ground) and +24V. No one worries about plugging into the wrong socket and you only have two types of receptacles for your "triple voltage" system.

We use this system in our shop, office and house. It looks right at home alongside the ac receptacles powered by our inverter. Numerous PV installers have settled on this standard INDEPENDENTLY, after experience with inferior material.

WE URGE OUR CUSTOMERS, AND THE INDUSTRY IN GENERAL, TO CONTINUE USING THE HORIZONTAL-PRONG STANDARD FOR 12 AND 24 VOLT DC POWER.

This 12/24 Volt system shown causes 12 Volt appliances to draw from one half of the battery bank, thus discharging the battery unevenly. There are several solutions to this problem:
1) Use a bare minimum of 12 Volt power. Inequity will be of little significance and will be compensated for when batteries finish-charge and equalize.
2) Switch 12 Volt appliances periodically from one side of the battery bank to the other. Caution: if your battery negative is grounded (as recommended in HP#6) and a 12 V radio's negative frame/antenna is grounded (for example) switching to the ungrounded side will cause a short circuit! Use of this technique is best left to techies who KNOW what they are doing.
3) The BEST SOLUTION involves the "VOLT MASTER" BATTERY EQUALIZER, an electronic device that compensates for uneven discharge by balancing the voltage between two battery sets. It also allows you to use DIFFERENT SIZES & AGES of batteries to upgrade your system from 12 to 24 Volts-- this would cause problems without the Equalizer.

Volt Master is a proven device made for trucks, busses and electric vehicles that need to run 12 Volt radios, etc. from their 24 V. (or higher) systems. It is a DC/DC converter with current ranges of 10, 20 and 50 Amps DC. The Vanner Volt-Master costs between $235 & $359 depending on model. It is available from two Home Power advertisers, Alternative Energy Engineering and Flowlight Solar Power.



Wiring in General
Use conventional hardware and wiring methods. Standard wiring practices are easiest, economical, approvable, and ultimately safest for your DC as well as ac wiring. Consult a Low Voltage Wire Size Chart (or see Home Power #2, pages 33 to 35) so you don't cheat yourself with undersized wire. Use efficient lighting (fluorescent &/or quartz-halogen) to reduce wire size requirements as well as energy consumption. Stranded wire is NOT electrically different from solid wire, just more flexible. We usually use welding cable for heavy lines to inverters because it is not so stiff.

Circuit Breakers, Fuses & Switches
Surprise! Ordinary 120/240 vac household breakers are SAFE and FUNCTIONAL at DC low voltages. We recommend "SQUARE-D" brand, which has been tested by factory engineers and judged safe up to 60 VDC. They are safer and easier to wire than the plastic automotive/RV fuse boxes often supplied for DC systems.

Another lucky break: Ordinary 120 vac wall switches (NOT mercury) work fine for low voltage DC lights. For over 5 Amps., order "T-Rated" switches from your electrical supplier. They are rated for DC and ac use. They click rather loudly, evidence of the fast break action required for higher DC currents.

SAFETY!
If you are not adept at house wiring, study text books on the subject and/or hire an electrician! A battery-based, low voltage electrical system has enough force behind it to burn down you house, just like conventional 120 vac power. This can happen if your system is not properly designed and wired. That's why electrical inspection is required for homes in general. Inspection is not always enforced for independently powered homes, but a few solar-electric fires may eventually convince the authorities otherwise.

About Codes and Standards
Your electrical inspector's "Bible" is the "NATIONAL ELECTRICAL CODE". However, like the rest of us sinners, he/she is allowed to vary from the occasional rule. The Code is a set of RECOMMENDATIONS. The inspector's judgement is based on state regulations and HIS/HER DISCRETION, both of which may vary from the Code. For instance, the Code presently calls for "twist-lock" connectors for DC. In the opinion of PV home specialists and engineers we have talked to, this requirement is NOT necessary for safety at low voltages and inspectors tend to agree. The Code also says that plugs and receptacles must be of a design that is not already an exsiting standard for another type of service. We were allowed to waive this recommendation for our DC home and shop because we don't use 240 volts. There are other connectors for that purpose.

ELECTRICAL INSPECTORS are intelligent people who are curious about our work. Their interest, first & foremost, is your long-term safety. If they hesitate to allow the unusual, it is only from a lack of knowledge. Teach them. Show them your books, catalogs and articles like this! Open

Plug-in lights

It is still rare in the UK to be able to buy a plug-in light with a plug attached. When you unpack the fitting you will probably find that the end of the flex has been stripped back ready to receive the plug. You may also find a label attached to the flex telling you how to wire it up. This is broadly applicable to old-fashioned round-pin plugs as well as more recent rectangular-pin plugs.

Choose plugs with care. The best quality rectangular-pin plugs have captive (non-removable) pins, a captive centre screw, and a cord grip consisting of two nylon jaws. The harder you pull on the flex, the more tightly the jaws hold it. This is an important safety feature; without it anyone tripping over a flex trailing across the floor could tear it out at the terminals, causing a short circuit next time the light is switched on.

When buying a new plug, either select one fitted with a 3amp fuse, or buy a supply of 3amp fuses to replace the 13amp one which is often fitted as standard. Use the surplus 3amp fuses to replace any 13amp fuses in plugs on any other light fittings that you own.

Lights with no metallic parts are fitted with two-core flex; there is no earth core, since there is no metalwork that could become live in the event of a fault. Fittings with any metal parts – even just a metal lampholder – must be fitted with three-core flex: live, neutral and earth.

Each fitting you wire up should have its own plug. Never be tempted to connect two (or more) flexes into the same plug just because you do not have enough socket outlets. You can use adaptors to connect up to three plugs to one socket outlet; however, this is not good practice as the leads can get tangled and there is a risk that the combined weight of adaptor and plugs will pull the assembly out of the socket, leading to poor electrical contact. It is better to increase the number of socket outlets, either by converting existing single sockets into double (or even triple) ones, or by adding completely new sockets as spurs from your existing power circuit, as described and illustrated on the opposite page.

Many plug-in lights are sold with only a comparatively short length of flex attached. Even in a home with ample power points, the lead may not be long enough to reach to the nearest socket. In this case you need to extend the flex. The best way of doing this is to remove the existing flex and replace it completely with a new piece of the required length (and of the same type and current rating). On some light fittings this may be difficult, and you will have to extend the flex instead. Use a special flex connector for this (shown below right) – either a one-piece connector, or a two-piece one with the "female" part connected to the flex that runs to the plug. The latter method ensures that if the connector is pulled apart while the flex is still plugged in, accidental contact with live pins cannot occur.

Wiring a plug

To wire a plug for a plug-in light:

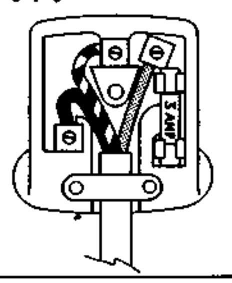
1 Open the plug and lay the flex in it, with the sheathing over the cord grip, to check that the flex cores will reach the terminals with 12mm extra for making the connections. Trim the cores if necessary, or cut back the sheath to expose more core.

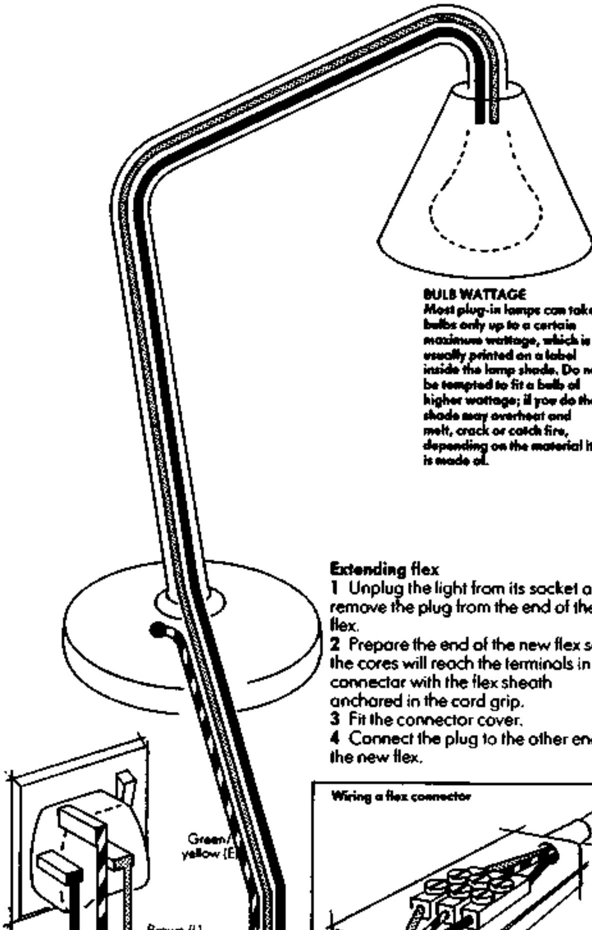
2 Connect the brown core to the live (L) terminal, the blue core to the neutral (N) terminal and the green/yellow core if present to the earth (E) terminal.

3 Secure the flex in the cord grip.

4 Fit a 3amp fuse and then replace the plug top.

Wiring a plug





BULB WATTAGE
Most plug-in lamps can take bulbs only up to a certain maximum wattage, which is usually printed on a label inside the lamp shade. Do not be tempted to fit a bulb of higher wattage; if you do the shade may overheat and melt, crack or catch fire, depending on the material it is made of.

Extending flex

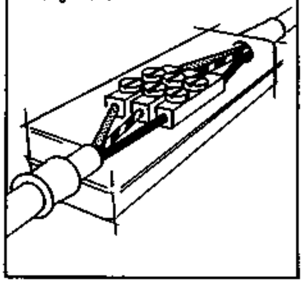
1 Unplug the light from its socket and remove the plug from the end of the flex.

2 Prepare the end of the new flex so the cores will reach the terminals in the connector with the flex sheath anchored in the cord grip.

3 Fit the connector cover.

4 Connect the plug to the other end of the new flex.

Wiring a flex connector



Gaining more socket outlets
There is no restriction on the number of socket outlets that can be part of a modern ring or radial power circuit. As well as adding sockets on the circuit cable itself, you can also add branch lines (or spurs) from the circuit to feed extra sockets, provided that the number of spurs taken from a circuit does not exceed the number of sockets on the main circuit.

The simplest approach is to convert all your existing single sockets into double (or triple) ones. What you do depends on whether your existing outlets are flush- or surface-mounted and on whether you want your new sockets to be flush or surface fittings. The options are diagrammed below.

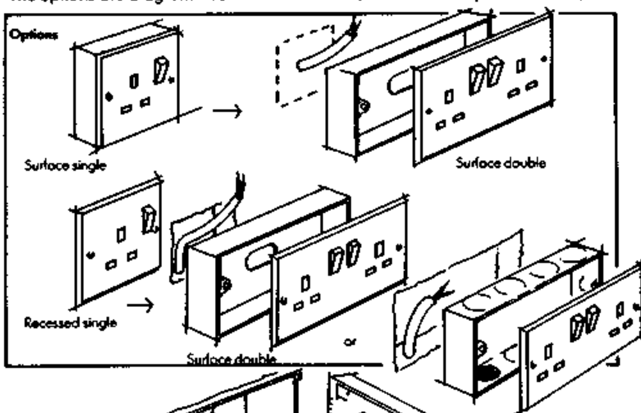
The easiest changeover is to exchange a surface single for a surface double socket. This involves turning off the power at the mains, disconnecting the existing faceplate, removing the old mounting box, fitting a new double one in its place and connecting up the new double faceplate. From a single flush to a double surface-mounted fitting is also an easy progression: you simply screw the new double box to the lugs of the old single box using the original faceplate fixing screws, then connect up the new faceplate.

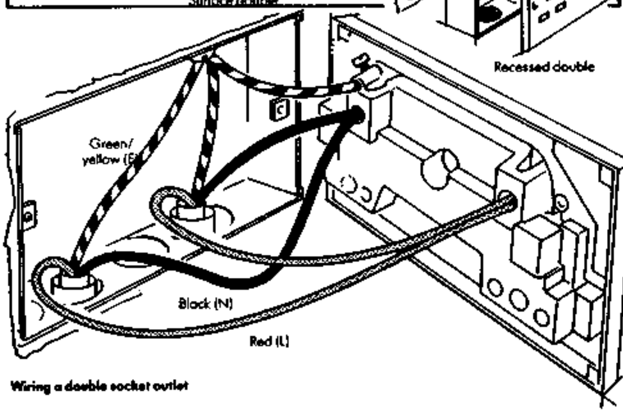
There is a little more work involved if you want your new double socket to be flush-fitting. If your existing single socket is flush-mounted, you have to remove the old faceplate and box, enlarge the hole in the wall to take a new double box and connect up the new faceplate. If the existing single socket is surface-mounted, you have to cut out a new double-sized hole in the wall.

If you want outlets in other locations, you must extend your existing circuits with spur cables to feed new sockets. There are two methods: you can either connect a spur cable into the back of an existing socket, or you can cut the existing circuit cable at a convenient point and connect in the spur using a three-terminal junction box.

The only drawback with the former method is the danger of contravening IEE Wiring Regulations. The socket you want to connect your spur cable into may not be on the main circuit; if it is itself a spur you are not allowed to extend it. To be sure of keeping within the safety regulations, follow these guidelines:

- If the existing socket has only one cable entering its box, it is on a spur and you cannot connect in a spur cable.
- If the existing socket has three cables entering its box, a spur has already been run from it and you may not add another.
- If two cables are present, the socket is probably on the main circuit and so you can run a spur from it. However, it may be an intermediate socket on a now prohibited two-socket spur. The only way to be sure is to call in an electrician to check the circuit.



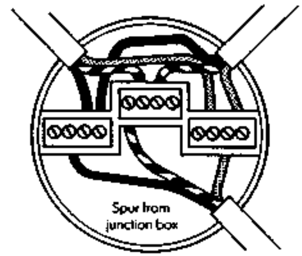


Wiring a double socket outlet

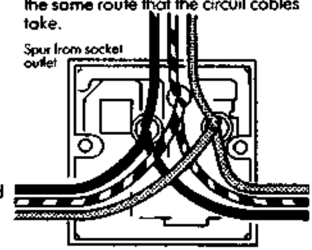
Wiring a socket outlet
Whatever changeover job you are tackling, you will be reconnecting the existing circuit cable (or cables: there may be more than one present) to the terminals of your new double socket faceplate. Do not disconnect any cable cores that have been twisted together; simply reconnect them to the new faceplate as they are, taking the red cores to the live (L) terminal, the black cores to the neutral (N) terminal and the earth cores to the earth (E) terminal. If the earth cores are bare, slip on a length of green/yellow striped PVC sleeving before connecting them up. Then fold the cable neatly back into the mounting box and screw on the faceplate.

Adding a spur: junction-box method
You can connect into the existing power circuit at any convenient point on its run using a 30amp three-terminal junction box. There are two types: a circular one used for connections within ceiling voids or under floors, where the box is screwed to the side of a joist; and a rectangular one used for installations where the circuit cables are run on the surface.

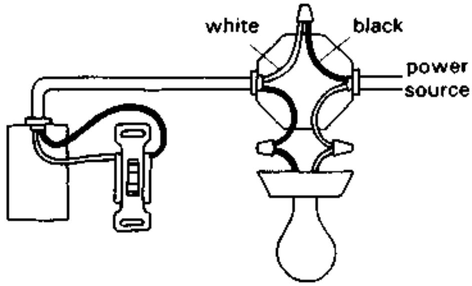
To fit a junction box, the first step is to cut off the power to the circuit: to do this, remove the appropriate circuit fuse or switch off the circuit MCB. Then screw the box base in position, cut the circuit cable, prepare the cut ends and connect the cores to the terminals – lives to the first terminal, neutrals to the second, earths to the third. Prepare the end of the branch cable and connect its cores to the box terminals too. Then screw on the junction box cover.



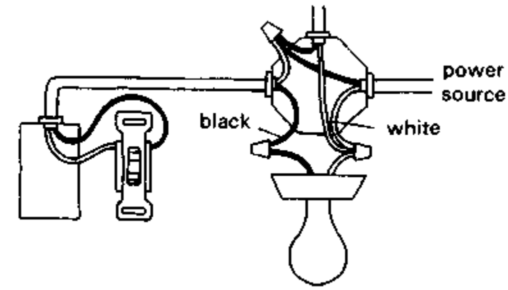
Adding a spur from a socket outlet
Unscrew the socket faceplate (again with the power off) and connect in the new spur cable to the faceplate terminals. It is usually easy to feed the new cable into the existing box along the same route that the circuit cables take.



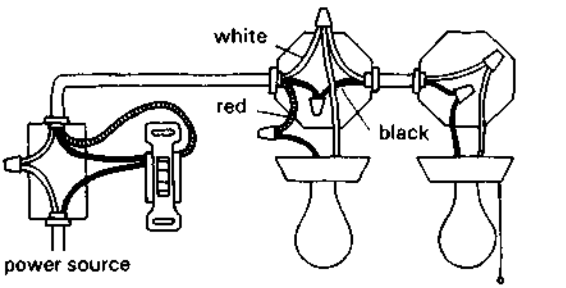
These illustrations show some of the more common types of connections. They should provide you with the information you need to wire many two-way switches, three-way switches, and other types of switches, lights, and outlets.



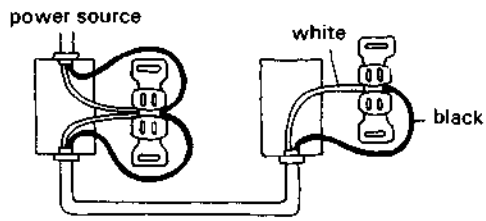
Wall switch controlling ceiling fixture at end of run



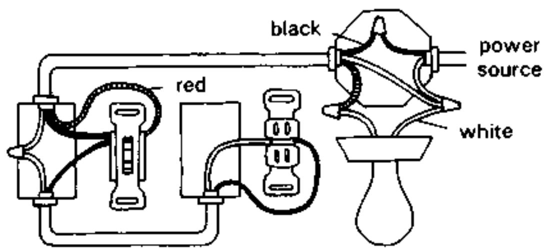
Wall switch controlling ceiling fixture in middle of run



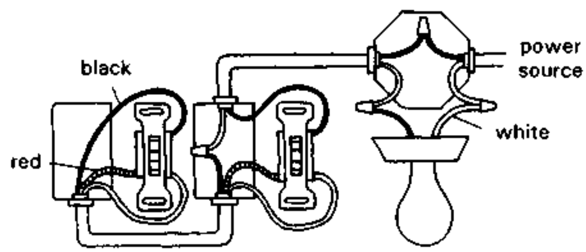
Two fixtures on same line controlled by different switches



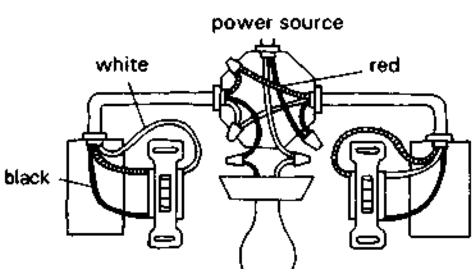
Adding a supplementary outlet



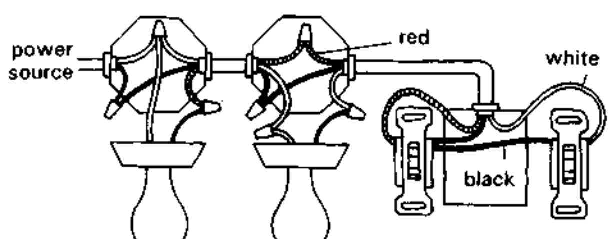
Adding a new switch and outlet to an existing fixture



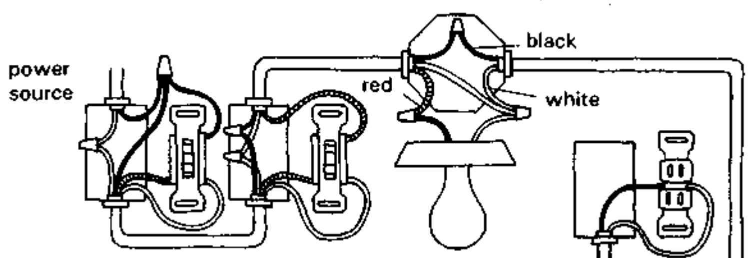
Same ceiling fixture controlled by two different switches



Ceiling fixture between two switches, controlled by either

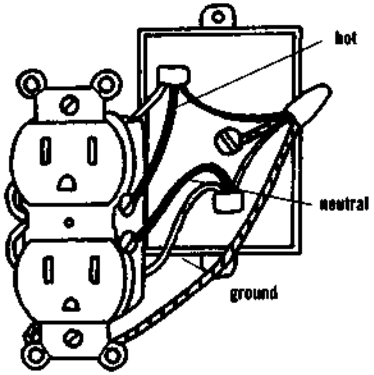


Two separate fixtures controlled by two switches

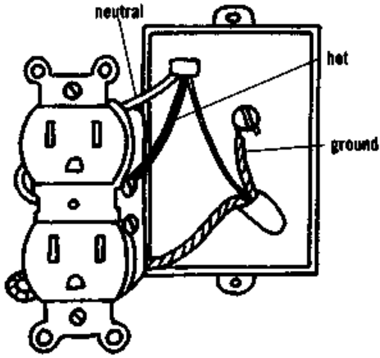


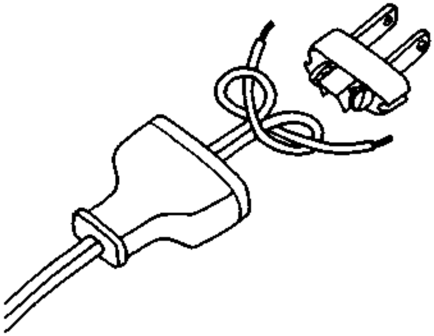
Fixture controlled by separate switches; outlets always hot

—from *Renovating Brick Houses*

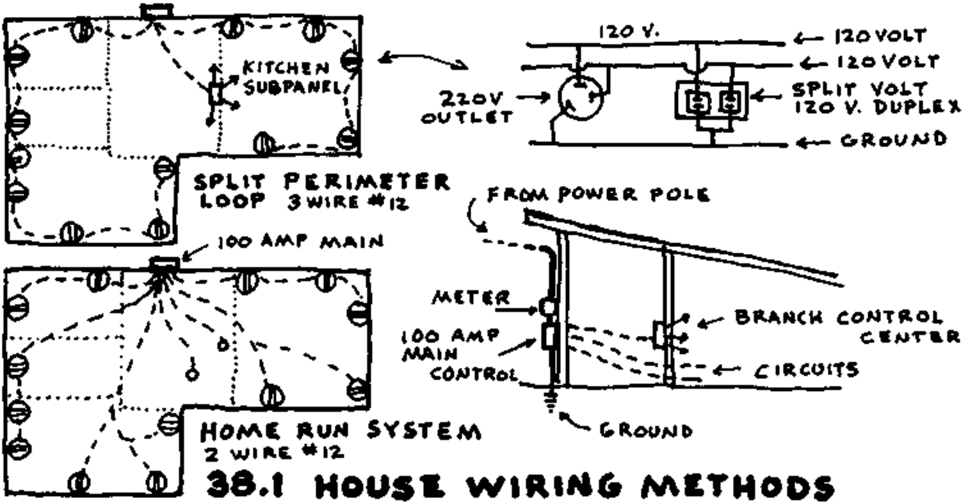


The outlet above is at the middle of the circuit; the one below is at the end.

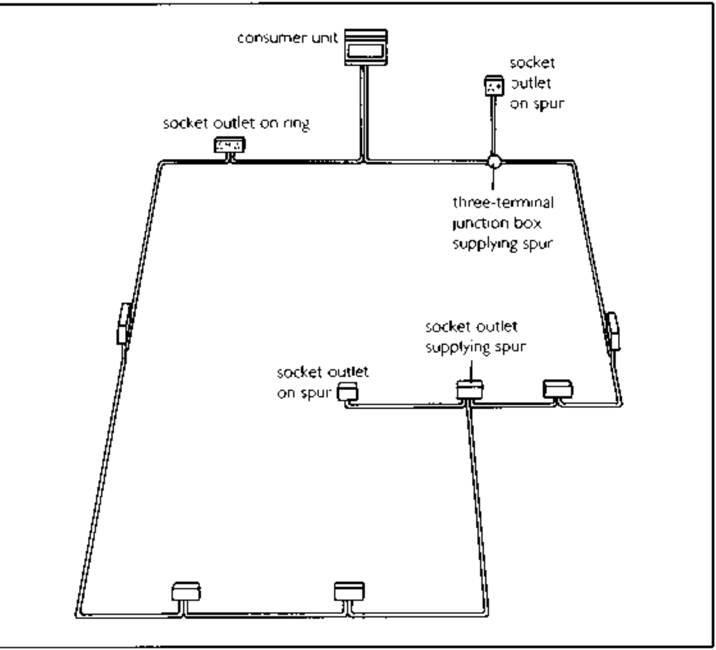




Connect a wire to a new plug by first unplugging the appliance and cutting off the old plug.



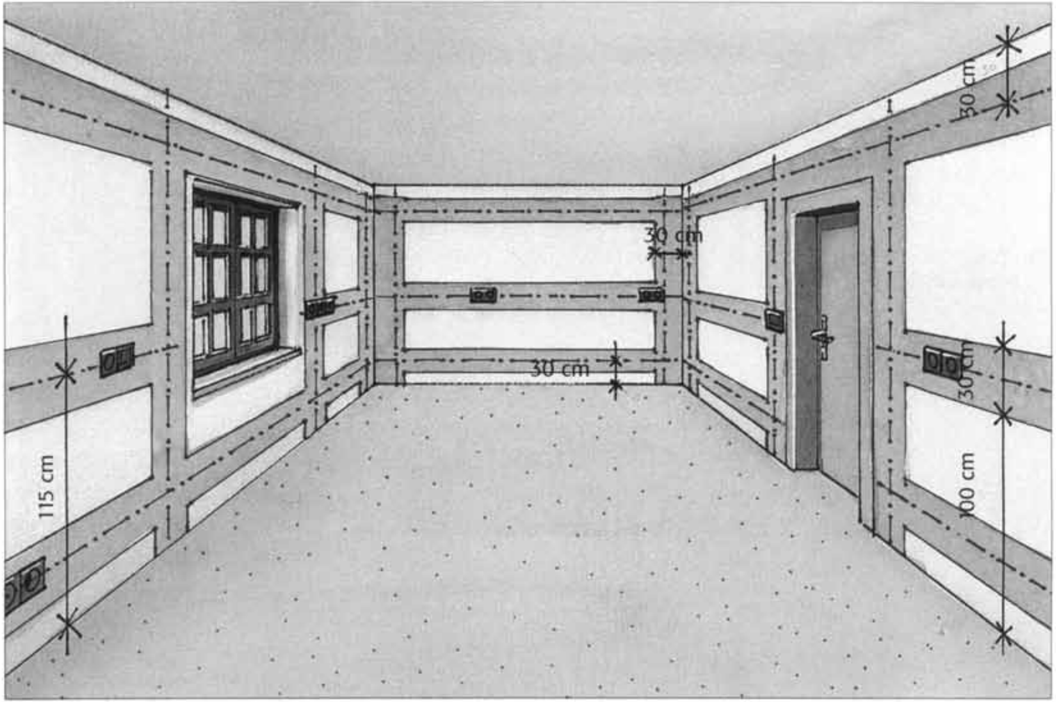
38.1 HOUSE WIRING METHODS

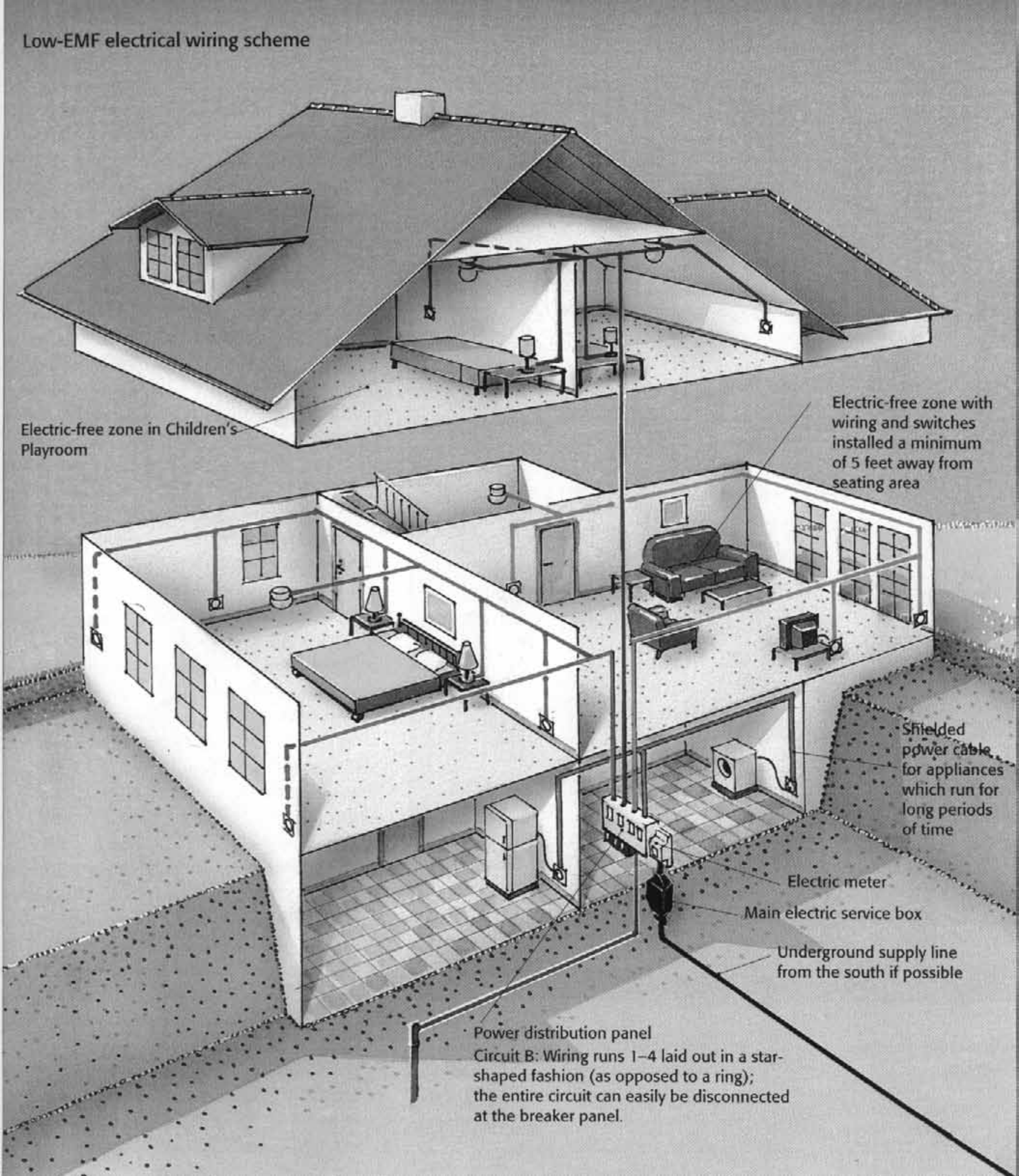


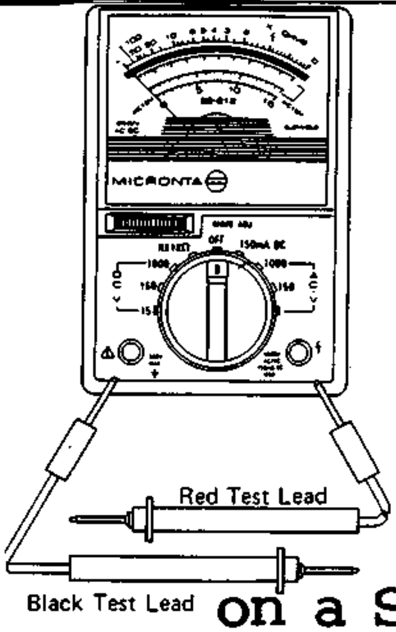
A ring circuit consists of a continuous loop of cable running out from and back to the consumer unit, supplying socket outlets either directly or by means of spur cables

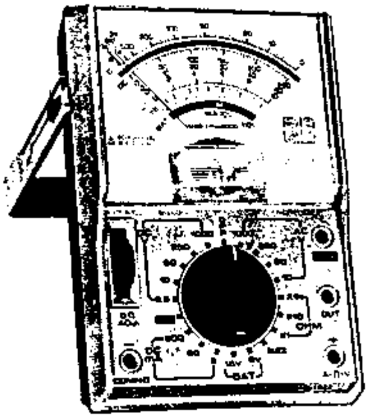
Installation zones

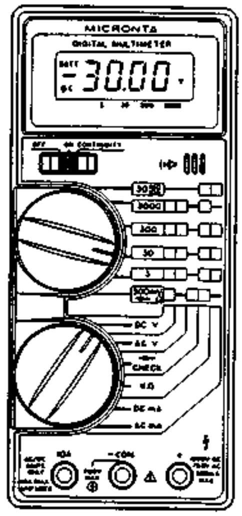
These are the areas in which receptacles, switches and cables can be installed safely. They ensure that no electrical wiring will be hit when drilling into the wall.




Low-EMF electrical wiring scheme
Electric-free zone in Children's Playroom
Electric-free zone with wiring and switches installed a minimum of 5 feet away from seating area
Shielded power cable for appliances which run for long periods of time
Electric meter
Main electric service box
Underground supply line from the south if possible
Power distribution panel
Circuit B: Wiring runs 1–4 laid out in a star-shaped fashion (as opposed to a ring); the entire circuit can easily be disconnected at the breaker panel.







Using a Multimeter on a Stand-Alone Power System

A multimeter is a very valuable diagnostic tool which, because of its mobility and multi-function capability can provide information that a stationary control board cannot. A multimeter is ideal for:

- Measuring Voltage of individual Battery Cells
- Measuring Voltage Drop in Cable and Connectors
- Measuring Charge Rate of individual Solar Panels
- Measuring Power Consumption of individual Lights and Appliances
- Checking Calibration of Meters on the Control Board
- Checking Light Bulbs and Diodes

In the following few pages we will discuss how to measure volts and amps and calculate watts and amp-hours. We will also discuss how to test if a circuit is complete or not (continuity test).

Buying a Multimeter

It would be advisable to get a multi-meter with either a 10 amp range or a 20 amp range. The voltage range would preferably be 0-15 volts for a 12 volt battery bank or 0-30 volts for a 24 volt battery bank. It would also be good to have a 0-3 volt range for testing individual cells of a lead-acid battery or a 0-2 volt range for testing individual cells of a nicad battery. For our purposes the ohms scale isn't so important other than for testing continuity.

It is also recommended to purchase yourself a set of insulated slip-on Alligator Clips.

If what you are attempting to measure is constantly fluctuating an analog meter (which has a needle pointing to a scale of numbers) is easier to read than a digital meter. For measuring the voltage of a battery bank and DC currents and voltages generally, a digital meter (which has an LCD display similar to the display of a calculator) is preferred.

HINTS

1. When using the meter, pay particular attention to polarities and check positive and negative points. The red lead connects to positive and the black lead to negative.
2. It is generally good practice to position one probe first (usually the negative probe), and get it secured with an alligator clip or by finger tightening a screw onto the probe before testing or probing with the other probe. This makes it easier to concentrate on only one probe.
3. If you are checking unknown currents and voltage, use highest range first, then next lower range, and so on until readings can be obtained.
4. For most accurate readings, keep the meter lying flat on a non-metallic surface. Also, use a range setting that results in a reading in the upper third of the meter scale.
5. With an analog meter, for exact readings, look at the scale from the point where the pointer and its reflection on the mirror behind the pointer come together; otherwise a reading error may result due to parallax.

WARNINGS

1. Do not apply voltage to probes while the range switch is in current or ohms position.
2. Testing AC wiring circuits can be dangerous. Never clamp on to a 'hot' wire (usually red or brown) since if you did so and then touched the other probe, you could receive an electric shock. For your own safety leave the AC diagnostics to a qualified electrician and just concentrate on the DC circuitry.

