Figure A1  The flow of water is an analogy to the flow of electricity.

Figure A1 shows how a weight placed on a body of water will cause the water to flow out of the pipe if it is allowed to. The flow of water could be measured in say litres per second, and would depend on the pressure being exerted.

A1.1 Electrical pressure: VOLTAGE

In Figure A1 the flow of water would soon cease due to the tank emptying. The concept of the circuit where the water returns to be pushed out again by a pump is illustrated in Figure A2. The pump is comparable with a **voltage source** which pushes the charge along. The strength of the voltage source, i.e. the voltage (symbol V) is measured in **Volts** (V). Typical voltages encountered in Stand-alone Power Systems are 12, 24, 48 and 110 Volts (d.c.) for the battery, and 240 Volts (a.c.) for electrical power which is supplied to ordinary domestic appliances etc. (The terms d.c. and a.c. are explained in section A4, page 8).

Figure A2  Electricity is almost always used in a circuit, where the flow of current circulates back to the source.
Unlike water pressure, voltage can only be measured between two points in the circuit, for example between the + terminal and the - terminal of a 12 V battery, between the active and neutral of a 240 V outlet, or between one end and the other end of a piece of wire.

A1.2 Flow of electricity: CURRENT

In electric circuits, it is the flow of charged particles (usually electrons) that constitutes a current. The amount of flow is called current (symbol I), and is measured in Amperes (A), often abbreviated to amps. One amp equates to the flow of several billion billion charges per second moving past any point in the circuit.

A1.3 Quantity of Charge

The quantity of charge is measured in coulombs (rarely), or in Amp-hours. One amp equals one coulomb per second. In renewable energy work, the units of amp-hours (Ah) are used because they are more convenient. For example, when charging a battery, one amp-hour is the quantity of charge which accumulates in the battery after being charged at 1 amp for 1 hour, or 2 A for ½ h, 10 A for 6 minutes etc.

A1.4 Restriction to flow: RESISTANCE

What will happen if you take the same pump and use it to push water around circuits with different diameter pipes? The narrower pipe will obviously constrict the flow of water more than the wide pipe. The pipe can be said to have a resistance to water flow - the smaller the pipe is, the greater the resistance will be.

![Figure A3](image)

The flow of water will be affected by the resistance of the pipe.

The resulting flow will be affected in the following way:

The greater the resistance, the smaller the flow;
the greater the pressure, the greater the flow.
In other words, the flow (i.e. quantity of water per second) is proportional to the pressure, but inversely proportional to the resistance. This concept of resistance is the same in electrical circuits (see Figure A4). The symbol for resistance is $R$ and the unit of measurement is the Ohm ($\Omega$).

![Diagram showing large and small current with resistance values]

**Figure A4**  The larger the resistance, the smaller the current flow.

In an electrical circuit, the current flow will be greater if the voltage is greater, or if the resistance is less. This relationship between voltage, current and resistance is summarised by an equation known as Ohm’s Law which is:

$$\text{Current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

This equation is very often used in its other forms:

$$V = I \times R$$

or

$$R = \frac{V}{I}$$

The following diagram can make it easier to remember Ohm’s Law:

![Diagram of Ohm's Law]

**Figure A5**  Ohm’s Law. To find any variable, cover up that variable and see the formula containing the other two. E.g. to find $R$, cover “R” and see $\frac{V}{I}$. 
A2 Energy in electrical circuits

Electrical resistance is caused by a restriction to the passage of electrons which is created by friction at the atomic level. In a similar way to mechanical friction, this electrical "friction" causes heating. The heat energy comes from the electricity, so there is a voltage drop between any point in a circuit, and a point further "downstream".

If the resistance is a load, for example a light, this conversion of energy is desirable. Where the resistance is not desirable, for example in the wires which connect a battery to a light, this constitutes an energy "loss" - an inefficiency in the system. Sometimes this loss is not noticeable unless you use a meter to measure the voltage. For example in a long length of cable, the energy lost (and the voltage lost) per metre of cable may be small, but over the whole length (e.g. 20 m) this may be substantial.

A2.1 Electrical power

In the water analogy, the power in water flow depends on both the flow and the pressure:
- a little water & high pressure = not much power
- a lot of water & low pressure = not much power
- lots of water & high pressure = lots of power

For any component in an electrical circuit, the electrical power consumed (converted) equals the product of the voltage across that component, times the current through it. As an equation, power is:

\[ \text{power} = \text{voltage} \times \text{current} \]

or

\[ P = V \times I \]

As usual, the units for power are watts (W).

\[ \begin{align*}
\text{POWER} & = 24V \times 100A \\
& = 2400 \text{ Watts} \\
\text{RESISTANCE} & = 0.24 \text{ Ohms}
\end{align*} \]

\[ \begin{align*}
\text{POWER} & = 24V \times 50A \\
& = 1200 \text{ Watts} \\
\text{RESISTANCE} & = 0.48 \text{ Ohms}
\end{align*} \]

**Figure A6** The power converted (i.e. produced or consumed) in a component is equal to the product of voltage by current. Note that the battery must produce as much power as the load consumes (assuming no loss in the wires).

