TRANSMISSION OF ELECTRICITY

Power plants long distance from cities – electricity transmitted over long distances – always losses in power lines ($P_{\text{loss}} = I^2 R$) – this loss minimized if power transmitted at high voltages.

In 2010 the total NSW electric energy production was about 100 000 GWh (gigawatt-hours). Much of this power was produced by seven coal-fired power stations. The largest of these is Bayswater with a capacity of 2640 MW from four 660 MW stream driven turbines. The Snowy Mountains hydroelectric scheme provides an additional capacity of 3740 MW. Several smaller hydro and gas turbine stations contribute a further 600 MW. These power stations are sited close to their source of energy - i.e. the coal fields or dams - because it is less costly (and more environmentally friendly) to transmit power than transport coal. Then the state power grid distributes the energy to the users.

Very high voltage AC (alternating current) transmission lines are required to efficiently transmit large amounts of power over long distances. AC voltages are always quoted as rms (“root mean square”) values, which is the square root of the average of the square of the voltage as it varies with time - in fact it is $V_0/\sqrt{2}$ where $V_0$ is the amplitude of the alternating potential. In Australia, normal household voltage is 240 V rms at a frequency of 50 Hz. The actual voltage signal therefore varies as a sine wave between ±340 V, with a period of 20 ms. In the US and Canada power is supplied at 110 V rms and 60 Hz.
In NSW the power is produced at rms voltages between 17 and 23 kV at the power stations. It is transformed up to transmission line voltages which are typically 132 or 330 kV, with some others at 220 and 500 kV. Most of these transmission lines are aluminium conductors suspended overhead on steel lattice towers. The conductors are insulated from the towers by porcelain, glass or synthetic insulators. Transmission lines may also be laid underground, but at much higher cost than overhead lines. However recent concerns with the possible effects of electromagnetic radiation from high voltage lines, plus the appearance of overhead lines, may make underground lines more attractive in the future, at least for short distances in urban areas.

Voltage levels must be reduced before the power can be used in the home or by industry. First, the power is delivered to substations where it is transformed to 66 or 132 kV to be sent, generally on wood or concrete poles, to zone substations where it transformed again to 11 or 22 kV. From this point, it is transmitted to various substations and local transformers where it is stepped down to 240 V for general use. You can see the local transformers on poles in the street or in cubicles at ground level. At the local transformer, one lead, known as the neutral (N) is connected to the earth via a thick cable with one end buried in the ground. The other wire from the transformer, the active lead (A) is thus at an rms potential of 240 V relative to the ground, i.e. to our surroundings. The active and neutral conductors are connected to the A and N points of the user’s outlet sockets. The user’s earth (E) point is connected as directly as possible to the ground close to the house. Since the neutral wires in the power lines carry large currents and since they have finite resistance (ideally the resistance would be zero) they cannot be at exactly the same potential at all places along the wire. The neutral is usually connected to the ground at several other points between the transformer and the houses in order to keep the neutral lead at a potential near earth potential (ie 0 V). This ensures that only the active lead is at a high potential which is less dangerous than having two high voltage wires.

The most common cause of electrocution is when a person comes into contact with the active lead so that current flows to earth through the person. In such circumstances the current in the neutral lead will be less than the current in the active lead - a situation that is referred to as earth leakage. A device, called an earth leakage circuit breaker, detects this imbalance and immediately cuts of the electrical supply. The active and neutral leads are wound in opposite senses on a ring of ferromagnetic material (usually referred to as a core). The function of the ferromagnetic core is to guide the magnetic flux from each winding through the third winding. When the currents in the active and neutral leads are equal the fluxes due to each cancel and there is no net flux through the third winding. If however there is leakage to earth from the active lead the fluxes will not cancel and there will be a net flux through the third coil. As the flux will be alternating (at a frequency of 50 Hz) it will induce an emf in the third coil. With the aid of further electronics this signal can be used to trigger a circuit breaker
that disconnects the mains supply. Other terms for earth leakage circuit breakers include core balance relays and earth leakage protectors. They can be installed as a single unit in the meter box of a domestic dwelling to provide protection for all power and light outlets. It is also possible to obtain portable units for use with individual appliances and power sockets that incorporate such devices. A typical power point unit will trip when an imbalance of greater than 10 mA is detected; in such circumstances the power cuts off within about 40 ms of the imbalance being detected.

Fig. 1. Transformers are used in the transmission of electrical energy from power plant to homes.

**Example**
A 330 kV transmission line is used to transmit electrical energy from a power station to a substation 50 km way. The resistance of the transmission line is 0.04 Ω.km⁻¹. If the power transferred via the transmission lines was 5.28 MW, calculate the current in the lines and the power loss in the transmission. Re-do the calculation for the transmission of the energy at only 240 V. Explain why it is necessary to use transformers to step up the voltages to very high values?

**Solution**
How to approach the problem (ISEE)
Type of problem: electric circuits
Knowledge: \( V = I R \) \( P = V I = I^2 R \)
Data: \( V_T = 330 \times 10^3 \) V \( \Delta x = 50 \) km \( R / \Delta x = 0.04 \) Ω.km⁻¹
\[ R = (0.04)(50) \Omega = 2.0 \Omega \quad P_T = 5.28 \times 10^6 \text{ W} \]
\[ I = ? \text{ A} \quad P_L = ? \quad V_T = 240 \text{ V} \]

Transmission at \( V_T = 330 \times 10^3 \) V
The transmission line current is
\[ I = \frac{P_T}{V_T} = \frac{5.28 \times 10^6}{330 \times 10^3} \text{ A} = 16.0 \text{ A} \]
The losses due to ohmic heating in the transmission lines
\[ P_L = I^2 R = (16)^2 (2) \text{ W} = 512 \text{ W} \]
Transmission at $V_T = 240 \text{ V}$

The transmission line current is

$$I = \frac{P_T}{V_T} = \frac{5.28 \times 10^6}{240} \text{ A} = 2.2 \times 10^4 \text{ A}$$

The losses due to ohmic heating in the transmission lines

$$P_L = I^2 R = \left(2.2 \times 10^4 \right)^2 (2) \text{ W} = 9.68 \times 10^8 \text{ W}$$

This is an impossible answer, more energy lost than transmitted. This is why electrical energy is transmitted at very high voltages as it significantly reduced ohmic heating losses. The great advantage and main reason for use of ac over DC voltages is that they can be easily stepped up or stepped down using transformers making the transmission of energy much simpler.

Questions and problems ([/p6/p6_problems.pdf])

P6060  P6336  P6506  P6835  P6838