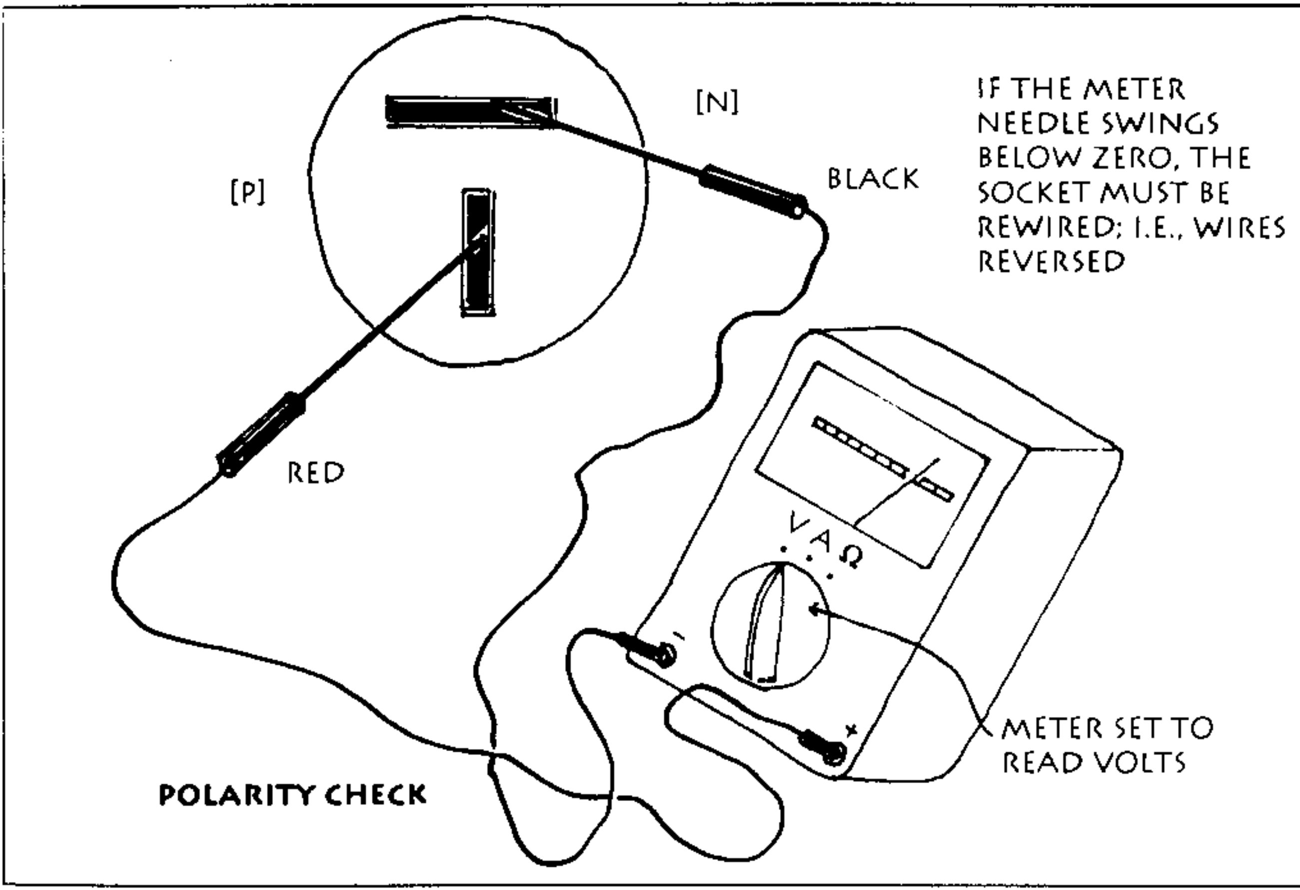
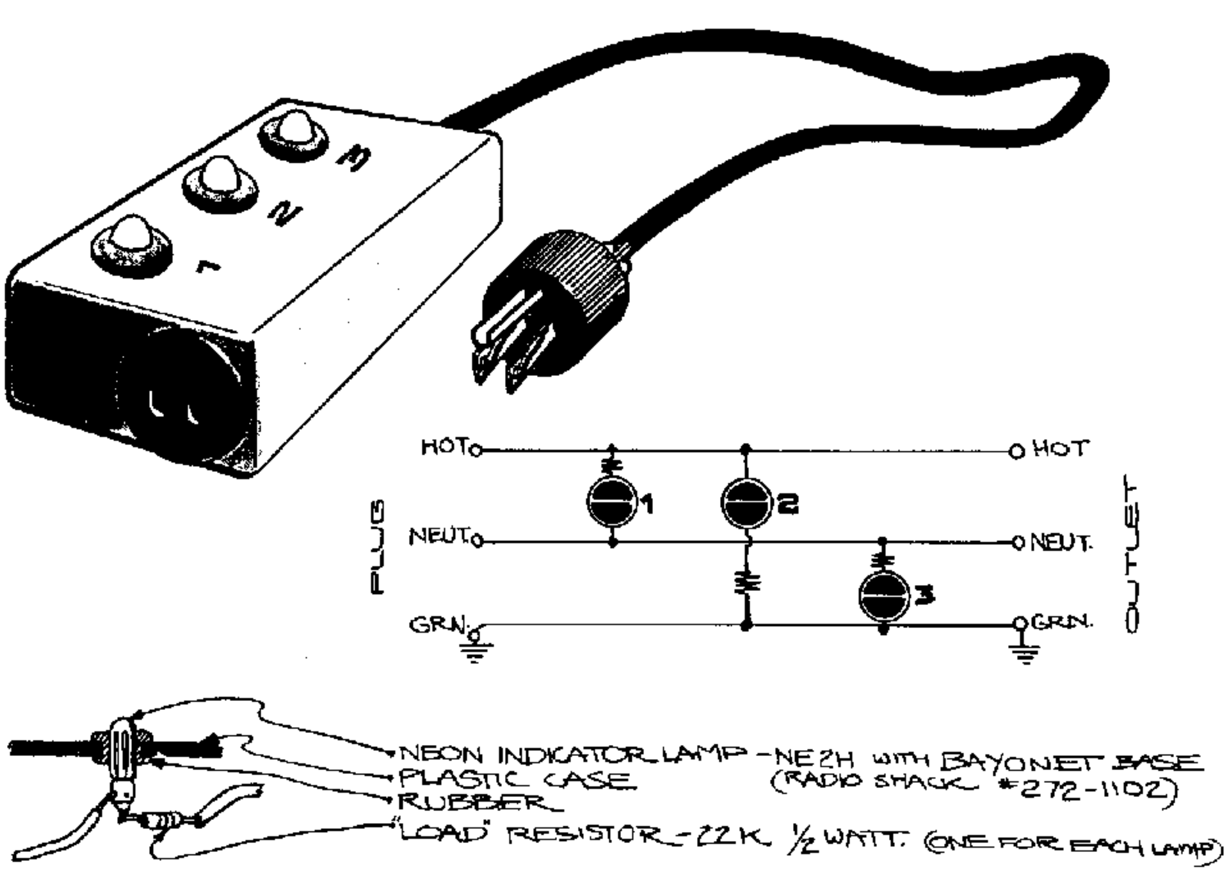


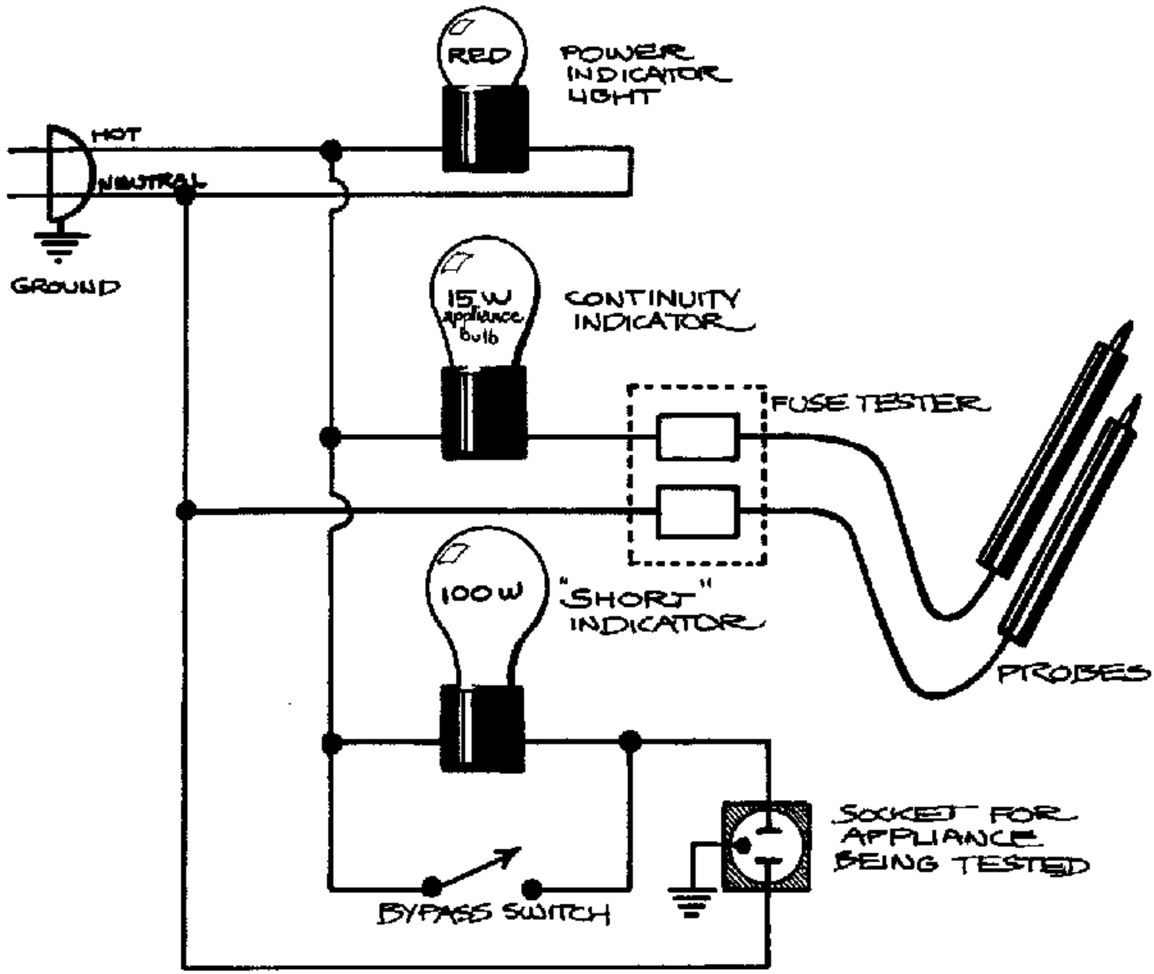
Figure 9-10. **A quick check with a multimeter will tell you whether the polarity is reversed.**



103 Outlet tester. This circuit can be built into any suitable box. Lamps are mounted by being pushed up through a rubber grommet (see detail above). Now plug tester into an outlet:

lamps 1 & 2 light up:	outlet is normal
none light up:	open "hot" lead
2 only lights up:	open "neutral" lead
1 only lights up:	open "ground" lead
2 & 3 light up:	"neutral" lead is "hot"
1 & 3 light up:	"neutral" and "hot" leads reversed

NOTE: Any condition other than lamps 1 & 2 lighting up is dangerous and should be corrected immediately.



APPLIANCE TESTER CIRUIT

105

1. Test outlet for correct polarity and wiring (see illustration 103)
2. Plug in tester; red light should go on, indicating the presence of power
3. Test for "open" wires and fuses with the continuity indicator
4. Test appliance by plugging it into the test socket (make sure by-pass switch is in "off" position). The 100-watt bulb should light dimly. If it does not light, the appliance is "open"; look for a broken connection or loose wire. If the lamp lights brightly, check for a short circuit. As a final test, the by-pass switch can be closed to provide full power to the appliance being tested (if tester has not indicated a short circuit).

NOTE: This tester will work with simple electromechanical appliances like toasters, blenders, irons, washers, dryers, and dishwashers. Electronically controlled devices cannot be accurately tested with this unit.

DO NOT TOUCH the tips of the probes or the metal fuse-tester contacts, as voltage is present. The tester is a useful tool for someone who has sufficient troubleshooting electrical know-how.

How to use a Multimeter

It is recommended to read the instruction manual of your multimeter before reading the following:

DC Voltage Measurement

Select the required DC voltage range (if in doubt start from the highest range and work your way down until a reading can be obtained) with the probes connected to the points to be measured.

Open Circuit Voltage

Open Circuit voltage (OCV) is the terminal voltage of a battery while at rest. This means that there is no charge or discharge of that battery. OCV is the most meaningful voltage of a battery as this can indicate state of charge. Each cell of a fully charged lead-acid battery should have an OCV of around 2.1 volts. At 50% discharge the OCV will be about 2.0 volts per cell. At around 1.8 volts per cell or less the battery is considered discharged.

It is good practice to occasionally compare the OCV of the component cells of a battery bank (if the intercell connectors are accessible). This will allow you to identify the sluggish cells. The sluggish cells should be given an identifying mark and used to regularly monitor the battery bank. The sluggish cells can then be used to identify when next to apply a boost charge to the battery bank. You never want a variation between the best and the worst cell of more than 0.05 volts.

A NiCad battery has an OCV of about 1.25 volts per cell and its variation between charged and discharged is difficult to measure as the voltage varies so little.

Charging Voltage

The voltage of a battery being charged can give you an indication of when that battery has reached full charge. This is NOT an OCV.

Whilst charging the voltage of a battery may not vary much for most of the charge and then rise quite dramatically once the battery is full. A Lead Acid battery voltage will rise to between 2.3 and 2.4 volts per cell when fully charged. If a Lead Acid battery has been left in a state of partial or total discharge for a long period of time (months) it may be sulphated and have a very high internal resistance in which case the charging voltage may behave as if the battery is full when in fact its not. Taking a specific gravity reading with a hydrometer will then tell you that in fact the battery is not fully charged (see battery section of 'Energy from Nature').

Whilst a NiCad battery is being charged the voltage may rise to 1.6 volts per cell. A NiCad battery never suffers from sulphation and the charging voltage can be used very reliably to determine that it is fully charged.

Measuring Voltage Drop

A voltage drop will only occur whilst there is a current flowing. Voltage drop is directly proportional to the amount of current flowing and the cable length. By comparing the voltage reading at one end of a cable to the reading taken at the other end you can obtain the voltage drop (subtract the lower reading from the higher reading).

To reduce the voltage drop you may need to increase the cable size and improve the connections.

DC Current Measurement

Select the required DC current range (if in doubt start from the highest range and work your way down until a reading can be obtained) with the test leads connected to the points to be measured. Amps are usually measured by breaking the continuity of the positive line and connecting an amp meter between these two points.

An amp-meter on a control board to measure discharge rate needs to able to read the power consumption of the maximum number of things that may be turned on at once. Such a meter would hardly register and hence would be almost useless in measuring the consumption if it is very low. A 12 volt electric fence energizer and a battery powered radio are two examples of appliances that are usually on for long periods of time whose power consumption is quite low. If an appliance is on continuously for a long period of time even a small power consumption will accumulate to be quite significant and from that point of view it is good to be able to measure it.

Testing the Current Consumption of a Light or Appliance

Make sure that the appliance or whatever that you are about to measure is turned off. If you have all your positive connections made at one common link it may be easiest to break the continuity at this point. Links often have numbers stamped into the brass to identify the wire locations. Simply undo the screws that hold the wire in question. Finger tighten the screws back onto your positive probe, fix an alligator clip onto the negative probe to hold onto the end of the wire that just came out of the link. Once all your connections are secure you can turn the appliance on and check its current consumption.

Checking the Charging Rate of a Solar Panel

Again you need to break the continuity of the positive line. This time you don't need to turn anything off first. This time the positive probe connects to a point that connects back to the panel and the negative probe connects to a point that goes on to the battery bank. You can isolate and measure individual solar panels by measuring on the solar panels directly or you can measure the output of all the solar panels combined by removing the solar fuse on the control board and using the fuse contacts as your test points.

Power (Watts) versus Current (Amps)

To calculate the power consumption of an appliance or the power output of a solar panel, simply multiply the measured current by the measured voltage.

Power Loss (Watts)

The power loss of cable and connectors is calculated by multiplying the measured voltage drop by the measured current flow (see 'Measuring Voltage Drop' and 'Testing the Current Consumption of a Light or Appliance' - above).

Amp-Hours and Watt-Hours

Amp-hours is calculated by multiplying the current (amps) by the number of hours that that current might have been flowing for. To calculate watt-hours, multiply amp-hours by measured volts.

Testing for Continuity

In order to measure continuity you need to have a voltage source.

If there is a poor connection or a break in the house wiring it can often be located by tracing the wires from the battery bank outwards and using the battery bank as your voltage source.

With the meter on the appropriate voltage scale start by measuring the voltage at the battery. Now move to the next location where you can connect your probes as you head towards the possible location of the fault.

If at any point you measure no voltage then there is a break in the wiring between the previous test point and this one.

If you measure a drastic voltage drop this may indicate a poor connection such as a wire that is almost broken, corrosion in a connector or a wire, or it may be due to undersized wiring.

Testing if a light bulb is OK

This test can only be applied to incandescent type light bulbs. Fluorescent lights will not respond to this test.

It would be easier in this case to use one of the ohms scales on the meter or to use the continuity function if it has one. To make these functions work the multimeter should have an internal battery.

Some multimeters have a built-in continuity function which often sounds a buzzer. Test this by selecting continuity on the range switch and touching the two probes together. If it buzzes try holding the probes onto the two contacts of the light bulb and see if it buzzes - if it does the light bulb is OK.

Using Ohms (Ω) for Continuity

If you do not have a continuity function on your multi-meter you can use one of the ohms scales.

If you select an ohms scale and touch the probes together you should see the needle of an analog meter move right across the scale and a digital meter should change from reading maximum resistance to zero. Most digital meters will show a high number which flashes (overrange) when the circuit is broken (no continuity). If you get the appropriate response from your meter, hold the two probes onto the light bulb contacts. If the needle of the analog meter moves across the scale or if the digital meter reads zero or a low number then there is continuity and the light bulb is OK.

Testing if a diode is OK

A diode is like a one-way valve. It should allow the current to only flow in one direction and prevent the current from flowing in the other direction. A good diode should show continuity in one direction and no continuity (or overrange) in the other.

Do not test the diode whilst there is an external voltage (eg solar panel) connected as this will effect the outcome and possibly damage the meter.

Connect the probes to the device you want to check and note the meter reading. Reverse the probes and note the second reading. If the one reading shows some value and the other is overrange, the device is good. If both readings are overrange, the device is faulty (open circuit). If both readings are very small or zero, the device is also faulty (short circuit).

APPENDIX B

Examples of Various PV Systems

These examples show some of the ways PV systems might be connected to meet the requirements of the National Electrical Code. The examples are presented for reference only and may require modification to meet site-specific and local jurisdiction requirements.

Figure B-1 shows a self-contained assembly with no external connections or user accessible to the electrical conductors. Such a unit might be an attic ventilation fan or a circulating pump on a domestic hot water system and might have UL certification as a unit. No disconnect switches or overcurrent devices are required in a properly designed unit, although an on-off switch might be desired. This unit will have no exposed metal surfaces that might come in contact with internal live parts and therefore would not require a grounding conductor. A system with external connections and wiring for a direct-drive load may or may not require disconnects and overcurrent protection. It depends on the design and the accessibility of live contacts.

It would be possible to design connectors that had no exposed live contacts for such a system, and the Code-required disconnects could be managed by unplugging the connectors. If all components and conductors were sized to handle 125-150 percent of the PV short-circuit current, overcurrent devices might not be required. Such a system might look like Figure B-2.

As the system becomes more complex with battery storage, additional articles of the NEC will apply. Multiple component systems with modules, charge controllers, and batteries imply that external wiring will be needed and service will be required periodically. The NEC dictates the disconnects and various other protective devices. Figure B-3 illustrates some of the safety and performance requirements for a small stand-alone system.

In Figure B-3, the conductors are sized for the needed ampacity and to minimize voltage drop.

The length of the wire and its resistance are calculated to keep potential short-circuit currents to a level that does not exceed the AIC of the circuit breakers. The battery bank will also be on the small side and most likely will be a sealed maintenance-free unit, further lowering the available short-circuit currents. Each circuit breaker might be replaced by a fuse and a switch, if care were taken to ensure that fuses could be serviced only when dead on both ends. Some charge controller designs may alleviate the need for the blocking diode. Note the method of connecting modules in parallel so one source circuit can be disconnected without disturbing the grounded conductor (if the system is grounded) of the other. Equipment grounds and three wire cables are needed to each load. In medium-size systems where multiple strings of modules are connected in parallel, attention should be given to blocking and bypass diodes. Modules may or may not have internal bypass diodes to overcome problems caused by shaded cells, and the manufacturer's recommendations should be followed in this area. Blocking diodes not only prevent batteries from discharging into the array at night, but prevent parallel strings of modules from forcing current into shaded strings.

Figure B-4 illustrates disconnects, overcurrent protection, short-circuit protection and diodes for a 1,500-watt stand-alone system. In very large arrays, blocking diodes might also be used at both ends of strings to prevent ground-fault currents from circulating.

Figure B-5 shows the use of bypass diodes on a long high-voltage string of modules to prevent reverse biasing of modules when shaded. Blocking diodes at each end of the strings prevent reverse-current flow in the entire string when it is shaded. Normally only one diode would be used, but the use of one at each end of the string will serve to minimize the possibility of circulating ground fault currents should they occur in high-voltage arrays. The cost of and the power lost in the blocking diodes must be weighed against the potential for damage if they are omitted.

On systems larger than about 2 kW and systems with array voltages greater than 200 volts, careful attention must be given to system grounding, ground fault protection, and system disconnects. Tradeoffs must be made between cost, additional safety, component and system reliability, and component availability. These tradeoffs can only be made on a site-by-site basis and need to be made by an engineer experienced in DC power systems.

Figure B-1. Totally Self-Contained System.

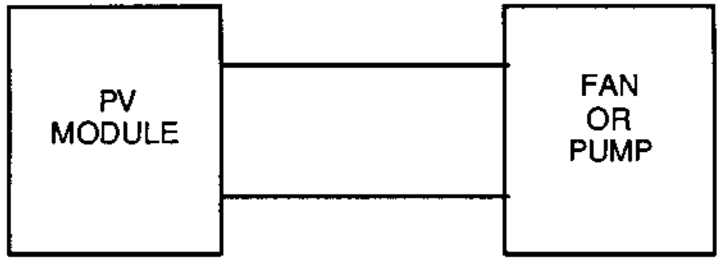


Figure B-2. Direct-Drive System—No Live Contacts.

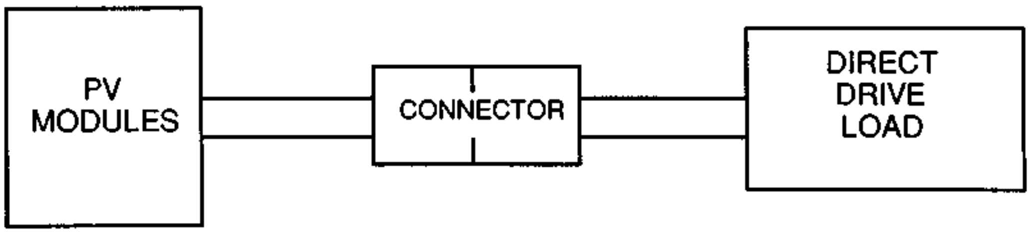


Figure B-3. Small System.

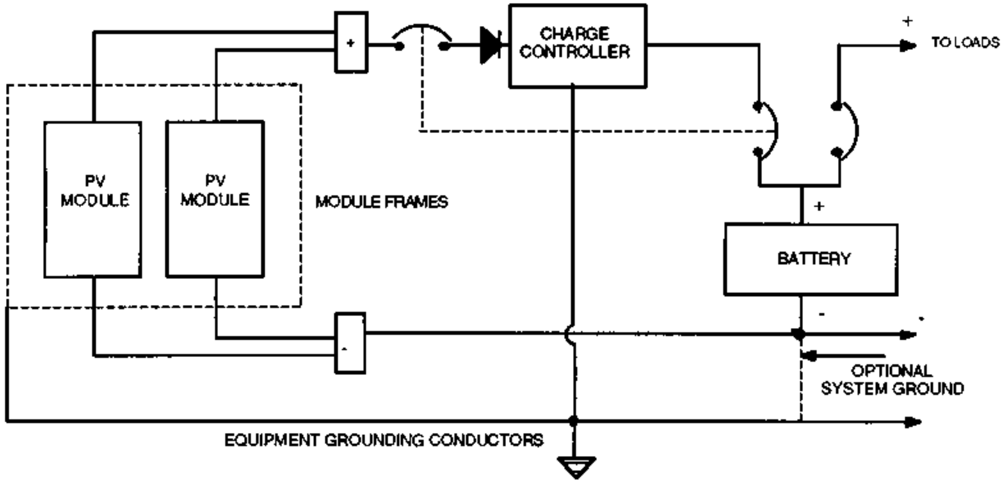


Figure B-4. Medium-Size Stand-Alone System.

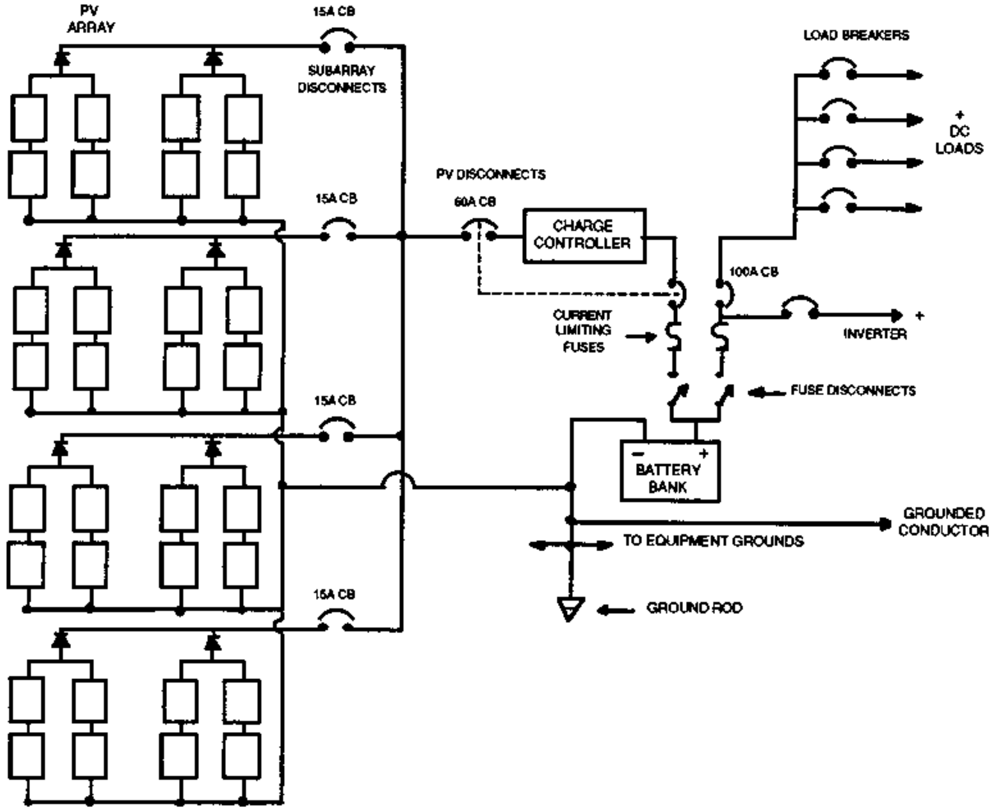
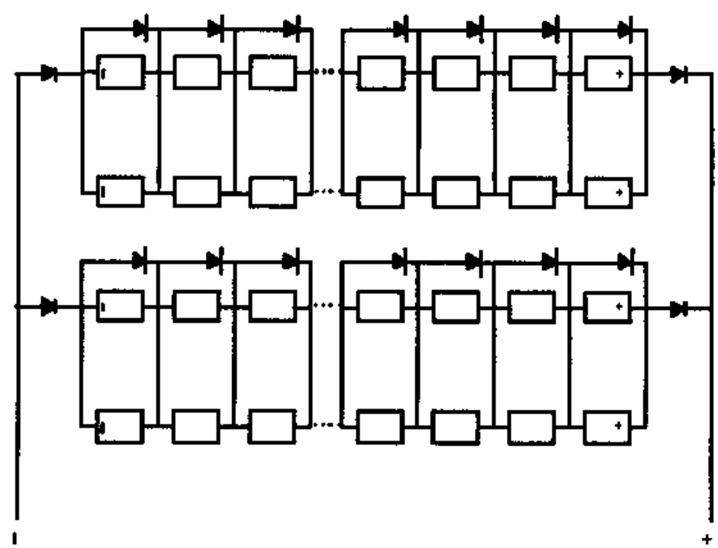


Figure B-5. Blocking and Bypass Diodes on Large Systems.



A solar electric system can be combined with other alternative methods of generating electricity. A solar/wind combination is particularly good since, quite often, either one or the other is available. The wind system manufacturer can help you hook the storage batteries to the wind system. With a blocking diode in each system, they won't interact with each other, but will independently charge your battery whenever they produce a sufficiently high voltage. Figure 2.12 is a simple circuit that will light a small pilot light whenever the system is actually charging the battery. The circuit draws all its power from the charging system and uses no current from the battery.

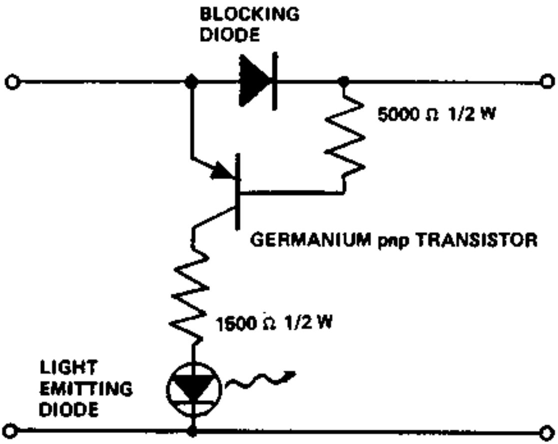


FIGURE 2.12–Simple circuit to indicate when battery is being charged. This circuit is powered by the solar array.

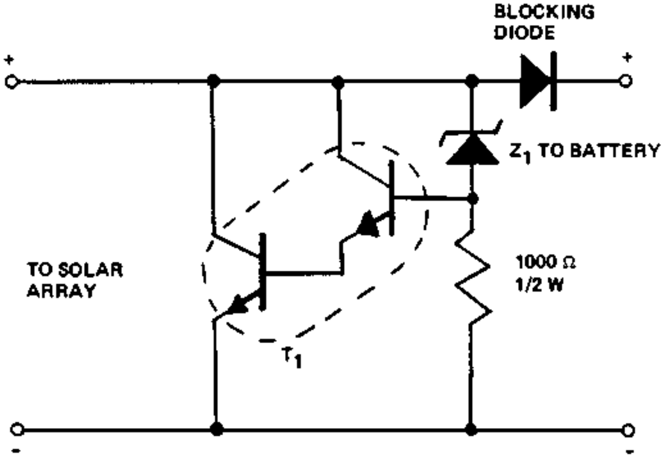
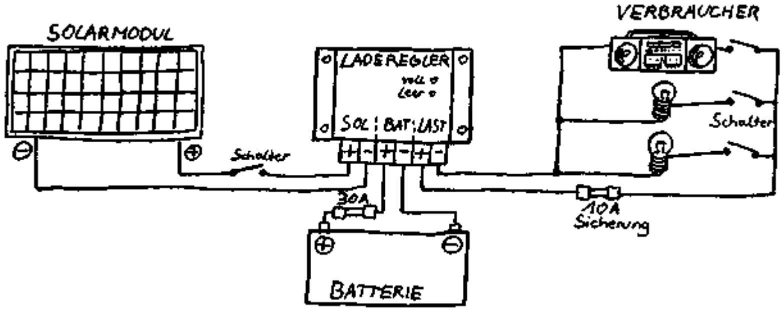


FIGURE 3.5—15-Volt shunt regulator with 20 amps maximum current handling capacity T_1 is 2n6282 npn power darlington. Transistor Z_1 is IN5352 15-volt Zener diode.

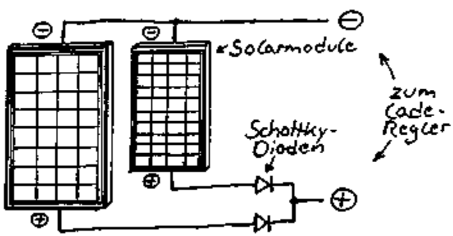
So sieht die Grundschaltung einer kleinen Solaranlage aus:



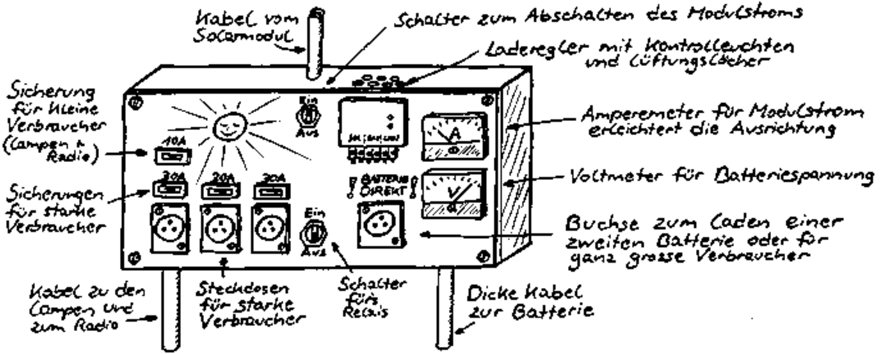
Von dieser Grundschaltung ausgehend, können wir die Anlage erweitern z.B. mit einer zweiten Batterie, einem Relais für grosse Verbraucher, oder mit einem zweitem Solarmodul.

Zusammenschalten von Solarmodulen:

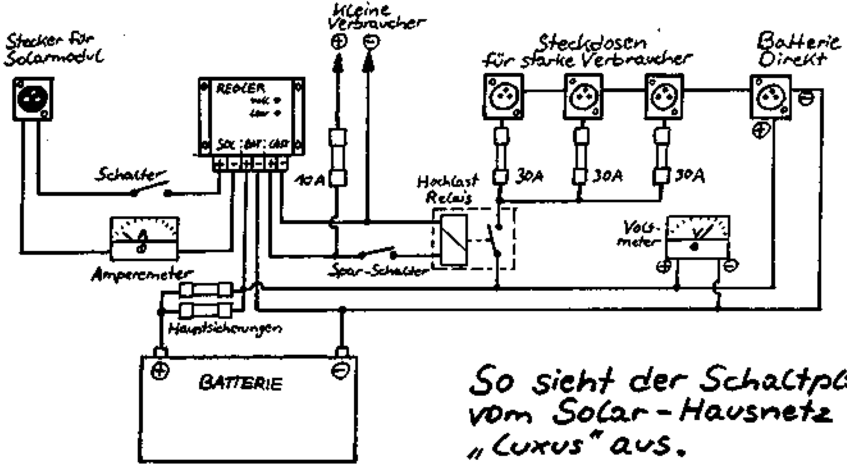
Wollen wir gleich mehrere Solarmodule über den gleichen Laderegler anschliessen, so muss dieser für die grösseren Modulströme geeignet sein. Wir sollten die beiden Module mit Schottky-Dioden voneinander entkoppeln, besonders dann, wenn zwei verschieden starke Module zusammen arbeiten sollen, weil sonst das stärkere Modul an das schwächere Strom abgeben würde.



So werden die Schottky-Dioden eingebaut. Der Strom kann so immer nur vom Modul wegfliessen.



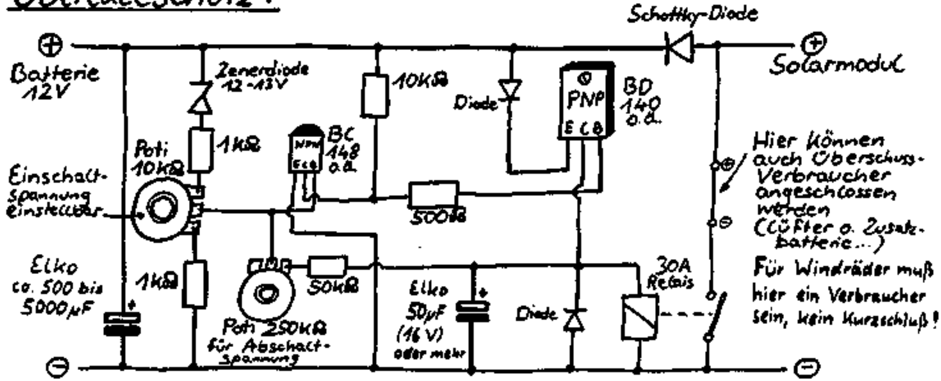
Kabel vom Solarmodul
Schalter zum Abschalten des Modulstroms
Laderegler mit Kontrolleuchten und Lüftungslöcher
Sicherung für kleine Verbraucher (Lampen + Radio)
10A
20A
20A
20A
Ein
Aus
Amperemeter für Modulstrom erleichtert die Ausrichtung
A
V
BATTERIE DIREKT
Voltmeter für Batteriespannung
Sicherungen für starke Verbraucher
Buchse zum Laden einer zweiten Batterie oder für ganz grosse Verbraucher
Kabel zu den Lampen und zum Radio
Steckdosen für starke Verbraucher
Schalter fürs Relais
Dicke Kabel zur Batterie



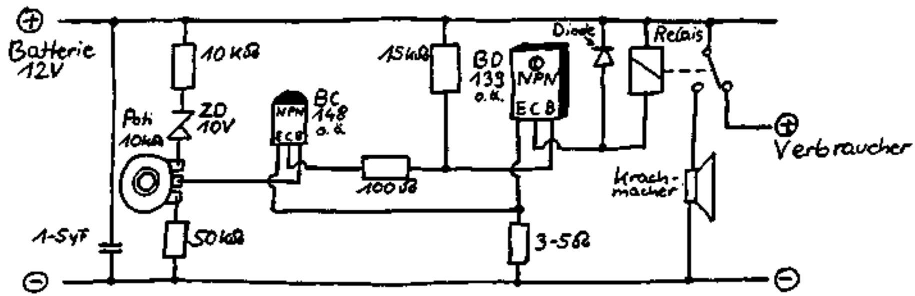
So sieht der Schaltplan vom Solar-Hausnetz „Luxus" aus.

Diese Schaltungen sind auch für Windräder geeignet!

Überladeschutz:



Tiefentladeschutz:



Wenn die Batterie leer ist, schaltet das Relais die Verbraucher ab und evtl. ein Warngerät, z.B. aus einem alten Quarz-Wecker zu.

