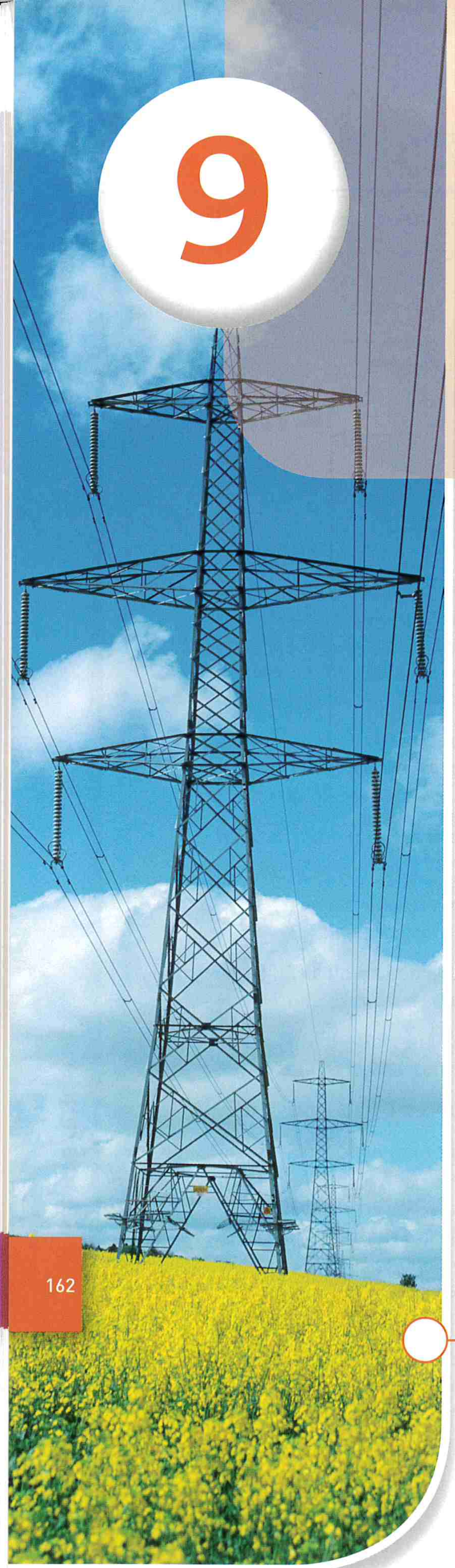


9 Alternating currents and transformers

PRIOR KNOWLEDGE

Before you start, make sure that you are confident in your knowledge and understanding of the following points:

- Electric current, I, is the rate of flow of charge, $\frac{\Delta Q}{\Delta t}$, measured in amperes (A).
- Potential difference (voltage), V, is the amount of electrical work done per unit charge, $\frac{W}{Q}$. Potential difference is measured in volts (V).
- Electric current, I, potential difference, V, and resistance, R, in a circuit are related to each other through the equation $V = IR$.
- Electrical power is the rate of doing electrical work, $P = VI = I^2R = \frac{V^2}{R}$
- The frequency, f, of a waveform is the number of complete waves per second and is measured in hertz (Hz).
- The time period, T, of a waveform, measured in seconds (s), is related to the frequency of the waveform, f, by $f = \frac{1}{T}$.
- The e.m.f. induced in a coil is $\varepsilon = -N\,d\phi/dt$, where ε is the induced e.m.f. (V), N is the number of turns on the coil, ϕ is the magnetic flux (Wb) and t is time (s).
- Eddy currents are generated in metal sheets by changes in magnetic flux. Eddy currents transfer electrical energy to heat energy.

TEST YOURSELF ON PRIOR KNOWLEDGE

1 An ac voltage has a time period of 0.004 s. What is the frequency of the voltage supply?
2 A current of 13 A flows through an electric fire element, which has a resistance of 14 Ω. Calculate the power dissipated by the fire in kW.
3 A bar magnet, which has poles measuring 1.5 cm × 1.5 cm, is pulled out of a coil in a time of 0.2 s. The coil has 10 000 turns and a resistance of 50 Ω. The average current flowing in the coil while the magnet is moving is about 35 mA. Estimate the flux density near the pole of the magnet.

