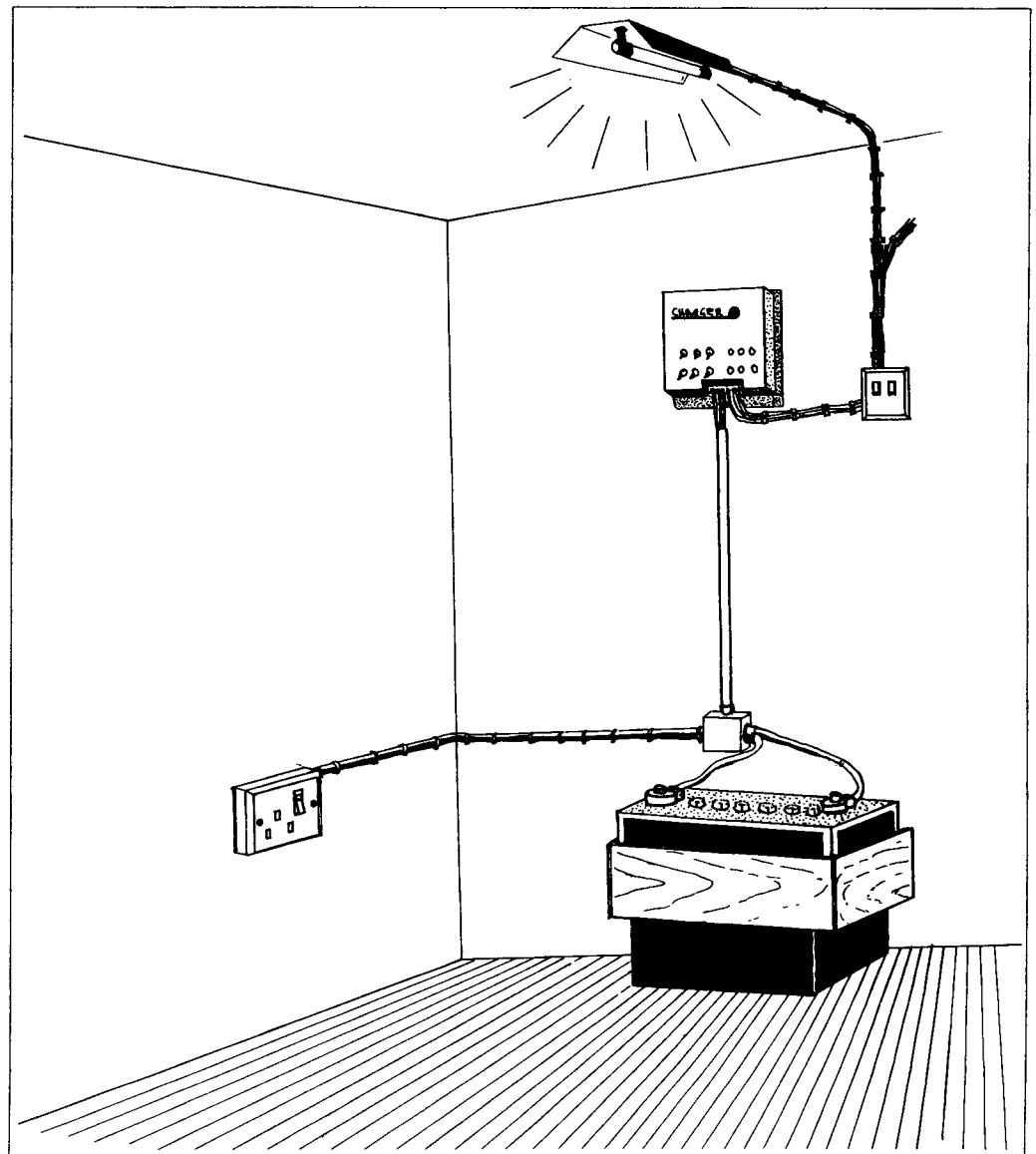


Chapter 8

Wiring and Fittings

This chapter describes low voltage dc cables and fittings for solar electric systems. Topics covered in the first sections include choosing cable size and type, choosing fittings (switches, fuses, connector strips, etc.) and the method of earthing the system. Tips on connecting cables are given. The theory of voltage drop is explained in some detail. Two methods of choosing proper cable size are presented with examples.





Wiring and Fittings

When installing solar electric systems, follow established wiring codes for local areas.