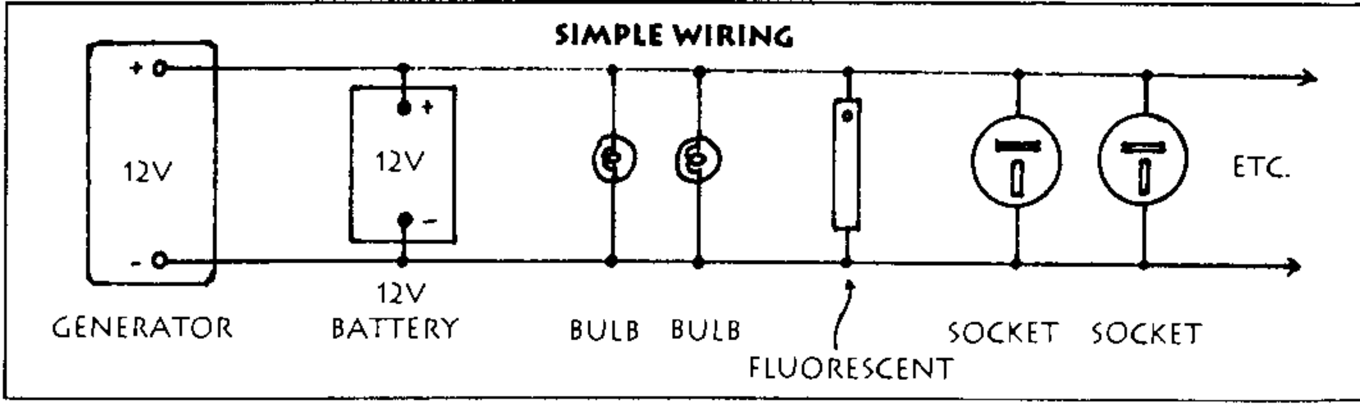


Figure 9-6. **The basics—this system would service a few light bulbs, a fluorescent light, radio, TV, etc.**

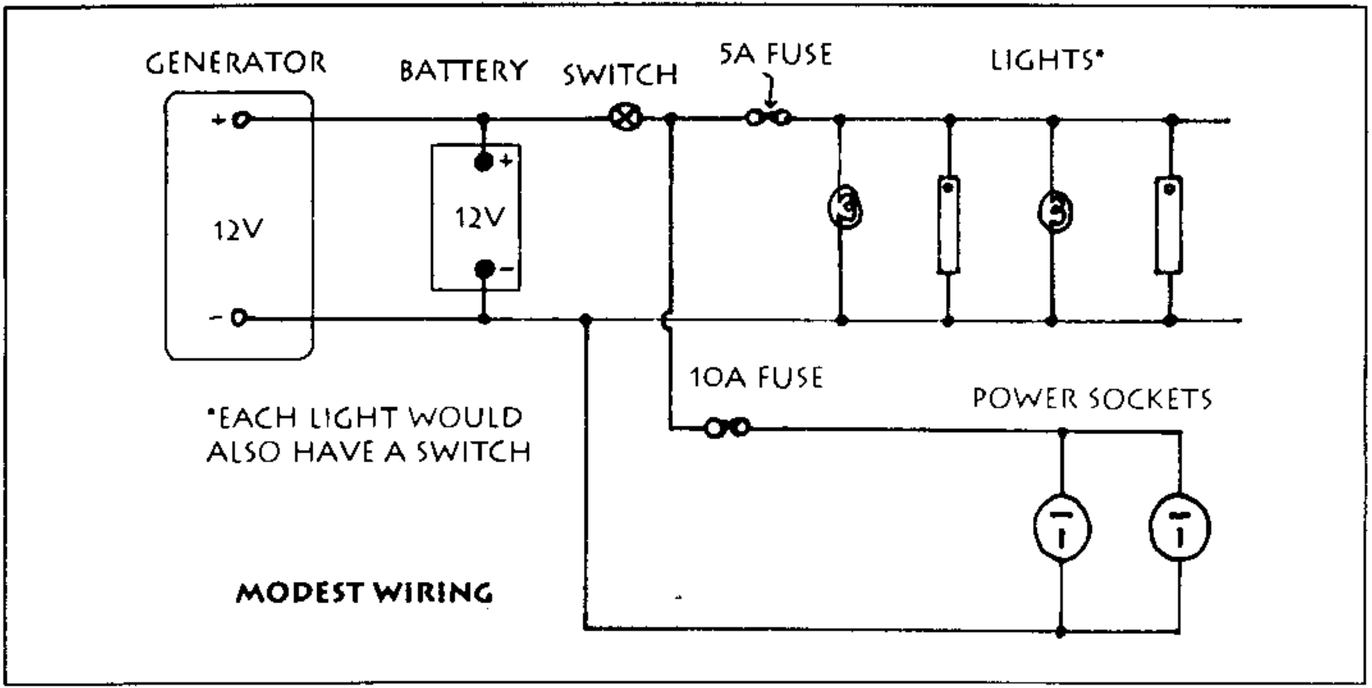


Figure 9-7. **This system, which is divided into two circuits, each protected by its own fuse, would be adequate for a small houseboat with moderate power demands.**

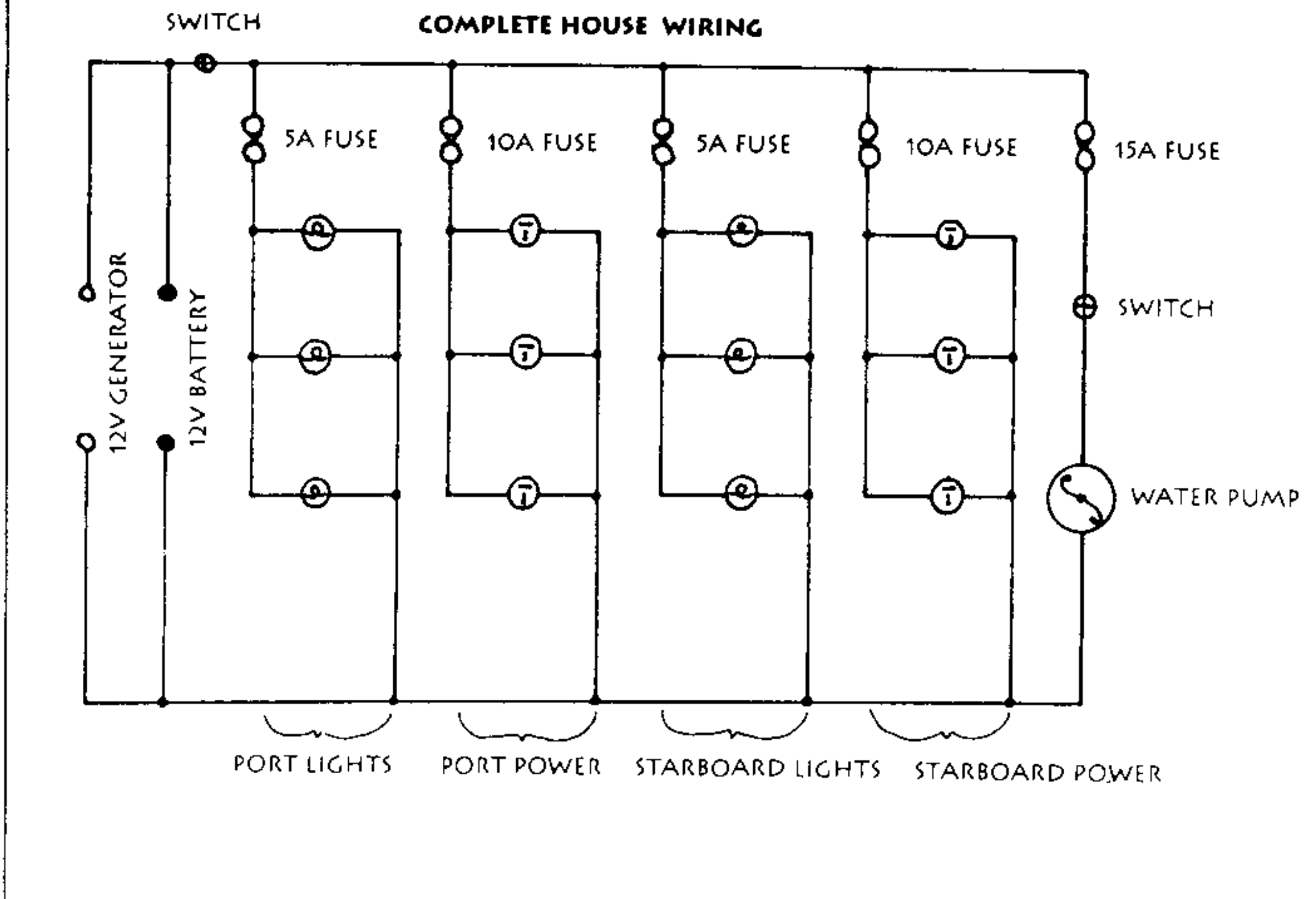


Figure 9-8. **This schematic illustrates a more sophisticated system that separates appliances according to current drain.**

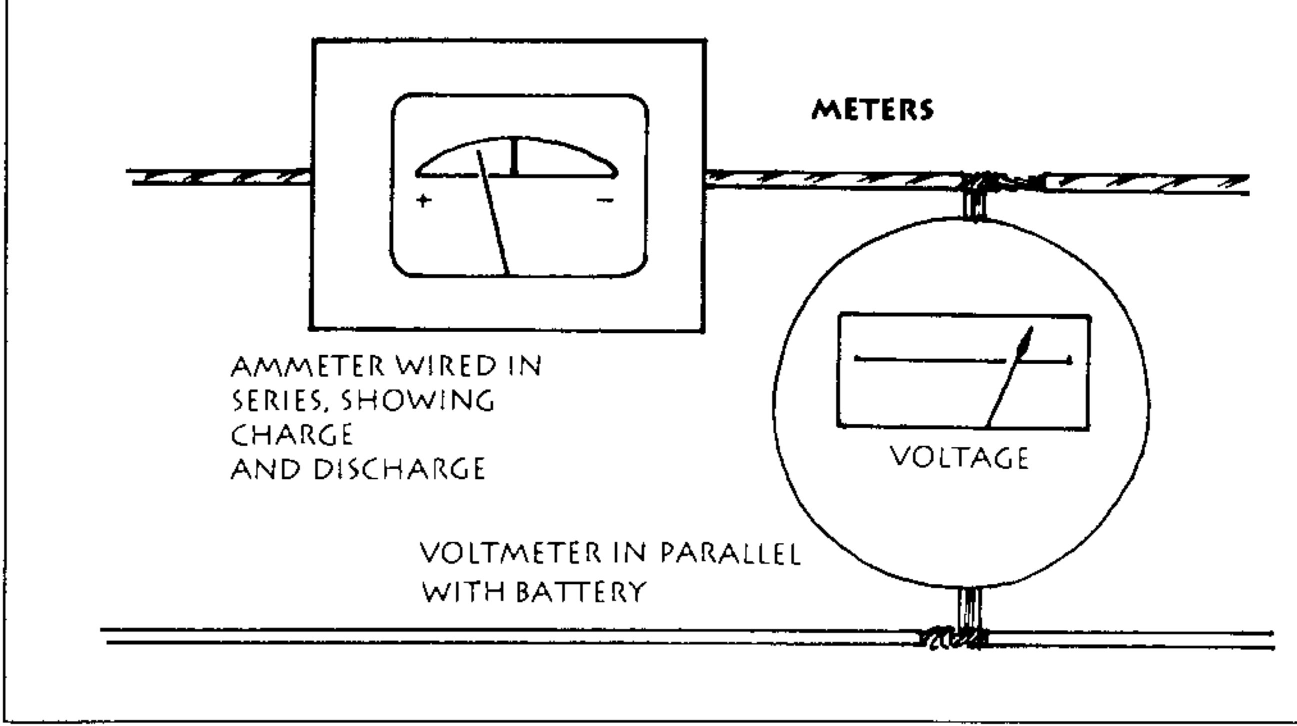


Figure 9-11. Installing ammeters and voltmeters.

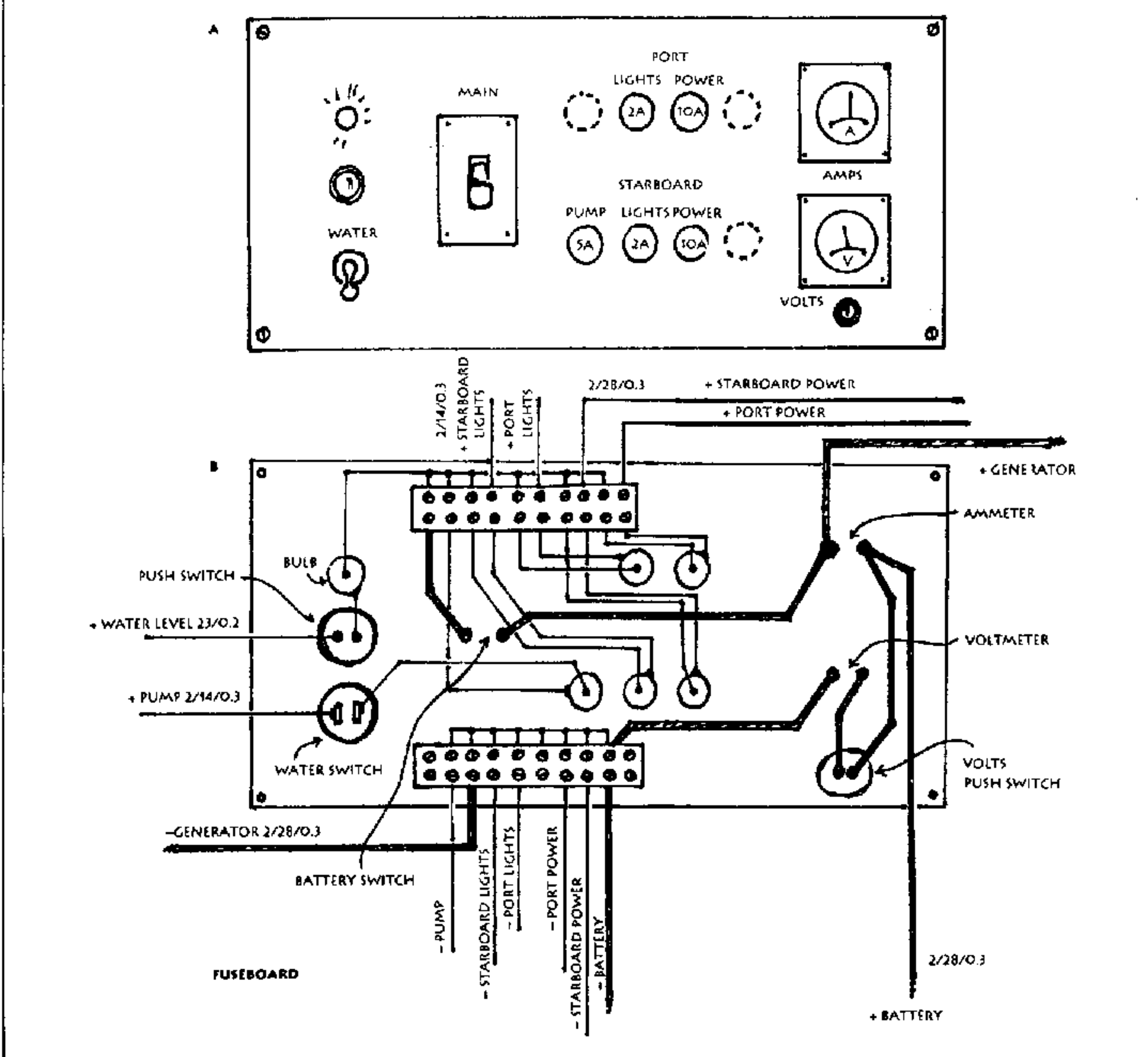
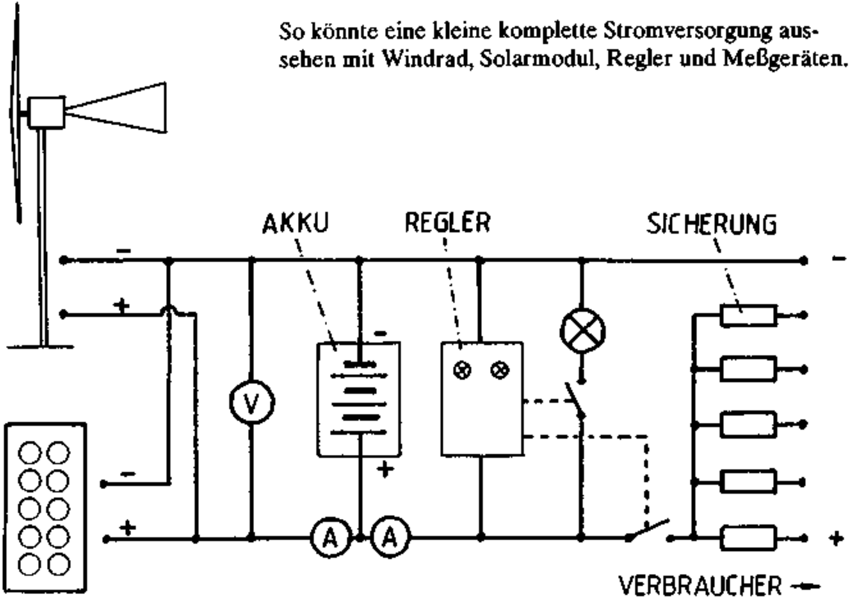


Figure 9-12. **A fuseboard makes order out of chaos, and it's a good place to mount your ammeter and voltmeter.**

So könnte eine kleine komplette Stromversorgung aussehen mit Windrad, Solarmodul, Regler und Meßgeräten.



…On Grounding

Mick Sagrillo with Richard Perez

Much has been written about the need to ground DC home power systems, how to do it, and the requirements of the National Electric Code (NEC). We are told that the negative line of a DC system must be connected to ground. I don't think anyone knows why, other than that it's "the law". I challenge this concept. I contend that grounding the negative leg of a DC system is useless and may even cause problems like increased shock danger, electrolysis, and interference with radio/electronic devices.

Background

This article grew out of a very lively conversation between Ken Olsen and Johnny Weiss of Solar Technology Institute, Jim Sievers of Iowa Alternative Energy, Richard Perez and myself over a pitcher of brews at the Midwest Renewable Energy Fair (MREF).

My (Mick's) experience comes primarily from wind systems. I also have dabbled with transportation systems (i.e., cars, trucks, trains, and planes), high voltage battery systems, large DC systems, hydroelectric, and PV systems. I have no experience with regulations or electrical code rationalizations. This information may have little to do with truth and justice of my statements, but needs to be stated for credibility.

My (Richard's) primary experience comes from PV systems. I have also been professionally involved in commercial television, and hold an FCC radio techie license. My background is in physics and electronics.

The Dilemma

Again, I maintain that grounding the negative leg of a DC system serves no useful purpose. It can actually cause problems that might not otherwise happen if the leg had not been grounded.

This does not mean that equipment should not be grounded. Towers, conduit, PV frameworks, and electrical equipment chassis should all be grounded. The reason for grounding is to protect equipment from direct lightning strikes and lightning's transient voltage surges. Grounding also dissipates the static charges present on electrical equipment, making the equipment less attractive to lightning. (For a thorough discussion of lightning protection see Home Power #24.)

Here are some of the reasons for not grounding the negative leg of a DC system.

Floating Systems vs. Grounded Systems

A DC wind generator (or three phase ac wind generator) is a 'floating system,' meaning that the current carrying conductors are only "hot," or have electric potential, in relation to each other. None of these current carrying legs are grounded. Grab the positive or negative leads, touch the ground and nothing will happen. The electric potential is only between the positive and negative of the system, It does not involve the ground, or another DC generator, a disconnected battery bank, nor any ac system. This constitutes a completely floating system. A floating system is isolated from everything but itself. Examples of floating systems are wind machines, PVs, microhydros, airplanes, automobiles, and boats. If you make connection between any current carrying conductor and ground, then nothing happens. If you get between the positive and negative, however, nasty shocks and/or burns can occur because you have become part of the current conducting path.

In 120/240 vac systems, we are taught not to come between any "hot" wire and ground. Ac is not only hot in relation to itself, but also relative to the ground. I think that this is where most of the confusion originates. In the United States, ac system codes ground the "neutral" conductor. This is not true for most of the rest of the world (all of Europe, South America, and Australia), which does not ground any of the current carrying conductors. That's right, virtually the entire world, except the USA, does not ground current carrying conductors. If you don't ground current carrying conductors, then items like ground fault interrupter circuits are not necessary.

Ground Loops and Ground Faults

Electricity flowing from one leg of a DC system through the ground creates a ground loop. The current then flows to the other leg of the DC system. How? Well, maybe through you if you are standing on that ground and happen to touch the other DC leg. Let's develop a scenario. I have a 120 VDC battery bank in my cellar, rated at 1440 Amp-hours. Fully charged, this battery bank contains 200 + kilowatt-hours worth of electricity! Assume that the negative side of this battery is connected to ground. Let's say that it has been raining, and the cellar floor is damp. If I went down to the cellar to fiddle with the batteries and touched a positive pole, guess what would happen? Fried Mick! I became part of a ground loop between the two hot battery terminals. This scenario is not far-fetched. In my cellar on humid spring days when the air was condensing on the cold battery cases, I have touched the negative or positive bus, had my bare arm brush against a case, and received quite a tingle.

A ground fault occurs when current leaks from a current carrying conductor to the ground. If the ground fault path has low resistance, then appreciable current will flow, creating a current loop to ground.

The danger for the generator or the electronics comes not from a single ground fault, but when a second ground fault happens, particularly if that second ground fault is of the opposite polarity from the first. In that event, the generator case, electronic equipment chassis, tower, or ground becomes a short circuit conduit between the positive and negative poles. This situation will also result if the negative line is grounded at the battery bank and a ground fault occurs in the positive circuit of the generator or electronics. The outcome is a current loop. Electricity does not flow to your batteries or inverter, but instead dissipates as heat in the short circuit. If this happens long enough, you will burn out the generator.

The situation is a different with inverters. Synchronous inverters with silicon controlled rectifiers (SCRs), bipolar transistors, or field effect transistors (FETs) will not tolerate ground faults or current loops. Typically, a synchronous inverter that is grounded on the ac side will short circuit and blow the power semiconductors. Synchronous inverters consider the negative leg of the DC system connected to ground as a ground fault.

Electrolysis

One final argument against grounding the negative leg of a wind system is the problem of electrolysis. A common practice of wind generator manufacturers in the 1920s and '30s was to ground the negative leg of the wind generator to the tower. This saved some materials in a highly competitive fledgling industry--only two slip rings and two slip ring brushes were needed, one for the positive and one for the field. The negative line of the machine was connected directly to the tower. The negative was then picked up at the tower's base and three wires, negative, positive and field, were brought into the house to the control panel.

After a decade or so, many of these towers began falling over. Close inspection of the tower at ground level revealed that the metal there was soft and spongy. The voltage in the tower leg set up a weak battery with the earth. Slowly, metal ions would disassociate from the tower and migrate from the tower legs into the earth. The tower became weakened at the soil line and eventually fell over.

Interestingly enough, at least one manufacturer capitalized on this idea. The Jacobs Wind Electric Company manufactured a wind plant that reversed this phenomenon for a special application— gas pipe lines. Cathodic plants, as they were called, had one leg of the generator connected to the gas line and the other leg buried in the ground. By pumping current from the ground to the pipeline, gas companies eliminated the maintenance caused by electrolysis in buried metal pipes.

Getting Grounded

To summarize, ac circuits brought to you by your friendly utility are grounded because the code says so. The current carrying wire is hot compared to the ground because the neutral is grounded at your mains panel. However, in DC circuits, the positive and negative leads are hot only in relation to each other, but not to the ground unless you ground one of them.

In both cases, an earth ground is used for lightning protection and static charge dissipation. However, ac and DC should never be grounded using the same grounding rod. The NEC prohibits using ac and DC in the same fuse box or junction box for safety reasons, but this should also apply to grounding rods to eliminate stray ac voltages on a DC line. A system should minimize the number of grounds to prevent electric pathways or stray voltages between multiple grounding rods.

This advice comes to you from an electronics person. The NEC was written for electricians, who want as many grounds as possible for safety reasons, but electronics people know that stray voltages develop between multiple grounds. These electrical pathways result in radio frequency interference (RFI), the familiar hum on communications equipment, radio and television. Somehow, the NEC will have to be changed to adapt to the needs of both electricians and electronics home power folks.

Guidelines
Some good rules to live by (pun intended) that have worked well for me and my customers:

1. Ground all wind tower legs, PV module frameworks, conduit, generator frames, and electrical equipment chassis.
2. Connect all indoor DC equipment cases to only one ground. The ground should be dedicated to DC equipment only. The DC ground should not include any current carrying conductors.
3. Connect all ac equipment to its own dedicated, NEC approved, ac ground. Use only one grounding rod to avoid stray voltages.
4. When working around batteries, temporarily ground the negative leg of the battery bank!
5. Never permanently ground either the positive or negative leg of a battery bank.
6. Never get between the positive leg and negative leg of a DC system.

One Final Story
I was recently contacted by an individual working on a wind system that was struck by lightning. Apparently lightning hit the incoming wires on the tower. The destruction was almost total: the tops were blown of all the batteries, and the battery shed burned to the ground. The control panels, inverters, and distribution panels inside the house were destroyed. Every outlet in the house had a three foot hole blown around it. The system used multiple grounds and had the negative leg of the battery bank grounded.

Had the system been floating, as it should have been, and had the system been grounded in only one place, less damage would have occurred. Banks that are floating usually have only one or two batteries destroyed.

Upon Further Review
I do not claim to be an expert on the NEC. I do, however, have a certain amount of expertise with wind electric systems. Maybe it is time that the home power people who produce their own electricity (photovoltaic, wind, hydro) sit down with the people responsible for the NEC and update them on what's happening on our individual scenes. It can only help!

Access
Mick Sagrillo has never been penalized for intentional grounding at Lake Michigan Wind & Sun, E3971 Bluebird Rd., Forestville, WI 54213 • 414-837-2267

Cables and Currents

John Wiles

In the early days (before NEC awareness), PV systems were wired with any wire that was at hand. Little attention was paid to the quality of the wire, its current carrying capability, or how it was connected. Experience with 12 years of large and small PV installations and the test of time along with help from the local electrical inspector has shown us better ways. Now, conductor types, ampacities, and terminals are a hot topic in the back rooms of most PV distributors, dealers, and installers. Conductor selection and ratings in various PV applications are the topic of this Code Corner.

Module Wiring

Rigid and flexible nonmetallic and metallic conduit can be used with modules having the appropriate conduit fittings on the junction boxes. If conduit is not required by a local code, Section 690-31 of the 1993 National Electrical Code (NEC) permits the use of single-conductor cable that is identified as sunlight resistant for PV module interconnections. Underground Feeder (Type UF), Service Entrance (Type SE), and Underground Service Entrance (Type USE) cables are allowed for module interconnects. Most UF cables are made with PVC insulation. Problems have been identified with PVC insulation when used in direct-current circuits where moisture is present. Under these conditions, the insulation dissolves. It is unknown whether PV module wiring in wet climates provides the conditions necessary for PVC insulation failure. It might be wise to use USE or SE cables in locations where the cables are in contact with standing water. Furthermore, although passing the Underwriters Laboratories (UL) standards for sunlight resistance, UF cable has shown signs of deterioration after only four years in hot, sunlight-exposed installations.

USE and SE cable are generally not marked sunlight resistant, but they have passed the sunlight resistance tests and most inspectors are familiar with the use of these cables outdoors in exposed locations. If the USE or SE cable has cross-linked polyethylene (marked XLPE or XLP) and is further marked RHW and RHH or RHW-2, it is one of the best, commonly available cables. Standard USE cable has only a 75°C insulation when wet. The RHW designation indicates rubber 75°C insulation for use in wet conditions, and the RHH indicates a rubber insulation, when dry, with a 90°C insulation. The new RHW-2 and USE-2 designations indicate insulation with a 90°C rating even when wet. SE cable has a slight advantage in that it has flame resistant additives that USE does not have. The Underwriters Laboratories label (UL) will ensure that the cable meets the highest quality standards and will be the most durable product.

Section 400-7(a)(10) allows the use of flexible cables to connect moving parts. Tracking flat-plate and concentrating PV modules are moving parts and these cables could be used. Types W and G are recognized by the NEC as flexible cables. Types SEO, SEOO, and the like usually have the necessary sunlight and weather resistance. These flexible cables are not allowed when connecting fixed arrays.

This wiring method using exposed, single-conductor cable is only allowed for module connections. At some point near the modules, the wiring method must be changed to one of the other methods meeting the requirements of the NEC. The exposed, single-conductor cables could be routed to a weather head and into conduit and then into the building and to the PV Disconnect Switch. Another alternative is to route the single-conductor cables to a junction box where the cables can be spliced to a jacketed, multiple-conductor cable like NM (Romex) or UF (Underground Feeder). These jacketed cables would then be installed with the required physical protection, and routed to the disconnect switch. NM cable, of course, can only be installed in indoor locations, while the UF cable has sunlight resistance and, with appropriate protection from physical damage, can be installed in outdoor locations.

Tray Cable (TC) comes in two or more conductor cables and is generally marked sunlight resistant, but some inspectors object to its use based on the NEC requirement in Section 340-4 to have it mechanically supported by a cable tray or other means. Also, Section 340-5 prohibits the use of tray cable as open cable on brackets or cleats. Tray Cable requires special calculations for current-carrying capacity (ampacity); the NEC must be consulted carefully when using this cable.

Temperature Derating

Because the PV modules are in the sunlight, they get significantly hotter than the surrounding air temperatures. Ambient air temperatures in some parts of the country may be as high as 45°C (113°F). The backs of the modules, the module junction boxes, and other nearby areas where the conductors must operate can have temperatures as high as 65°C to 75°C. The ampacity of the cables used to connect the modules must be derated for these higher temperatures.

Most installations should use an ambient temperature of 65°C to derate the conductors. In hot locations, with no ventilation provided for the back of the modules (e.g. mounted directly on a roof), a 75°C temperature should be used in the temperature derating calculations. In less sunny, cooler sections of the country, maximum module temperatures might be lower.

An Example

In a particular installation, it has been decided to use number 10 AWG conductors because of the size of the module terminals. Single conductor number 10 AWG USE-2 cable has been ordered with XLPE, RHW-2, and UL markings which indicate a 90°C temperature rating. The modules are mounted on a rack on a brown shingled roof, but for esthetic reasons, the spacing between the modules and the roof is only two inches. The wiring is to be in free air (not in conduit) so Table 310-17 in the NEC may be used. Since the 90°C module terminal rating matches the USE-2/RHH wire temperature rating of 90°C, the cable can be operated at the maximum temperature for which it was rated. In Table 310-17, Number 10 AWG cable with 90°C insulation has an ampacity (current carrying capacity) of 55 Amps at ambient temperatures of 30°C. A footnote to the table notes that number 10 AWG conductors may not have an overcurrent device rated at more than 30 Amps. Because the modules have little ventilation space and the roof is brown, the area between the modules and the roof and in the module junction boxes can be expected to be as high as 75°C on hot, sunny days. The ampacity of the conductor must be derated for this temperature which is the ambient temperature in which the conductors operate. Ampacity Correction Factors are presented in the lower section of Table 310-17. For conductors rated at 90°C, the derating factor is 0.41 yielding a number 10 AWG cable with a derated ampacity of 22.6 Amps (55 x 0.41).

Furthermore, Section 690-8 requires that a 25% safety factor be used when sizing the conductors so that they will not be operated continuously at more than 80% of the rated ampacity. This calculation indicates that the maximum short-circuit current that this conductor can handle is 18.1 Amps (22.6/1.25). The sum of all short-circuit currents for all of the modules connected in parallel on this number 10 AWG USE-2 cable should not exceed 18.1 Amps.

If the modules were spaced six or more inches from the roof, the maximum operating temperature would drop to about 65°C on hot, sunny days. In this case, a derating factor of 0.58 is given which, when multiplied by the 55 Amp rating of the cable at 30°C, gives a derated ampacity of 31.9 Amps (55 x 0.58). After the 25% safety factor is applied, the maximum short-circuit current that can be carried by this cable is 25.5 Amps (31.9/1.25).

Interior Wiring

All interior wiring of DC PV source circuits and DC and ac load circuits must comply with all aspects of the NEC. The cables for DC circuits are similar in most cases to that required for ac circuits. In some cases a larger size conductor is used to reduce voltage drop in DC circuits, but the installer must ascertain that switches and outlets have terminals that will take the larger conductors.

Battery and Inverter Cables

Large conductors such as the 2/0–4/0 AWG cables used to connect batteries and inverters are very stiff if made with building wire such as THHN or USE with 19 strands of copper. The inspector may require the use of such cable because the NEC requires it to be used in fixed installations and the inspector frequently sees electricians using these stiff cables in standard ac power installations. The NEC also requires that space be allocated for wire bending and connection areas when installing equipment using these large cables. Use of these cables requires the proper tools, available from electrical supply houses, to deal with the stiffness.

Most PV installers use either battery cable (controlled by SAE Standards) or welding cable for the larger cables. These cables have numerous small strands that provide a degree of flexibility not found in the more rigid building cables. Stand-alone inverters and large battery cells are being manufactured with flexible cables attached, but these products are generally designed for mobile applications or industrial applications which do not fall under the NEC. The flexibility makes for ease of installation, but the NEC does not make definite provisions for their use in fixed installations. If the flexible cables are used, they should be UL Listed, acid resistant, and installed in conduit. Flexible, Type W single-conductor cables are available and identified for extra hard usage. UL Listed, flexible welding cable is also available, but is not recognized in the NEC for this use.

There are restrictions in Section 400-8 that prohibit these flexible cables from being run through walls or being attached to building surfaces. Section 400-10 of the NEC also requires that strain relief be used wherever flexible cables are connected. This would indicate that if the inspector approves their use, it will most likely be for short runs to a nearby junction box where the flexible cables are connected to a standard, stiff cable. A proposal will be submitted for the 1996 NEC that permits this particular use of flexible cables in an otherwise fixed installation.

Manufacturers of inverters are starting to deliver products with the necessary conduit fittings that will allow the use of the more rigid standard building cables. Underwriters Laboratories is addressing the cable and cable termination requirements as they develop standards for the inverters and battery systems used in residential and commercial PV systems falling under the NEC.

High-Current Cables
The inverter-to-battery cables should be sized based on the inverter continuous power rating at the lowest battery voltage. More and more systems are being installed with large inverters, backup generators, and auxiliary battery chargers. Deep-well pumps filling large storage tanks present a significant load especially when other DC and ac loads are being used simultaneously. If the inverter has the ability to deliver continuous power, and a generator, micro hydro, or the PV array can hold the batteries above the low voltage disconnect point, then that exact situation can and will occur. For example, the 85% efficient inverter is rated at 2000 Watts on a 12 Volt system with a low voltage disconnect of 10.5 Volts, the input current under full power is 2000/.85/10.5 = 224 Amps. The 25% safety factor increases this to 280 Amps and Table 310-16 of the NEC indicates that 250 MCM cable (one size larger than 4/0) in conduit should be used.

Summary
Cables and equipment that meet the requirements established by the NEC are available and can be used for PV installations. Ampacity calculations that are related to high-temperature PV installations are required. In some cases, waivers by the electrical inspector may be required. In other instances, new (to the PV installer) installation techniques may have to be used to deal with the existing, required cables.

Access
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Clarifying Confusing Cables

John Wiles

Sponsored by The Photovoltaic Systems Assistance Center
Sandia National Laboratories

The National Electrical Code (NEC)® contains numerous references to different cable and conductor types. Some types are intended for fixed, non-moving installations. Other types are designated for installations where various parts must move. Some cable types can be used in either fixed or moving installations. Each cable type is designated by a series of letters and numbers that refer to the size of the conductor and the type of insulation. This Code Corner will attempt to shed a little light on the murky subject of conductors and cables.

Conductors, Cables, or Wires?

A conductor is something that is meant to conduct or carry electricity. It is normally made of copper, but can also be made of other metals like aluminum. Today, however, copper is the most commonly used conductor in both PV and residential electrical systems. It can be bare, with no covering or electrical insulation, or insulated.

The size of the conductor is expressed as an American Wire Gauge (AWG) with designations from number 27 AWG, the smallest size mentioned in the NEC®, to number 4/0 AWG or 0000 AWG (called "4 aught"). Conductors larger than 4/0 AWG are specified in kcmil (thousands of circular mils), a cross-sectional area designation, and range from 250 kcmil up to 2000 kcmil (with a diameter of about 1.6 inches).

Conductors may be solid copper (usually 6 AWG and smaller) or may be stranded. Stranded conductor is composed of several strands of a smaller conductor twisted together. Typical stranded conductors from 18 AWG through number 2 AWG have seven strands. Conductors from 1 AWG through 4/0 AWG have 19 strands. Conductors 250 kcmil through 500 kcmil have 37 strands. In each of these sizes, conductors are available on special order that have considerably more strands for added flexibility. For example, a 4/0 AWG conductor may have 437 strands of very small copper conductors rather than the 19 strands in the standard conductor.

Cables are usually defined as conductors covered by insulation, although in many cases, the term conductor and cable are used interchangeably. Cables may have only a single conductor, or may have multiple, individually-insulated conductors. Some multiple conductor cables have an external insulating outer covering or sheath. Others do not, and the individual conductors are just twisted together.

The term "wires" is used in the NEC® to refer to the general use of cables or conductors. Reference may be made to a wiring system, wire size, wire sag, and similar terms.

Grouping of Cable Types

In the NEC®, there are two distinct groups of cables. One group represents the building-wiring types of cables. They are primarily used in fixed, non-moving installations such as buildings and are the principle types of cables used in wiring PV systems. These types of cables are identified in Table 310-13 of the NEC®, and the proper methods of installing these cables may be found in Chapter 3 of the NEC®.

The second grouping of cable types is the Flexible Cords and Cables found in Article 400 of the NEC® and described in Table 400-4. These cables are used where there is motion between two parts that are electrically wired together. Such cables are used on appliances, tools, elevators, cranes, and other industrial applications. PV trackers represent a moving installation where flexible cords could be used.

These types of cables are specifically prohibited in Section 400-8 of the NEC® from being used as a replacement for fixed wiring. One of the reasons for this prohibition is that flexible cords have not been tested, evaluated, or listed for fixed uses such as being placed in conduit or run through walls. Another reason is that these flexible cables are generally installed in exposed locations where damage is readily visible and the need for replacement is evident. There are numerous other prohibited uses where the code says that if a fixed, building-wire cable can be used, the fixed cable is to be used in lieu of a flexible cable.

Insulations and Cable Markings
Cables have insulations that are made of different materials for different applications. The letters and numbers of the outer covering of the cable provide information on the cable and where it can be used. The tables in Chapter 3 and Article 300 of the NEC® generally specify under what conditions each cable type can be used. Listed below are some of the cables that can be used in PV systems starting with the building-wire types of cables.

Cables for PV module connections
Exposed, single-conductor cables are allowed for PV module connections by NEC® Section 690-31. The following are the types allowed:

USE: Underground Service Entrance • 75°C, wet insulation rating • Heat and moisture resistant • Sunlight resistant, but not marked as such.

USE-2: As above, but with a 90°C, wet insulation rating. The most commonly recommended cable for PV module wiring.

UF: Underground Feeder • 60°C, wet insulation rating • Not sunlight resistant unless marked • Hard to find and not recommended due to the low, 60°C temperature rating.

SE: Service Entrance • Temperature rating is variable and is marked on the jacket • Sunlight resistant, but not marked • Hard to find in a single conductor.

PV modules may also be connected with conductors installed in conduit (metal, plastic, flexible, rigid, etc.). Since the conduits are exposed to the elements, they are considered to be wet locations (even in the hot, dry, sunny Southwest), and wet-rated conductors with 90°C insulation should be used for PV module wiring. The following types are the cables typically used.

THWN-2: Moisture and heat-resistant thermoplastic • 90°C, wet and dry insulation rating • May also be marked THHN. A cable marked only with THHN is not suitable for use in exposed conduits.

THW-2: Moisture and heat-resistant thermoplastic • 90°C, wet and dry insulation rating • May also be marked THHW.

RHW-2: Moisture and heat-resistant thermoset (rubber) • 90°C, wet and dry insulation rating • May also be marked USE-2 and/or RHH.

XHHW-2: Moisture and heat-resistant thermoset (cross-linked synthetic polymer) • 90°C, wet and dry insulation rating.

In these and other markings on cables, the letters and numbers have meaning.

T: Thermoplastic insulation

R: Thermoset insulation (rubber or synthetic rubber)

X: Cross-linked synthetic polymer insulation

H: High temperature (usually 75°C when dry or damp)

HH: Higher temperature (usually 90°C when dry or damp)

W: Moisture resistant (usually 60°C when wet)

N: Nylon jacket

-2: High temperature and moisture resistance (90°C wet or dry)

Combinations of these letters and numbers change the definitions somewhat.

Wiring away from the PV modules must be one of the building-wire type of wiring systems. These methods are discussed in Chapter 3 of the NEC®. Single-conductor exposed cables are generally not allowed nor are unjacketed multiple-conductor cables.

If protected from mechanical damage and not exposed to high temperatures, a UF multiple-conductor jacketed cable might be used. However, since the cable is limited to 60°C by Section 339 of the NEC®, it is generally not applicable outside the structure where higher temperature ratings are required.

Inside the structure, the conductors listed above may be used inside conduit. Additionally, since the temperature requirements are less, and the conduits are no longer exposed, 75°C, damp-rated insulation versions of these conductors may also be used (THHN, THW, RHW, XHHW, or RH). Local electrical codes generally require conductors in conduit for all commercial wiring.

Non-metallic sheathed cable (Type NM) also know as Romex® is commonly used for interior residential wiring where it can be installed properly inside walls in accordance with NEC® Section 336. Note that type NM cable is specifically excluded from storage-battery room applications.

PV Trackers
Trackers contain moving parts and as such may be wired with flexible cables. However, the slow rotation rates of trackers (1300 revolutions per decade) generally allow the use of the stiffer building-wire types of cable, and are therefore recommended. Also available are building-wire types of cables with extra-fine strands for additional flexibility where required.

If flexible cables are to be used, then types identified in Article 400 of the NEC® are appropriate. The markings shown below should always be accompanied with the letters “W-A” to indicate that the cable is suitable for outdoor use.

Flexible cords suitable for PV tracker connections on trackers are: SE, SEO, SEOO, SJ, SJE, SJEO, SJEOO, SJO, SJOO, SJT, SJTO, SJTOO, SO, and SOO. These are all hard-service or extra-hard-service flexible cords. With the “W-A” rating, they are also suitable for outdoor use. Again, each of the letters has meaning:

S: Hard Service Flexible Cord

SJ: Junior Hard Service Flexible Cord

E: Thermoplastic elastomer insulation

T: Thermoplastic insulation

O: Jacket is oil resistant

OO: Jacket and Conductors are oil resistant

Battery Cables

Battery-to-inverter cables are usually large in size. They should be installed in conduit when being used between the battery enclosure and other equipment. As mentioned above, extra-flexible building-wire cables are available that may make the installation somewhat easier. Extra-flexible types that are available include THW, RHW, and USE. Since most batteries are in sheltered areas, cables with only a damp-rated, 75°C insulation are required.

Section 690-74 of the NEC® allows the use of Article 400 flexible cables for inter-cell battery connections as well as the connections from the battery to a fixed-wiring system. Since single-conductor Article 400 cables (types SC and W-this is not welding cable) are not readily available, it is suggested that extra-flexible, building-wire types of cables be used for connections to the battery when it is deemed necessary to use flexible cables.

Welding cables and automotive battery cables are not recognized by the NEC® for use in wiring electrical power systems.

Listed Cables

All conductors (except bare) and all cables should have all size and insulation type information plus the listing mark printed on them. The listing mark will normally be the “UL”, indicating that Underwriters Laboratories, Inc. has evaluated the cable for the intended use.

Summary

The choice of the proper cables for PV installations is relatively straightforward. Most cables are available locally or are stocked by PV distributors. Using the correct cable in each application will ensure a durable, safe, long-lasting PV system.

Questions or Comments?

If you have questions about the NEC® or the implementation of PV systems following the requirements of the NEC®, feel free to call, fax, email, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV Industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy.

Access

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SAFETY ALERT

John Wiles

A potential safety problem exists when a stand-alone 120-volt inverter is connected to a house or other structure wired for 120/240-volt alternating current. All PV Dealer/Installers and individuals who have installed such systems should review the following information carefully and take corrective actions where necessary.

Stand-alone PV and PV/Hybrid systems are frequently connected to a building, structure, or house that has been previously completely wired for 120/240-volts ac and has a standard service entrance and load center.

These structures may employ one or more circuits that the National Electrical Code ® (NEC ®) identifies as a multiwire branch circuit. See Section 100 in the NEC, “Branch Circuit, Multiwire” for a complete definition. These circuits take a three-conductor-plus-ground feeder from the 120/240-volt load center and run it to the loads in the structure where two separate 120-volt branch circuits are split out. Each branch circuit uses one of the 120-volt hot, ungrounded conductors from the 120/240-volt feeder and the common neutral conductor.

In a utility-connected system or a PV system with a 120/240-volt stacked pair of inverters, the 120/240-volt power consists of two 120-volt lines that are 180 degrees out of phase. The currents in the common neutral in the multiwire branch circuit are limited to the difference in currents from any unbalanced load. If the loads on each of the separate branch circuits were equal, then the currents in the common neutral would be zero.

