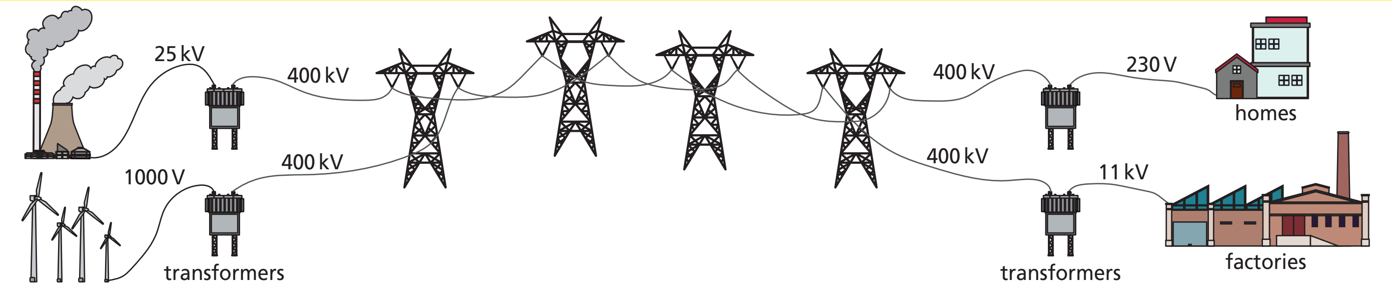
Physics review

Powerful connections

1 The National Grid



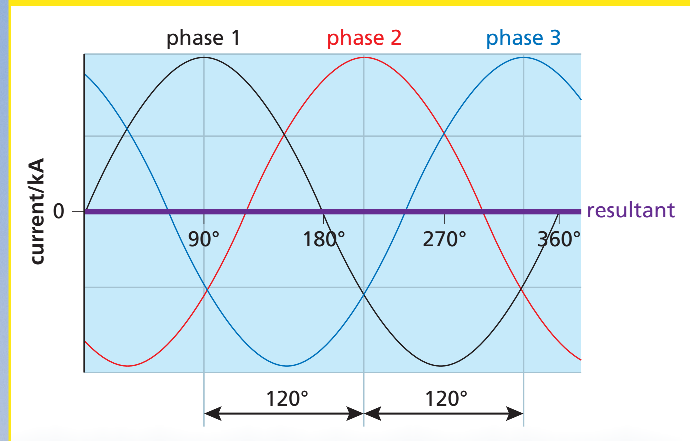
The demand for electricity is expected to grow in the coming years as we increasingly adopt more sustainable technologies, such as heat pumps and electric transport. This will place huge pressure on the National Grid (1), which is the interconnected network of transmission lines and transformers that transfer electricity from where it is generated to where it is needed.

Power stations often generate electricity that has a voltage of about 25 kV, compared with wind turbines with a voltage of about 1000 V. Step-up transformers are used to increase these voltages to the size of voltage used in the National Grid. At the end of transmission lines step-down transformers are used to reduce the voltage to the right size: 230 V for domestic use, 33 kV, 11 kV or 450 V for factories, and 33 kV for electric trains.

The biggest transmission lines in the UK carry voltages of 400 kV, with currents of over 1000 A. Each one can transfer around 500 million joules of energy each second (500 MW). This size of current is enough to make transmission lines hot, and they often work at up to 90°C.

Transmission lines carry alternating current (a.c.) and are the live wires in huge circuits that connect with all the appliances we use in our homes, our lighting, and everything else that uses electricity from the National Grid. Usually, transmission lines are in threes, each carrying an alternating current 120° out of phase with that in each of the other two (2). Adding the currents in each transmission line gives a resultant of zero.

2 Three-phase electric supply



Electricity from each phase is usually supplied separately, but on the other side of the circuit from the live connections the currents of each phase are added together. This means that the current in the neutral wire returning, for example, to a power station, is close to zero. The neutral wire is the smaller single wire between the tops of the 400 kV pylons.