A qualified electrician should supervise the planning and installation of any electric system.

Previous chapters discuss the parts of solar electric systems. Harvested energy is distributed between these parts using electric cables and fittings. To make efficient use of the energy collected by the modules and stored in batteries, you must choose cables and fittings carefully. Wiring procedures are much the same in low voltage dc systems as with 240 V ac systems, but there are some important differences, as explained below. Houses that have previously been wired for mains or generator power can easily be adapted to use solar electric power.

House Wiring Cable

Make sure you choose the proper cable size when planning your system. Wiring cable manufactured in East Africa is available in 1.0 mm², 1.5 mm², 2.5 mm², 4.0 mm², 6.0 mm², and 10 mm² (this number refers to the cross-sectional area of the wire). 240 volt ac systems normally distribute power using wiring cable with a cross-sectional area of 1.0 or 1.5 mm², but this wire is too small for solar electric systems. Low voltage dc systems in small households normally use 2.5 mm² cable (without a separate earth wire) which is also known as 2.5 mm² twin flat. The black wire serves as the negative 'earth', and the red wire is the positive 'live' wire.

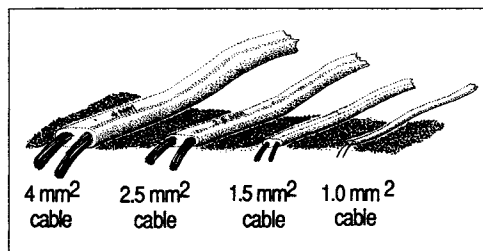


Figure 8.1
Wiring cable

In solar electric systems, multi-stranded wire should be used instead of single-stranded wire. Those cables laid where they will be exposed to the sun should be *sunlight resistant*. The insulation of 2.5 mm² twin flat is somewhat resistant to sunlight (it should last about 5 years before shredding), but common single insulated strands of wire are not sunlight resis-

tant. When wires pass underground or up outside walls, they should be run through *conduit*, a special type of plastic pipe used for enclosing electric wire.

Switches, Sockets and Fuses

Switches. Switches are used to turn lamps, appliances and other loads ON and OFF. They also serve the important purpose of disconnecting modules, batteries and loads during servicing and emergencies.

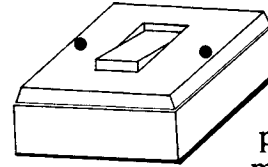


Figure 8.2
Standard switch

DC-type switches are preferred for low voltage solar electric systems. However, because they are not readily available in East Africa, installers commonly use *standard* 240 V ac switches. Standard light switches are sized at 3 and 5 amps, and can safely be used for lamps of up to 36 and 60 watts respectively in 12 volt dc systems.

Sockets. Sockets (or power outlets) are devices into which the plug is inserted to access power for an appliance. Low voltage, high current dc sockets are recommended for solar electric systems. As with switches, however, low voltage sockets are not readily available in East Africa. For this reason, standard 240 V ac sockets with switches are commonly used in small solar electric systems. These sockets, usually rated at 13 amps, are capable of providing current for loads up to about 150 W. If a larger load (i.e. a colour TV) is to be used in a solar electric system, ask an electrician or the appliance dealer to help locate a suitably sized socket.

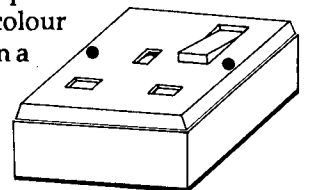


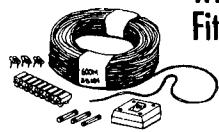
Figure 8.3
Socket

Fuses and Miniature Circuit Breakers (MCB's). Fuses are devices placed in the circuit between the battery and the load to prevent damage from high current to appliances, modules and charge controller circuitry. Because batteries are capable of delivering a very high current, there is a risk of a fire or damage to the system in the

Warning:

Never plug 240 V ac appliances into sockets wired with 12 V dc current. If standard 240 V ac sockets are used in a solar electric system, tell everyone who uses the system not to plug in any equipment without checking its voltage. Accidental connection of ac appliances into dc power will destroy the ac appliance and may cause a shock to the unlucky user.

Wiring and Fittings



Fuses are devices placed in the circuit between the battery and the load to prevent damage from high current to appliances, modules and charge controller circuitry.

More system problems are caused by bad connections than by failures of the equipment itself.

event of a short circuit.