A neutral conductor overload may arise when a single 120-volt inverter is tied to both of the hot input conductors on the 120/240-volt load center. This is a common practice for stand-alone PV homes and I do it in my house. At this point, the two hot 120-volt conductors are being delivered voltage from the single 120-volt inverter and that voltage is in phase on both conductors. In the multiwire branch circuits, the return currents from each of the separate branch circuits *add* in the common neutral. A sketch of the multiwire branch circuit is presented below. Additional information can be found in the NEC in Sections 100, 210-4, 240-20(b), and 300-13(b), and in the NEC Handbook.

Each branch circuit is protected by a circuit breaker in the ungrounded conductor in the load center. The neutral conductor is usually the same size as the ungrounded conductors and can be overloaded with the in-phase return currents. The circuit breakers will pass current up to the ampacity of the protected conductors, but when both branch circuits are loaded more than 50%, the unprotected, common-neutral conductor is *overloaded and may be carrying up to twice the currents that it was rated for.*

A definite fire and safety hazard exists. All existing stand-alone PV installations using single inverters tied to both ungrounded conductors at the service entrance should be examined for multiwire branch circuits.

The NEC requires that multiwire branch circuits in *some, but not all, cases* have the two circuit breakers tied together with a common handle (or use a two-pole circuit breaker) so that both circuits are dead at the same time under fault conditions and for servicing. This common-handle, side-by-side circuit breaker rated at 15 or 20 amps may be one indication that multiwire branch circuits have been used. Common handle circuit breakers rated at 30 amps and higher are usually dedicated to 240-volt circuits for ranges, hot water heaters, dryers, and the like.

Examination of the wiring in the load center may show a three-wire cable (14 or 12 AWG conductors) with a bare equipment grounding conductor leaving the load center. This may be connected to a multiwire branch circuit. The circuit breakers connected to this cable and the outputs of this cable should be traced to determine the presence or absence of a multiwire branch circuit.

The multiwire circuits must be disconnected or rewired as separate circuits (“home runs”) from the load center. Another option is to limit the output of the inverter with a circuit breaker rated at the ampacity of the neutral conductor (usually 15 amps).

With 4000 watt (33-amp) inverters, a 15-amp circuit breaker on the output will certainly limit the output but won’t be very popular (only half power output).

A copy of a draft proposal for the 1999 NEC is presented below that addresses this problem.

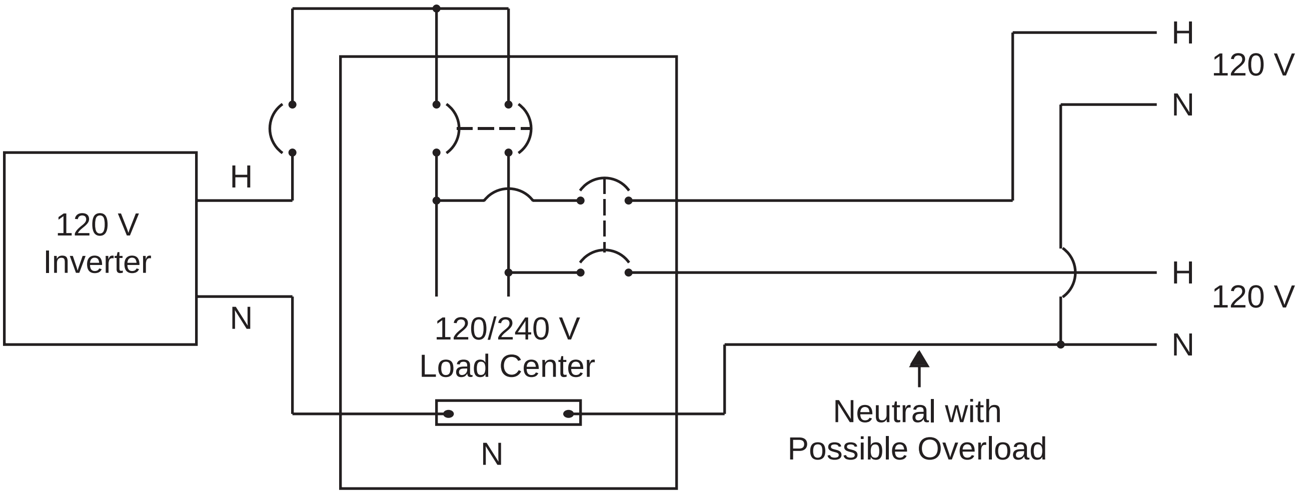

Diagram of a multiwire branch circuit

Draft Proposal for the 1999 National Electrical Code
This draft proposal, if accepted, will provide exceptions to NEC Section 690-14. This section requires that PV systems comply with the provisions of NEC Article 230, Part F, which covers service entrances. Some electrical inspectors are raising the issue that if a house is wired with a 120/240-volt service entrance at 100 amps, then the PV system must supply 120/240 volts at 100 amps — that would require a $240,000 PV system! Exception 3 to Section 690-14 will permit the PV system to deliver power (current) to the house at less than the rating of the service entrance. Exceptions 4 & 5, shown in the next paragraphs, will allow a 120-volt inverter to feed a 120/240-volt service entrance. The Exceptions are followed by substantiation for the Code Making Panel that must vote on the proposal.

Draft Exception
Exception No. 4: The inverter output of a stand-alone photovoltaic power source shall be permitted to supply 120 volts to a single-phase, three-wire 120/240-volt service entrance or main disconnect when there are no 240-volt outlets and when there are no multiwire branch circuits. In all installations, the rating of the output overcurrent device connected to the photovoltaic inverter shall be less than the rating of the neutral conductor in the load center or service disconnect device in the structure.

Exception No. 5: Where 120-volt multiwire branch circuits are present, the output overcurrent device connected to the photovoltaic inverter shall be rated at no more than the ampacity of the smallest common neutral conductor in the multiwire branch circuits.

Substantiation
Most inverters in stand-alone photovoltaic power systems have a single 120-volt output. It is common practice to connect this single output to both (in parallel) ungrounded conductors of a single-phase 120/240-volt, three-wire load center and supply current in phase to all 120-volt outlets and appliances. If 240-volt loads were inadvertently connected to the premises wiring, there would be no safety issue since the two ungrounded conductors have voltages that are in phase which would supply the 240-volt connected device with zero volts.

Some residences and other structures are wired with multiwire branch circuits where the two ungrounded conductors of the 120/240-volt single-phase system supply current to separate 120-volt circuits with a common return neutral conductor. If both 120-volt circuits were connected to loads, the return currents in the neutral would be in phase when driven by a 120-volt inverter and this could cause an overloaded neutral conductor while not tripping any overcurrent device. These exceptions recognize this condition and prevent the connection if multiwire branch circuits are present. If they are present, then limiting the maximum current delivered by the inverter through the use of an appropriate overcurrent device will protect the neutral conductors.

It is possible, though unlikely, that a large inverter could be connected to a small load center and overload the neutral in the load center. The last sentence in Exception 4 prevents this from happening.

Summary
There are houses and other buildings that are wired with multiwire branch circuits. The practice is quite common in some areas of the country. Please check your existing installations.

If anyone determines that multiwire branch circuits are common practice in a certain part of the country, please share that information widely and notify me.

Please distribute this article as widely as possible throughout the PV community.

Access

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An NEC Article 690 Task Group, chartered by NFPA, is working on the 1999 NEC with a Technical Review Committee from the Solar Energy Industries Association (SEIA). Those wishing to actively participate should contact Ward Bower at Sandia National Laboratories • 505-844-5206

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Specifying PV Wiring

Richard Perez

Questions flood into HP Central via mail and phone. High on the hit parade is, "What size wire do I need to hook-up my PV array?" Well, here's the straight info on specifying wire gauge between the photovoltaics and the controller/battery. Electricity produced by photovoltaics is low voltage. Low power loss in low voltage wiring is essential for effective performance.

A Short History

I feel that the subject of wiring and interconnection is so important and so misunderstood, that we have run many articles about this subject. Here's a list: HP2-pg 11, HP2-pg 33, HP3-pg 40, HP4-pg 33, HP6-pg 35, HP7- pg.36. Wiring articles after HP11 are listed under Basic Electric in the index in this issue, see page 49.

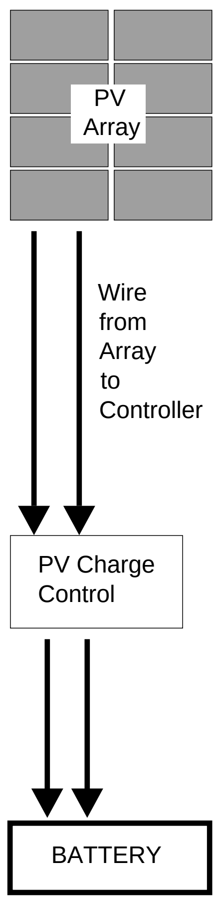
This article doesn't probe the depths of Ohm's Law and the Copper Wire Table. Here the work is done for you. You have only to look up your situation on the tables. You must, however, use the tables properly if you are to get real answers instead of bogus info.

Wiring on the PV Array

A photovoltaic array consists of several PV panels wired in parallel (12 Volt systems) or in series/parallel (24 Volt systems). The interconnects between the individual modules can be made with 10 gauge copper wire. Use stranded, copper wire with a "USE" or "UF" insulation because these outer coatings will resist sunlight degradation. Use of 10 gauge is practical because the current from an individual module is low (≈3 Amps.) and the distances are short (usually <2 feet). These wires connect to the better-quality PV panels with ring connectors. Solder these ring connectors to the wire! If you are using panels that don't take ring connectors, then tin the wire ends with solder before installation. See page 35 of this issue for soldering info.

Wiring between the PV Array and the Controller

This is really what we are interested in here. The distance between the array and the control is often many feet, and is different for each system. Since the PV controller is usually located very near the batteries, the distance here is not a problem. This is not the case with the array to controller circuit. Often we have to mount the PV array some distance from the battery in order to get the array into a better, more sunny, location. The illustration to right shows the PV array to Controller wiring circuit covered here.



The Tables

On the next page, there are two wiring tables. Both tables are for copper wire only. The upper table is for 12 Volt systems and the lower for 24 Volt systems. The upper horizontal row of each table contains the PV array current in Amperes. The left most, vertical column contains the round trip wire length in feet. Now, this is ROUND TRIP! If the array is 100 feet from the controller, then 200 feet of wire is required (two conductors).

The information on these tables was computed on the following criteria. The wiring efficiency must be 97.5% efficient. Efficiency was computed as power through the circuit minus the power lost to the voltage drop in the wiring . The wire is also specified by ampacity. Ampacity is the current handling capability of a conductor regardless of its length. Ampacity is directly proportional to the cross-sectional area (diameter) of the wire.

Using the Tables

Use the upper table for 12 Volts and the lower table for 24 Volts. Locate your array's current on the upper row. Now locate your round trip wiring length in feet on the left most, vertical column. The correct wire gauge number is located at the intersection of the row and column you have chosen. The wire gauge number is American Wire Gauge (AWG). Please note that the computer designates "00" gauge as -1,"000" gauge as -2,"0000" gauge as -3.

If you want even higher wiring efficiency, then use the next larger wire gauge. If you live in an area that is hot (average daytime temperature >90°F. for at least six months yearly) then use the next larger wire size. Remember, as the wire diameter gets larger the AWG number gets smaller. Since you may want to add more PV panels to your array in the future, specify the wire for the biggest array you think you will ever use. Wire doesn't wear out, so if you buy wire that is large enough, you will never have to replace it.

I bought the BIG Wire, so I'm in, right?

Not quite. Even the largest wire can be rendered completely ineffective by poor electrical connections to the wire. A series electrical circuit is like a chain- only as strong as its weakest link. Each and every element in a series circuit must be low loss in order for the entire circuit to be low loss. It only takes one funky connection to shoot down the whole circuit. Solder all low voltage connections wherever possible. The article on page 35 of this issue gives you all the soldering info you need to make your investment in large wire permanent.

Access

I have the original, working spreadsheets that generated these tables. These spreadsheets are in Excel 2.2 for the Macintosh computer. If you want a copy of the spreadsheets, send me a 3.5 inch diskette in a mailer with return postage included. Richard Perez, C/O Home Power Magazine, POB 130, Hornbrook, CA 96044.

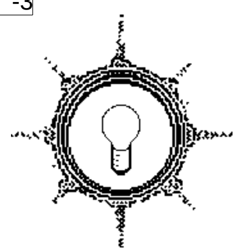
12 VDC

PV ARRAY CURRENT IN AMPERES.

		6	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
R	25	13	10	10	9	8	7	6	6	5	4	4	4	3	3	2	2	2	1	1	0	0	0
O	30	13	10	9	8	7	7	6	5	4	4	3	3	2	2	2	1	1	1	0	0	0	0
U	35	12	9	8	7	7	6	5	4	4	3	3	2	2	1	1	1	0	0	0	0	-1	-1
N	40	11	8	7	7	6	5	4	4	3	2	2	1	1	1	0	0	0	-1	-1	-1	-1	-1
D	45	11	8	7	6	6	5	4	3	3	2	1	1	1	0	0	0	-1	-1	-1	-2	-2	-2
	50	10	7	7	6	5	4	4	3	2	1	1	1	0	0	-1	-1	-1	-1	-2	-2	-2	-2
T	60	10	7	6	5	4	4	3	2	1	1	0	0	-1	-1	-1	-2	-2	-2	-3	-3	-3	-3
R	70	9	6	5	4	4	3	2	1	1	0	0	-1	-1	-2	-2	-2	-3	-3	-3	-3		
I	80	8	5	4	4	3	2	1	1	0	-1	-1	-1	-2	-2	-3	-3	-3					
P	90	8	5	4	3	3	2	1	0	0	-1	-2	-2	-2	-3	-3	-3						
	100	7	4	4	3	2	1	1	0	-1	-1	-2	-2	-3	-3								
W	125	7	4	3	2	1	1	0	-1	-2	-2	-3	-3										
I	150	6	3	2	1	0	0	-1	-2	-3	-3												
R	175	5	2	1	0	0	-1	-2	-3	-3													
E	200	4	1	1	0	-1	-1	-2	-3														
	225	4	1	0	-1	-1	-2	-3															
L	250	4	1	0	-1	-2	-2	-3															
E	275	3	0	-1	-2	-2	-3																
N	300	3	0	-1	-2	-3	-3																
G	325	2	-1	-2	-2	-3																	
T	350	2	-1	-2	-3	-3																	
H	375	2	-1	-2	-3																		
	400	1	-1	-2	-3																		
in	425	1	-2	-3																			
	450	1	-2	-3																			
F	475	1	-2	-3																			
E	500	1	-2	-3																			
E	600	0	-3																				
T	700	-1																					

Specification Voltage 15 VDC
for 12 VDC PV Applications

Wiring is specified for a power efficiency of 97.5%
and/or correct ampacity



Codes

The body of the table contains the Wire Gauge Number
"0" Wire is designated by 0
"00" Wire is designated by -1
"000" Wire is designated by -2
"0000" Wire is designated by -3

Wiring power efficiency is specified at 68°F.
If ambient temperature is > 90°F., use the next gauge larger wire

24 VDC

PV ARRAY CURRENT IN AMPERES.

		6	12	15	18	21	24	30	36	42	48	54	60	66	72	78	84	90	96	102	108	114	120
R	25	14	13	12	12	10	8	6	6	6	6	6	6	4	4	4	2	2	2	2	0	0	0
O	30	14	13	12	11	10	8	6	6	6	6	6	6	4	4	4	2	2	2	2	0	0	0
U	35	14	12	11	10	10	8	6	6	6	6	6	5	4	4	4	2	2	2	2	0	0	0
N	40	14	11	10	10	9	8	6	6	6	5	5	4	4	4	3	2	2	2	2	0	0	0
D	45	14	11	10	9	9	8	6	6	6	5	4	4	4	3	3	2	2	2	2	0	0	0
	50	13	10	10	9	8	7	6	6	5	4	4	4	3	3	2	2	2	1	1	0	0	0
T	60	13	10	9	8	7	7	6	5	4	4	3	3	2	2	2	1	1	1	0	0	0	0
R	70	12	9	8	7	7	6	5	4	4	3	3	2	2	1	1	1	0	0	0	0	-1	-1
I	80	11	8	7	7	6	5	4	4	3	2	2	1	1	1	0	0	0	-1	-1	-1	-1	-1
P	90	11	8	7	6	6	5	4	3	3	2	1	1	1	0	0	0	-1	-1	-1	-2	-2	-2
	100	10	7	7	6	5	4	4	3	2	1	1	1	0	0	-1	-1	-1	-1	-2	-2	-2	-2
W	125	10	7	6	5	4	4	3	2	1	1	0	0	-1	-1	-2	-2	-2	-2	-3	-3	-3	-3
I	150	9	6	5	4	3	3	2	1	0	0	-1	-1	-2	-2	-2	-3	-3	-3				
R	175	8	5	4	3	3	2	1	0	0	-1	-1	-2	-2	-3	-3	-3						
E	200	7	4	4	3	2	1	1	0	-1	-1	-2	-2	-3	-3								
	225	7	4	3	2	2	1	0	-1	-1	-2	-3	-3	-3									
L	250	7	4	3	2	1	1	0	-1	-2	-2	-3	-3										
E	275	6	3	2	1	1	0	-1	-2	-2	-3	-3											
N	300	6	3	2	1	0	0	-1	-2	-3	-3												
G	325	5	2	1	1	0	-1	-2	-2	-3													
T	350	5	2	1	0	0	-1	-2	-3	-3													
H	375	5	2	1	0	-1	-1	-2	-3														
	400	4	1	1	0	-1	-1	-2	-3														
in	425	4	1	0	-1	-1	-2	-3															
	450	4	1	0	-1	-1	-2	-3															
F	475	4	1	0	-1	-2	-2	-3															
E	500	4	1	0	-1	-2	-2	-3															
E	600	3	0	-1	-2	-3	-3																
T	700	2	-1	-2	-3	-3																	
	800	1	-1	-2	-3																		

Specification Voltage 30 VDC
for 24 VDC PV Applications

Wiring is specified for a power efficiency of 97.5%
and/or correct ampacity

Codes

The body of the table contains the Wire Gauge Number
"0" Wire is designated by 0
"00" Wire is designated by -1
"000" Wire is designated by -2
"0000" Wire is designated by -3

Wiring power efficiency is specified at 68°F.
If ambient temperature is > 90°F., use the next gauge larger wire

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The Good, The Bad, and The Ugly

John Wiles

In the last two months I have been involved in two aspects of PV power systems that have created conflicting emotions. First, I had an opportunity to visit and inspect a number of PV systems that have been installed within the last year in the Southwest. After seeing these systems, I was ashamed to be a part of the PV Industry. More on those systems later. Second, I attended a facilitated discussion with other members of the PV industry. The results from this conference will evolve into a PV system procurement manual for municipalities and counties. The members of the PV industry that participated in this all-day discussion and the results left me with very warm feelings about the future of PV.

Inspection of Southwest PV Sites

First the bad news. A large southwest utility had purchased the systems at the sites I visited via competitively bid contracts. In some cases the specifications were tight, in others quite loose. The largest installation, a 100 KW utility-interactive system was sold, designed, and installed by a small company specializing in large-scale PV systems. Another small PV systems house sold and designed other grid-connected systems. Local electricians did those installations, using kits supplied by the design firm.

A company that sells PV-powered hydro pumps had sold, designed, and installed a water pumping system to run sprinklers for an athletic field. I also inspected a lighting system designed by a major PV distributor and sold and installed by a regional PV dealer. Another regional PV dealer had designed and installed PV lighting.

These systems were not as good or as safe as they could have been. Some of the systems had failed after only a year.

Grid Connected 100 KW System

For the most part, this system was a delight to inspect and test. The installers has used high-quality components and workmanship. Although the inverter was experiencing some operational problems, the manufacturer quickly identified and remedied them. Only in one area did I see a need for additional safety features. The main number 4 AWG conductors from the row-combining boxes to the inverter were not protected from faults. I recommended that fuses be added at the inverter to protect these cables.

Grid Connected 2.5 KW System

The installation used 16 AWG conductors to connect the modules to the inverter. The cables were held in a tray and were rated for 8 amps (NEC Section 340-7 and Table 402-5). The 15 amp fuses at the DC disconnect did not provide overcurrent protection for this cable.

The modules had a rated short-circuit current of about 7 amps, but short currents could be higher on clear days near solar noon. When the inverter was off-line or detected a ground fault, it automatically shorted the array, subjecting the cables to overheating. An 8-10 amp fuse should be installed in the string junction box to protect these cables. An 8 amp fuse meets the NEC cable ampacity requirements, but the high operating currents exceeds this.

The use of 2000 volt cable used in this system was an excellent choice since the operating voltage is near or over 600 volts. I noted some cable damage caused by sharp conduit edges.

Cable under-sizing was also a problem. The 10 AWG ac output cable only handled 30 amps; however the inverter output circuit was rated for 34 amps (4KW). The inverters internal 50-amp fuse did nothing to protect the undersized cable. Although the inverter can't deliver more than 34 amps of current when connected to the 2.5 KW array, the output cable should be 8 AWG, rated for at least 42.5 amps.

Disconnect switches were mounted high on a wall, out of reach.

Suggestions:

1. Change and fuse module conductors to handle the larger 12–13 amp current seen at peak power operation.
2. Replace the present unfused ac disconnect with a fused ac disconnect. Identify the circuit breaker in the building's ac load center for back-feeding. Secure it to the load center enclosure with additional mechanical fasteners.
3. Protect all metal conduit and fittings with insulating

bushings to prevent cable damage on sharp metal edges. Replace the Bussmann NOS DC input fuses (which have only a factory DC rating) with Littlefuse IDSR fuses which are UL-Listed for use at 600 Volts DC.

4. Mount disconnect switches so that the handles are no higher than 6.5 feet above the floor.

Grid Connected 2 KW System
The comments on the preceding installation apply to this one, even though the inverter had been removed when inspected.

The ambient-air temperature sensor was mislocated. It should have been mounted outside, exposed to the same air temperature as the modules.

PV Powered Sprinkler System
This system pumped water up from a well to supply sprinklers on an athletic field. The site was a hazardous nightmare. To start off, I could find no equipment or system ground, ground rod, or surge protection!

The system had other major mechanical and electrical safety problems caused by poor workmanship. The well pump motor shaft was left exposed. The enclosure containing the sprinkler pumps and controls was crowded and lacked enough space to work safety.

I found electrical junction boxes mounted at or slightly above ground level. They were already corroding. The installers had put a load center designed for indoor use in an exposed outdoor location. An open right-angle pull box held cable splices.

They had used hugely oversized 100 amp fuses to protect very small conductors. Wires and cables lacked any labels indicating wire size or routing. Battery cables were not protected from fault currents. Circuit breakers were used as disconnects with no fault current protection. Charge controllers were mounted in outdoor locations where dirt and moisture would cause the mechanical relays to fail prematurely.

Battery water levels had fallen below the tops of the plates, indicating possible battery damage. The charge controllers were cycling and the battery voltage was 28.2. The batteries were not insulated and their performance suffered in cold weather. The system failed to include compensation during charge. The builders installed multiple battery charge controllers instead of a single large one. Battery terminals were not sealed and had already begun to corrode.

Every aspect of the system was sloppy. The designer had ignored row-to-row module shading at low sun angles during the winter. This caused unnecessary and annoying reductions in power output.

Major inefficiencies marred system performance. Multiple small pumps were operating in parallel when a single large DC motor connected to a single sprinkler pump would have wasted less energy. Use of battery storage severely affected water pumping efficiency. Possibly 50% or more of the PV energy was being lost in battery charging/discharging! To avoid these losses, PV systems for water pumping usually omit batteries and feed energy directly to the load. The sprinklers did not appear to be designed for athletic field use. They didn't have provisions for contact from above and were eroding nearby soil. The low-quality externally mounted sprinkler timer mechanism was already rusting.

Suggestions:
Safety
1. First and foremost, GROUND THE SYSTEM! Don't even think of operating it before this is done.
2. Have a qualified electrician rewire the system using the proper cables, overcurrent devices, disconnects and enclosures.
3. Add surge protection on the PV and motor conductors.

Function
1. Redesign the entire system. Increase the north-south spacing between rows of modules to reduce winter shading.
2. Eliminate the batteries except for a small one to power any timers or control devices. Operate the pumps in the daytime only, connect the PV array directly to the well pump to fill the tank. Reconnect the PV array directly to a large sprinkler pump with zone valves to water the field.
3. Use a linear current booster to get better early morning and late afternoon performance.
4. Use full-tank and empty-tank switches to control the charge between well pump and sprinkler pump operation.
5. Use a simple timer to control and operate the zone valves. This may require a small battery system and an inverter. Timer operation may not be accurate with devices that sync off the 60 Hz powerline frequency. Radio Shack has 120 volt ac timers that generate their own reference frequency and are accurate even if the inverter's frequency output varies.
6. Use a day-of-the-week timer or manual override switch to avoid watering the grass on game days.

Lighting System
This installation had only one module powering an 18-watt lamp and probably couldn't procure much light on cold, short winter days. It also had functional and safety problems.

Safety was badly neglected. The system was not grounded and had no surge protection devices. It lacked any disconnect for the PV or the batteries. No properly rated overcurrent devices were installed to protect array or battery wiring. Exposed battery terminals represented a safety hazard for service personnel and had no anti-corrosion protection.

The batteries were located in the same compartment as electrical devices; a major mistake. Even with catalytic recombiner caps, batteries produce corrosive gases and hydrogen gas. Even sealed batteries may vent explosive gas under some conditions. Enclosures should be partitioned with hermetic seals and be well vented. Batteries should be mounted above electrical components to allow hydrogen gas to escape upward and be mounted in acid-proof containers to avoid corroding metal surfaces.

The rest wasn't much better. Battery water was low, but still above the plates. There was insufficient space to properly water the batteries or service the system. Batteries were not insulated against cold weather and the charge controller lacked any temperature compensation or regulation. The timing device appeared overly complicated and inappropriate for this environment. It had already failed.

Suggestions
Modify the system, in order of priority, as follows:

1. Ground the pole, all equipment cases, and the negative conductor of the system (if allowed by the lighting fixture design). Add surge arrestors on cables to PV modules and lamp.
2. Add pull-out fuse holder/disconnects with appropriately rated DC fuses for PV and battery conductors.
3. Seal off the battery compartment and vent it outside.
4. Spray battery terminals with Permatex battery-terminal fluid after installation. Cover exposed battery terminals.
5. Replace the separate charge and lighting controllers with a combined PV lighting/charge controller.

Flashing Lights - Pedestrian Crossing
This system had a sufficient number of modules and sealed batteries to perform well. Safety-wise it had major deficits, including no apparent system ground. One of the brackets holding the flashing light was cracked open.

All of my preceding comments about battery safety apply here, with one important addition. The system is located near the roadway where passing vehicles could strike the battery enclosure. If one did, the battery terminals could contact the metal enclosure—with possibly explosive results.

Suggestions:
1. Ground the pole, the equipment and the negative conductor unless there are equipment restrictions to the contrary. Add surge suppression to the PV and lighting circuits.
2. Add the fused disconnect previously described.
3. Fully insulate and protect the battery terminals and surrounding metal surfaces.
4. Consider enclosing the base of the lights with protective barricades.
5. Insulate the battery compartment.
6. Repair or replace the broken bracket.

Specifications and Bids
The results of my inspection were disheartening. The PV industry can do and has done better. I have seen systems that are well designed, safe, and performed as specified without unexpected failures. To some extent the problem lies with the purchaser, who writes loose specifications and then goes looking for the lowest bidder. As in all other endeavors, you get what you pay for. Low bid, loosely-specified PV systems usually turn out to be unsafe and give less than optimum performance.

When purchasers get tired of poorly performing PV systems, they will start tightening contract performance specifications and demanding warranties. In future contracts, PV purchasers will examine a company's past performance and history of customer satisfaction.

To help prospective PV purchasers and encourage higher standards in the PV industry, I have begun developing a PV procurement manual. Parts of this are outlined below. It is intended for municipalities, utilities, and other agencies. The PV industry must look at these requirements and use them to design, bid, and install better systems.

Photovoltaic Power Systems: Specifying and Verifying Performance
Photovoltaic (PV) Power Systems are a relatively new technology. Few systems are available off-the-shelf for any particular application or level of power output. PVs initial cost is often higher than the cost of other non-renewable power systems. Reliability has been a problem; prospective PV buyers cannot always assume long-term, maintenance-free performance. Cost and reliability issues create a dilemma for those who want PV.

Although it is not legally mandated in every jurisdiction, the National Electrical Code (NEC) contains a comprehensive set of requirements and good engineering practices that can ensure a safe and durable PV installation. The NEC should be called out as a basic requirement in any system.

The following spectrum of procurement styles and performance assessments cover the range of PV purchases.

Minimum Technical Expertise

1. Procure a Turn Key installed system with performance specifications.
2. Write performance guarantees and warrantees into the contract. A maintenance contract will usually be required. Penalties are required for delays in delivery and poor performance.
3. Performance is assessed by easily observable or measurable output quantities. The quantities may be directly observed or read from standard meters. For instance: A PV-powered light must produce usable illumination from dusk to dawn, 365 days per year for five years. A specified amount and quality of AC energy in kilowatt hours is to be produced each month for ten years.

The vendor is fully contractually responsible for the initial and long-term performance of the system.

Moderate Technical Expertise

1. Determine the required performance specifications.
2. Initiate bids for a system that meets those specifications.
3. Require the following milestones in the contract.

A. Review and acceptance of system sizing and performance design calculations.
B. Safety review of electrical and mechanical design.
C. Inspection of electrical and mechanical installation.
D. Performance testing of the installed system.
E. Require long term performance and maintenance warranties as needed.
F. Perform periodic testing if output not easily observable.

If not otherwise specifically contracted, initial and long term performance of the system is the responsibility of the owner.

Expansion of the milestone tasks in this section is presented in the Milestone Section that follows.

Substantial Technical Expertise

1. Design the system with in-house personnel, specify components, procure material, build system, and install system.
2. Set up a maintenance program, if required.
3. Test and evaluate installed system at time of installation and yearly thereafter. Install monitoring hardware if necessary (larger systems) and monitor system performance.

There are no system performance warranties. The individual components have factory warranties.

System Contract Milestones

Write contracts so that each of the following milestones are reviewed and approved by the purchaser before moving on to the next. The contract should require timely submission of data necessary to evaluate these milestones. State that the vendor must implement any required changes to the design, material, or installation before approval will be granted.

Make it clear that purchaser approval of any or all of these milestones does not relieve the vendor from meeting any system performance or warrantee contractual requirements.

System Sizing Review

The vendor must furnish all information and calculations used to size the array, inverter, and storage system (if any). They should also provide sources of data or actual data for solar insolation and weather used in these calculations. The vendor should give the efficiencies of components such as charge controllers, inverters, and other electronic devices.

System Safety Review

The vendor and purchaser will review the detailed electrical and mechanical design for safe engineering practices. This review shall be made early in the contract before any equipment is purchased.

The review should examine the electrical design for compliance with the requirements of the National Electrical Code (NEC) in the following areas:

1. Short-circuit currents in all conductors.
2. Conductor voltage and ampacity ratings.
3. Overcurrent device ratings and locations.
4. Disconnect ratings and locations.

The vendor will furnish full and complete electrical specifications for each component used. These include manufacturer’s specification and ratings and any equations or tables (NEC) used in the electrical design. The vendor must also use UL-Listed (or equivalent) components where possible.

Qualified civil engineers will examine the mechanical design for compliance with applicable building codes. Emphasis will be placed on wind and snow loadings and other factors affecting the durability and safety of the exposed systems.

The planned battery storage installation should provide the necessary degree of safety for operating and maintenance personnel.

System Installation Inspection

After the system has been installed, inspect to determine if the equipment in the electrical and mechanical design is installed safely and durable.

Conduct the following tests:

1. Perform dry and wet insulation tests on the conductors and PV array.
2. Verify the mechanical and electrical integrity of electrical connections.
3. Assess the mechanical operation of disconnects and overcurrent devices.
4. Verify the installation of a grounding system and equipment grounds.
5. Perform appropriate mechanical inspections as required.
6. Verify the performance of the module/array tracking system (if used).

System Performance Testing
Use the following electrical tests to determine the performance of the system immediately after installation. Perform only the measurements needed to verify contracted performance specifications.

1. Perform I-V Curve Tests on modules, strings, or array.
2. Rate the DC array output at standard test conditions (STC).
3. Measure the efficiency of the inverter.
4. Measure the storage system capacity.
5. Measure the power produced by the system under STC.
6. Measure the AC voltage, current and harmonic distortion produced.
7. Measure the frequency stability.

Continuing System Evaluation
If the output of the system is not readily observable, or the output decreases over time, it may be necessary to perform some or all of the tests listed under “System Performance Testing” on a periodic basis. The test results might be used to establish the need for system or component maintenance. They could also be used to identify trends in system performance that could be used to prevent system failures.

Access
Author: John C. Wiles, Southwest Technology Development Institute • New Mexico State University • Box 30,001/Dept. 3 SOLAR • Las Cruces, NM 88005 • 505-646-6105

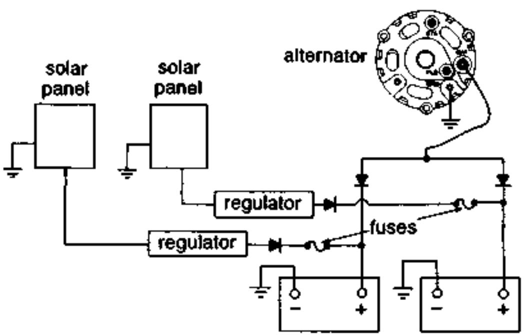


Figure 5-39. Regulated solar panels with diodes in the regulators. Note that some regulators with a *nighttime dropout* function do not require a diode.

Figure 5-41A. Unregulated solar panel. If the panel is installed upstream of the main blocking diodes, it will not need its own diode.

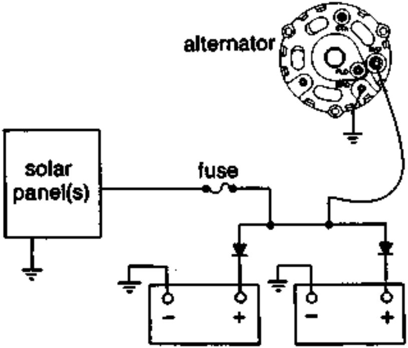
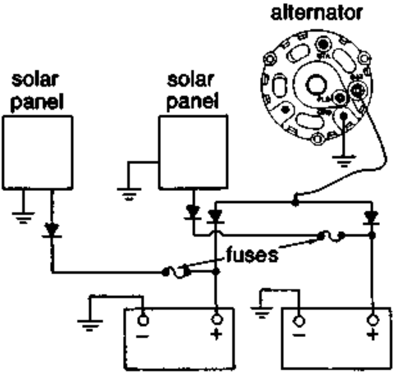


Figure 5-41B. Unregulated solar panels with diodes. The diodes may be better omitted (see the text).



