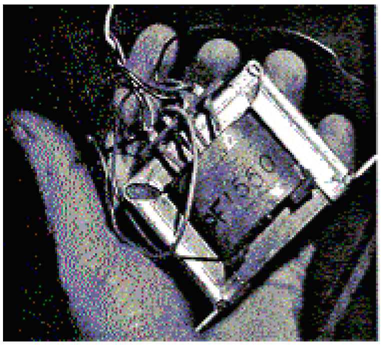
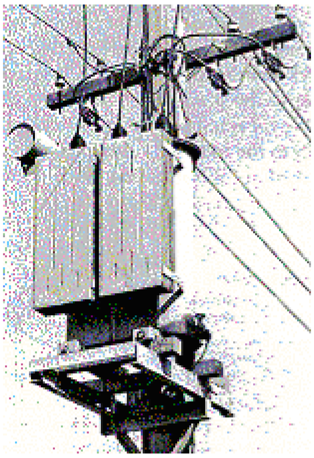
Transformers and Transmission

- **compare sinusoidal AC voltages produced as a result of the uniform rotation of a loop in a constant magnetic field with reference to frequency, period, amplitude, peak-to-peak voltage (*V*p-p) and peak-to-peak current (*I*p-p);**
- **compare alternating voltage expressed as the root-mean-square (rms) to a constant DC voltage developing the same power in a resistive component.**
- **convert between rms, peak and peak-to-peak values of voltage and current;**
- **analyse transformer action with reference to electromagnetic induction for an ideal transformer:** $\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$
- **analyse the supply of power by considering transmission losses across transmission lines**
- **identify the advantage of the use of AC power as domestic power supply.**

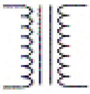




Transformers

Transformers are a major component of the electrical distribution system. They

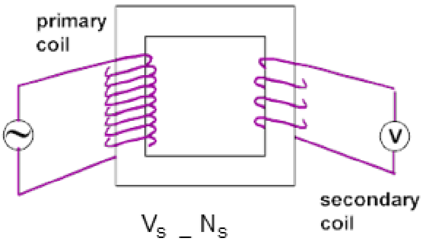
- enable energy losses in transmission lines to be reduced.
- are used to change household power supply (240 Volts) to usable voltages in appliances
- have the circuit symbol



What are Transformers?

A transformer consists of three major components:

- an iron core shaped in U or square shape
- a primary coil wound around one side of the iron
- a secondary coil wound around the other side of the iron



$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

The alternating current in the primary coil generates an alternating magnetic field in the iron core.
This alternating field passes through the secondary coil and induces an EMF in the secondary coil.

The ratio of the voltage across the secondary to the voltage across the primary coil is equal to the ratio of the turns

Voltage stepping

The purpose of a transformer is to either step up or step down a voltage. When stepping up a voltage, the output voltage is greater than the input voltage. In a perfect transfer of magnetic flux is assumed then energy (power) is conserved.

Input power = Output power

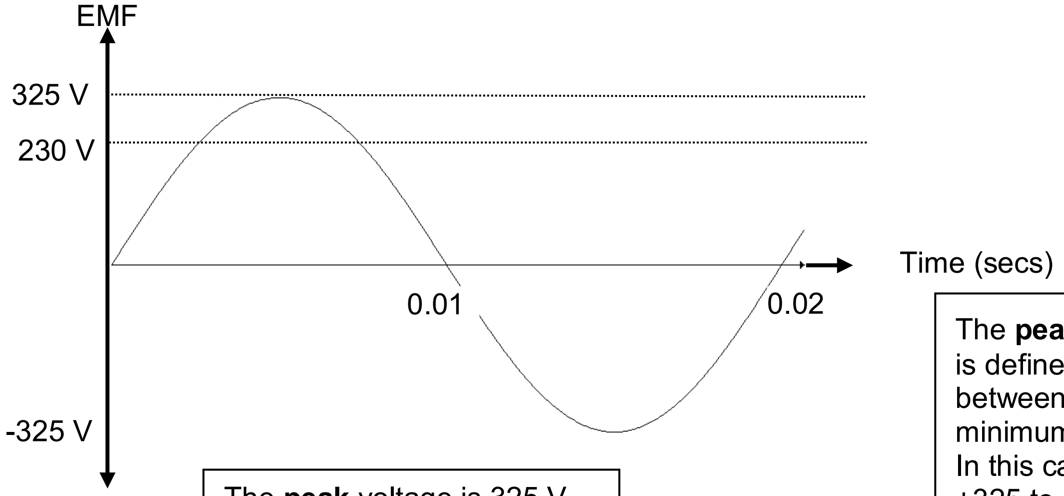
$$P_{IN} = P_{OUT} \qquad \Rightarrow \qquad \frac{I_P}{I_s} = \frac{V_S}{V_P} = \frac{N_S}{N_P}$$
$$V_P I_P = V_S I_S$$