When a short occurs, the fuse "blows" (i.e. a strip of wire inside melts) and opens the circuit so that current cannot flow. Once a fuse has blown, the cause of the high current should be investigated and repaired before replacing the fuse with a new one of the same size.

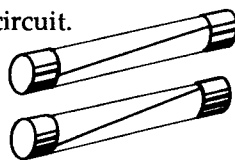


Figure 8.4
Cartridge-type fuses

Miniature circuit breakers are small switches that automatically break the circuit when there is a short circuit. They can be switched back ON once the wiring problem has been corrected.

If the solar electric system contains a charge controller, a fuse is usually positioned inside the control itself. If there is no control, or if there are loads that need to be protected independently, then fuses should be included in the circuit. Small systems usually require only one fuse to protect the load. Larger systems should have a fuse to protect each major circuit.

Sizing Fuses. Fuses are rated in amps according to the current demand of the circuit they are protecting. They are sized to 'blow' when the current is 20% greater than the maximum expected current in the circuit. If, for example, there is a short circuit in one of the appliances, the circuit draws much more than the rated current (i.e. more than 20% higher), and the fuse rapidly heats up, 'blows' and opens the circuit.

In East Africa, radio dealers and electronic equipment shops stock fuses of various sizes, ranging from 0.25 amps to 30 amps or larger. For circuits 5 amps and above, cartridge-type fuses are commonly used. Below 5 amps, simple wire fuses or glass 'automotive' type fuses are used.

To calculate the required fuse size for each major circuit, follow the following steps (see also Worksheet 4, page 110):

- 1) List the circuits that need to be protected. Determine the maximum possible power required by adding the

power in watts of all loads (Column B on Worksheet). This is the power drawn when all appliances and lamps are turned ON.

- 2) Change the power to current in amps by dividing it by the system voltage. This is the maximum rated current in the circuit (Column C).
- 3) Increase this figure by 20% of its value (i.e. multiply this figure by 1.2, see Column D).

This is the size of the fuse required.

Example: If a twelve volt system circuit includes a 15W television and three 8 watt lamps, then the maximum power is 39 watts.

$$15W + 8W + 8W + 8W = 39 \text{ watts}$$

Divide the power by the system voltage (12 volt):

$$39 \text{ watts} \div 12 \text{ volts} = 3.25 \text{ amps}$$

Increase this figure by 20%:

$$3.25 \text{ amps} \times 1.2 = 3.9 \text{ amps}$$

In the above circuit example, a 4 amp fuse should be used.

Making Connections

Wires in solar electric systems should be connected securely, safely and carefully. More system problems are caused by *bad connections* than by failures of the equipment itself. The following tips are given to help make sure that the initial connections last a long time.

Use connector strips. Never connect wires by twisting. Connector strips are insulated screw-down wire clamps used to connect wires together in solar electric systems. They are used instead of junction boxes because the largest size cable that junction boxes can fit is only 1.5mm². Connector strips are available in several sizes to fit 2.5mm² or larger wire.

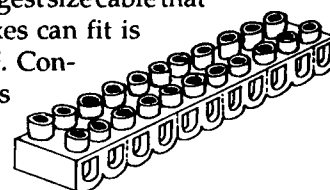


Figure 8.5
Connector strips



Wiring and Fittings

Neat wiring not only looks better, it is easier to service and less likely to get tangled, or crossed and shorted.

Prepare wire ends carefully. Strip 1/2 to 1 centimetre of insulation from the end of the wire. Make sure the wire is clean. Then, before fixing the wire to a terminal or connector, twist the end.

Use weatherproof boxes and conduit when connecting wires outdoors. If connected outdoors, wires should be enclosed in junction boxes. Make sure there is extra wire for entry and exit from junction boxes.

Avoid twisting wires around terminals. Use a crimp tool (see Figure 11.1, page 83) if one is available, to fix ring-type or spade-type ends to the wire. These are less likely to be pulled off or to be affected by corrosion. If the installation site is near the ocean, solder terminal connections so that they do not corrode.

Inspect all connections after installing. Make sure no wires are loose. Check for places where bare wire might overlap and cause a short circuit.

Be neat in wiring. Neat wiring not only looks better, it is easier to service and less likely to get tangled, or crossed and shorted. Align wires coming from terminal strips so that they are straight.