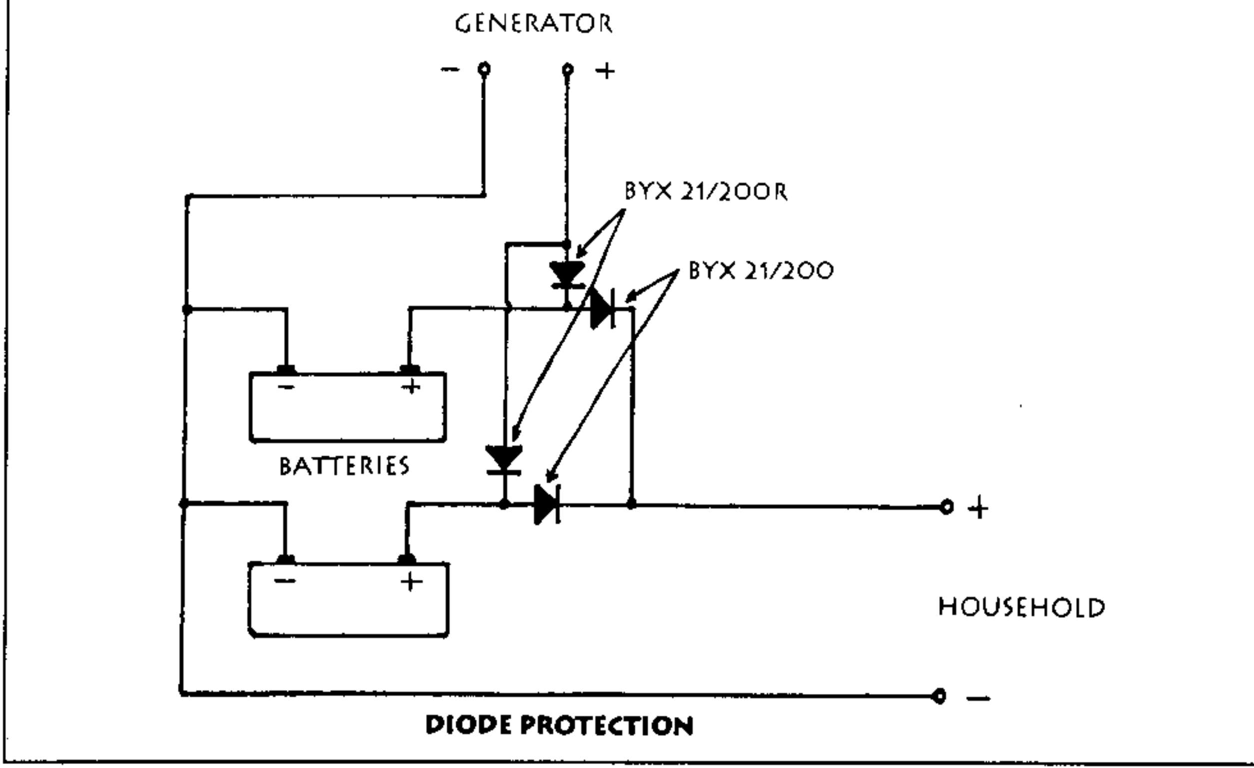


Figure 9-14. **Diodes allow current to flow in only one direction, protecting batteries from accidental discharge.**

Abb. 4.13 Soweit in den einzelnen Modulen nicht bereits Bypaßdioden **B** vom Hersteller eingesetzt wurden, sollten sie zusätzlich an die Anschluß klemmen **A** der einzelnen Module angebracht werden. Eine gemeinsame Entladeschutz-Diode (Schottky-Diode) **Sch** muß an den Modulenausgang nicht integriert werden, wenn ein Verbraucher im Direktbetrieb angeschlossen wird. Wenn in den Modulen Schottky-Dioden bereits vom Hersteller ange bracht wurden, sollten sie – bis auf das letzte oberste Modul – bei einer derartigen Serienschaltung entfernt werden. Sie verursachen einen unnötigen Spannungsverlust. Die Schottky-Diode soll einen angeschlossenen Akku vor Entladen über das Modul schützen (Näheres siehe Kap. 6)

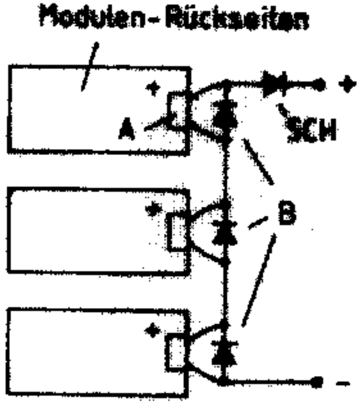


Abb. 4.14 Module, die in Serie geschaltet werden, dürfen zwar unterschiedliche Spannungen haben, aber sollten dieselben Nennstromwerte aufweisen. Sie sollten auch bevorzugt von demselben Hersteller (und aus derselben Serie) stammen. Für gelegentliche Experimente dürfen beliebig unterschiedliche Module in Serie verschaltet werden. Bypaßdioden sind dabei für den Schutz der leistungsschwächeren Module wichtig

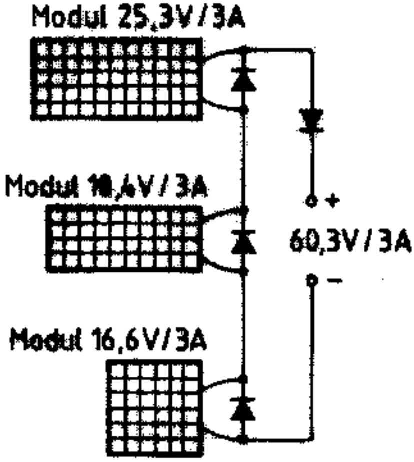
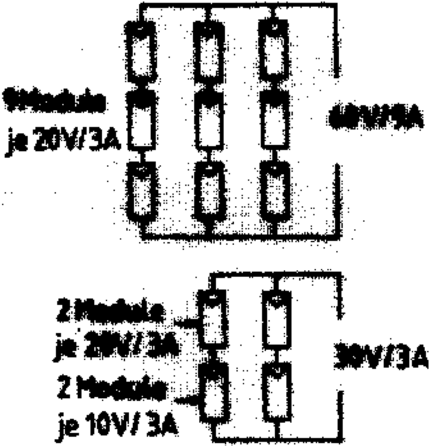


Abb. 4.15 Dachmodule der netzgekoppelten Anlagen werden oft seriell- parallel verschaltet, um höhere Spannungs- und Leistungswerte für den Wechselrichter zu erreichen. Gegen das Mischen von Modulen unterschiedlicher Spannung (nach dem unteren Beispiel) ist zwar theoretisch nichts einzuwenden, aber praktisch ist es nicht zu empfehlen. Es besteht immerhin die Möglichkeit, daß hier auch Module von demselben Hersteller dennoch herstellungsbedingte Unterschiede aufweisen. Bemerkung: hier sind die Module in den gebräuchlichen Zeichensymbolen gezeichnet. Diese Symbole sind sowohl für Einzelzellen, als für Module einheitlich



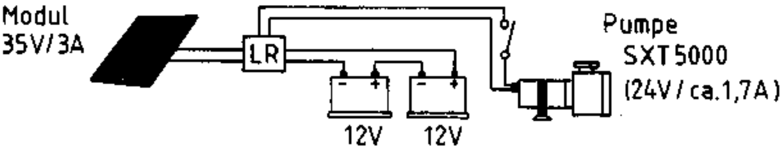


Abb. 16.1 Pumpenbetrieb über einen 24 V-Akku. Die Pumpe SXT 5000 arbeitet in einem Spannungsbereich zwischen 8 und 36 Volt. Bei einer Versorgungsspannung von 24 V weist sie eine Förderleistung von ca. 2500 l/Std. auf (Förderhöhe ca. 2,2 m)

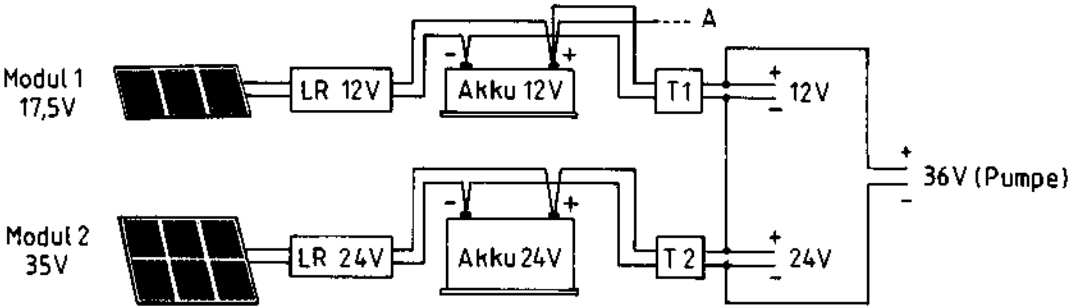
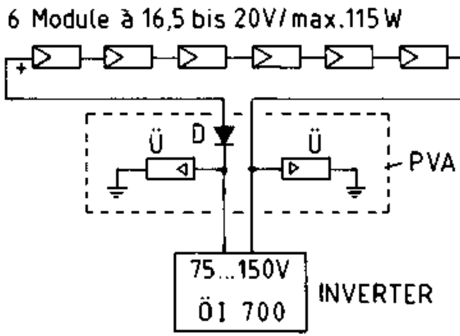


Abb. 16.2 Eine Photovoltaik-Anlage für mehrere Versorgungsspannungen: Die 36 V-Spannung eignet sich hervorragend für die Pumpen SXT 5000 (Strombedarf 2,5 A, Förderleistung max. 5000 l/St.) oder SXT 7000 (Stromverbrauch 3 A, Förderl. 7000 l/Std.). Tiefentladeschutz **T1**, **T2** kann hier laut Schaltplan erst zwischen die Akkus und Verbraucher angeschlossen werden. Evtl. wichtige elektronische Überwachungsschaltungen oder Alarmgeber können direkt z.B. an den Spannungsausgang **A** angeschlossen werden (der Tiefentladeschutz kann sie somit nicht abschalten). Die angegebenen Nennspannungswerte der Module eignen sich nicht für den Winterbetrieb (hier wäre eine Erhöhung um ca. 15 bis 20% wünschenswert). Der Modulen-Nennstrom sollte jeweils mindestens 1,5% der Akkukapazität betragen. Die Akkukapazität dürfte für den Einsatz während der Periode März bis Oktober so gewählt werden, daß hier die Verbraucher ohne Nachladen 14 Tage lang versorgt sein können

a)



b)

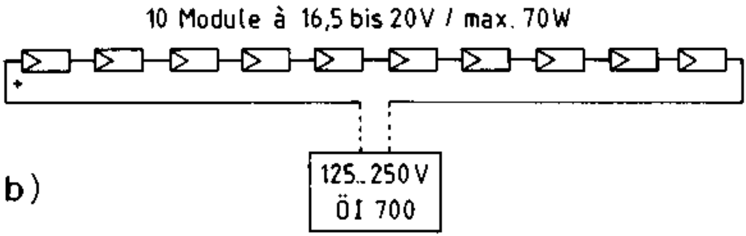


Abb. 20.3 Schaltbeispiele der Modulenanordnung für den AEG-Öko-Inverter 700: a) eine Kette mit sechs Modulen läßt sich über einen kleinen Anschlußkasten an den Inverter sehr einfach anschließen. Im Verteilerkasten befindet sich (werkseits) neben dem Überspannungschutz **Ü** auch noch eine Schutzdiode (Schottky-Diode **D**). Es wird hier damit gerechnet, daß in den verwendeten Modulen keine Schutzdioden intern eingebaut sind. Der Öko-Inverter wurde hier auf einen Eingangsspannungs-Bereich von 75 bis 150 V umgeschaltet; b) eine andere Alternative mit zehn Modulen in Serie; hier muß der Inverter-Eingang auf seinen höchsten Spannungsbereich von 125 bis 250 V umgeschaltet werden (weiter ändert sich an der Installation nichts)

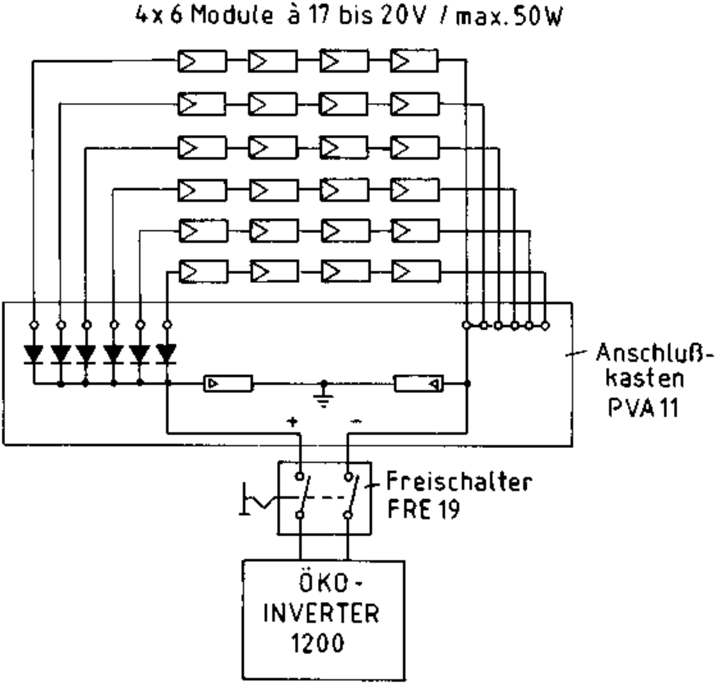


Abb. 20.4 Schaltbeispiel der Modulenanordnung für den AEG-Öko-Inverter 1200: hier wird eine seriell-parallele Schaltung angewendet; sie kann jedoch beliebig anders gestaltet werden, vorausgesetzt die Spannungen aller parallelen Ketten sind möglichst genau gleich, die Leerlaufspannung überschreitet hier nicht 100 Volt und die Nennleistung des ganzen Photovoltaik-Generators bleibt unterhalb von 1200 W

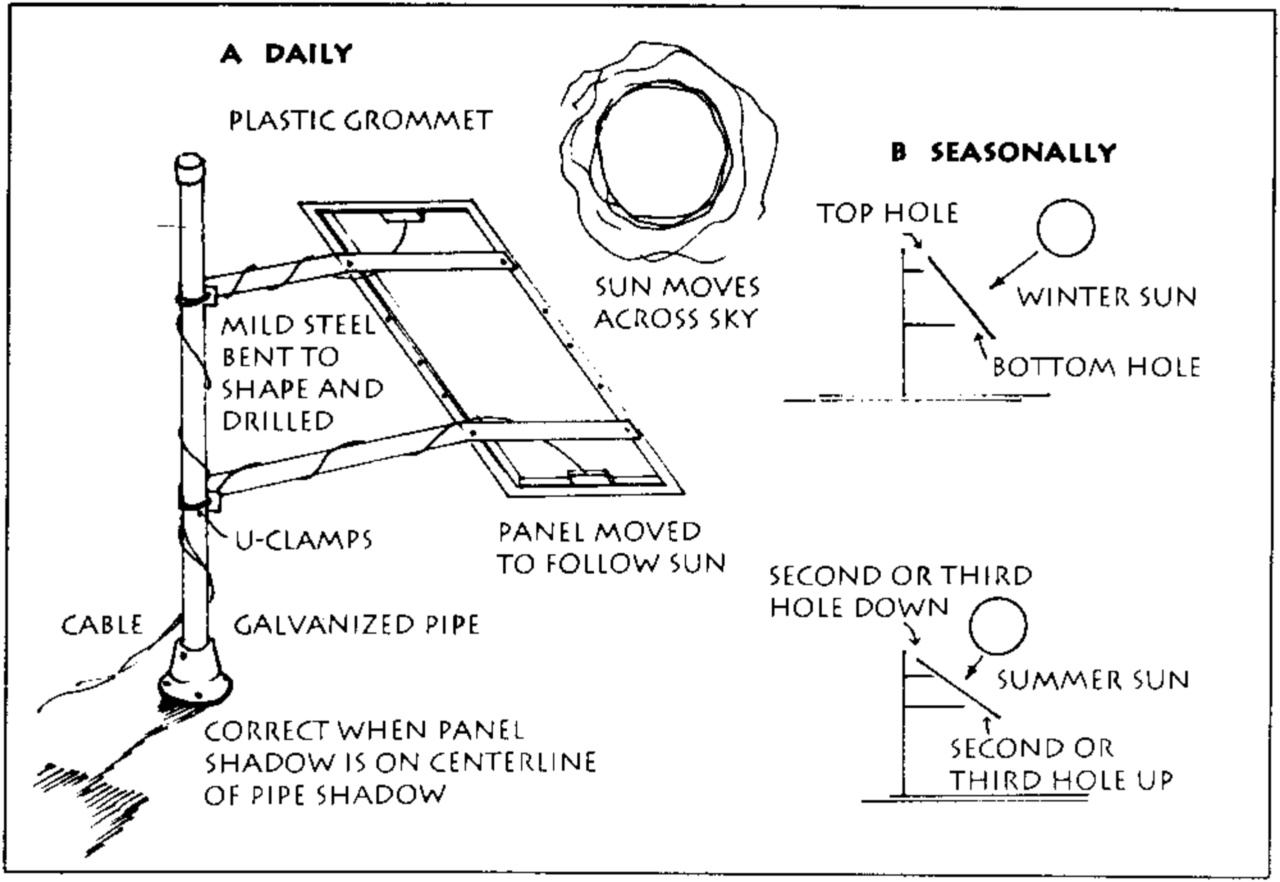
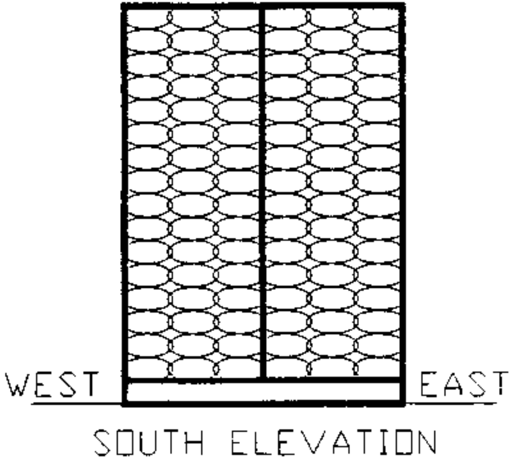
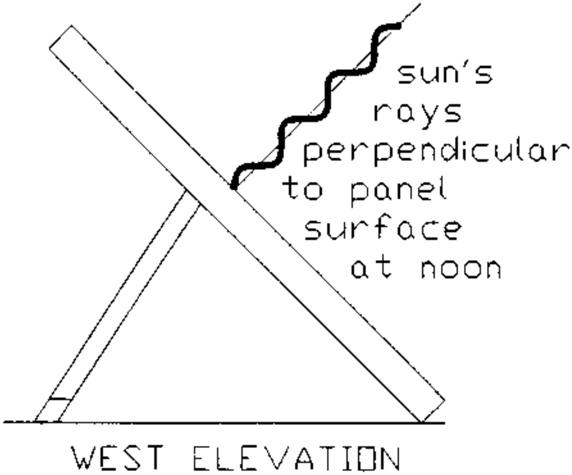


Figure 9-2. **Open-air brackets allow you to angle solar panels according to the season and time of day.**





Solar Panel Alignment for the Northern Hemisphere

(Direction is reversed for the Southern Hemisphere)

A rough estimate would add 15° to your latitude for winter
and subtract 15° from your latitude for summer

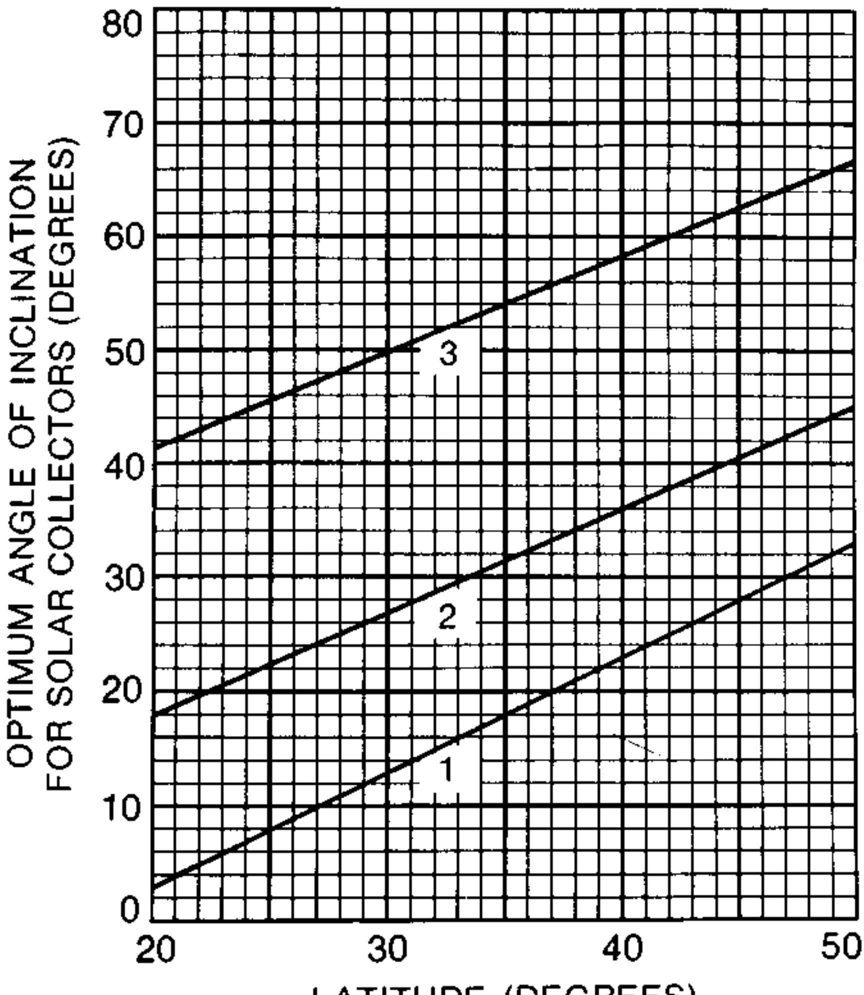
If you'll use the heat collector all year round, as for heating in winter and for swimming-pool heating in summer, plus year-round domestic water heating, you incline it at an angle *equal to your local latitude*. At a latitude of 42 degrees north, as in the Connecticut area, your collector should be inclined 42 degrees from the horizontal.

If you are chiefly interested in sun heating in *winter only,* your collector should be inclined more steeply to be perpendicular to the rays of the winter sun, which is much lower in the sky. So you *add* 10 or 15 degrees to the latitude to determine the correct inclination. If you add 15 degrees (usually preferred) to the 42-degree latitude mentioned above, your collector will be inclined at 57 degrees to the horizontal.

If you intend to use the collector mainly in summer, as for pool heating to extend the swimming season, you *subtract* 15 degrees from the latitude. At 42 degrees latitude, this would give your collector an inclination of 27 degrees. This angle, much closer to horizontal, aims your collector higher toward the sky to match the higher summer sun.

Naturally, the sun's rays are not perpendicular to the collector throughout the day, regardless of the angle setting. Relatively, the sun starts its movement from the eastern horizon, and "rises" to maximum height at noon, then moves gradually downward until it "sets" in the west. So the actual angle at which its rays reach the collector varies constantly throughout the day, reducing the collection rate as the sun angle moves farther from perpendicular to the collector. This is another minus factor. The inclination angles mentioned above, however, are the most efficient compromise for fixed-position collectors.

OPTIMUM COLLECTOR ANGLE VERSUS LATITUDE



Base the inclination of your heat collector on your latitude plus number of degrees indicated on graph for winter heating. Line 1 is for summer maximum, line 2 for year-round maximum, line 3 for winter maximum, as in home heating.

Monat	Wh/Tag	Ah/Tag
Januar	77,5	6,5
Februar	140	12
März	222	18,5
April	300	25
Mai	360	30
Juni	360	30
Juli	360	30
August	360	30
September	302	27,5
Oktober	170	14
November	87,5	7
Dezember	62,5	5

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Bild 5.2 Durchschnittlich erzeugte Energiemenge in Wattstunden/Tag mit einem Solarmodul von 100 W.

Tabelle 5.1. Empfohlene Neigungswinkel nach Süden in Mitteleuropa.

Jahreszeit	Neigungswinkel
Frühjahr	40...60°
Sommer	20...50°
Herbst	40...60°
fester Neigungswinkel	40...70°

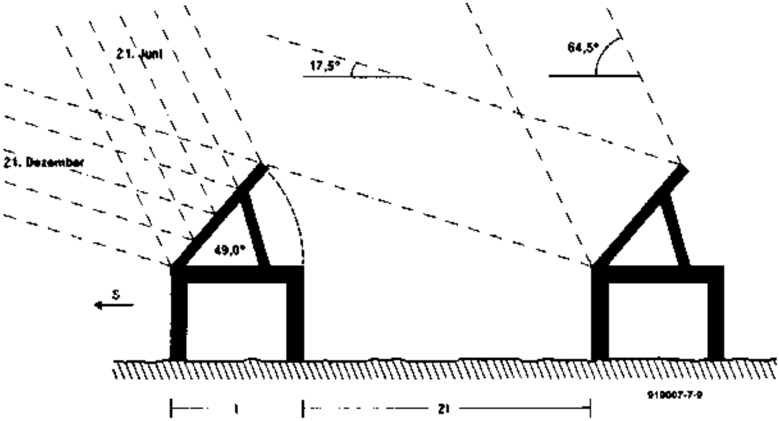


Bild 5.4. Aufstellung von Solarmodulen mit Raumverbrauch.

Tabelle 5.2. Korrekturfaktoren für die Globalstrahlung bei Neigung der Solargeneratorfläche.

Neigung	Frühjahr	Sommer	Herbst	Winter
30°	1,3	1,00	1,3	1,7
50°	1,4	0,90	1,4	2,3
70°	1,3	0,65	1,3	2,4
90°	1,0	0,40	1,0	2,3

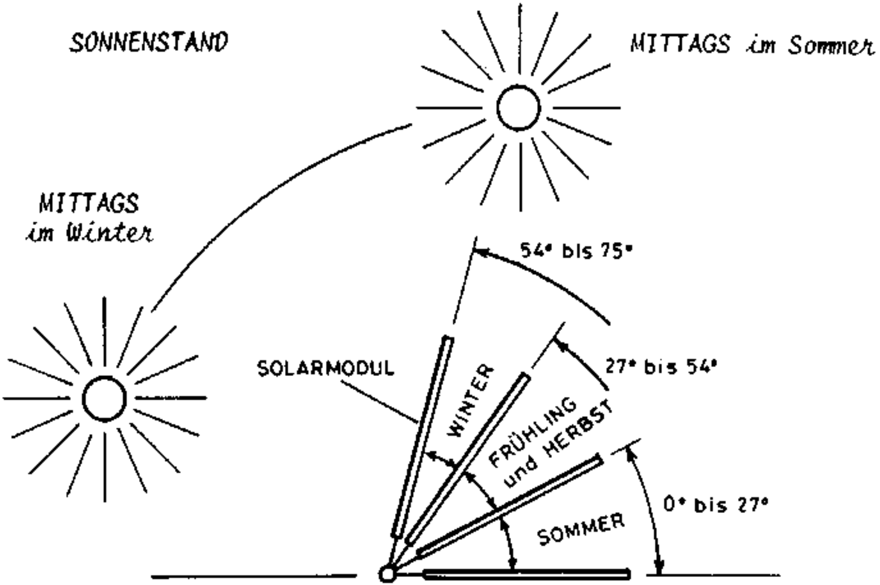


Abb. 10.7 Optimaler jahreszeitbezogener Neigungswinkel einer Solarzellenfläche

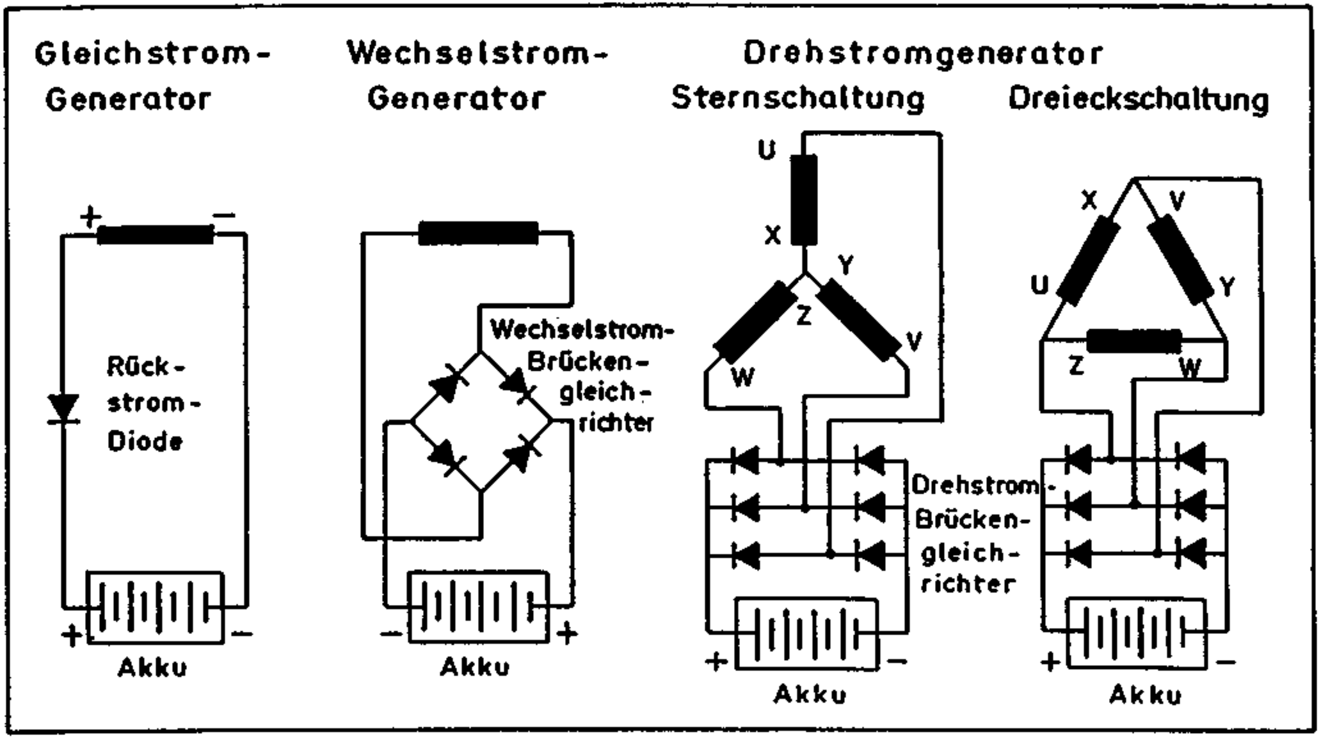
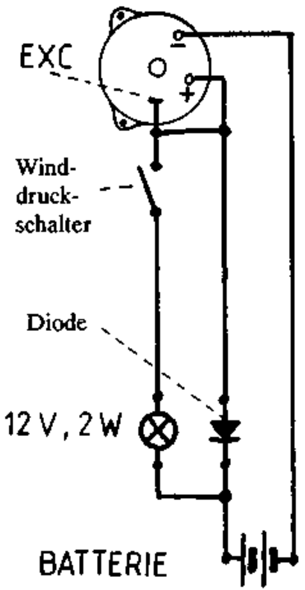
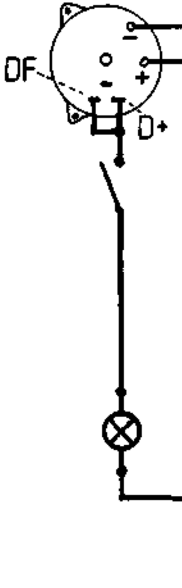


Abb. 22: Schaltungen zum Anschluß verschiedener Generatoren an einen Akkumulator

Generator aus der ENTE

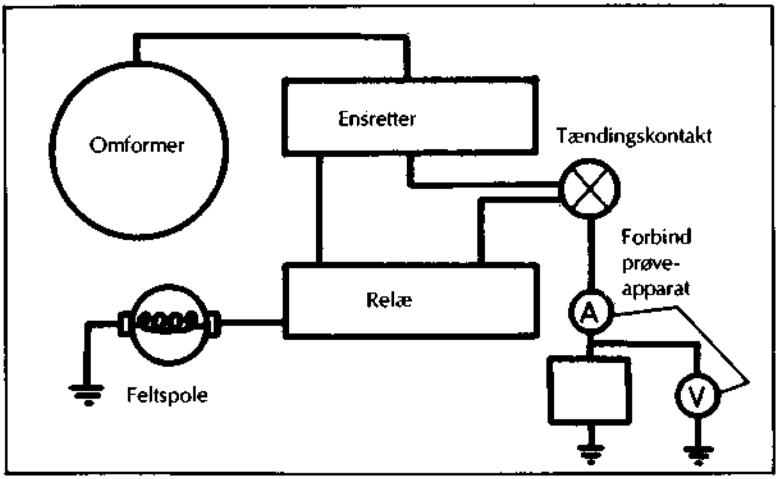


BOSCH - Lichtmaschine

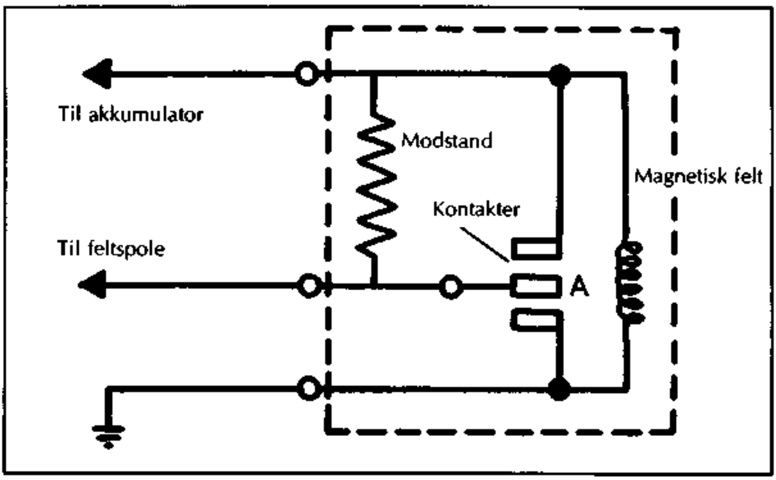


Die äußere Beschaltung des Generators

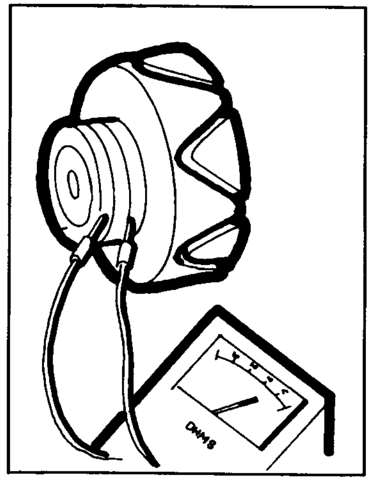
Afprøvning af 3-faset anlæg



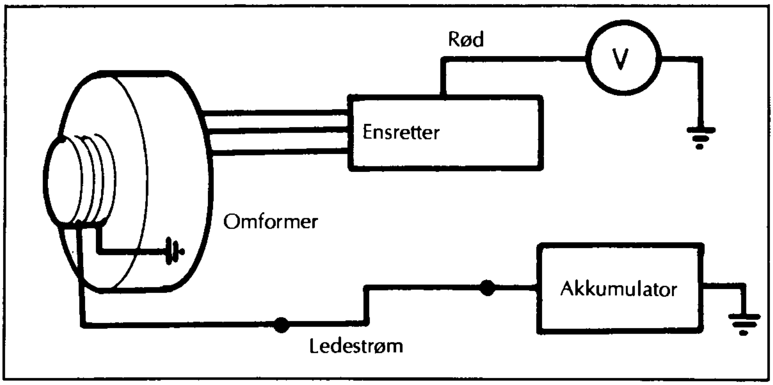
7 Generatorer som bruger elektromagnetens feltspole i stedet for permanent magnet-rotation, er af samme slags som sidstnævnte type på foregående side. Der er en ensretter, en spændingsregulator, som gør det ud for det samme som en Zener-diode og batteriet. Det er fordi ensretteren bruger flere dioder, og der er ikke en ens standard for farvekoderne. En instruktionsbog/værkstedsbog er nødvendig for at foretage en ohmmeter-prøve. Alternativt kan en ensretter udskiftes, hvis den ikke er helt i orden.
Der er to reguleringsmuligheder: den første er en solidt monteret type, som bruger Zener-diode og en sikring. Igen er arbejdet vanskeligt uden perfekte instruktioner fra fabrikken. At forbinde et amperemeter mellem batteriets kabler, vil give et fingerpeg om den generelle tilstand. Der skal være lidt afladning at læse på amperemeteret ved tomgang. En lille ladespænding ved flere omdrejninger, og topspænding, når amperemeteret igen viser NUL – men med fuld ladespænding.



2 For alle prøver af ladesystemerne: batteriet skal være i orden og med topspænding. Ellers vil resultaterne blive misvisende. Det er ikke mindst gældende for den type anlæg, hvor strømmen fra batteriet supplerer kraften fra magnetfelterne. Den mekaniske regulatortype er vist på tegningen her. Som ved 1 kontrolleres den i kredsløbet eksisterende kraft, forstærket via feltspolen. Generatorens produktion er afhængig af hastighed og kraften af de magnetiske felter. Der er bevægelige kontaktpunkter. De skal være rene, og mødes på hele kontaktfladen. Når kontakterne berører hinanden, vil kraft fra batteriet blive ført direkte til feltspolen for at give maksimal spænding. Den skal, afhængigt af batteriets spænding, være omkring 13,5 volt til 14,5 volt. Kontakterne skal være i midterposition som vist, og omløbet kan kun nå feltspolen via en modstand, så omløbsfarten er dæmpet sammen med kraften fra feltspolen.
Tiltager batteriets spænding, vil kontakten bevæge sig mod A, det nederste punkt, og effektivt starte generatorens spænding igen. Det sker ved 14,5 til 15 volt. Når spændingen falder, går kontakten mod midterposition, klar til et nyt kredsløb. Tolerancen skal normalt være 0,012 til 0,016 tomme. Justering sker ved forsigtigt at bøje kontaktarmen, til man har den rette spænding og det perfekte kredsløb.



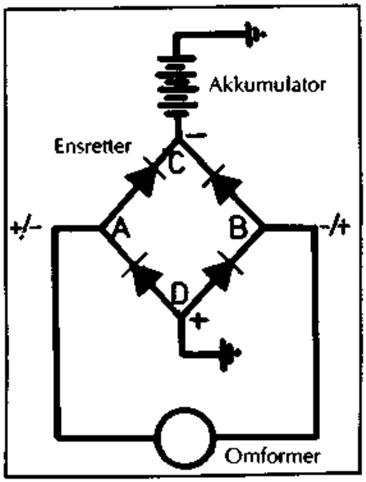
3 En generator med fejl skal først undersøges for stelforbindelse – og om den kører ens. Feltspolen skal vise ensretning på rundt regnet 5 ohm. Med børster/kul fjernet fra slæberingen, eller et stykke isolerende pap eller folie anbragt mellem dem og ringene, må der ikke være forbindelse mellem slæberingene hver for sig – og stel. Stærk modstand eller stelforbindelse viser, at vikling eller isolering er skadet, og tændspolen skal udskiftes. Statorspolerne har en lavere modstand, normalt mindre end 1 ohm, som skal kunne vises ret konstant uden udsving – og de må ikke have stelforbindelse.



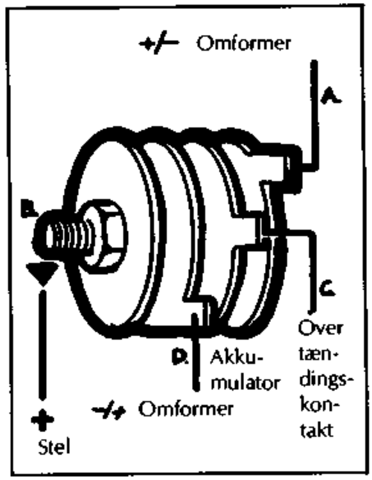
4 En generator uden produktion nok kan også testes således: fjern forbindelsen fra ensretteren til batteriet, normalt et rødt kabel, forbind et voltmeter til kablet og sæt stelforbindelse til voltmeteret. Lav en forbindelse direkte fra batteriet til feltspolen, via en af reguleringerne, og reguler til fuld produktion. Start motoren og aflæs voltmeteret som følger:
24 volts udslag ved 1500 omdr. min.
34 volts udslag ved 2000 omdr. min.
40 volts udslag ved 2500 omdr. min.

Hvis der er mere end ganske få volts forskel på denne tabel og det der aflæses, er spolens vikling skadet. Svingende aflæsning med udslag kan skyldes en dårlig forbindelse eller ensretterfejl.
Husk: De fleste elektriske komponenter er ensrettet, og dermed ret følsomme over for vendinger af polerne. De skal forbindes den rigtige vej i kredsløbet. Husk, at batteriet altid skal være afmonteret når der arbejdes med det elektriske system. Naturligvis skal det monteres igen når der skal testes – hvor dette er foreskrevet.

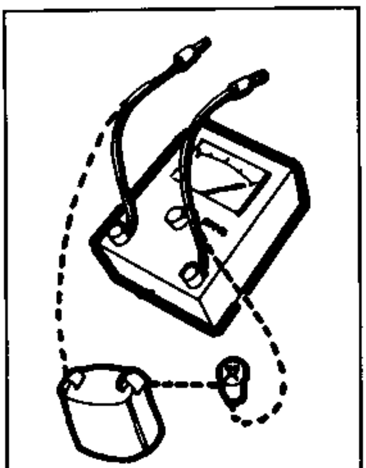
Ensrettere



1 Ensretteren transformerer spændingen, høj eller lav, til det nødvendige niveau, for hele tiden at kunne føde batteriet. Den er bygget med fire ledere, konstrueret så de kun tillader elektrisk strøm at passere én vej. Lad os forudsætte, at der går en elektrisk impuls fra ÷ til +, og at lederne er lavet til at løbe i pilens retning på skemaet. Så vil også kraften fra generatoren til A og B bølge fra + til ÷, altså modsatte vej. De er indstillet som en slags 1-vejs system gennem ensretterpladerne, således at batteriets forbindelse, C, altid er ÷ og stelforbindelsen, D, altid er +.



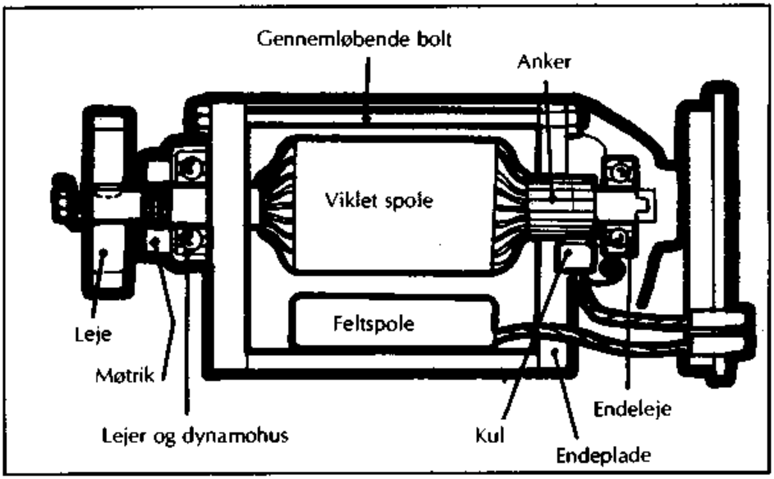
2 Den skitserede konstruktion af en ensretter. Forbindelsen D sker ved hjælp af en skrue, så den kan bruges til at montere/indbygge en ensretter på stellet, for at skaffe stelforbindelse. Dette er Lucas-typen, hvor de to generator-forbindelser altid er de udgående, og batteriforbindelserne altid i midten.
Nogle japanske maskiner har en lignende konstruktion som basis, mens andre har helt op til 9 dioder, og andre igen har en indbygget spændingsregulator. Skal man teste disse typer skal man følge instruktionsbogen/værkstedshåndbogen meget nøje.



3 Den almindelige 4-diodede ensretter kan testes ganske enkelt uden videre: brug et ohm-meter og en pære som vist på skitsen. Aflæsningen skal være høj i én retning, og lav i den anden retning. I teorien skal den anden retning være NUL, men man kan godt acceptere et ganske lille udslag. Men sådan kan du aflæse resultatet.

Forbindelsen:	**Antal ohm:**	**Lyset i pæren:**
A til C	meget højt	meget svagt – eller helt væk
C til A	meget lavt	klart skin
A til D	meget lavt	klart skin
D til A	meget højt	ganske svagt
B til C	meget højt	ganske svagt
C til B	meget lavt	klart skin
B til D	meget lavt	klart skin
D til B	meget højt	ganske svagt

Dynamoer



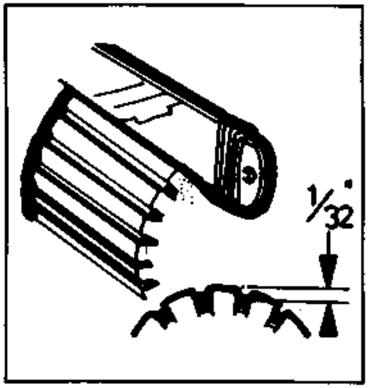
1 Mange ældre britiske maskiner var bygget med dynamoer, som uden om en ensretter forsynede batteriet med strøm. Ladestrømmen blev kontrolleret af en slags regulering, som afskar strømmen. På mange japanske maskiner er der samme system: man reducerer lademængden ved at indbygge en feltspole i systemet. Den afskærende del er der for at beskytte batteriet og dets afladning, selv om en motor går ganske få omdrejninger, og i virkeligheden ikke er i stand til at forsyne batteriet med tilstrækkelig spænding. Så holder batteriet alligevel sin fulde spænding.