Mains electricity

Electricity is generated and transmitted around the country in the form of alternating currents (ac) and voltages. These are used because they can be transformed to high voltages and very low currents in order to minimise the thermal energy lost as the current travels through the wires of the National Grid (Figure 9.1). Only about 2–3% of the electrical energy from the generators is lost as heat, saving energy, carbon emissions and money.

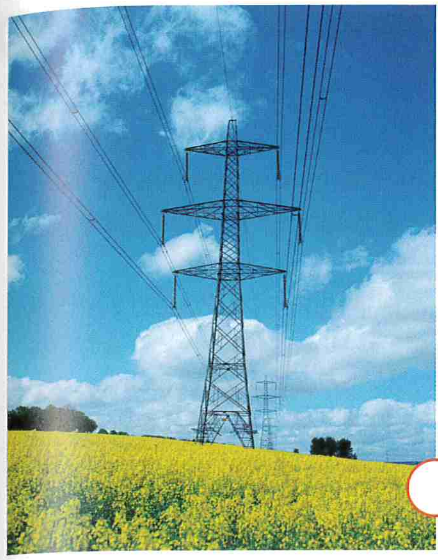


Figure 9.1 Electricity supply pylons – part of the National Grid.

Alternating current is delivered by the National Grid to consumers as a sinusoidally varying supply with a frequency of 50 Hz, and a range of different voltages, depending on the customer. Household mains has a nominal voltage of 230 V, although this value varies throughout the day depending on the demand and supply of electricity. The maximum current that can be drawn by a single domestic supply is about 65 A. The electrical socket ring main in your house has a maximum current of 13 A protected by a fuse or a circuit breaker. However, it is only lamps, heaters, cookers and devices such as vacuum cleaners and mowers, with large electric motors, that use ac directly off the mains. Most other devices work at much lower voltages and as direct currents (dc). This means that devices such as televisions, computers and games consoles all require a separate (or built-in) step-down transformer that converts 230 V ac into (for example) 12 V dc.

Alternating current and voltage

Alternating currents and voltages move in one direction for half of their cycle and in the opposite direction for the other half. Mains electricity comes in a sinusoidally changing pattern, with the magnitude of the current or the voltage continuously varying between maximum positive and negative values. The peak value of the voltage (or potential difference) is the maximum value in either the positive or negative direction, with respect to zero. The peak-to-peak value of the voltage is measured from one peak in the positive direction to the other peak (called a trough) in the negative direction (see Figure 9.2).

Peak voltage is half the peak-to-peak voltage, and is equivalent to the amplitude of the waveform.

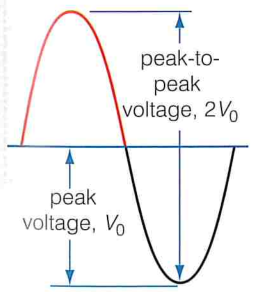


Figure 9.2 An alternating electrical waveform.

The **peak voltage**, V_0, of the alternating waveform is half the peak-to-peak voltage, and is equivalent to the amplitude of the waveform. For a given component such as a resistor, the peak current I_0 and peak voltage V_0 are related to each other through the equation

$$V_0 = I_0R$$

Comparing ac and dc equivalents

As alternating currents and voltages vary continuously, what value is used in calculations that gives the same effect as the equivalent direct current or voltage?

The average values cannot be used, because the average values are both zero – there is the same amount of signal above zero as there is below zero. The values chosen are the root mean square (r.m.s.) voltage and current. When multiplied together, these quantities produce the same power in a resistor as would be produced by the same dc values. This can be expressed more easily in the form of the equation:

$$P = V_{dc}I_{dc} = V_{rms}I_{rms}$$

A sinusoidal alternating voltage, V, varying with time, t, can be represented by the equation

$$V = V_0\sin(2\pi ft)$$

where V_0 is the peak voltage, and f is the frequency of the supply. This is shown on the graph in Figure 9.3.

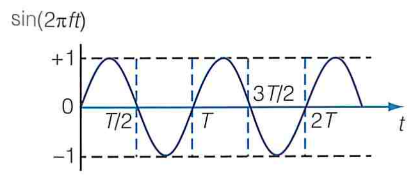


Figure 9.3 Alternating voltage.