In the example shown above, the power delivered to the load in the left diagram is double the power delivered to the load in the right diagram since twice the current is flowing.
A3  Series and parallel connection

A3.1  Series connection

Where voltage sources or water pumps are connected in a row or in series, the overall effect is to cumulatively increase the voltage or water pressure.

In the case of the water circuit shown in Figure A7 below, the output pressure of Pump 1 becomes the input pressure of Pump 2. The output of Pump 2 in turn becomes the input to Pump 3 which adds its own increase in water pressure. Overall, the total increase in water pressure is the sum of the individual increases in pressure by each pump. The amount of water flowing through all three pumps is identical since the water delivered to the subsequent pump must first pass through the preceding pump.

![Figure A7](image)

Figure A7  The total pressure produced by the three pumps is the sum of the pressure produced by each one.

Likewise, voltage sources connected in series each add their individual push to electrons passing through it. They work as if there is a single voltage source equal to the sum of the individual sources. As with the water flow in the pump example the same charge flow must pass through each source so the electric current through each is the same.

![Figure A8](image)

Figure A8  The total voltage is equal to the sum of the voltages for series connected components. This is the equivalent to Figure A7.
Figure A9 Two sources of electrical power (e.g. solar panels) connected in series, showing the currents, voltages and polarities in detail.

The voltage across two series connected components is equal to the sum of the individual component voltages.

\[ V_{\text{tot}} = V_1 + V_2 \]

The current through two series connected components is equal to the current through either of the individual components.

\[ I_{\text{tot}} = I_1 = I_2 \]

A3.2 Parallel connection

Identical pumps can be connected with a common water entry an exit point for water as shown below. When we do this they have the capability of pumping a greater amount of water than an individual pump. Water leaving both pumps will be at the same pressure due to the common entry and exit points. It is important to note that the actual current flowing will depend on the restrictions in the water circuit. At the least, this arrangement has the capacity to deliver twice the water of a single pump system.

Figure A10 Pumps connected in parallel can deliver the sum of the flows from each pump (don’t be fooled by pipe sizes!!).

Likewise, voltage sources connected in parallel push electrons out at a similar pressure, but are now capable of pushing out twice as many. Thus we have the same voltage as one source but the ability to supply twice the current.
Figure A11  The total current equals the sum of the currents through each component.

\[ I_{\text{total}} = I_1 + I_2 \]

Figure A12  Two sources of electrical power (e.g. solar panels) connected in parallel, showing the currents, voltages and polarities in detail.

The voltage across two parallel connected components is equal to the voltage of either of the individual components.

\[ V_{\text{tot}} = V_1 = V_2 \]

The current through two parallel connected components is equal to the sum of the individual currents.

\[ I_{\text{tot}} = I_1 + I_2 \]

**Important note:**
The descriptions above hold true for any components connected in series, or in parallel, whether they are voltage sources, current sources or loads. The difference is that a load will consume electrical power rather than produce it - and current flows into the + terminal rather than out of it. Also note that voltage sources (e.g. batteries) must have the same voltage rating if they are to be connected in parallel. For example two 12 V car batteries can be connected in parallel, but a 12 V and 6 V battery in parallel will probably create some smoke!
**A4  A.C. and D.C. electricity**

**A4.1  D.C. (Direct current)**

Direct current (d.c.) is the term given to electricity when the voltage does not change polarity (i.e. the positive (+) terminal always stays positive with respect to the negative (-) terminal). Generally this means that the current always flows in one direction. However, for a device such as a battery, the current will flow into the battery when it is charging and out of the battery when it is discharging. This is still called d.c. electricity.

Devices such as batteries and solar cells work on d.c..

**A4.2  A.C. (Alternating current)**

Alternating current (a.c.) is the term given to electricity when the voltage changes polarity at a regular intervals. One complete cycle occurs when the polarity changes from + to - then back to + again. A.C. is characterised by its frequency (f), which is the number of cycles per second. This is expressed in Hertz (Hz). In Australia, mains electricity has a frequency of 50 Hz, at 240 V.

Note that there is no such thing as a + or - terminal for a.c. devices or circuits, since the polarity is constantly changing. The terms active and neutral are used to distinguish between the two terminals of an a.c. supply.

The mains electricity supply, generating sets and very large wind turbines all produce a.c..

**A5  Diodes**

This section introduces the simplest electronic device: the diode.

The electronic diode can be likened to the one way or check valve when using the water flow analogy. Higher water pressure on one side of the valve will cause the valve to open and water is allowed to flow.

![Figure A13](image)  A one way valve in the open position.

If, however, the reverse occurs and the higher pressure is now on the opposite side of the valve, the valve will shut and no flow will result.

![Figure A14](image)  A one way valve in the closed position.
The electronic diode responds in the same way when voltages are used instead of pressures. When the left hand side has a positive voltage with respect to the right hand side, as shown below, the diode will allow current flow. Note that the direction of that flow is given by the arrow direction in the diode symbol itself.

![Diode Symbol]

**Figure A15** A diode in the conducting state.

If the voltage is reversed resulting in the situation shown below, the diode blocks current flow.

![Diode Symbol]

**Figure A16** A diode in the non-conducting state.