It can be seen that in a step-up transformer,

- the number of secondary turns exceeds that in the primary coil, and
- the current is stepped down by the same factor by which the potential difference is stepped up.

Measuring AC Voltage

When comparing DC and AC power supplies, it is necessary to carry out conversions to make a true comparison. Below is a regular sinusoidal AC voltage, as could be produced by a generator.



The **peak** voltage is 325 V

The **peak-to-peak** voltage V_{PP} is defined as the difference between the maximum and minimum
In this case,
+325 to –325 = 650 V

The **Root Mean Square (RMS)** voltage is the square root of the mean of the square of the potential difference. This complicated value is used because it gives the value of the DC potential difference that has the same heating effect as the alternating potential.

To convert:

RMS to Peak	$\times \sqrt{2}$	Peak to RMS	$\div \sqrt{2}$
Peak to Peak-Peak	$\times 2$	Peak-Peak to Peak	$\div 2$
RMS to Peak-Peak	$\times 2\sqrt{2}$	Peak-Peak to RMS	$\div 2\sqrt{2}$

In formulas you need to use all values in the same unit, i.e. All RMS, or Peak, or Peak - Peak.

Any AC current can be given an RMS equivalent value in exactly the same manner. When doing calculations involving power **always** use the RMS values, unless otherwise stated.

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Electrical distribution system

Resistance of power lines is proportional to the length of the lines. The longer the wires, the more important the transmission losses become. The larger diameter of the wire, the less the resistance, but the greater the weight, cost and the higher the supports need to be. It is paramount to reduce the power losses in cables.

$$P_{Loss} = V_{Loss} \times I_{Transmission}$$

But, $V_{Loss} = I_{transmission} \times R$

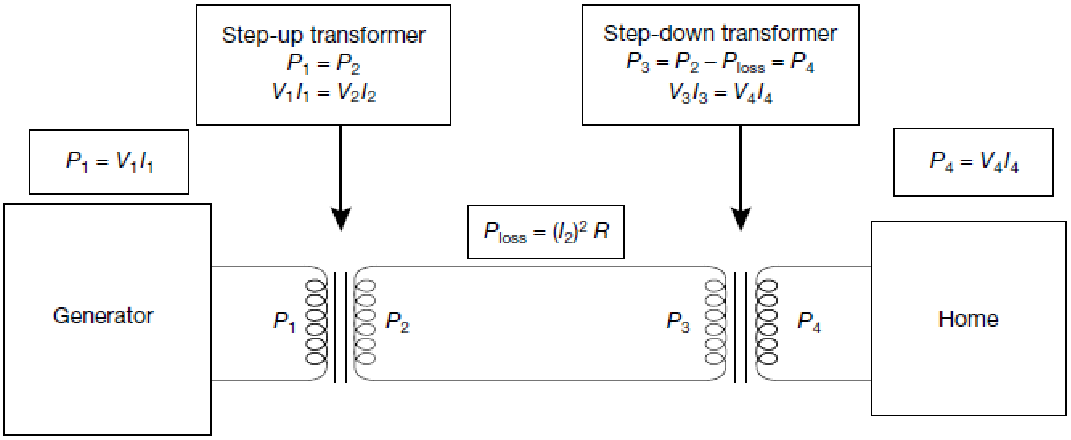
$$\Rightarrow P_{Loss} = I^2_{Transmission} \times R$$

Transmitting at high voltages and relatively low current reduces power losses. This requires stepping up the voltage at the power station and stepping it down for industrial and domestic use.