If this voltage is applied across a fixed resistor, R, then the power dissipated by the resistor is equal to

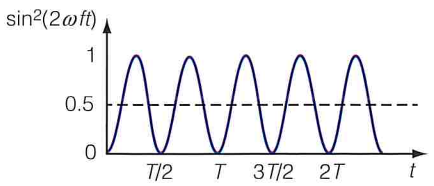


Figure 9.4 The $\sin^2$ graph.

$$P = \frac{V^2}{R} = \frac{V_0^2 \sin^2(2\pi ft)}{R}$$

The average power is the power we need to compare to an equivalent constant dc value, but as $\frac{V_0^2}{R}$ is constant in this equation, we only need to find the average value of $\sin^2(2\pi ft)$. This can be done by analysing the graph of the function in Figure 9.4.

It can be seen from Figure 9.4 that the average value of $\sin^2(2\pi ft) = 0.5$, so

$$P = \frac{\frac{1}{2}V_0^2}{R}$$

This will be the same power as that for an equivalent constant dc value of voltage, V_{dc}:

$$P = \frac{\frac{1}{2}V_0^2}{R} = \frac{V_{dc}^2}{R}$$

Hence we obtain

$$\frac{V_0^2}{2} = V_{dc}^2$$

$$V_{dc} = \sqrt{\frac{V_0^2}{2}}$$

and

$$V_{dc} = V_{rms} = \frac{V_0}{\sqrt{2}}$$

As the alternating current varies in phase with the voltage, using a similar reasoning yields

$$I_{rms} = \frac{I_0}{\sqrt{2}}$$

As a result, the mean alternating power, P_{mean}, which is equivalent to the dc power, is given by

$$P_{mean} = V_{rms}I_{rms}$$

and the peak alternating power, P_{peak}, is given by

$$P_{peak} = V_0 I_0$$

Hence, finally we have

$$P_{mean} = \frac{V_0}{\sqrt{2}} \times \frac{I_0}{\sqrt{2}} = \frac{V_0 I_0}{2} = \frac{P_{peak}}{2}$$

In other words, the mean power dissipated through a fixed resistor by an alternating current and voltage is equal to half the peak power dissipated.

EXAMPLE

Mains power

The given UK mains voltage is 230 V ac – this is an r.m.s. value. The largest power that can usually be drawn from a local grid is 15 kW – this is the mean value, equivalent to a dc supply.

1 What is the r.m.s. current?

Answer

Use the equation for P_{mean} from the text:

$$P_{mean} = V_{rms}I_{rms}$$

$$I_{rms} = \frac{P_{mean}}{V_{rms}} = \frac{15\text{ kW}}{230\text{ V}}$$

$= 65.2\text{ A} = 65\text{ A}$ (2 s.f.)

2 What are the peak power, peak voltage and peak current?

Answer

Combine the equations for V_0 and I_0 from the text to give the equation for P_{peak}:

$$V_0 = V_{rms} \times \sqrt{2}$$

$= 230\text{ V} \times \sqrt{2}$

$= 325.3\text{ V} = 330\text{ V}$ (2 s.f.)

$$I_0 = I_{rms} \times \sqrt{2}$$

$= 65.2\text{ A} \times \sqrt{2}$

$= 92.2\text{ A} = 92\text{ A}$ (2 s.f.)

$$P_{peak} = V_0 I_0$$

$= 325.3\text{ V} \times 92.2\text{ A}$

$= 29993\text{ W} = 30\text{ kW}$ (2 s.f.)

We can then use these values to calculate the peak-to-peak values of p.d. and current:

$V_{peak\text{-}to\text{-}peak} = 2V_0 = 650\text{ V}$ (2 s.f.)

$I_{peak\text{-}to\text{-}peak} = 2I_0 = 180\text{ A}$ (2 s.f.)

TEST YOURSELF

1 What is meant by the 'root mean square' (r.m.s.) voltage?

2 An ac power supply delivers $V_{rms} = 6.0\text{ V}$ to a fixed resistor of resistance $R = 2.5\,\Omega$. Calculate:
 a) the r.m.s. current through the resistor
 b) the mean power delivered to the resistor
 c) the peak power delivered to the resistor.