Dynamoen er oftest bygget ind lige foran motoren eller lige bag cylinderblokken. Den kan trækkes af tandhjul, af en kæde eller af en rem. Lejerne er pakket med HMP-fedt, (HYPOID som tåler højere varmegrader) og må aldrig smøres med olie. I øvrigt er det mest almindeligt, at man udskifter en hel dynamo med en brugt renoveret hos forhandleren. Det er lettere end timelange afprøvninger og reparationer.

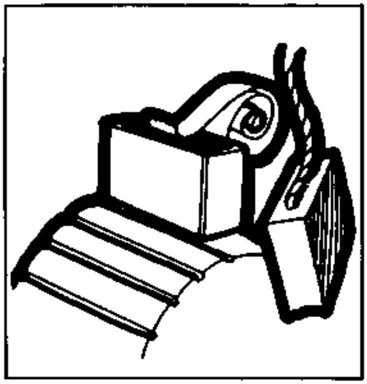
Hvis det viser sig nødvendigt at reparere en dynamo, skal den afmonteres. Det kræver en aftrækker til at tage det direkte trækhjul på dynamoen. Husk, ved tandhjulsdrevne dynamoer, at de ikke må flyttes fra deres leje uden nøjagtigt diagram over samlingen igen. Der er normalt afmærkning på hjulene.

I den anden ende af dynamoen skal dækslet skrues af – via et spændebånd. Tag fjedrene i kulholderne ud. Skru det sorte endedæksel af, som holdes af to lange skruer ind i dynamoen. Indvendig er der to ledninger, som skal afmonteres fra deres forbindelser. Skru så de to lange endeskruer, som holder pladerne, ud. Herefter kan dynamoankeret tages ud med lejer på enderne. Brug et ganske let slag på den anden ende – efter naturligvis at have fjernet endemøtrikken.

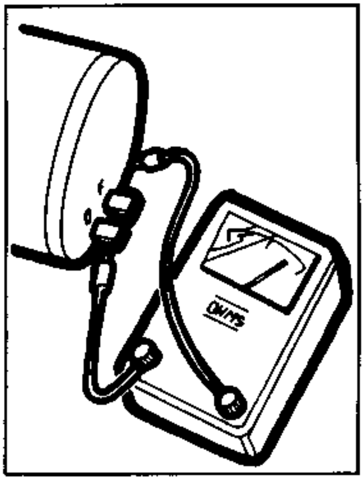
Lejerne skal vaskes omhyggeligt i benzin. Se efter om der er slør, slitage, støj når de roterer. Så skal de skiftes ud. Kan de bruges, eller monteres nye, skal de pakkes igen med HMP-fedt. Ikke for meget, blot så lejet er godt beskyttet. Pakninger skal udskiftes, og vær omhyggelig når nye lægges ind på plads, at de ikke ødelægges af skruer og andet.



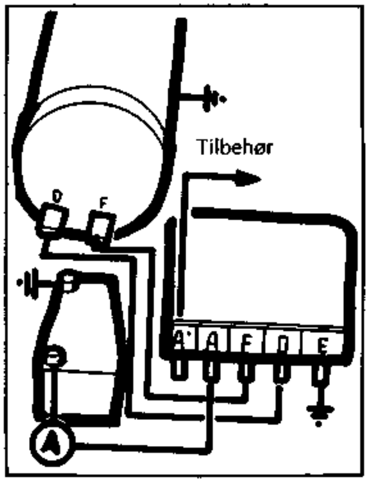
2 Ankerets slæbering skal undersøges omhyggeligt. Renses mellem viklings-enderne, og pudses omhyggeligt af med fint smergel hvis der er tegn på slid. Måske en blød klud med lidt benzin kan rense ankeret rent. Rillerne i ankeret, mellem viklingsenderne, kan måske forsigtigt renses med en nedstrygerklinge, som er slebet ned i enden til det rette mål.



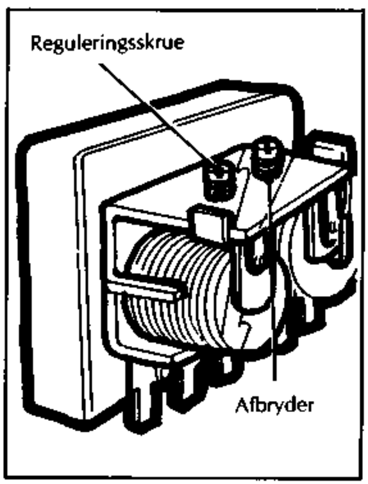
3 Normal vedligeholdelse er begrænset til at se efter kullene en gang imellem. Kontroller, at de kan bevæge sig frit op og ned i kulholderen, at fjedrene er i orden. Puds dem eventuelt med en fin fil så berøringsfladerne til ankeret bliver størst mulige. Men udskift kullene hvis de ser ud til at være udtjente.



4 Feltspolen, F, har stelforbindelse direkte til dynamohuset. Se efter at denne forbindelse er helt i orden. Modstanden skal være fra 2,8 til 3,2 ohm, afhængigt af model og type. Lavere modstand tyder på fejl i isolering. En høj modstand tyder på fejl i viklingerne af spolen. Spolerne kan afprøves ved at holde et kabel fra ohm-meteret til hvert kul, og dreje ankeret langsomt rundt.



5 Alle forbindelserne i dynamoen er normalt kodet med bogstaver. Se efter instruktionsbogens anvisninger – eller spørg på værkstedet. Ekstra tilbehør, som monteres af andre end fabrikken, skal man så vidt mulig altid montere med en 35 amperes sikring. Så er man garderet.



6 Indstilling af relæ. På tidligere modeller skal man fjerne A-lederen og sætte et tyndt stykke papir mellem sluk-kontakterne. På nyere relæer skal man afmontere A og A1 og forbinde dem med hinanden. Forbind et voltmeter med + til stelforbindelsen, eller til punktet E, og med ÷ til D. Start motoren forsigtigt og kør op til 3000 omdr. min. Så skal voltmeteret vise 8 til 8,4 volt på 6-volts anlæg, eller fra 16 til 16,6 volt på 12-volts anlæg. Herefter skal voltmeter-forbindelserne byttes for at skaffe et kredsløb med stelforbindelse. Regulatorskruen skal drejes lidt ad gangen i urets retning for at give mere spænding, og modsat urets retning for at nedsætte spændingen. Lav ombytningerne hurtigt og præcist. Ellers kan vindingerne blive varme, og give falsk udslag. Efter hvert eneste skal motoren stoppes, og igen startes forsigtigt op til 4.500 omdr. min., på hvilket punkt spændingen ikke må overstige 8,9 volt og 17,1 volt for de to slags anlæg.

Indstilling af tidspunkt for at relæet slår fra eller til: forbind et amperemeter mellem dynamo og D-reguleringen, og et voltmeter mellem D-regulering og en stelforbindelse. Start motoren og lad den langsomt få mere gas til kontakterne slår fra eller til. Det kan ses tydeligt ved et kraftigt udslag på voltmeternålen. Det skal ske ved 6,3 til 6,7 volt, henholdsvis 12,7 til 13,3 volt på 12-volts anlæg. Udslagsskruen reguleres så i urets retning for større spænding – og modsat.

Amperemeteret skal vise ens udslag når kontakterne lukker. Stop motoren, og se afladningen på amperemeteret når kontakterne er åbne. Den skal være mellem 3 og 5 ampere. For at kontrollere spændingstabet: skil forbindelsen ved A ad, og forbind i stedet et voltmeter mellem A og stelforbindelsen. Kør motoren op til 3000 omdr. og lad omdrejningstallet falde langsomt, til det punkt, hvor kontakterne skal åbne. Så falder spændingen til NUL på et punkt mellem 4,8 og 5,5 volt, henholdsvis 8,5 til 11 volt.

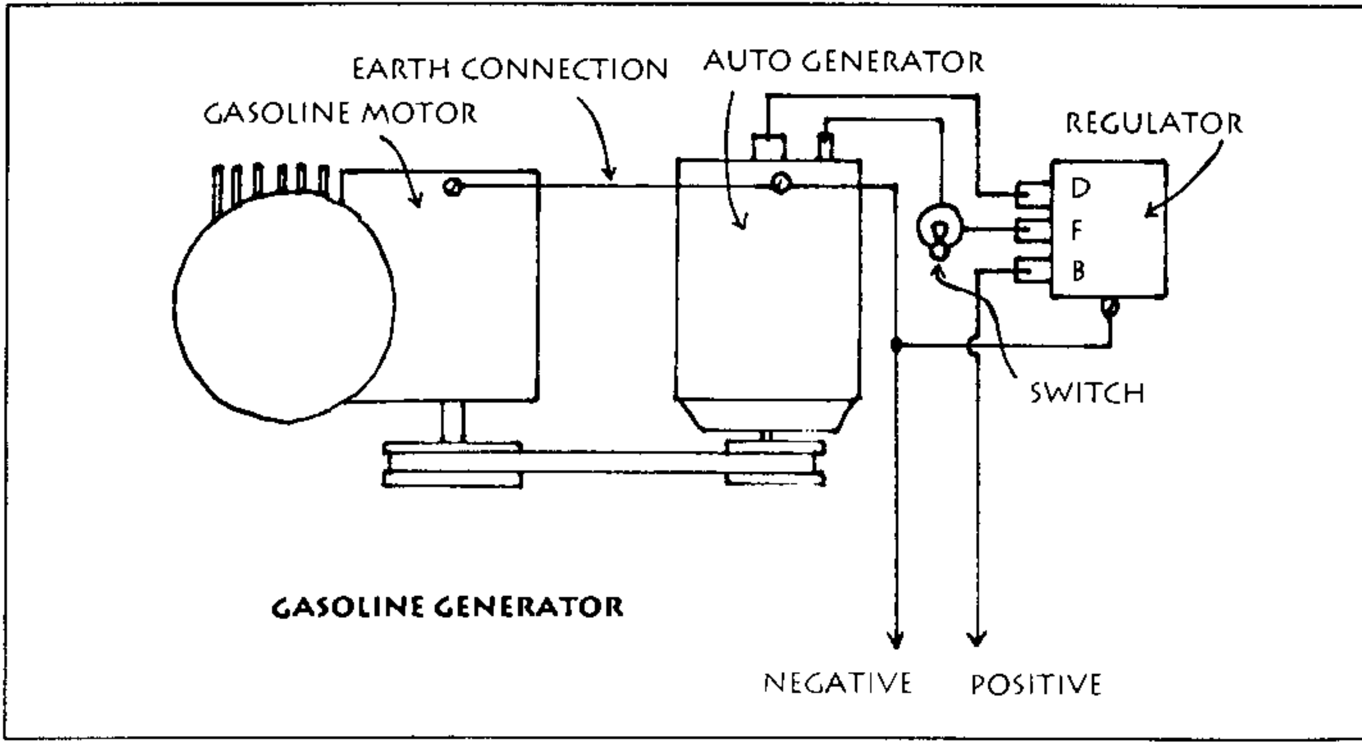
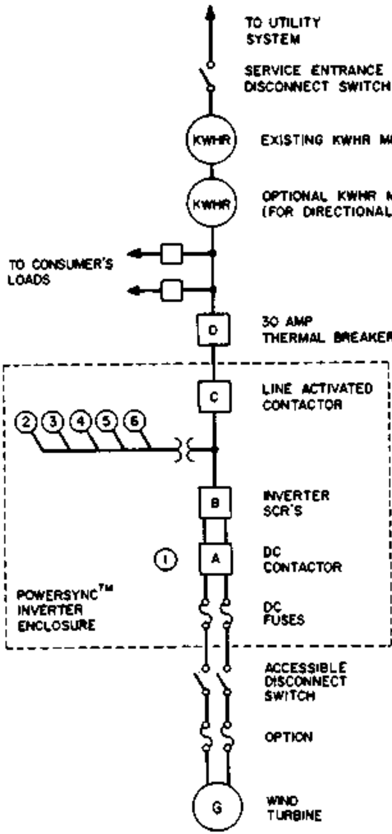


Figure 9-5. **This wiring diagram gives you the basics for constructing a gasoline generator similar to the one shown in Figure 9-4.**



DEVICE NO	FUNCTION	ACTIVATES DEVICE
1	DC OVERVOLTAGE	A,B
2	SYNCHRONIZATION CONTROL	B
3	AC DISTORTION DETECTION	B
4	AC OVERCURRENT	B
5	AC UNDERVOLTAGE	A,B,C
6	AC LINE LOSS	A,B,C

Figure 15-1. Utilities usually require line drawings such as this before they will permit an interconnection. The schematic tells them how the wind system will be interconnected with their lines and what precautions have been taken to protect their linemen. (Bergey Windpower Co.)

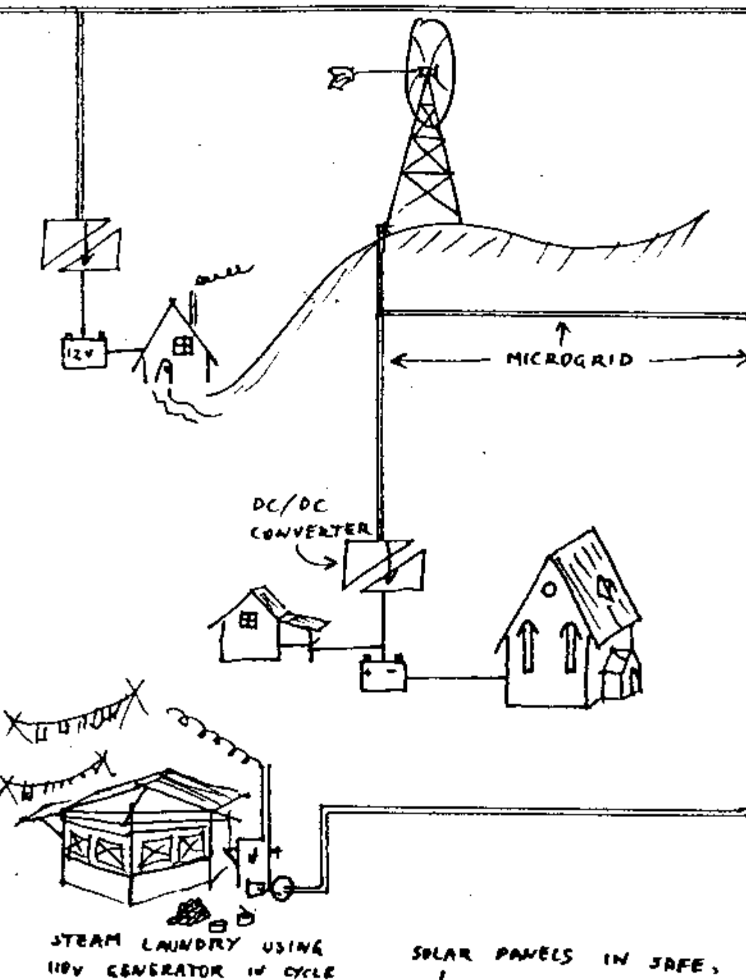
Development of Microgrid

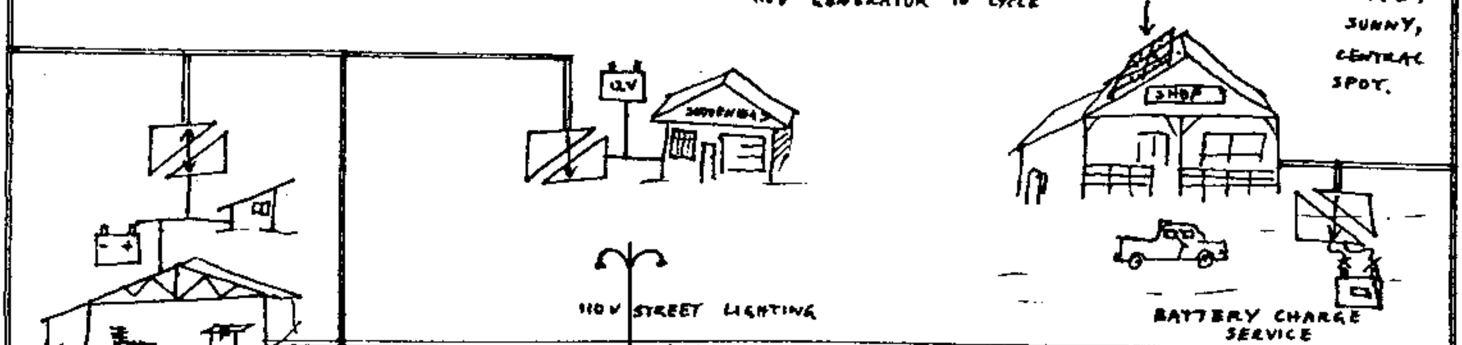
After experience of running grids on 32V AC, 60V DC, 100V DC, and 240V AC we have decided that 100V DC is the best standard because:

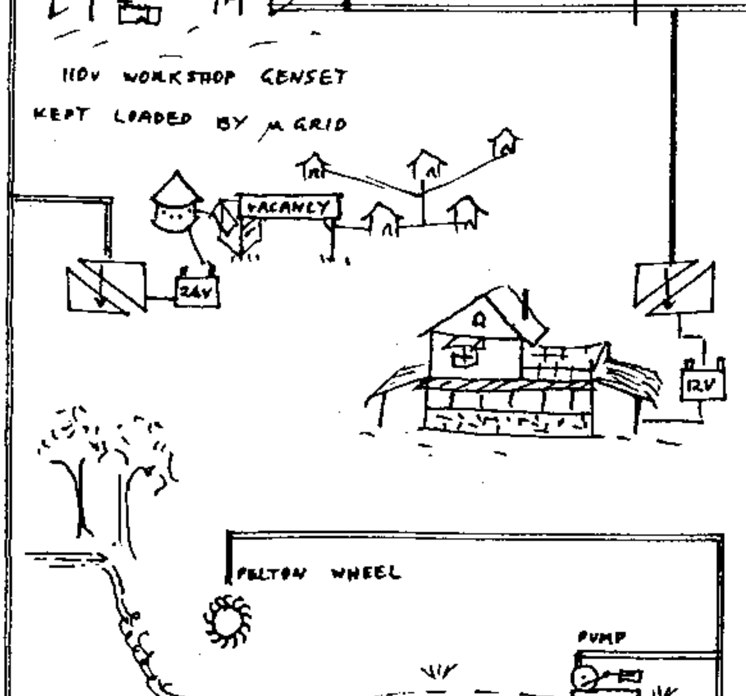
- it suits transistors well;
- the voltage is high enough to keep wire size reasonably small;
- it is covered by Extra Low Voltage wiring standards; and
- being DC it is far easier to feed power into the grid without worrying about phase or stability.
- Faults do not take out the whole system. They simply isolate sections of it;
- Fault finding is easy;
- Alteration is easy, and
- Expansion is easy.

A disadvantage of DC is that transformers cannot be used to simply convert voltage up and down again to transmit power long distances.

This has now changed with the advent of modern power electronics and we now have the DC/DC converter which is the equivalent of the transformer, but can actually do more because the ratio of input to output voltage is not fixed and can be continuously varying according to requirements. Behaviour under fault conditions can also be configured so that the system is self managing.







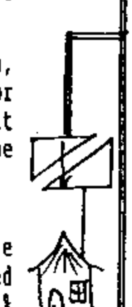
Energy Sources and Locations

Methods of powering a 100V microgrid include arrays of solar panels, a 110 volt generator, 110 volt version of RPC micro-hydro unit, 110 volt wind turbine, a rectifier from a bigger minigrid, the mains grid, or any combination of the above! Note that some of these generators may need a linear shunt regulator to clamp the voltage at 140 in the event of production exceeding demand. This could be a load such as a hot water heater. The geographical layout of the power sources/loads is flexible to suit the site, up to about 2 km.

The loads, as well as the points of generation, can be anywhere required as long as the conductor cross-section is appropriate to the current flowing in that section of the grid. This is one of the key practical advantages of the system.

Disadvantages of AC distribution

The mains power in eastern Australia is an example of a very large AC grid. Such a grid must be sized to supply peak loads to remote areas with 5% voltage tolerance. This means it uses very thick cable, very high voltage, and lots of capital outlay.



RUNNING CABLE OVERHEAD

If you want to extend your electricity supply beyond the house walls, you can run the circuit cable in one of two ways: overhead or underground. The former is easier and quicker to install, but the latter is far less obtrusive and is also safer in the long run.

Overhead wiring is a popular and economical way to provide a power supply to an outbuilding, especially if it is relatively close to the house. It is not really practical for wiring to garden lights or outdoor socket outlets, which are normally given an underground supply (see pages 126-7).

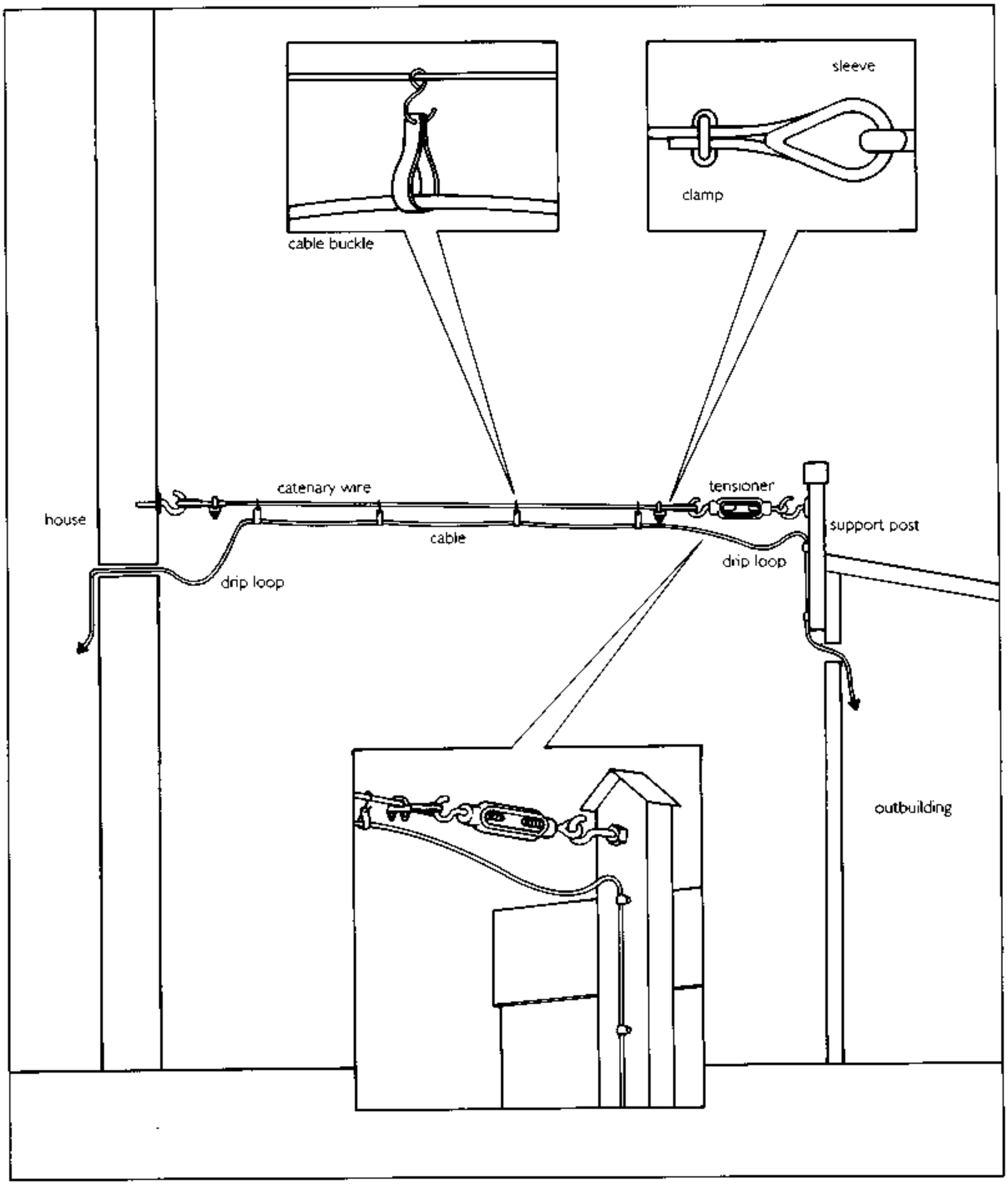
1 Plan out the cable run, checking spans and ground clearances so you can decide where the cable should leave the house, how it will reach the outbuilding and whether a catenary wire is needed. Attach a support post to the outbuilding if necessary to achieve adequate clearance.

THINGS YOU NEED

- 2.5mm² two-core-and-earth cable for 20-amp circuits
- 4mm² cable for 30-amp ones
- 16mm round PVC conduit
- 20mm steel conduit, saddles and PVC bushes plus earth cable and connector (optional)

For runs over 3m

- Galvanized catenary wire
- Eyebolt fixings
- Tensioner
- Cable buckles and clips
- Earth cable connector
- 4mm² single-core earth cable
- Support posts if required



2 If a catenary wire is needed, fit an expansion anchor with an open eyebolt at the house end of the cable run and attach a tensioner to it. Fit another eyebolt to the outbuilding or the support post, and attach one end of the catenary wire securely to it. Draw the other end of the wire through the tensioner and pull it as tight as possible by hand and clamp it. Then turn the tensioner with a screwdriver to pull the wire taut.

3 Drill a hole through the house wall (just below the eyebolt position if a catenary wire is being used), angling it slightly upwards to discourage water penetration, and insert a length of 16mm round PVC conduit to prevent the cable from chafing. Make an entry hole at the outbuilding, again sleeving it if it passes through masonry.

4 Unroll the circuit cable and feed one end in through the hole in the house wall. Take it back to the consumer unit position by the most convenient route, leaving ample slack there for the final circuit connection to be made.

5 For spans of less than 3m, simply draw the cable across from the house to the outbuilding and secure it to the support post there with cable clips.

Check that the ground clearance is adequate, then feed the cable into the outbuilding ready for connection to its electrical equipment (see page 133).

6 If steel conduit is being used to provide additional protection for the cable span, secure the length (a maximum of 3m; 10ft) to the buildings or support posts with conduit saddles. Fit a PVC bush to each end of the conduit, feed the cable through it and take it into the building.

7 If a catenary wire is being used, form a drip loop where the cable emerges from the house wall. This is a 'droop' in the cable which allows rainwater to fall to the ground and keeps it away from the house wall. Then attach the cable to the wire at about 230mm (9in) intervals with cable buckles. When you reach the outbuilding, form another drip loop before clipping the cable down the support post and into the building.

8 Attach the earth cable connector to the free end of the catenary wire next to the tensioner or to the steel conduit. Then run a length of $4mm^2$ single-core earth cable from the connector through the hole in the house wall and back along the circuit cable route to the house's main earthing point. Connect it to the earth terminal.

9 Complete all the wiring within the outbuilding (see pages 133) before making the final circuit connections inside the house.

Wiring regulations

Ordinary PVC-sheathed cable can be used for the entire run, and if the span between the house and the outbuilding is less than 3m (10ft) the cable needs no additional support so long as care is taken to prevent the cable from chafing where it passes through walls. It can, however, be given extra protection by being run in a single unjointed length of 20mm diameter steel conduit. The maximum span if conduit is used is again 3m, and the conduit ends must be fitted with PVC bushes to prevent the cable from chafing on the metal. The conduit itself must also be earthed.

If the span is longer than 3m, the cable must be supported by a catenary wire to which it is bound by suitable buckles. The catenary wire is a multi-stranded galvanized steel wire, available from electrical suppliers, which is secured to stout eye bolts at each end of the span. Fitting a tensioning device at one end makes it easier to pull the wire taut and prevent sagging. The wire must be earthed to the house's main earthing point with a length of $4mm^2$ single-core earth cable.

Both unsupported and supported overhead cables must have adequate ground clearance to prevent them from being damaged accidentally. Where there is only pedestrian traffic, the minimum clearance allowed is 3.5m (11ft 6in), or 3m (10ft) if steel conduit is used; this must be increased to 5.2m (17ft) over driveways and other areas with vehicle access, and conduit is not allowed in these locations.

On long runs, intermediate supports will have to be provided for the cable and the catenary wire, in the form of posts tall enough to give the necessary ground clearance. This is when overhead cable runs become obtrusive (and also more expensive), since you are not allowed to extend existing fence posts to carry the cable; it must have independent supports.

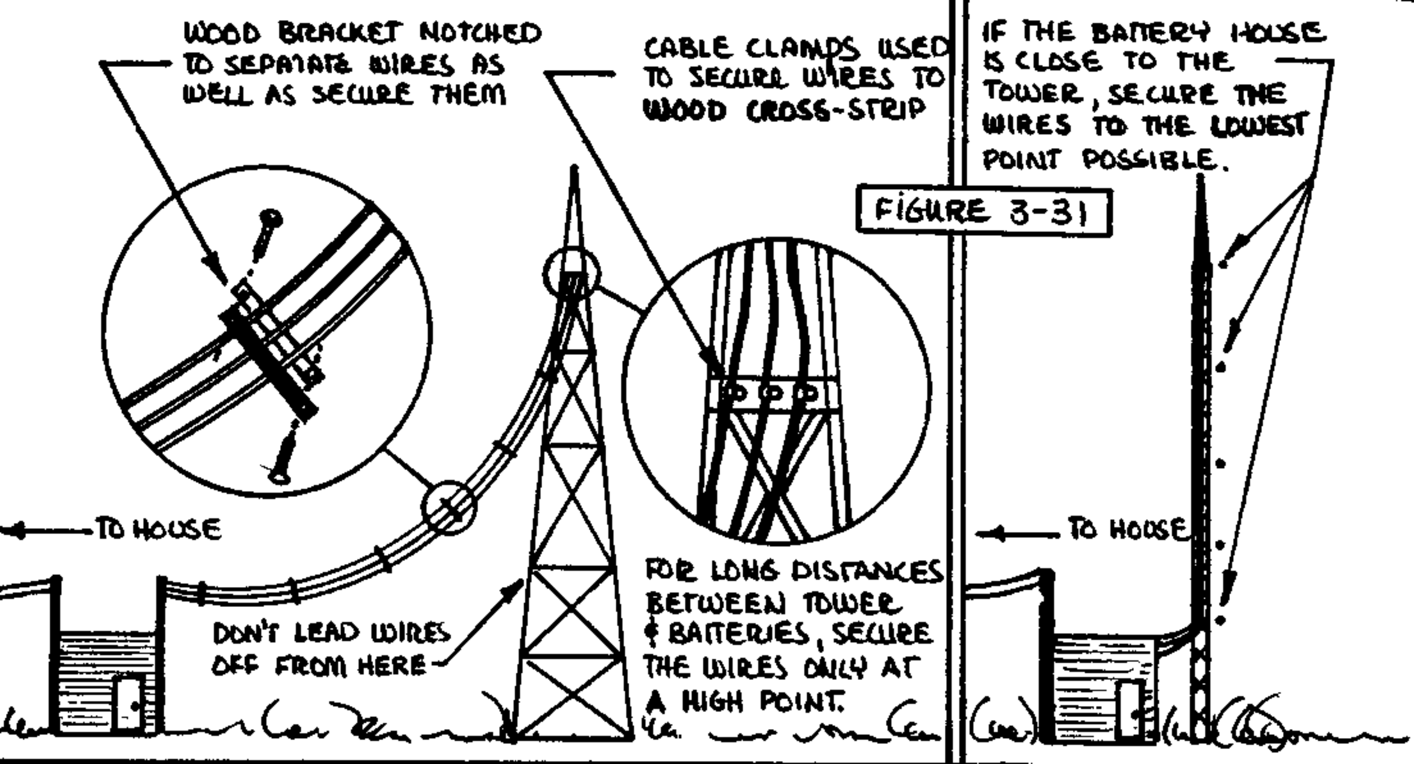
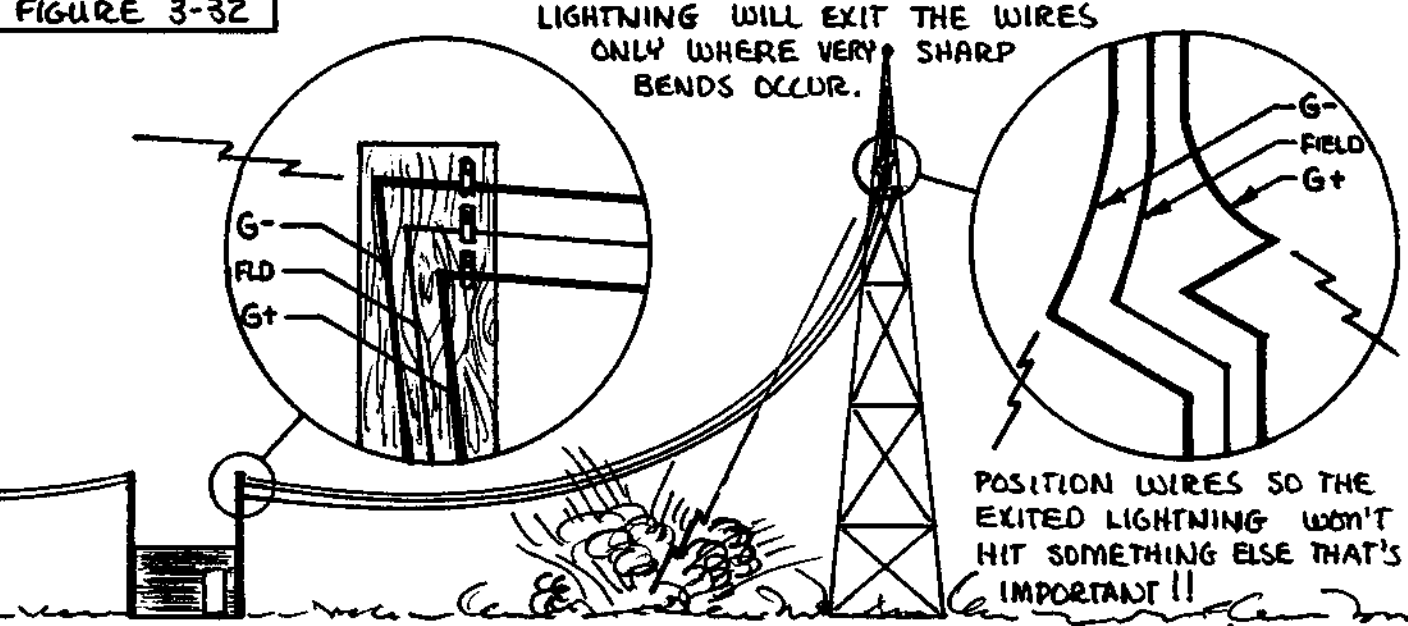

WOOD BRACKET NOTCHED TO SEPARATE WIRES AS WELL AS SECURE THEM
CABLE CLAMPS USED TO SECURE WIRES TO WOOD CROSS-STRIP
IF THE BATTERY HOUSE IS CLOSE TO THE TOWER, SECURE THE WIRES TO THE LOWEST POINT POSSIBLE.
TO HOUSE
TO HOUSE
FOR LONG DISTANCES BETWEEN TOWER & BATTERIES, SECURE THE WIRES ONLY AT A HIGH POINT.
DON'T LEAD WIRES OFF FROM HERE

FIGURE 3-31

FIGURE 3-32


LIGHTNING WILL EXIT THE WIRES ONLY WHERE VERY SHARP BENDS OCCUR.
G-
FLD
G+
G-
FIELD
G+
POSITION WIRES SO THE EXITED LIGHTNING WON'T HIT SOMETHING ELSE THAT'S IMPORTANT !!

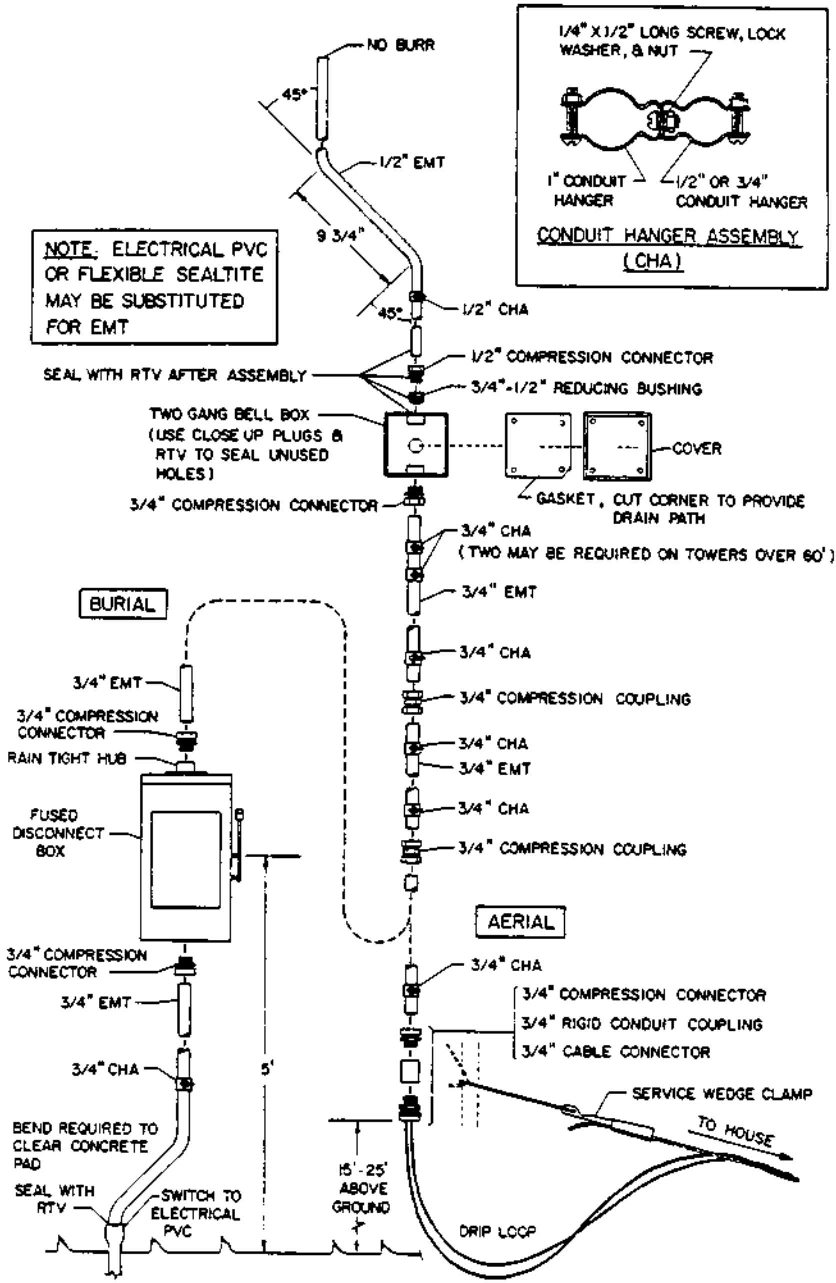
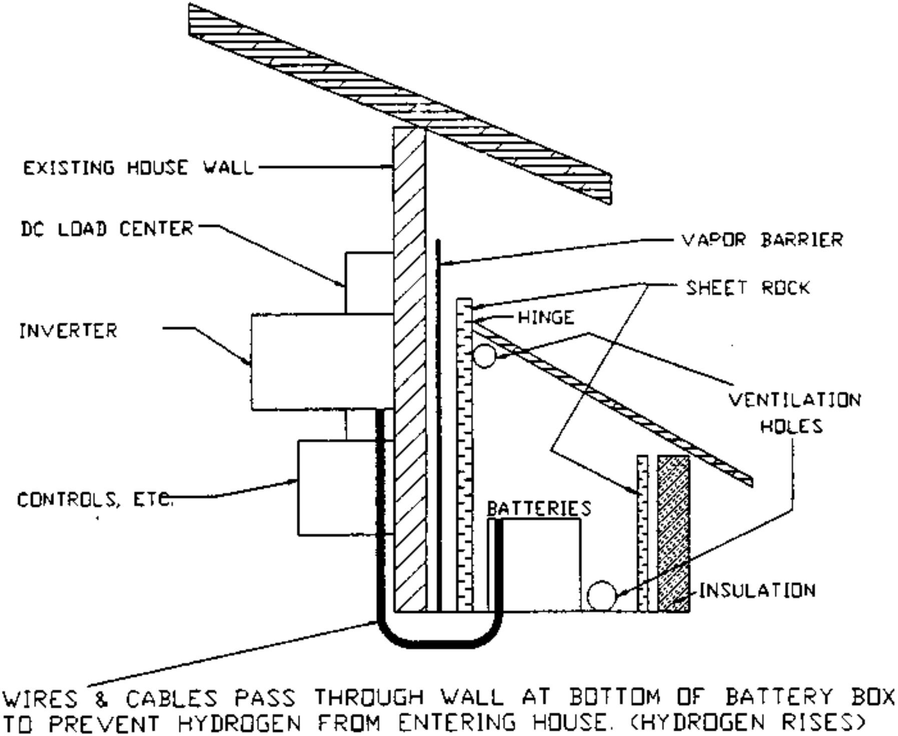


Figure 14-12. Tower conduit assembly. Power cables from the wind machine should be protected within conduit. (Bergey Windpower Co.)