The values quoted here for voltages and currents are root-mean-square values (3). Root-mean-square current is the square root of the mean value of the current squared. It gives the size of the average current in either direction:

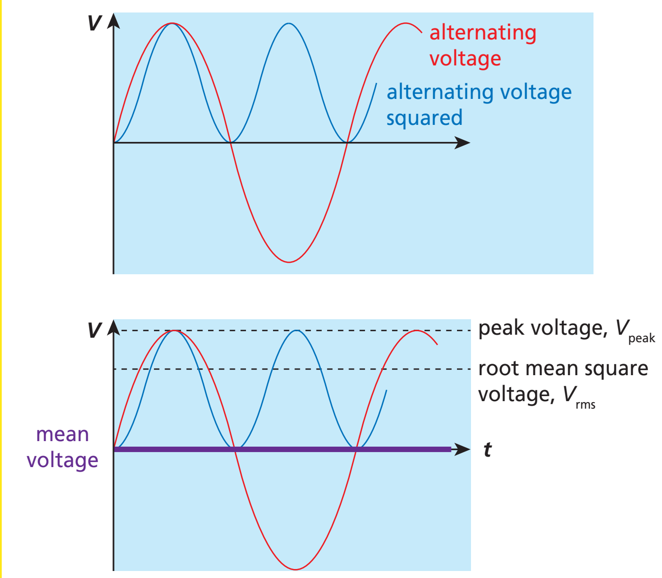
$$I_{rms} = \frac{I_{peak}}{\sqrt{2}} \text{ and } V_{rms} = \frac{V_{peak}}{\sqrt{2}}$$

The power transferred by a transmission line is:

$$P = I_{rms} \times V_{rms}$$

3 Root-mean-square voltage

The value of a.c. voltage is alternatively positive and negative, with an average value of zero, no matter what size the peak voltage. Squaring the voltage gives only positive values, and the root mean square voltage is equal to the average *size* of the voltage, with no indication of direction.



For a 400 kV line:

$$500\,000\,000\,\text{W} = 1250\,\text{A} \times 400\,000\,\text{V}$$

If the same power were transferred at 230 V (mains voltage):

$$500\,000\,000\,\text{W} \approx 2\,000\,000\,\text{A} \times 230\,\text{V}$$

Heating by a current of this size would instantly melt (or vaporise) the transmission lines.

A 400 kV transmission line has a diameter of about 5 cm (4). This means that it has a very low resistance of about 3 Ω per 100 km. To calculate the power dissipated to the surroundings by heating, $P = I \times V$ is used again, but the voltage is now equal to the drop in voltage along the length of the transmission line because of its resistance. This could be measured, but, since $V = I \times R$, it can more easily be calculated using:

$$P_{dissipated} = (I_{rms})^2 \times R$$

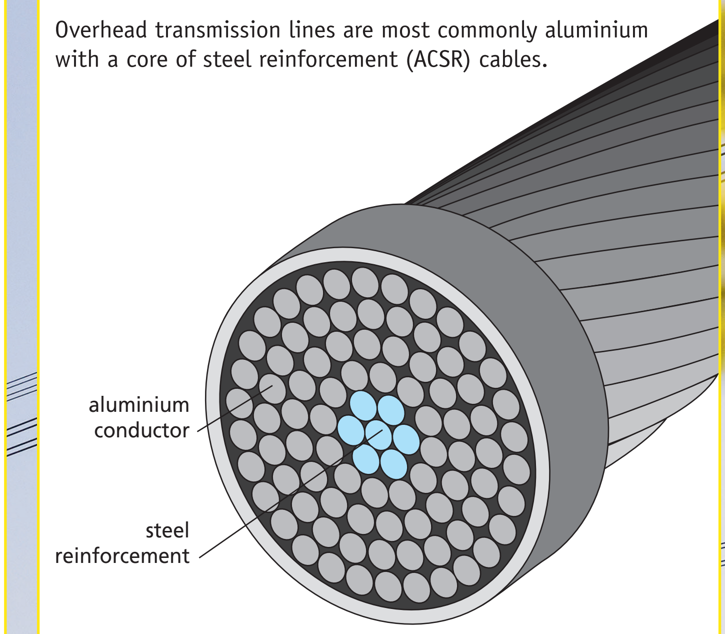
Along 100 km of 400 kV transmission line:

$$P_{dissipated} = (1250)^2 \times 3 \approx 5\,\text{MW}$$

which is about 1% of the power transferred. Across the National Grid, up to 10% of power is dissipated by heating.

4 Cross-section of a 400 kV overhead transmission line

Overhead transmission lines are most commonly aluminium with a core of steel reinforcement (ACSR) cables.



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