3 In the USA, the nominal r.m.s. voltage is 120 V. If the mean power delivered to a US domestic house is the same as that to a UK house (15 kW), calculate:
 a) the r.m.s. current delivered
 b) the peak voltage delivered
 c) the peak power delivered.

4 The ac motor for a (UK) mains washing machine works with a peak power of 400 W. Calculate:
 a) the mean power drawn by the motor
 b) the r.m.s. current through the motor.

Using an oscilloscope to display waveforms

Analysing alternating waveforms is best done by displaying the waveform using an oscilloscope. Oscilloscopes are a form of visual, calibrated voltmeter, where the operator is able to alter how the waveform is displayed. First, it is possible to control the time taken for the signal to move across the screen by adjusting the *timebase* – often labelled time/div. Secondly, the amplitude of the signal displayed on the calibrated screen can be controlled by adjusting the *y-sensitivity* – this is also known as the vertical sensitivity, *y*-gain or simply volts/div. The timebase (in seconds) provides a scale for the *x*-axis of the screen and indicates the time taken for the signal to move horizontally across one square on the screen. Using the square grid on the screen to measure the number of horizontal squares between two successive peaks (or troughs) allows the period of the waveform to be determined and hence the frequency. The oscilloscope also makes it very easy to measure the peak-to-peak value of the wave by counting vertical squares and then using the *y*-sensitivity (usually calibrated in volts, millivolts or microvolts) to apply a scale.

EXAMPLE

Oscilloscope with a dc signal

The oscilloscope in Figure 9.5 is displaying a dc signal (from a battery for example). Describe the signal.

Answer

The timebase is set to 20 ms/div, so, because there are 10 horizontal divisions on the screen grid, the signal takes 200 ms (0.2 s) to travel from one side of the screen to the other. The y-sensitivity is set to 1 V/div, and the signal is 2.4 divisions vertically up from the centre line. This makes the voltage of the signal 2.4 V.

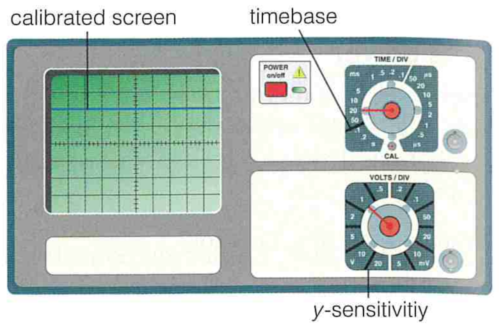


Figure 9.5 Oscilloscope displaying a dc signal.

EXAMPLE

Oscilloscope with an ac waveform

The oscilloscope in Figure 9.6 illustrates an ac waveform from a signal generator. Describe the waveform.

Answer

In this case the timebase and y-sensitivities have not changed. There are five horizontal divisions between the two successive peaks or troughs, and this corresponds to a time period of 100 ms. The frequency of the signal is therefore

$$\text{frequency} = \frac{1}{\text{time period}} = \frac{1}{100 \times 10^{-3}\ \text{s}} = 10\ \text{Hz}$$

The peak-to-peak voltage measured from the bottom of a trough to the top of a peak on the screen is six divisions, corresponding to 6 V. This corresponds to a peak voltage of 3 V and $V_{rms} = \frac{3\ \text{V}}{\sqrt{2}} = 2.1\ \text{V}$.

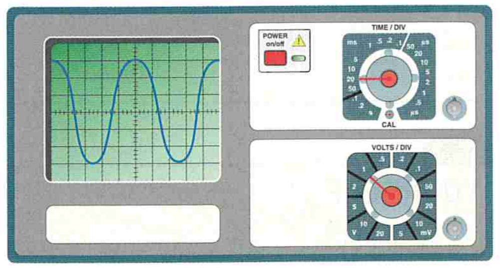


Figure 9.6 Oscilloscope displaying an ac waveform.

ACTIVITY

Virtual oscilloscopes and signal generators

There are many excellent *virtual oscilloscope* and *signal generator simulations* and *apps* available on-line. Using the keywords in italics as search terms in a search engine will take you to a range of different versions, although they all operate using the same principles as the real thing illustrated in Figures 9.5 and 9.6.