Recommended Battery Enclosure

Increasing Storage Capacity

Okay -- now let's deal with improving the basic control circuit (given in Fig. 4-5). The first question is -- how much capacity does the battery have? If we were using a 52-amp alternator, and operating at 14 volts, we'd have 728 watts (total generator capacity). If we had a 55 amp-hour battery (12-volt automotive), we could 'store' 660 watts (approx.) in this battery. If the wind were strong enuff to operate the alternator at capacity (728 watts) for just a little less than one hour (60 minutes) we would be able to store in the battery as much energy as it could 'hold.' If we were to take another battery (of equal capacity) and place it in 'parallel' with the first battery (see Fig. 4-6A for this 'arrangement'), we could expect to store twice the energy that just one could, which would be 1320 watts (2 X 660 watts); of course, the wind would have to operate the alternator at capacity for twice the period of time. In fact, we may add even more batteries. They don't all have to be the same capacity (amp-hour rating), yet, their storage capacity in watts (amp-hour rating times voltage) is additive!

Let's try an example; suppose we have four 12-volt automotive batteries and their ratings are (in amp-hours) 45, 50, 60, and 60. If we add these together, we get 215 amp-hours; now, if we multiply this times the final battery voltage (12.6 volts), we get 2710 watts (this would be the absolute power we could expect to realize -- a more real figure, after considering battery efficiency, transmission line losses, heat and water disassociation losses, would be 75% of this figure, or 2032 watts usable power out). With the alternator's maximum power output at 728 watts, it would take 3 hours running at full capacity to fill these batteries, or 6 hours at 1/2 the full capacity of the alternator (364 watts), or 12 hours at 1/4 the full capacity of the alternator (182 watts). Get the picture?

What happens if we use 6-volt, heavy-duty batteries? Well, the alternator can charge 6-volt batteries but the regulator would have to be modified; a better way of using these batteries is to hook two of them in series (see Fig. 4-6B for this arrangement) to make the equivalent of a 12-volt battery (the voltage here is additive but the amp-hour capacity is the same as just one). If both of these batteries were 180 amp-hour capacity, then the total storage capacity (for the two of them) is 2160 watts (or again using a 75% overall efficiency, we could realistically expect 1620 watts usable power out). Again, using a 728-watt alternator running at full capacity, we could expect these to be charged to their full storage capacity in a little over 2 hours, or in 4 hours at 1/2 the capacity of the alternator (364 watts), or in 8 hours at 1/4 the capacity of the alternator (182 watts). To double this storage capacity (to 3240 watts), two more 6-volt batteries (each of the above amp-hour rating) could be placed in 'series' with eath other, and then in 'parallel' with the original two (see Fig. 4-6C).

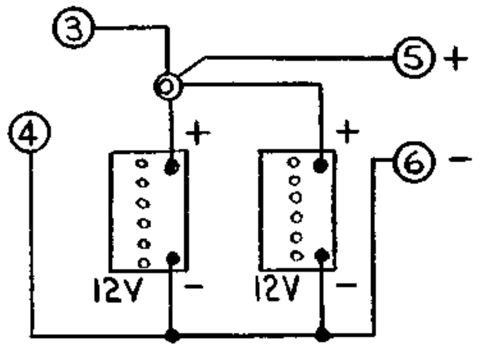


FIG. 4-6A: BATTERIES IN PARALLEL

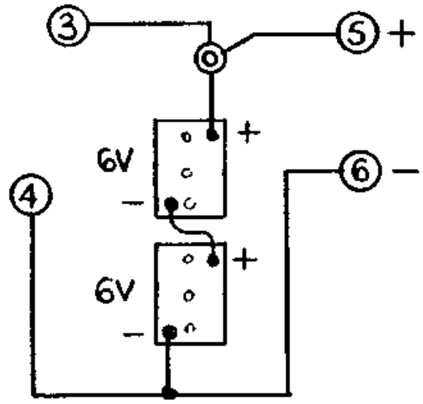


FIG. 4-6B: BATTERIES IN SERIES

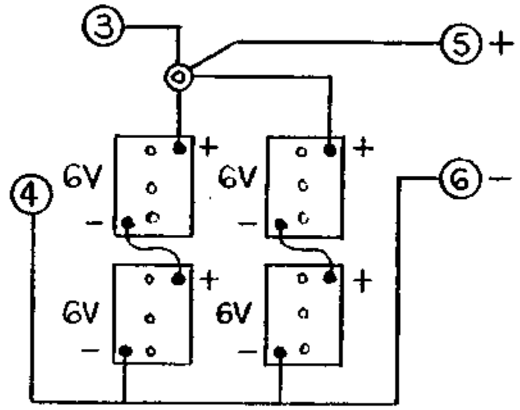


FIG. 4-6C: SERIES/PARALLEL BATTERIES

This appears to be the proper time (and place) to indicate a few things about parallel and series operation of batteries.

(1) try to get batteries of equal amp-hour capacity when using 12-volt automotive batteries. You can use a wide variety of ratings but you may have to install diodes (see Fig. 4-7A) to prevent them from discharging into one another (or into the weakest one, of least capacity, or most 'local action' -- self-discharge). For each battery, 2 diodes would be required; they are not very expensive, nor are they difficult to install, but it's a bit of a hassle.

(2) you must use batteries of equal amp-hour capacity if you are using 6-volt batteries and arranging them in series (or the lower-capacity battery will restrict proper charge/discharge of the higher one, perhaps with irreparable damage to itself). Diodes are only required if a 'set' (consisting of two 6-volt'ers in in series) is in parallel with another set of dissimilar capacity; for each 'different' set, 2 diodes would be required. Diodes would not necessarily be required if the paralleled 'sets' were of equal amp-hour capacity. (See Fig. 4-7B.)

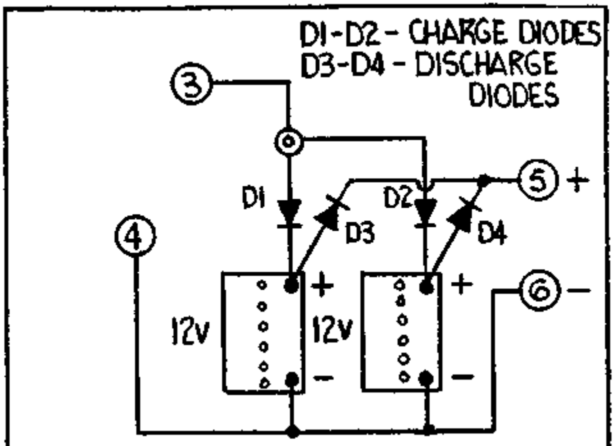


FIG. 4-7A: DISSIMILAR BATTERIES

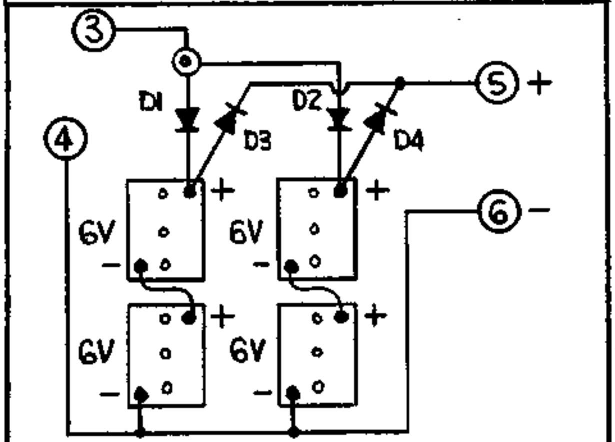


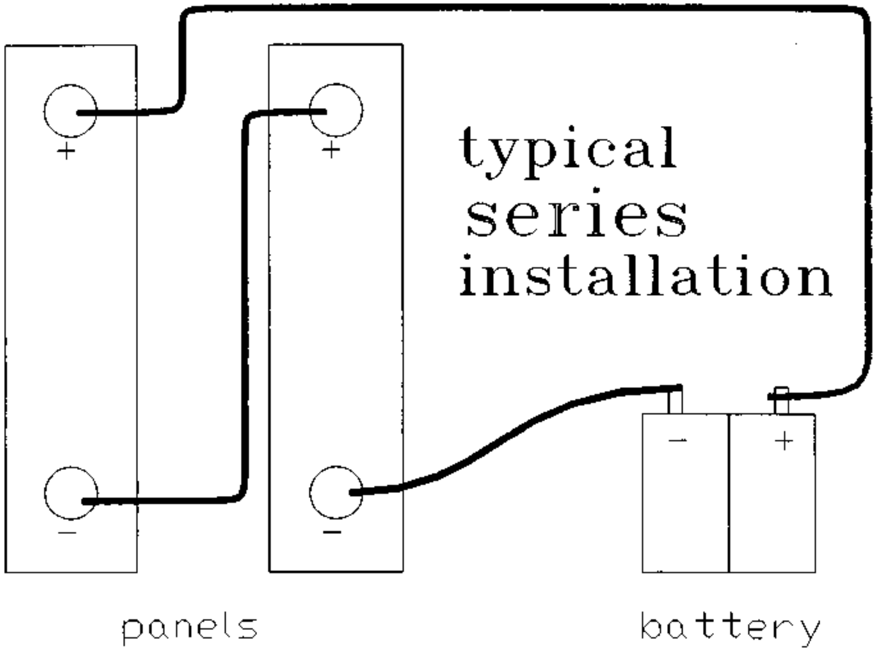
FIG. 4-7B: DISSIMILAR BATTERY SETS

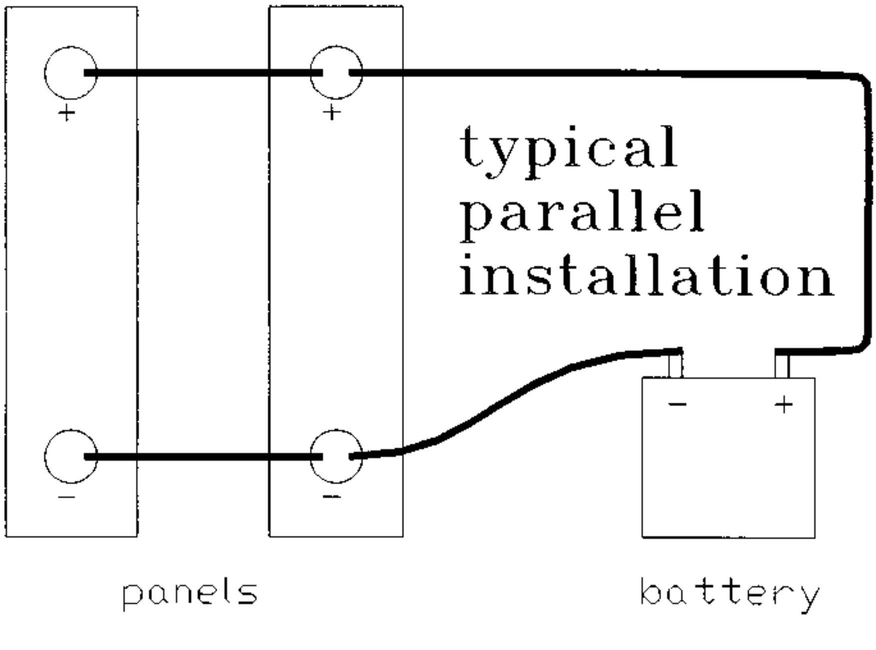
(3) there is a limit to the number of batteries that you should place in parallel but the number depends primarily on what size alternator (rating) you have and how much wind you experience. As indicated in Chapter 3 - Batteries - undercharing is just as serious a mistake as overcharging; too many batteries, then, will prevent any one of them from being fully charged. At the same time, too few batteries will 'lose' some of the wind's energy. 'Too few' and 'too many' vary with the installation's location so they are tough to determine. The thing to look for is whether or not the batteries are fully charged by an 'average blow'; if 'yes,' increase the capacity and, if 'no,' maybe you have too many! To start out with, a good rule of thumb is:

(1) the number of batteries should not exceed 1/10th the alternator rating and

(2) the combined amp-hour ratings of the batteries should not exceed 5 times the alternator rating.

For example: a 60-amp alternator should use a maximum of six batteries (60 ÷ 10) and their combined amp-hour capacity should not exceed 300 amp-hours (5 x 60); with six batteries, this means an average (individual, or per battery) rating of 50 amp-hours (300 ÷ 6). However, 5 batteries of 60 amp-hour capacity or 4 batteries of 75 amp-hour capacity or 3 batteries of 100 amp-hour capacity, or 2 batteries of 150 amp-hour capacity could also be used.


typical
series
installation
+
+
−
−
−
+
panels
battery


typical
parallel
installation
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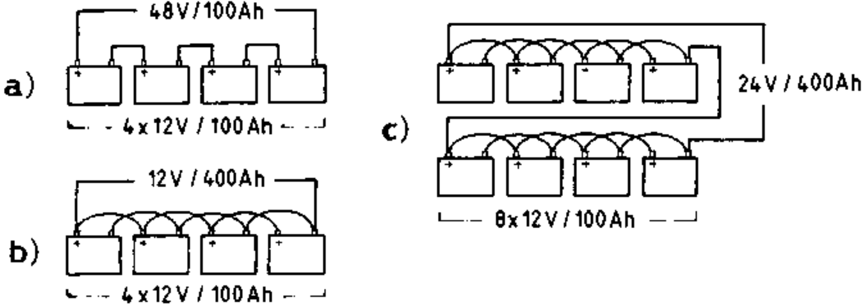


Abb. 5.5 Akkumulatoren: a) in Serienschaltung; b) in Parallelschaltung; c) in kombinierter Serien/ Parallelschaltung

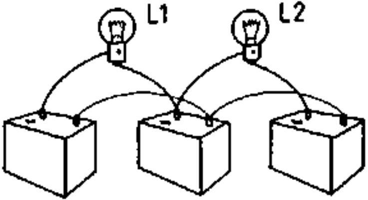


Abb. 5.6 Bevor zwei oder mehrere Bleiakkumulatoren parallel miteinander elektrisch leitend verbunden werden, sollten ihre Spannungen mit Hilfe von Widerständen oder Autolampen gegenseitig ausgeglichen werden

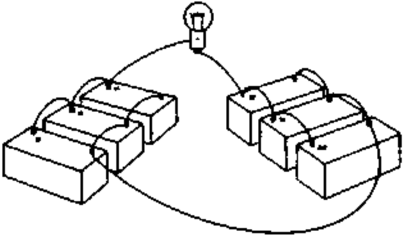


Abb. 5.7 Wenn relativ viele Batterien miteinender parallel verschaltet werden sollen, ist ein vorhergehender Spannungsausgleich nach Abb. 5.6 und danach, wie hier abgebildet, empfehlenswert

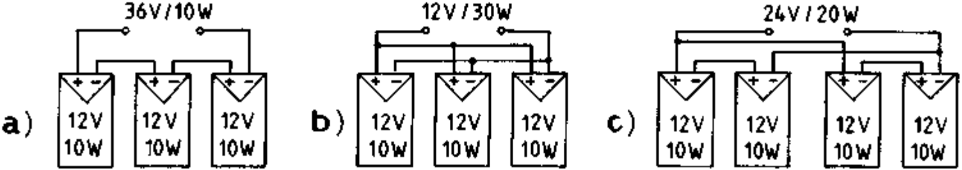
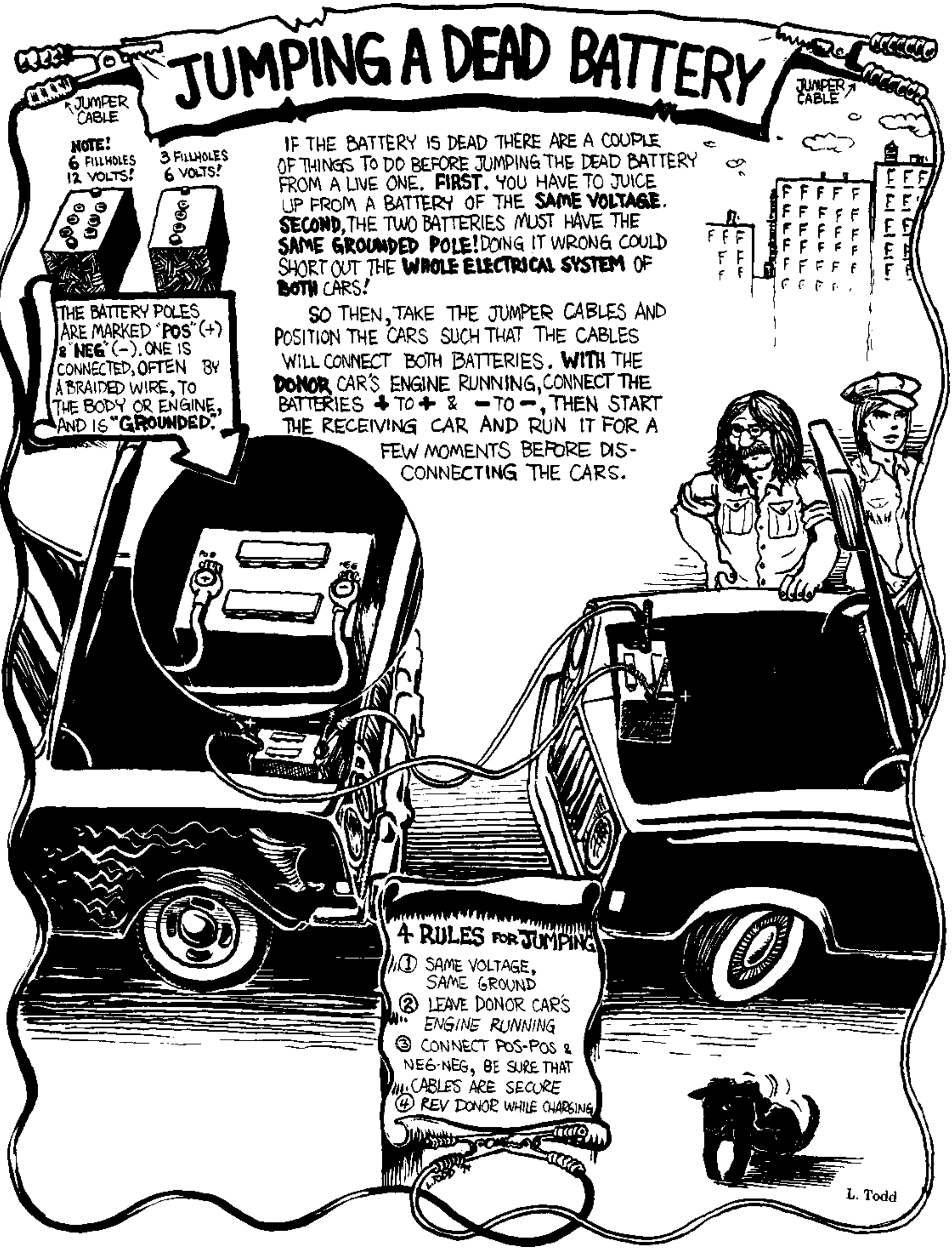


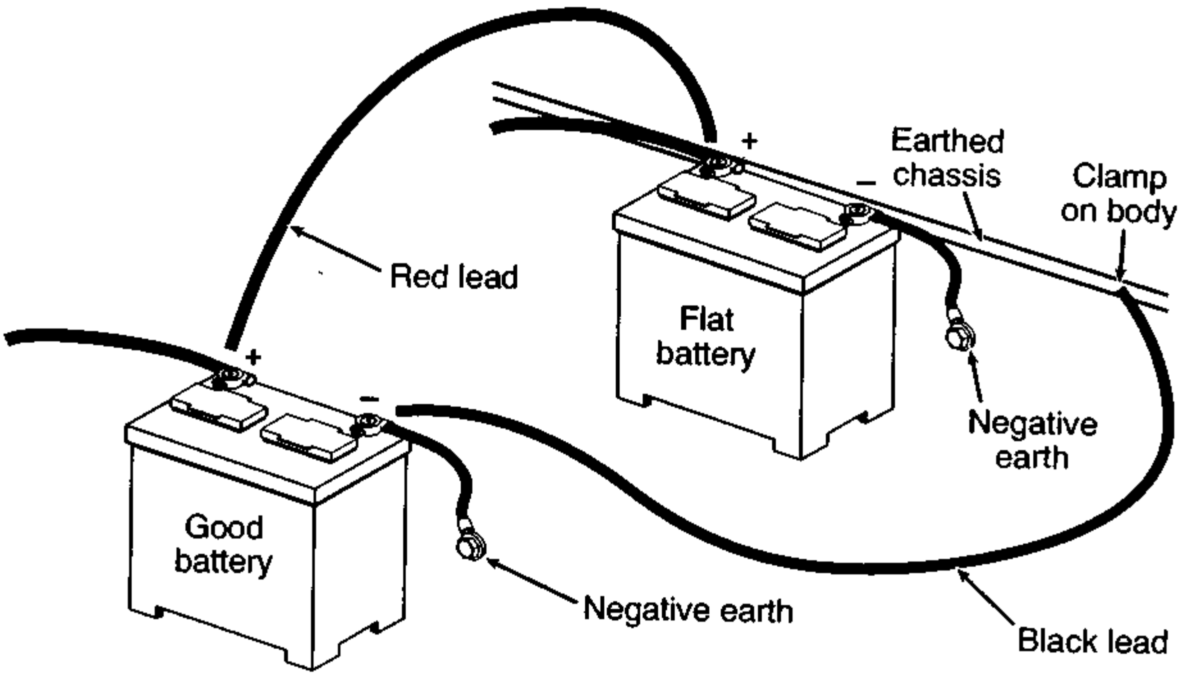
Abb. 11.5 Solarzellenmodule (die hier durch das gängige Schaltsymbol ersetzt sind) lassen sich - ähnlich, wie Batterien - seriell, parallel oder seriell/parallel miteinander verschalten. Aus Modulen derselben Marke und mit identischen technischen Parametern können somit beliebig große Solarzellenflächen mit erwünschten Nennleistungen und Nennspannungen zusammengestellt werden


JUMPING A DEAD BATTERY
JUMPER CABLE
JUMPER CABLE
NOTE! 6 FILLHOLES 12 VOLTS!
3 FILLHOLES 6 VOLTS!
IF THE BATTERY IS DEAD THERE ARE A COUPLE OF THINGS TO DO BEFORE JUMPING THE DEAD BATTERY FROM A LIVE ONE. FIRST, YOU HAVE TO JUICE UP FROM A BATTERY OF THE SAME VOLTAGE. SECOND, THE TWO BATTERIES MUST HAVE THE SAME GROUNDED POLE! DOING IT WRONG COULD SHORT OUT THE WHOLE ELECTRICAL SYSTEM OF BOTH CARS!
SO THEN, TAKE THE JUMPER CABLES AND POSITION THE CARS SUCH THAT THE CABLES WILL CONNECT BOTH BATTERIES. WITH THE DONOR CAR'S ENGINE RUNNING, CONNECT THE BATTERIES + TO + & − TO −, THEN START THE RECEIVING CAR AND RUN IT FOR A FEW MOMENTS BEFORE DISCONNECTING THE CARS.
THE BATTERY POLES ARE MARKED "POS" (+) & "NEG" (−). ONE IS CONNECTED, OFTEN BY A BRAIDED WIRE, TO THE BODY OR ENGINE, AND IS "GROUNDED".
4 RULES FOR JUMPING
① SAME VOLTAGE, SAME GROUND
② LEAVE DONOR CAR'S ENGINE RUNNING
③ CONNECT POS-POS & NEG-NEG, BE SURE THAT CABLES ARE SECURE
④ REV DONOR WHILE CHARGING
L. Todd

Warning

The incorrect connection of jump leads can seriously damage electronic components. Follow the correct procedure, referring to Figure 13.1.

- Check that the batteries are of the same voltage and earthed (usually the negative terminal is connected to earth). Check that the flat battery is topped up with distilled water.
- Connect the red lead to the positive terminals of each battery. Connect the black lead to the negative terminal of the charged battery and to an earthed part of the chassis of the engine with the flat battery 0.5m away from the battery. This is to reduce the risk of a spark igniting any hydrogen gas that may be given off by the batteries when the final connection is made.
- If the charged battery is connected to another engine, start this engine and run it at a fast idle. The engine with the flat battery should now start. If it does not – check the connections and try again. If it still will not start, refer to Tables 13.3 or 13.6 below.
- Stop the engine with the charged battery and disconnect the jump leads in the reverse order to the way they were connected. Make sure the loose ends do not touch each other or either machine.



Jump lead battery connection

POLARITY OF THE BATTERY may differ in some cars. The British Land Rover, for example, has a positive ground and most American-made vehicles have negative ground. This polarity must be carefully observed, or the battery and possibly the generator or voltage regulator will be damaged. If the car is marked for positive ground, connect the positive pole of the battery to the frame of the car; on negative polarity, connect the negative pole of the battery to the chassis.

If in doubt as to the polarity of a battery due to the markings wearing off, a potato can be used to find the plus and minus poles. Connect wires to each pole of the battery, and push the other ends into the cut face of half a potato, about a quarter inch (6 mm) apart. Bubbles will form around the negative wire.

Batteries
Lead Acid

WARNING - FIRE HAZARD

A Low voltage power supply is just as likely to cause a fire if a short circuit occurs as with any other voltage. Please use suitable fuses or circuit breakers near the battery and between the battery and any other power sources. Also ensure that electrical conductors such as metal objects cannot accidentally fall across the battery terminals.

Exploding Battery: Batteries generate explosive gases during operation and when charging. Flames, sparks, burning cigarettes or other ignition sources must be kept away at all times. Ensure that there are no loose metal objects around the batteries that can be blown down by a strong wind or knocked onto the battery terminals. Similarly sparks can be generated at the battery due to a poor connection.

Always shield eyes when working near batteries. Battery charging should be carried out in a well ventilated area - never in a closed room. Always turn battery charger off before disconnecting a battery.

BATTERY SAFETY

Battery acid can cause burns. Use extreme care when handling acid. If electrolyte is spilled or splashed onto clothing or the body, wash with water and neutralize with a solution of baking soda and water. Electrolyte splashed into the eyes is extremely dangerous. If this occurs, force eyes open and wash with clean cool water for five minutes and call a doctor. A solution of 1 table-spoon of bicarbonate of soda to 1 pint of water should be kept readily available and in view near the battery bank. This solution will neutralize the acid and hence be a more effective eye-wash in the event of such an accident.

BATTERY ACID

Otherwise referred to as electrolyte. The water used for diluting acid and for topping up must be free of mineral impurities. Distilled water, demineralized water, or rain water may be used. Never use tap water as the effect of impurities is cumulative and detrimental to the battery.

NOTE: Do NOT add battery acid to the battery unless under the specific directions of a battery technician.

Placement of Batteries

Place batteries on a firm, solid and level support. Weight of batteries should be equally distributed over the base area. Batteries should not be in direct contact with a cold surface such as concrete. If the base of the battery stays cold, the acid will not mix readily and will tend to stratify (most concentrated acid at the bottom and least concentrated at the top). It is recommended that you use an insulating material such as rubber or vinyl under the batteries that will not be affected by the corrosive properties of battery acid.

Battery Connections

Make as few connections directly to the battery as possible. It is desirable to have a fully fused Control Board from which all other connections can be made.

Before making your connection to the battery, first smear petroleum jelly (eg Vaseline) over the terminal post to prevent or reduce the likelihood of battery acid creeping up the terminal post and rapidly corroding your connector.

Make sure that the connector is fixed very firmly and that it is making good contact with the terminal post to reduce voltage drop.

Do not increase your battery capacity by connecting several small batteries in parallel. The more parallel connections there are, the more prone the system is to uneven charging due to lazy cells and unequal cell characteristics. This will cause an overall reduction in expected battery life and increase maintenance requirements.

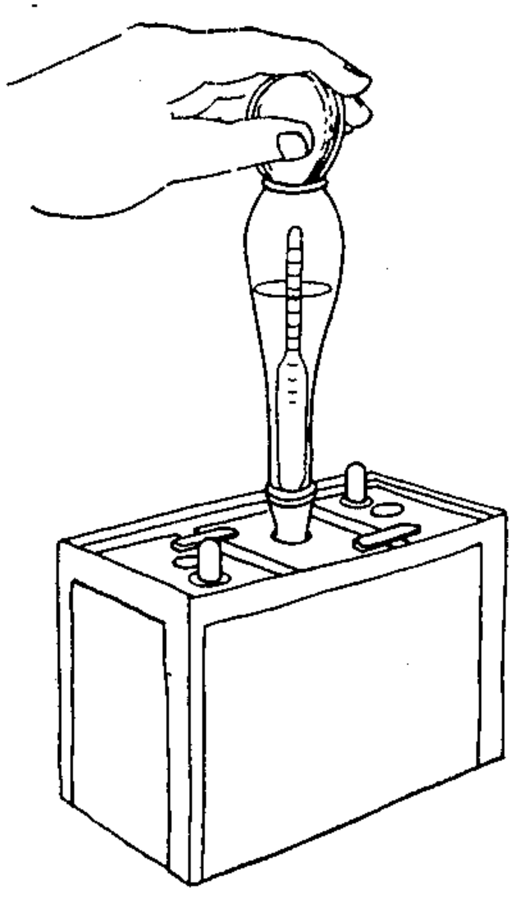
DO NOT LIFT BATTERY BY TERMINAL POSTS

Cycling of Batteries

The life of a battery is related to how many times and how deeply it can be cycled (charged and discharged). A cycle is defined as one charge, to fully charged, and one discharge, to almost fully discharged. An 80% discharge is regarded as 'deep'. However, for maximum life, lead-acid batteries should be discharged as little as possible. We recommend that your average cycle should be no deeper than about 20%, and never beyond 50%.

A standard car battery can only take about twenty deep discharges before it becomes completely useless.

If you have an all year round hydro potential then you may get away with only a very small battery bank (equal to your daily usage) because the battery bank is getting charged 24 hours per day. If you only have an intermittent flow, then a hydro system may be an excellent back-up for a solar power system.



Testing specific gravity of a battery

Care of Battery

1. Visual inspection: Check electrolyte level at least once a month. If the batteries are fully charged and still charging, water loss may increase. It is advisable that a suitable charging regulator be installed to prevent overcharging of the battery. Overcharging is indicated if the battery is bubbling vigorously.

2. Hydrometer Test: Check the electrolyte level, to ensure that it is above the plates in all cells.

   If it is below the plates, the test cannot be carried out until water is added and the battery charged to mix the water and residual acid in the battery. It is important to ensure that the plates do not remain exposed to air and allowed to dry and oxidize (see notes on page 32).

   The state of charge of each cell can be measured with a hydrometer to determine the specific gravity of the electrolyte (specific gravity is its weight compared to water).

Using Hydrometer

Draw the acid into the hydrometer, so that the float is lifted free and not touching the top or the bottom. The barrel must be held vertically and the eye level with the surface of the liquid. Disregard the curvature of the liquid against the glass.

Generally the battery state of charge is as follows:

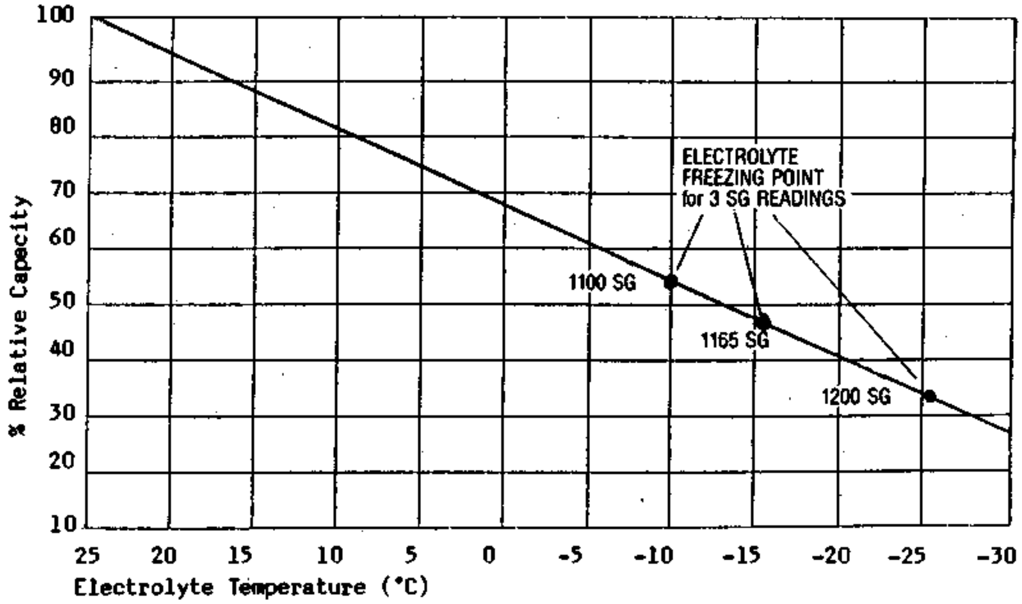
SG (25°C)	Volts	State of Charge
1.260	6.32 / 12.65	100%
1.220	less than 6.22 / 12.45	75%
1.180	less than 6.10 / 12.20	50%
1.120	less than 6.00 / 12.00	Discharged

Cell temperature corrections should be applied if accurate readings are required. 0.004 points should be added or subtracted for each 5°C +/- variation from 25°C.

3. Voltage Test: Voltage readings should be taken whilst the batteries are neither charging nor discharging (nothing connected and turned on). Immediately after either charging or discharging the battery voltage may not have stabilized. The voltage will settle down in about 30 minutes after charge or discharge are discontinued.

The Rainbow Power Company can supply you with battery connectors, control board, fuses, suitable electric cable, charging systems etc. Do not hesitate to contact us for more advice, information, service etc.

Effect of Electrolyte Temperature on Battery Capacity



Power Supply Batteries

What Type and Size of Battery?

For power and lighting purposes (eg in a home situation) it is recommended that an appropriately sized Deep Cycle Battery Bank be used. Vehicular batteries (other than traction batteries) are usually not Deep Cycle Batteries and are not appropriate for a house power supply system.

The size of the battery bank may be determined by the size and expected usage patterns of the overall electrical installation. Both the size of the battery bank and the limitations to the user of the power supply must in turn be determined by the size of the charging system and the frequency of charging.

It is not advisable to increase the battery bank by putting several batteries in parallel. A 12 volt battery does however consist of six 2 volt cells in series to make the required 12 volts. What we are saying here is to avoid adding several smaller 12 volt banks to each other to make up a larger one, it makes for a much more complex monitoring system and could mean that you do a lot of damage to the entire battery bank if just one 2 volt cell breaks down. More storage should be attained by acquiring a larger battery bank, and not by adding small ones in parallel.

Above 200 Amp-Hours you will find that the bank will consist of either two 6 volt units connected in series or six 2 volt units connected in series. With the individual 2 volt cells, if there is a problem with one cell it is only a matter of replacing it without having to replace an entire battery. By not having one battery bank connected in parallel to another battery bank, you will not have damaged one battery bank by discharging it into a dead cell of the other bank.

Battery Bank Size - Amp Hours

The amount of potential electricity stored in a battery is measured in Amp-Hours (AH). For every 100 Amp-Hours of battery storage you will need the equivalent of at least 60 watts of Solar Panel. For photo-voltaic installations, about 5 days storage capacity to reach a 50% discharged condition is usually recommended.

We suggest that you have a battery storage capacity of 10 to 15 times your daily use for solar or wind charging and 5 to 10 times for generator charging. The size of both the battery bank and the charging system may be dictated by the size of the inverter you wish to run, particularly if the inverter is a large one (eg over 600 watts).

Battery Bank Size - Voltage

The most commonly used voltage is 12 volts. There is quite an extensive range of lights and appliances available for this voltage. Higher battery voltages (usually multiples of 12) are used:

- If only 240 volts is required via a large inverter (ie over 1200 watts)
- If long cable runs and high currents are required

Although 32 volt systems were once common, this voltage is now gradually being phased out.

To plan a power system to suit your budget we invite you to discuss it with one of our staff.

INSTALLATION

The following points must be heeded when installing your battery bank:

1 Lead Acid Batteries should be installed in a cool well ventilated area, well away from any source of heat and from windows admitting direct sunlight.

2. Open stands should allow access from both sides for maintenance and cleaning.

3. Always keep cells upright to avoid damage or displacement of plate assemblies.

4. Never lift cells by the terminal lugs; large cells may be lifted by their handles (if fitted) or by means of a sling made of plastic sheeting.

5. Cells must be placed on a flat surface for even weight distribution, and should never be rested on the edges of packing cases etc.

6. Levers of any kind must not be used to position cells, instead a cell must be lifted bodily and lowered gently into position.

7. Never slide a battery across a floor; this particularly applies to those with acrylic cases.

8. When batteries are installed in cabinets, adequate ventilation must be provided to avoid a dangerous concentration of hydrogen. Cabinet doors should be open during gas charging.

9. Stands should provide support for at least 50% of the base area. It is recommended that timber supporting rails should be covered on top and sides with rubber or PVC at least 1/16" thick.

10. No metal should be in contact with plastic cell containers.

11. Battery connection links should be kept as short as practical, terminals should be cleaned and the connecting lugs firmly tightened using stainless steel bolts - do not over tighten. Grease-impregnated felt washers should be placed under the lugs to arrest corrosion. The interconnecting lug faces on Telecom type batteries must be cleaned, and if necessary squared with a coarse file. The lugs are bolted together, the lug, bolt and nut being lightly coated with petroleum jelly before assembly. The correct size spanner must be used; pliers or grips must not be used or damage may result. Nuts must not be over-tightened.

12. During normal battery life, positive plates may expand and increase in length by 5%. Intercell connections must therefore be soft lead or flexible. Heavy bus bars or charging leads must be able to accommodate some movement.

MONITORING AND MAINTENANCE

A battery bank will need to be monitored and will need a certain amount of attention from time to time. First of all, a battery bank must be charged and remain as fully charged as possible. It is advisable, in a home power situation that you have an amp-meter to show the rate of charge and a volt-meter to give some idea of the state of the batteries. Both of these meters should be mounted in such a position that they are noticed frequently. This strategy will make you more familiar with what to expect and make you aware of a problem when it arises, such as no amps showing when the batteries are supposed to be charging.

You will need to take note of the rate of water loss of the battery bank and make sure it is topped up before the level drops to less than one centimeter above the plates or to the lower level marked on some batteries. Bring it to the bottom of the filler wells or to the upper (high) level specified by the manufacturers. Only top the battery up with distilled water or clean rain water collected in plastic or glass. Do not over-fill. It is advisable to take specific gravity (SG) measurements of all the cells of the battery bank once in a while with a hydrometer (see page 33).

CHARGING THE BATTERY

The word 'gas' here refers to a gas given off by the acid due to electrolysis of the water. If continued at a high rate this gassing can be quite a violent boiling action and will result in loss of water and plate damage.