Earthing the System

Earth wires protect against electric shocks to people and against damage to the system from lightning. Earth wires (called 'ground wires' by Americans) provide an easy path for electricity to travel through if a live wire accidentally touches the casing of an appliance, control box or module. They are commonly attached from the metal casings of appliances or modules to a rod driven into the ground. In ac systems, one of the three wires in the plug is an earth wire.

Low voltage dc systems are earthed by connecting the negative (black) wire to earth. This is accomplished by connecting the negative battery terminal to an earthing rod.

It is also desirable to earth the frames and negative terminals of all modules in a system, as well as any valuable appliances that you do not want to risk destroying. In reality, most small solar electric systems are not earthed. This has not been a serious problem, because the small loads of solar electric systems are low voltage and do not carry high enough currents to necessitate earthing (although large loads should *always* be earthed).

However, in areas where lightning storms are common, earth wires are advisable on arrays of two or more modules to guard against lightning damage (one dealer in Kenya reports that at least four of his systems have been struck by lightning). Earthing wires allow the electrical energy from lightning to pass into the ground without damaging the module, controller, or loads.

Solar modules are earthed by running thick gauge earth wires from the frame and negative terminal of each module to an earthing rod driven into the ground. If there are several modules in a system, earthing wires from each module should be connected to one cable which runs to the

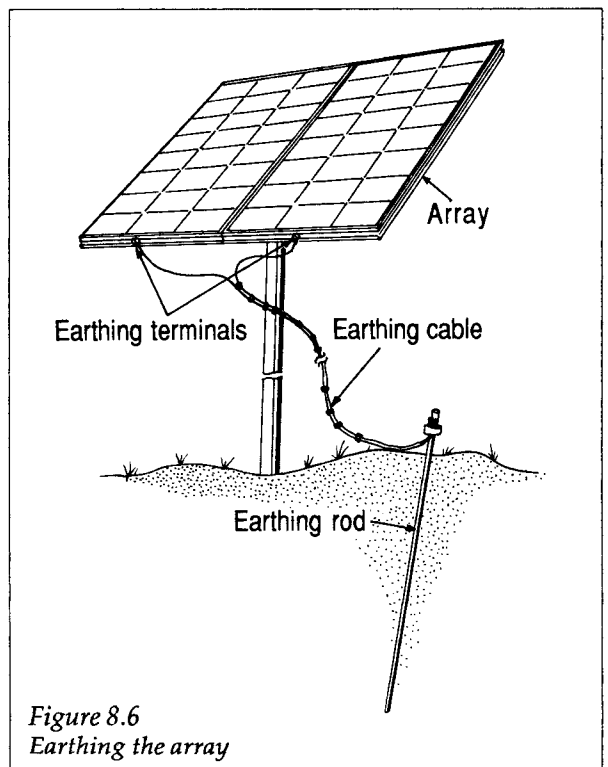


Figure 8.6
Earthing the array

It is desirable to earth the frames and negative terminals of all modules in a system, as well as any valuable appliances that you do not want to risk destroying.

Wiring and Fittings



As with water pipes, cables with large cross-sectional area allow more current to flow.

earthing rod. Some 40 Wp or larger modules have a terminal for the attachment of earthing wires. For example, Arco (Siemens) modules include a self-tapping screw to which the earth wire is fixed (see Figure 8.6). This screw is inserted into a designated hole in the side of the module, and the earth wire is wrapped around it before it is tightened (Note that the wire should be connected to the negative terminal, as well). An earth wire should also be attached to the mounting structure itself.

Wire Size, Voltage Drop and Maximum Wire Runs

As with water pipes, cables with a large cross sectional area allow more current to flow than those with small cross sections (see Figure 8.7). The size of a wire thus determines the amount of current that can pass through it. Unfortunately, low voltage systems require a *higher current* to carry the same power as high voltage systems. In long cable runs, energy is lost as heat through the resistance of the wire to the flow of electricity. If the wire cross section is not large enough to support the current, a voltage drop will occur over the length of the cable. This may damage or cause poor performance in lamps and appliances

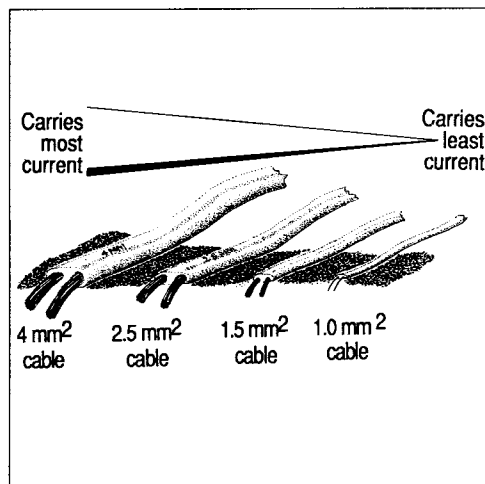


Figure 8.7
Larger wire sizes carry more current

The example below considers the difference in current flow between wires that connect separate 24 watt lamps to a 12 V battery and 240 V ac grid power (see Figure 8.8).