In order to transmit large blocks of power (for Melbourne up to 5×10^9 W) over transmission lines, it is necessary to use a high voltage (500 kV), only then can the current be kept down to a reasonable level 1×10^4 A). If the power was transmitted at 250 V it would require a current of 2×10^7 amps to supply the power to Melbourne.

The power is transmitted in AC current because of its guaranteed voltage level over long distances. AC is also advantageous in its ability to be transformed either up or down. In contrast DC current is unable to be transformed necessitating transmission of large amounts of power, which would increase the energy loss resulting from large voltage drops.

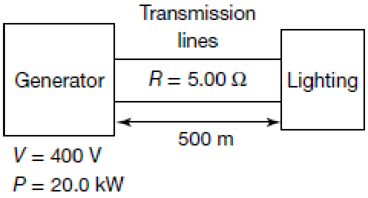
The power loss in the transmission lines is equal to $P_{loss} = IV = I^2R$, where V is the voltage drop across the lines, I is the current through the lines and R is the resistance of the wires. Be careful not to confuse the voltage drop in the transmission lines with the voltage supplied from the generator. In order to minimise power loss in the transmission wires, large amounts of power produced by the generator need to be transmitted using a very low current. Development of the transformer meant that the AC supply voltage from the generator could be connected to a step-up transformer, allowing transmission lines to increase the voltage supplied by the generator and decrease the current, and so reduce energy loss in the transmission lines.
However, at the other end of the transmission line, the high voltage supplied would be unsuitable, and possibly dangerous, for domestic appliances. So a step-down transformer is used to bring the voltage back down to a safe level for home use.



Example:

a. **A 20.0 kW, 400 V_{RMS} diesel generator supplies power for the 400 V_{RMS} lights on a film set at an outside location. The 500 m transmission cables have a resistance of 5.00 Ω.**
  i. **What is the current in the cables?**
  ii. **What is the voltage drop across the transmission cables?**
  iii. **What is the power loss in the cables as a percentage of the power supplied by the generator?**
  iv. **What is the voltage supplied to the lighting?**

b. **Repeat the calculations in part (a), but this time increase the generator voltage by a factor of 20 and, prior to connection to the lights, reduce the voltage by a factor of 20.**

THINK	**WRITE**
a. i. 1 Draw a diagram showing all known information.	a. i. 
2 The current in the cables is equal to the current coming from the generator. For the generator: $P = 20\,000$ W; $V = 400$ VUse $P = VI$ to determine the current through the cables. (Note: Using $V = IR$ with $V = 400$ V and $R = 5.0\ \Omega$ is incorrect because 400 V is the voltage supplied by the generator, it is not the voltage drop across the cables.)	$P = VI$ $I = \frac{P}{V}$ $= \frac{20\,000}{400}$ $= 50.0\text{ A}$ The current through the cables is 50.0 A.
ii. In the cables, $I = 50$ A and $R = 5.0\ \Omega$. Use $V = IR$ to determine the voltage drop across the cables.	ii. $V = IR$ $= 50.0 \times 5.00$ $= 250\text{ V}$ The voltage drop across the cables is 250 V.
iii. 1 In the cables, $I = 50$ A and $R = 5.0\ \Omega$. Use $P_{loss} = I^2R$ to determine the power lost in the cables. (Note: This answer could have been obtained by using $P = VI$, with $V = 250$ V from solution ii; however, there is a risk that 400 V may be used by mistake, so it is better to use I^2R.)	iii. $P_{loss} = I^2R$ $= 50.0 \times 50.0 \times 5.00$ $= 12\,500\text{ W}$
2 Determine the power loss as a percentage of the power supplied by the generator.	$\%P_{loss} = \frac{12\,500}{20\,000} \times \frac{100}{1}$ $= 62.5\%$

iv. The voltage supplied by the generator is shared between the transmission cables and the lights:

$V_{\text{generator}} = V_{\text{cables}} + V_{\text{lights}}$

where $V_{\text{generator}} = 400$ V and $V_{\text{cables}} = 250$ V.

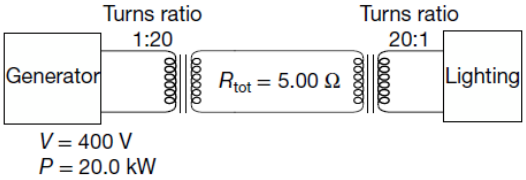
iv. $V_{\text{generator}} = V_{\text{cables}} + V_{\text{lights}}$

$$\begin{aligned} V_{\text{lights}} &= V_{\text{generator}} - V_{\text{cables}} \\ &= 400\text{ V} - 250\text{ V} \\ &= 150\text{ V} \end{aligned}$$

At this distance, the voltage drop across the cables is too much to leave sufficient voltage to operate the lights at their designated voltage. Given the noise of the generators, they cannot be moved closer. Therefore, step-up and step-down transformers with turns ratios of 20 are used to reduce the power loss in the cables and increase the voltage at the lights.

b. i. 1 Draw a diagram showing all known information.

b. i.



2 Determine the voltage in the secondary coil of the step-up transformer.

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$\frac{400}{V_2} = \frac{1}{20}$$

$$\begin{aligned} V_2 &= 20 \times 400 \\ &= 8000\text{ V} \end{aligned}$$

3 The current in the cables is equal to the current coming from the secondary coil of the step-up transformer.

Use $P = VI$ to determine the current in the secondary coil of the transformer, and hence the cables, assuming an ideal transformer.

$P_1 = P_2 = 20\,000$ W; $V_2 = 8000$ V

$P_1 = P_2 = V_2 I_2$

$$\begin{aligned} I_2 &= \frac{P_1}{V_2} \\ &= \frac{20\,000}{8000} \\ &= 2.50\text{ A} \end{aligned}$$

ii. In the cables, $I = 2.50$ A and $R = 5.00\ \Omega$. Use $V = IR$ to determine the voltage drop across the cables.

ii. $V = IR$

$$\begin{aligned} &= 2.50 \times 5.00 \\ &= 12.5\text{ V} \end{aligned}$$

The voltage drop across the cables is 12.5 V.

iii. 1 In the cables, $I = 2.50$ A and $R = 5.00\ \Omega$. Use $P_{\text{loss}} = I^2R$ to determine the power loss

iii.

$$\begin{aligned} P_{\text{loss}} &= I^2R \\ &= 2.50 \times 2.50 \times 5.00 \\ &= 31.3\text{ W} \end{aligned}$$

2 Determine the power loss as a percentage of the power supplied by the generator.

$$\begin{aligned} \%\,P_{\text{loss}} &= \frac{31.25}{20\,000} \times \frac{100}{1} \\ &= 0.156\% \end{aligned}$$

This is $\left(\frac{1}{20}\right)^2$ or $\frac{1}{400}$ of the original power loss! This is an impressive reduction.

iv. 1 The voltage supplied to the primary coil of the step-down transformer is the voltage from the secondary coil of the step-up transformer minus the voltage drop across the cables.

2 Determine the voltage in the secondary coil of the step-down transformer.

iv. Voltage supplied to the step-down transformer is therefore:

8000 V – 12.5 V = 7988 V

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

$$\frac{7988}{V_2} = \frac{20}{1}$$

$$V_2 = \frac{7988}{20}$$

$$\approx 400\text{ V}$$