These points must be born in mind:

1. If a battery is left in a partially discharged state for an extended period, sulphation of the plates will occur, which if allowed to proceed, results in irreversible loss of capacity.

2 If a cell is maintained at a constant voltage without any cycling, 'stratification' of the electrolyte into layers of differing densities will occur. This can be minimized by occasionally charging the battery to a gassing voltage (ie some bubbling occurs).

CHARGE LEVEL OF BATTERY

The charged or discharged condition of a lead-acid battery is indicated by the colour of the positive plate*, the voltage, and the strength (specific gravity) of the electrolyte.

* see page 37 for definitions

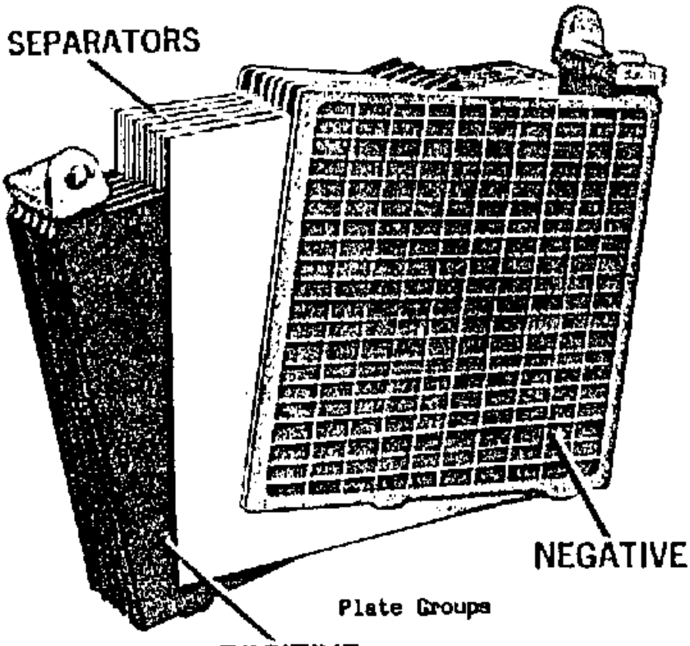
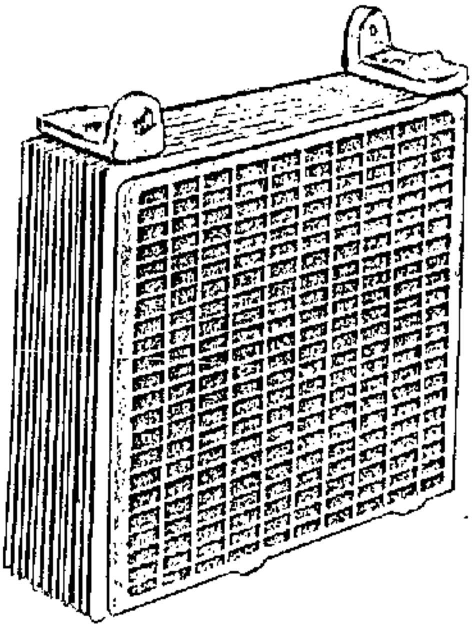


Plate Groups


Assembled Element

ELECTROLYTE LEVEL

Many batteries have markings on the cases to show the maximum and minimum advisable levels of the electrolyte. The lead plates in the battery must be submerged completely by the electrolyte, but there must also be a certain amount of headroom to allow the battery to gas without causing the electrolyte to spill out of the battery case.

Visual Inspection

In a fully charged battery, the positive plate is a dark chocolate brown colour (caused by the presence of lead peroxide) and the negative plate is light grey (the original lead colour).

After having ascertained the approximate state of charge of the battery you can get a rough idea of how it is behaving under charge by observing whether it is gassing and how much it is gassing. The word gassing refers to the little bubbles that constantly come to the surface during charge. If it is a very vigorous action, like a pot of boiling water, then the battery is either charging too fast or no longer needs a charge. Lots of very tiny bubbles (the size of pin pricks) is desirable.

If you have a clear-cased battery you can also inspect the amount of sediment that has accumulated in the sediment space at the bottom of the battery. If there is a lot of sediment in the sediment space it would indicate that the battery has lost its active material from the plates and consequently lost some of its amp-hour capacity*.

Voltage

The voltage of a fully charged lead-acid battery can be as high as 13.2 volts (disconnected) after charging. During charging it may be much higher (see pages 34 and 35). This falls rapidly when the battery is first discharged and will remain steady at around 12.6 volts, very slowly reducing down to 12 volts as the discharge continues. When the battery is more than 50% discharged the voltage will reduce more and more rapidly until at about 11 volts, the battery is considered discharged.

Open Circuit Voltage

The most meaningful voltage reading of a battery is referred to as the Open Circuit Voltage (OCV). The OCV is defined as the terminal voltage (the voltage at the battery terminals) of a battery while at rest or not under load and with no charge going in. After being disconnected from the charging circuit, the higher battery terminal voltage gradually decays over a period of several hours to reach the stabilized OCV.

Under load or discharge conditions, the terminal voltage is less than the OCV, due to the internal resistance of the battery and the speed of the electrolytic (the liquid in the battery) reaction. When the battery is disconnected from the load, the OCV will gradually recover and rise to a level only slightly less than it was prior to the discharge.

If a battery is fully charged, the OCV will be around 12.6 volts. At 50% discharge the OCV will be around 12 volts. For maximum battery life it is recommended that the daily discharge depth should not exceed 10% (OCV = 12.5 volts) of the battery's amp-hour capacity and at the worst operating condition should not go beyond 50% (OCV = 12.0 volts) of its amp-hour capacity. This can occur with a photo-voltaic system during a prolonged rainy period.

Specific Gravity

The hydrometer measures the Specific Gravity (SG) of a battery. You will find that the electrolyte in the hydrometer tends to curve up at the edges against the glass. This curvature is referred to as a meniscus. The SG reading should be taken from the bottom of the meniscus.

The SG is a measure of the concentration of the acid in a battery. Due to chemical action caused by charging and discharging, the proportion of sulphuric acid (SG = 1.8) to water (SG = 1) in the electrolyte and therefore, the SG of the electrolyte, gradually increases during charge and decreases during discharge.

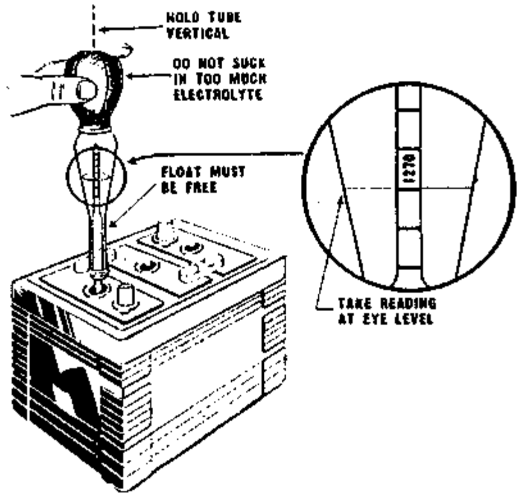
The complete working range of SG lies between the limits of 1.1 and 1.3. If below 1.1, damage may be caused by the plates becoming hydrated, while if above 1.3 the plates and separators are liable to be corroded.

The SG of the electrolyte of a fully charged battery is between 1.215 and 1.28, depending on the battery type. When the SG falls to about 1.175 the battery is considered to be discharged and needs charging.

The SG is often multiplied by 1000 and the hydrometer scale marked accordingly. SG readings should be referred to a temperature of 25°C. A temperature that is significantly at variance with this temperature will cause a change of viscosity of the electrolyte and needs to be taken into account when the SG is measured. Refer to the SG versus temperature graph. A significantly lower temperature will also cause a sluggishness of the battery.

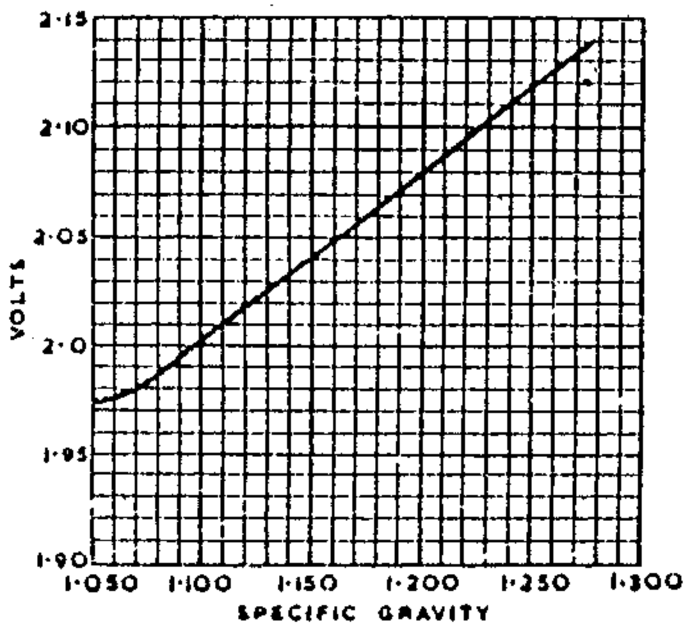
Owing to the time required for the diffusion of the electrolyte, the change in SG lags behind the charge or discharge by an amount which depends on the characteristics and dimensions of individual cells and the rate of charge or discharge. Consequently, the SG will continue to rise for a short period after the charge has been terminated and similarly may continue to fall after a discharge has been terminated, although, if the end of the discharge is at a low rate the lag may not be noticeable.

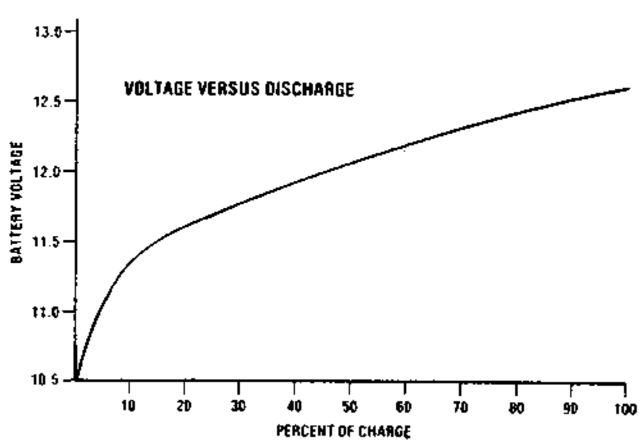
Only add distilled water to the electrolyte. Do not add acid, unless under the instruction and supervision of a Rainbow Power Company Battery Technician. Do not add water with impurities as these impurities will be accumulative over time and will cause problems. Do not take a SG reading just after topping up with water.

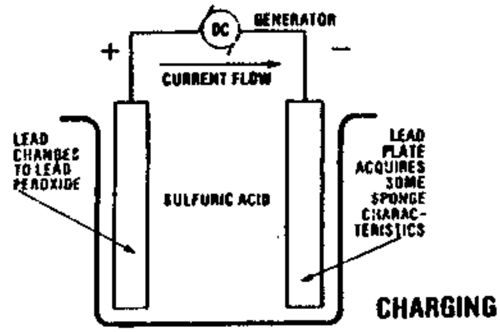


Checking specific gravity of battery with hydrometer.

How to use a hydrometer to check the specific gravity of a battery.







Discharged Battery

If a battery is left standing in a discharged condition for any length of time, the sulphate from the sulphuric acid combines with lead and forms lead sulphate which hardens on the negative plates. This compound becomes increasingly harder and more crystalline in composition and becomes increasingly more difficult to be broken down by charging. In the process the lead sulphate also expands and buckles the plates which in turn can cause irrepairable damage to the battery.

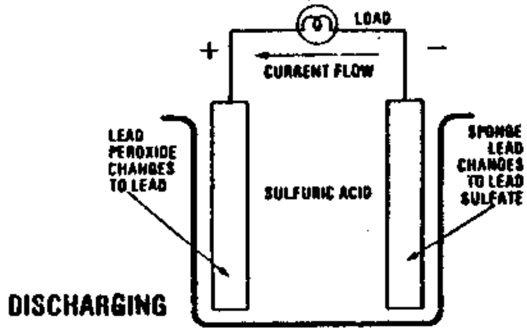
Batteries in this condition are referred to as 'sulphated'. If they are neglected for too long, they are useless and can be discarded. If it hasn't been left too long, a sulphated battery can be brought back into service by a constant slow charge over a long period of time. Fast charging a badly sulphated battery will probably ruin it.

Some tell tale signs of a sulphated battery are a gradual darkening of the negative plate accompanied by a white deposit on its surface whereas the positive plate changes to light brown sometimes under cover of a black scale which peels. The internal resistance of the battery increases resulting in a higher voltage on charge. As sulphation involves a reduction of the electrolyte concentration, never add acid to improve the density as this will only aggravate the condition.

Overcharging

Overcharging and boiling a battery is also damaging. Severe overcharging causes a lot of heat and gas. This may cause the plates to buckle, the separators to weaken and the water to evaporate. The bubbling action also causes active material to be shed from the plates, thereby decreasing the amp-hour capacity. The evaporation of the water can cause the plates to be exposed to the air and deteriorate due to oxidation.

During normal charging, the liberation of gas occurs to a very slight extent when the battery rises to about 13.8 volts, while normal gassing occurs when the voltage has risen to about 14.2 volts. While the initial release of gas from the plates is determined by cell voltage, the volume of gas is a function of the rate of charge. A violent bubbling action and a gradual temperature increase are warning signs that your battery is being overcharged.



VOLTAGE REGULATION

It is advisable to install some kind of regulating device to prevent batteries from overcharging. The voltage at which the batteries may need to be regulated depends on several factors. These factors include whether you have a constant or periodic charging source. Solar panels, wind generators and petrol generators can all be considered as periodic charging sources, they may only be charging for a few hours each day or a few days in the week.

Under any regulated charge the electrolyte will, however, tend to stratify so that a boost charge should be applied at between one and six monthly intervals.

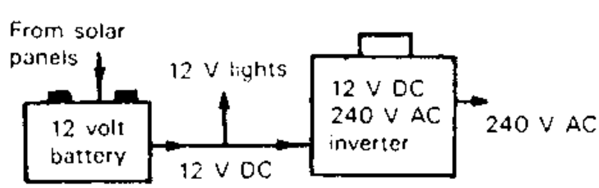
Boost charging serves to both stir up the electrolyte to overcome stratification, and to equalize the voltages between the cells. The highest and lowest cell voltages should not differ by more than 0.05 volts. A boost or gas charge will normally rectify any voltage variations.

The Rainbow Power Company sells a range of regulators. We invite you to contact our staff to discuss with you and design a suitable power system to meet your requirements and then to advise you on the operation and maintenance of that system.

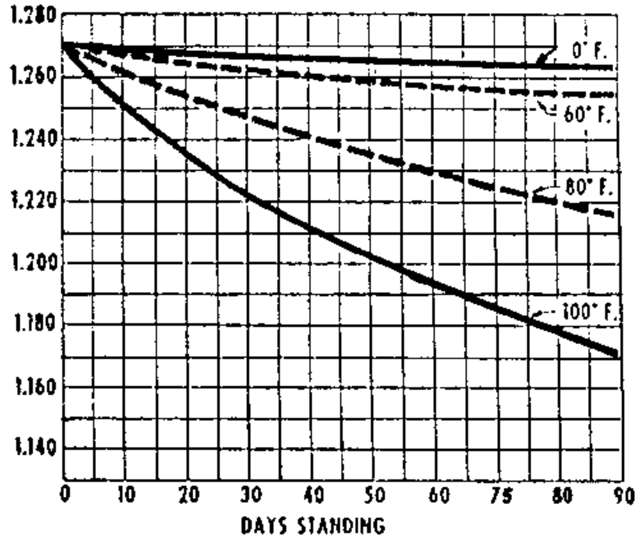
Cycling

Cycling is the process of partially discharging a battery and then charging it back up to full or nearly full charge. This may be a manual process or it may be carried out by a charger which automatically cuts in and out at predetermined cell voltages. It may be 'shallow' or 'deep'.

It is preferable to cycle a lead-acid battery bank as 'shallow' as possible. Even though you are using a Deep Cycle Battery its life expectancy increases as a result of not cycling it too deeply. You should never discharge your battery by more than 50% in the worst instance and stay within 10% to 20% during average daily operating conditions.



A lead-acid battery will self discharge over a period of time if left standing and not connected to any charging source.



BATTERY CARE CHECK LIST

1. Keep battery clean and dry - dampness lets electric current leak away.
2. Keep vent plugs in place to stop dirt falling into cells.
3. A thin coating of petroleum jelly will keep all terminals and connections free from corrosion.
4. For topping up the cells, use either distilled water or clean rainwater preferably collected in glass or plastic. Never top up the battery with anything other than distilled water or rainwater. Do not top up battery with acid, unless on the advice of a Rainbow Power Company Technician.
5. Make sure that the positive and negative plates inside the battery are covered with electrolyte at all times. Do not overfill.
6. Avoid adding water to a battery just prior to taking a SG reading, as the reading will be misleading. If water has to be added, the battery should be charged for a while to mix it with the electrolyte thoroughly before the reading is taken.

Maintenance Schedule:

(i)	Check SG of electrolyte	1 month
(ii)	Check level of electrolyte-top up if necessary	1 month
(iii)	After boost charge, check cell voltages. These should correspond to each other to within 0.05 volts	1 - 6 months
(iv)	Check tightness of terminals and remove corrosion if necessary	6 months

DO NOT: top up battery cell with water when the battery is in a state of discharge. If the electrolyte level is very low, top up only to make sure the plates are covered and no more. The fluid level rises with the charge level, so if water is added when the battery is discharged, it may overflow on charging and lose electrolyte.

DO NOT: 'tap' into part of your battery bank to obtain lower voltages for running lower voltage appliances. You will damage the battery bank by discharging some cells in relation to the rest of the battery bank.

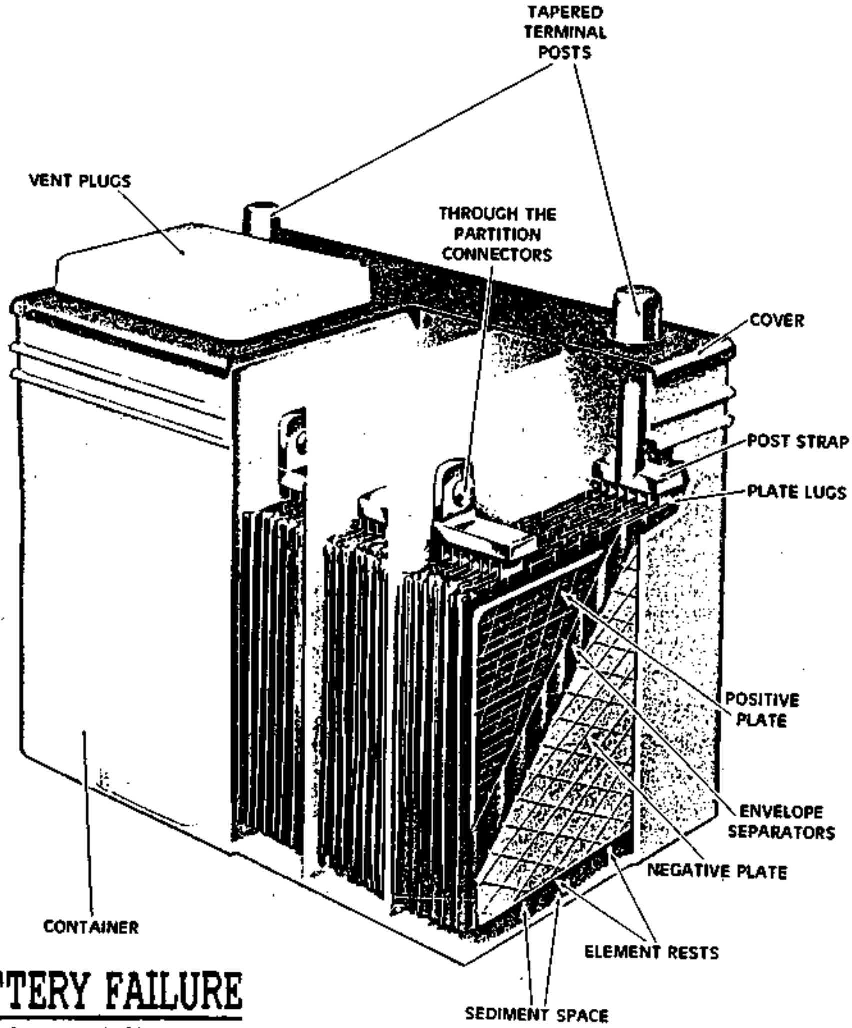
DO NOT: lift batteries by the lugs or terminals. Batteries need to be adequately supported from underneath.

DO NOT: go near the batteries with an open flame or cigarette. You may cause the batteries to explode.

DO NOT: overcharge your battery bank to the point of heating the cells up. This will cause internal damage. It is acceptable to charge to the point of the electrolyte bubbling. You may need to add water if the electrolyte level goes down.

DO NOT: install batteries in parallel if it can be avoided. To increase battery capacity you should endeavor to get a single bank of the required amp-hour capacity rather than smaller batteries hooked up in parallel. For example, six 2 volt cells connected in series to provide 500 amp-hours of capacity is preferable to two 12 volt, 250 amphour batteries connected in parallel. Batteries in parallel should either be protected or electrically isolated through the use of diodes or fuses. This will ensure that if one battery fails due to a shorted cell, the current rushing from the good battery to the defective battery does not overheat the conductor risking a fire. It will also save the charge and perhaps the life of the sound battery.

DO NOT: use alligator clips or other sprung jaw methods as sparking often occurs when they are removed or attached. Hydrogen gas is generated by batteries under charge which is very explosive in the presence of air. Sparking can ignite it. The resulting explosion will not only destroy the battery but also injure the person holding the alligator clips with flying debris and battery acid.



BATTERY FAILURE

The capacity of a battery indicates the ability of the battery to deliver an electric current at a given rate for a specified time. If the battery appears to have lost capacity it may be because it hasn't been recharged thoroughly, or it may be sulphated or else the battery may be approaching the end of its useful life.

A battery will lose active material from the plates due to frequent cycling, movement and vibration. This material will settle in the sediment chamber and thus ceases to play an active part in the battery's function. This results in a gradual loss of capacity throughout the battery's useful life.

A battery may stop functioning very suddenly if an internal short circuit is caused. Such a short circuit may be the result of the sediment in the sediment chamber coming into contact with both positive and negative plates. Otherwise it may be that the plates have come into contact with each other as a result of buckling of the plates or "treeing" between the plates. "Treeing" is the result of a very slow recharge rate (500 hours or more) when the spongy lead deposits on the negative plates in a "tree" like formation. This may eventually bridge the gap between the positive and negative plates.

Another possible cause of failure of a lead-acid battery is when the contacts between plates, straps, terminals and/or intercell connectors are broken.

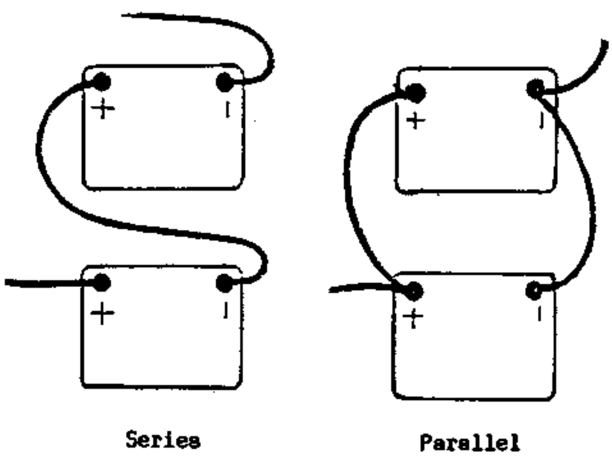
Battery Replacement

If there are any signs that the battery bank is not performing well, first check whether the batteries are fully charged or not.

The battery probably needs replacement if:

1. one cell voltage is far below the others.
2. the battery fails to charge.
3. the battery fails to hold its charge or voltage.

An investigation by a Rainbow Power Company Battery Technician can determine whether the batteries need replacing. The battery age and usage pattern may give some clue as to the outcome of such investigation.



Definitions

Amps - is the measure of the flow rate of electrons through a conductor.

Amp-Hour - is the number of amps (charge or discharge) multiplied by the number of hours for which this charge or discharge continues.

Amp-Hour Capacity - is the number of amp-hours normally available from the fully charged state to the end of discharge (about 11 volts for a 12 volt battery). The standard discharge rate is either an 8 or 10 hour discharge.

Automotive Battery - (also referred to as Starting, Lighting, Ignition Battery) - a battery specifically designed for motor vehicles with many thin plates to provide a high current for a short period and yet be relatively small and light.
Boost Charge - is a recharge which takes place at a voltage higher than the normal floating voltage. Is also referred to as gas charge, refresher charge and equalizing charge.

Charge - is the process of chemical change when a battery receives and stores energy from a charging source.

Charge Rate - is the rate of chemical change of a battery expressed in hours (for a 100% charge)

Cycle Operation - is a method in which batteries are taken through a process of discharge and recharge.

Deep Cycle - is a working cycle in which the discharge proceeds beyond 50% of the 10 hour rate capacity.

Deep Cycle Battery - a battery designed to be able to cope with some deep cycling without losing too much amp hour capacity. One way of achieving this is by the utilization of a thicker pasted plate than is found in vehicular batteries.

Desulphation - is the treatment given to a sulphated battery. See Sulphation.

Discharge - is the process of chemical change when a cell delivers energy to the load.

Discharge Rate - is the rate of chemical change of a battery expressed in hours (for a 100% discharge).

Electrolyte - in the case of lead-acid batteries is a diluted solution of sulphuric acid which acts as the medium by which chemical change takes place between itself and the lead-plates with which it reacts during charge and discharge.

Equalizing Charge - is a process which brings all cells of a battery to a fully charged state by correcting small irregularities in the state of charge of individual cells. It is a form of boost charge with the intent of equalizing cell voltages.

Float Operation - is a method in which batteries are theoretically preserved in a fully charged state by maintaining all cell voltages above but close to the true open circuit voltage (OCV).

Gas Charge - is a boost charge which takes place at the end of a recharge and at a voltage above 14.1 volts for a 12 volt battery bank.

Headroom - liberated space in battery container above the normal acid level.

Open Circuit Voltage - The terminal voltage of a battery while at rest (neither charging nor discharging).

Plate - inside each cell of a lead acid battery are a series of positive and negative plates. All the positives plates are connected to each other and to the positive terminal of each cell, and likewise with the negative plates and the negative terminals. Between each alternate set of plates are non reactive plate separators.

Recharge - is the restoration of the battery to its maximum amp hour capacity after a discharge.

Sediment Space - The space between the bottom of the plates and the bottom of the container. Also referred to as footroom.

Shallow Cycle - is a working cycle which does not discharge beyond 50% of the 10 hour rate capacity.

Specific Gravity - is the ratio between the weight of equal volumes of a substance and pure water.

Sulphation - an undesirable process that takes place on the plates of a lead-acid battery as a result of the battery being left in a discharged or semi-discharged state for a long period of time, resulting in the seriously reduced capacity of the battery. Deep Sulphation may cause permanent damage or may be reverseable with an involved treatment.

Volts - is the force that causes electrons to flow between two points of a conductor. Also referred to as electromagnetic force (emf) and potential difference.

Watts - is a combination of volts and amps. With a 12 volt system, the wattage of an appliance is the amps used by the appliance multiplied by 12. With a charging system such as photo-voltaic solar panels which are rated in watts, your expected charge rate (in amps) may be as low as watts divided by 15 (instead of 12) because of the voltage differential between charging source and battery and the fact that a fully charged 12 volt battery may be in excess of 14 volts. Watts is a measure of power. Also referred to as volt-amps or VA.

Watt-Hours - is the same as amp-hours multiplied by voltage.

In certain cases of generator repairs, it may become necessary to prepare new field coils. The new coil is wound on a special winding machine (Fig. 84) making use of coil formers (Fig. 85) of the same shape as the pole cores,

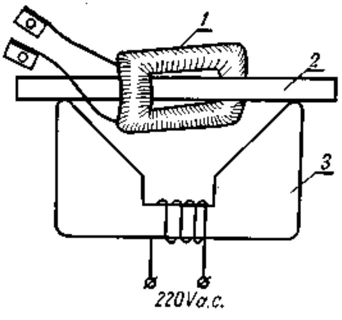


Fig. 82. Testing field coil for shorted turns on inductor:

1—field coil; 2—low-carbon steel bar; 3—inductor

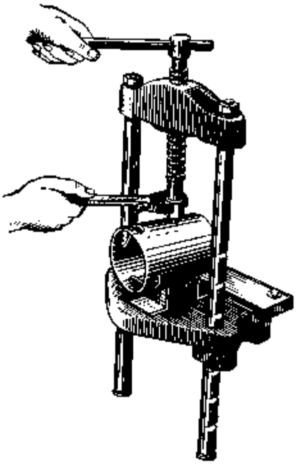


Fig. 83. Turning out pole screws

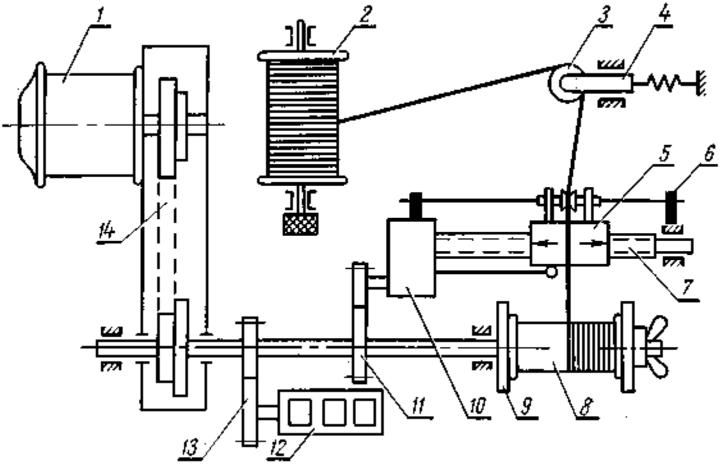


Fig. 84. Kinematic diagram of coil-winding machine:

1—electric motor; 2—wire reel; 3—roller; 4—tensioning device; 5—carriage; 6—carriage guide; 7—lead screw; 8—coil being wound; 9—faceplate; 10—reversing mechanism; 11 and 13—auxiliary reducing gears; 12—turn counter; 14—main reducing gear but of side dimensions greater by 0.6 to 0.8 mm. The winding data for some types of generators is given in Table 20.

After the coil has been wound, impregnate it with paraffin, apply a wrapping of cotton tape, and press the coil fitted in the shaping template (Fig. 86). Impregnate the shaped coil with No. 1154 glyptal varnish or grade 321-B water-emulsion varnish and dry in an oven for

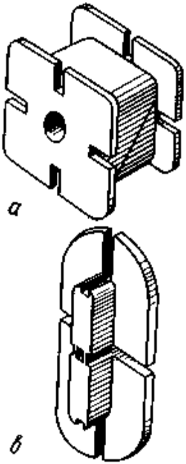


Fig. 85. Coil formers: *a*—two-flange; *b*—single-flange

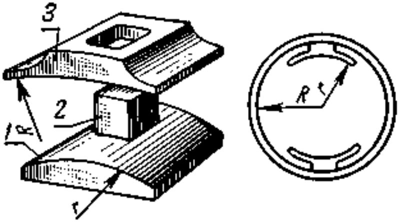


Fig. 86. Coil shaping template: *1*—base; *2*—core; *3*—top plate

one hour at a temperature of 18 to 22°C, and then for another hour at a temperature of 90 to 100°C. Impregnate the coil once more and dry it at a temperature of 110°C for two hours.

Fit the coil on the pole cores, connect the field winding to a storage battery and check for correct sequence of magnetic polarity by means of a compass.

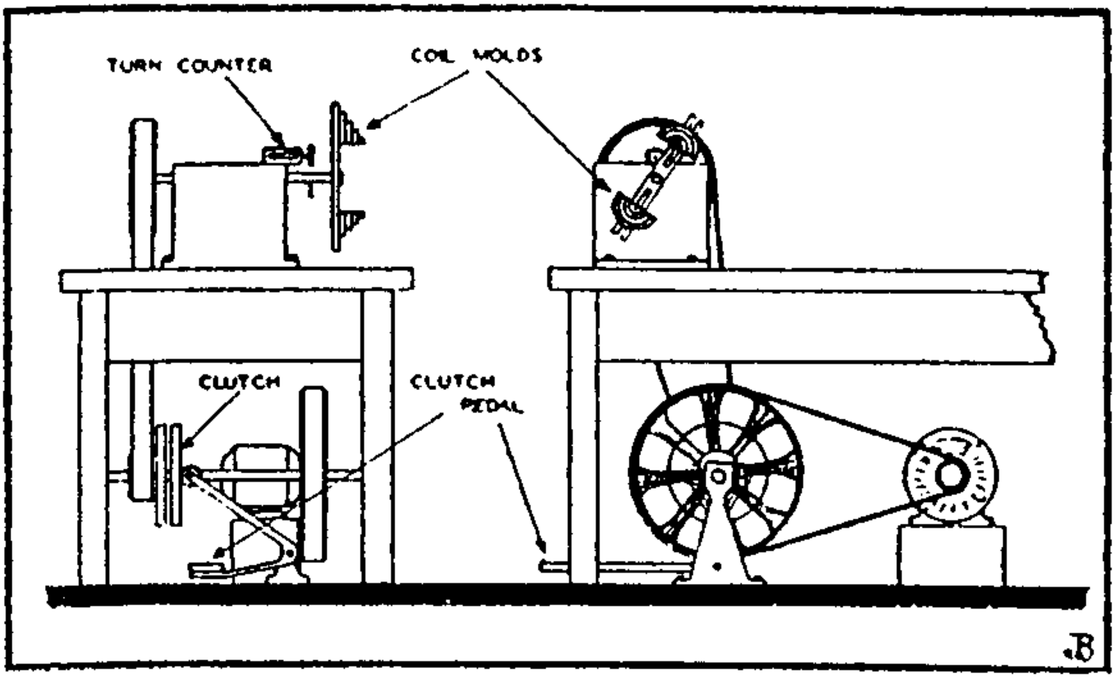


Fig. 3. Two views of a practical and easily constructed coil group winding machine . .

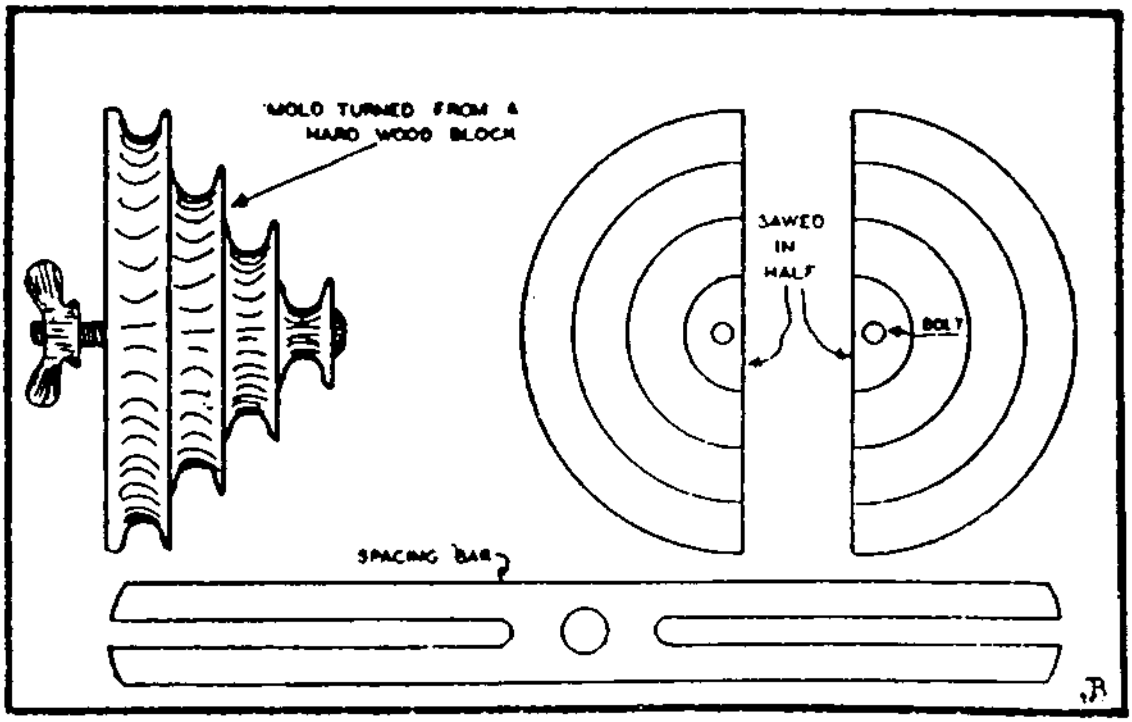


Fig. 4. The details of the molds used with the winding machine of Fig. 3

Place new strips of pressboard in the armature slots so that they close the slots and fit closely to their surface.

Wind the armatures by hand or on a simple device of the type shown in Fig. 90, wherein the shaft of armature *4* is mounted on faceplate *6* in special changeable holders *5* so that the armature fits closely to support shoe *7*. Wire *2* being wound is tensioned by rollers *3*.

Wind the armature in accordance with the winding data presented in Table 20.

Most d.c. generators have a lap winding, the diagram of which is shown in **Fig. 91**.

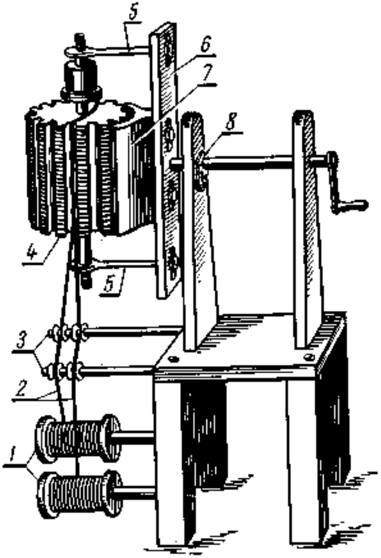


Fig. 90. Arrangement for manual winding of armature coils:

1—reels carrying wire; *2*—wires; *3*—tensioning grooved rollers; *4*—armature; *5*—armature holders; *6*—faceplate; *7*—support shoe; *8*—ratchet gearing

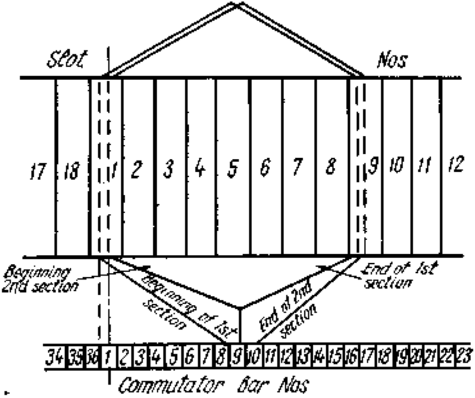


Fig. 91. Armature lap winding

Special Coil-winding Device.—For winding coils of practically any shape the special device shown in Fig. 283 has been

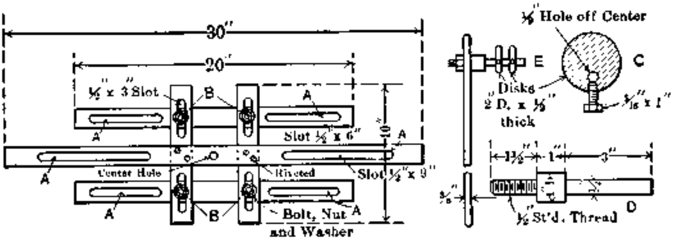


FIG. 283.—Framework for use in winding different shapes of armature coils.

devised by Frank Huskinson (*Electrical World*, July 27, 1918). It consists of an iron framework held together with four bolts shown at *B*. By loosening the nuts of these bolts the two outside members can be adjusted for any width of coil needed. To give the coil the proper shape, disks such as marked *C* are clamped on the piece *D* and the latter inserted in the slots marked *A* in the frame. The view at *E* shows how these disks appear when the bolt *D* is in its proper place in the frame. When forming the coils the wire is wound around six of the bolts or pegs and between the disks mounted on them.