Example:

The Power Law (see Appendix 2) is used to determine the current flowing in each wire.

$$\boxed{\text{Power (watts)}} = \boxed{\text{Voltage (volts)}} \times \boxed{\text{Current (amps)}}$$

A 24 watt globe lamp consumes 24 watts of power regardless of whether it is designed to work with a 240 V ac or 12 V dc power supply. However, to produce the same power as high voltage ac, more current must flow in the low voltage lamp. Figure 8.8 shows the current draw of high and low voltage lamps. Note that the current drawn by the high voltage lamp, 0.1 amps, is 20 times less than the low voltage lamp's current of 2.0 amps.

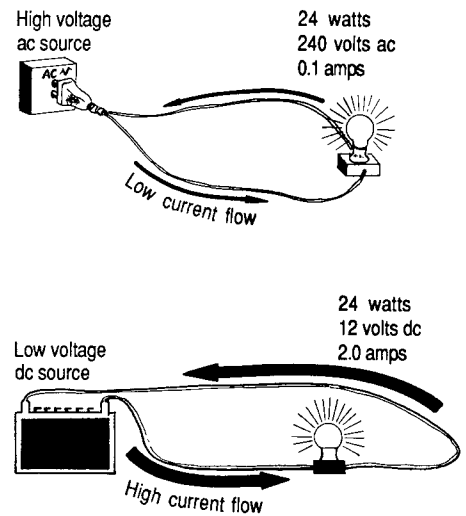
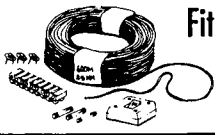


Figure 8.8
Current flow in high and low voltage systems

The above discussion makes it clear that low voltage systems use a much higher current than high voltage systems. Cables for low voltage systems must be large enough in diameter to carry this high current. In small home systems, 2.5 mm² wire is usually sufficient for all short cable runs; however, it is still good practice to calculate the voltage drop for all cables, especially those that connect solar modules and batteries.

Wiring and Fittings



Voltage drop is a loss of voltage (and hence power) due to resistance in long runs of cable.

What is Voltage Drop?

As mentioned above, voltage drop is a loss of voltage (and hence power) due to resistance in long runs of cable. It occurs in all wire runs, but is only a serious problem in low voltage systems with long cable runs.

Suppose that the 24W lamp operated from a battery in the above example is located in a kitchen 50 metres from the battery (see Figure 8.10, page 56). How much of a voltage drop will there be if a 1.5 mm² cable carries the power to the lamp? Will the voltage drop affect the performance of the lamp? If so, what wire size should be used?

These questions need to be answered before installing the lamp. Whether voltage drop will affect an appliance depends on the appliance (fluorescent lamps may be ruined when run at a voltage below the recommended level). It is good practice not to allow voltage drops of more than 5% on a cable, but in most cases equipment in small systems can tolerate up to 10% voltage drops.

If the conditions in the box to the right hold true for your system, you do not need to go through the wire sizing process. Use 2.5 mm² cable through out.

Note:

In very small systems, all connections can safely be made using 2.5 mm² wiring cable. In such cases, calculations do not need to be made. Use 2.5 mm² for all connections if all three of the following conditions are true for the system:

- no wire run is more than 16 metres long;
- the module is rated at 40 Wp or below; and,
- no wire carries a current greater than 4 amps.

Whether the wire size chosen in a cable run is large enough can be determined in either of two ways: By using Maximum Wire Run tables or by calculating the voltage drop. Both methods are described in the following sections.

For either method, first follow the instructions below (see Worksheet 4, page 110):

- 1) List each wire run together with its one way distance. Write them in Columns A and B in the worksheet.
- 2) Find the current passing through each wire. To do this, add the power in watts of all the lamps and appliances on each wire run, and divide by the voltage. Write this on the worksheet in Column C.
- 3) Use the Maximum Wire Run tables (see page 55) to determine the maximum length that can be used with a given type of wire. Alternatively, follow the instructions for calculating the exact voltage drop for each run on page 55.

Using Maximum Wire Run Tables

Tables 8.2 and 8.3 give the maximum run of cable that can be used between modules, batteries, and loads in 12 and 24 volt systems under various currents. They should be used as described below:

- First, calculate the current in amps that the wire will carry (as entered in column C of the worksheet). If in a 12 volt system, for example, there are two 8 watt lamps at the end of a wire, the current being carried by the wire is 1.3 amps (8W x 2 lamps + 12 volts = 1.3 amps).

Voltage Drop Table						
Column A Cable run (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/ No)

Figure 8.9
Voltage drop table



Wiring and Fittings

Table 8.2: 12 Volt System Maximum Wire Length in Metres (0.6 V max voltage drop, or 5%)

Wire Size (mm ²)	Load Current			
	2 amps	4 amps	6 amps	10 amps
1.5	11 metres	6 metres	4 metres	2 metres
2.5	19	9	6	4
4.0	30	15	10	6
6.0	44	22	15	9
10.0	75	38	25	15

Table 8.3: 24 Volt System Maximum Wire Length in Metres (2.0 V max voltage drop)

Wire Size (mm ²)	Load Current			
	2 amps	4 amps	6 amps	10 amps
1.5	37 metres	19 metres	12 metres	7 metres
2.5	63	31	21	13
4.0	100	50	33	20
6.0	147	74	49	29
10.0	250	125	83	50

Increasing system voltage decreases voltage drops in long runs.

- Next, read from the table the load current in amps that is closest to this figure. If the current is not listed in the tables, read the next higher figure. (For example, in Table 8.2, if the current to be carried is 3 amps, read down the 4 amp column).
- Read across the row for the corresponding wire size. In a 12V system, for example, if the current to be carried by the cable is 4 amps, and the wire size is 2.5 mm², then the maximum distance that the appliance can be placed from the source is 9 metres.

Example 1

The 24W lamp mentioned on page 53 draws 2.0 amps at 12 volts. Reading down the 2.0 amp column, the maximum distance that a 1.5 mm² cable carrying 2 amps could support without a 5% voltage drop (i.e. 0.6 volts) is 11 metres. The maximum distance a 2.5 mm² wire could run without significant losses is 19 metres. A 4 mm² cable would safely be able to carry 2 amps up to 30 metres.

Note from Table 8.3, that if the lamp was

run on 24 volts dc, the voltage drop is much less, and that even a 1.5 mm² wire could be used to transmit the current 37 metres at that voltage. Increasing system voltage decreases voltage drops in long runs.

Calculating Voltage Drop

Instead of using the above tables, it is possible to calculate the voltage drop on a cable run using simple electric principles. Ohm's Law states that voltage is equal to the current in amps multiplied by the resistance in ohms (see Appendix 2). This can be used to calculate the voltage drop in a circuit as follows:

$$\boxed{\text{Voltage drop (volts)}} = \boxed{\text{Current, I (amps)}} \times \boxed{\text{Resistance, R (Ohms)}}$$

To calculate voltage drop, one must first know three values:

- the current flow through the wire in amps (I);
- the distance of the cable run in metres; and,



Wiring and Fittings

- the resistance factor, K , of the intended cable in ohms per metre (see Table 8.4). Multiplying the distance of the wire by the resistance factor gives the total resistance, R .

The voltage drop in each wire is calculated, using Worksheet 4 (see pages 71 & 110), as follows:

1. Identify each cable run and note its one-way length in Columns A & B.
2. Determine the maximum current that each cable will carry as described on page 54. Write this down in column C.
3. Determine the *resistance factor*, K , of the intended cable using Table 8.4. Note this value in Column D. For example, a 1.5 mm² copper wire has a K value of 0.027 ohms per metre.
4. Calculate the *total resistance* of the cable by multiplying the resistance factor (Column D) by the distance of the wire (Column B):

$$\boxed{\text{Total Resistance (ohms)}} = \boxed{\text{Resistance Factor, K (ohms/metre)}} \times \boxed{\text{Length of Cable (metres)}}$$

Write this value in Column E.

5. Using Ohm's Law, calculate the voltage drop through each cable. The voltage drop will be equal to the *total resistance* (Column E) multiplied by the maximum current carried in the wire (Column C). If the voltage drop

Table 8.4: Resistance Factors for Copper Cables

Wire Area (mm ²)	Resistance Factor, K (ohms/metre)
1.0	0.040
1.5	0.027
2.5	0.016
4.0	0.010
6.0	0.0068
10.0	0.0040
16.0	0.0026

is greater than 5%, consider using a larger diameter cable. If the voltage drop is greater than 10%, use a larger cable.

$$V_{\text{drop}} = \text{maximum current (Column C)} \times \text{total resistance (Column E)}$$

Example 2 shows how to use the worksheet to calculate voltage drop in a systematic manner.

Example 2:

Suppose electricity is provided for a 24 watt lamp in a kitchen 50 metres from the power source using 1.5 mm² cable. Using Ohm's Law, it is possible to compare the voltage drop of a 240 V ac system with a 12 V dc system (see Figure 8.10 & 8.11).

1. The current passing through and the length of each wire is given in Table 8.5. For a 12 volt system this is 2 amps.
2. The resistance factor of the 1.5 mm² cable, from Table 8.4, is 0.027 ohms/metre.

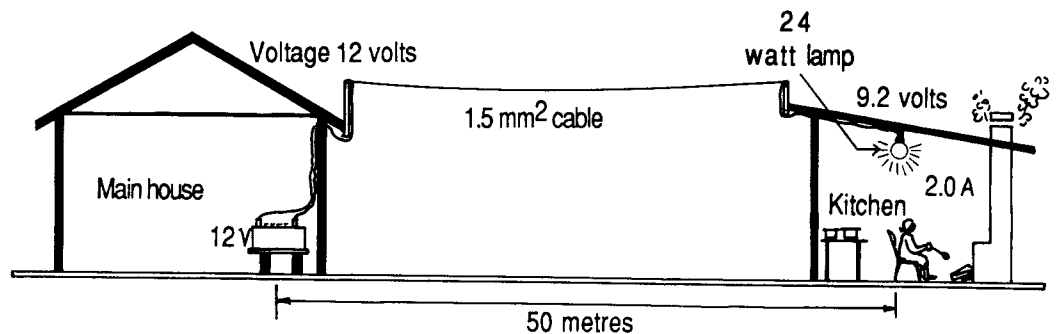


Figure 8.10
Voltage drop in a 12 volt dc system

Ohms Law:
voltage drop =
current x resistance



Wiring and Fittings

Table 8.5: Example Calculation of Voltage Drop in High and Low Voltage Systems

	240 volt ac globe lamp	12 volt dc globe lamp
Current (amps)	0.1 amp	2.0 amps
Length of Wire (m)	50m	50m
Resistance Factor, K (1.5 mm ² cable)	0.027 ohms/m	0.027 ohms/m
Total Resistance (K x 50 metres)	1.35 ohms	1.35 ohms
Voltage drop	0.12 volts	2.8 volts
Voltage at Lamp	240 volts	9.2
Percent Voltage Drop (%)	< 0.1%	23.3%

- The total resistance of the wire is calculated by multiplying the resistance factor by the length of the wire. Note that the number is equal for both 240 V ac and 12 V dc because the wire is the same in each case.
- Next, as per Ohm's Law, the total resistance is multiplied by the current carried in the wire. This gives the voltage drop.

For the 240 V cable, there is little voltage drop over 50 metres. This shows the advantage of high voltage ac power for trans-

mitting electricity over long distances.

However, for the 12 volt lamp, the voltage drop is 23%. This drop is too high, and a larger diameter wire size needs to be used. Voltage drops over 5% are not recommended; but, because of the high cost of thicker cable, drops of up to 10% may be allowed in small systems to save money. In the example above, a 4.0 mm² cable gives a voltage drop of less than 10%. Note that 50 metre cable runs in small solar electric systems are not appropriate because of the large voltage drop and the high cost of the cable.

Voltage Drop Table						
Column A Cable run (list each major run)	Column B Distance of cable (metres)	Column C Maximum current (amps)	Column D K value of intended wire (ohms/metre)	Column E Total resistance (ohms)	Column F Voltage drop (volts)	Is voltage drop too high? (Yes/No)
Main House to Kitchen	50 M	2 A	0.027 Ω/m	1.35 Ω	2.8 V	Yes

Figure 8.11 Filled voltage drop table for example 2