Some simulations are just oscilloscopes, and these rely on an external signal being generated and fed through the computer's sound card or microphone. Be careful when doing this – use an external device that does not exceed the sound card's input voltage (a tablet is ideal for this).

Other simulations have a built-in signal generator that allows you to generate an alternating signal directly for display on the oscilloscope screen.

Use one of these simulations to familiarise yourself with the controls of the oscilloscope, so that when you come to use the real thing you will be able to analyse alternating waveforms and extract the relevant key information, such as the frequency and the peak-to-peak values. You could also use your simulation to analyse the voltage signals coming off different music tracks, although the rapidly varying voltages may be tricky to measure unless the simulation has a 'Hold' or 'Freeze' function. Alternatively you could speak or sing directly into the sound card and use the oscilloscope and your voice to analyse some alternating signals.

Transformers

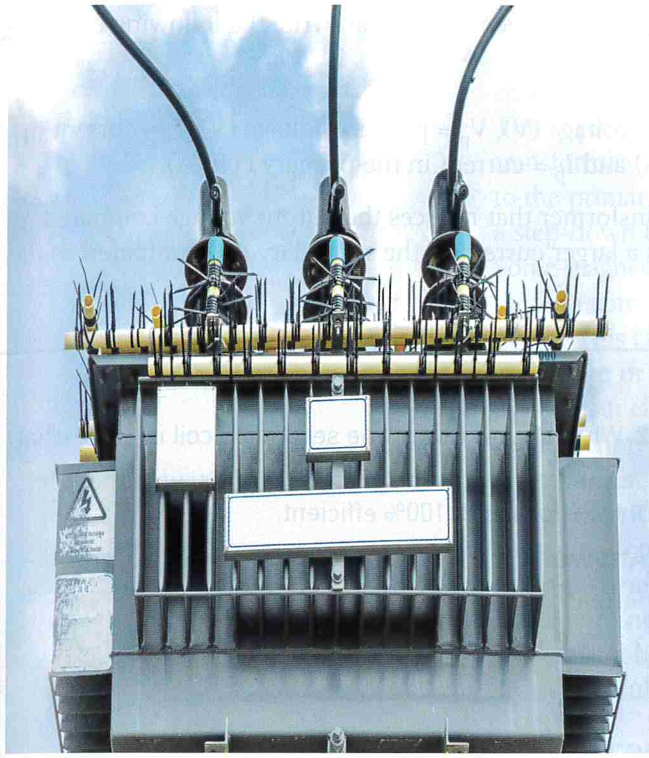


Figure 9.7 Step-up transformers increase the generated voltage from 25 000 V to 400 000 V.

Many devices use transformers to increase or reduce the voltage of an alternating voltage supply. Transformers are used by the National Grid to increase the voltage generated in power stations up to 400 000 V, so that energy can be saved as electricity is transmitted around the country. Then transformers are used to reduce this high voltage for safe use in the home. Figure 9.7 shows the transformers used to step up the voltage in a power station.

Structure of a transformer

The structure of a transformer is simple. It consists of two coils of wire linked by a soft iron core as shown in Figure 9.8.

An alternating current in the primary coil creates a changing magnetic field in the core, which is made of a soft magnetic material such as iron. The secondary coil is also wound round the core. As the magnetic flux in the core changes, the magnetic flux linkage to the secondary coil changes and an e.m.f. is induced in the secondary coil. Because transformers use electromagnetic induction, they only work with an ac supply.

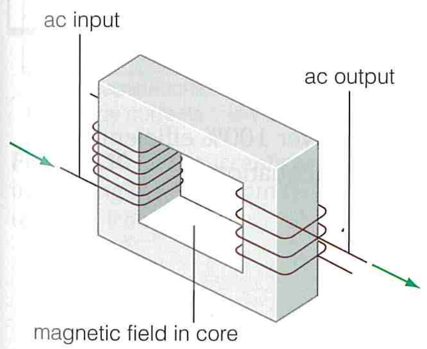


Figure 9.8 The structure of a transformer.

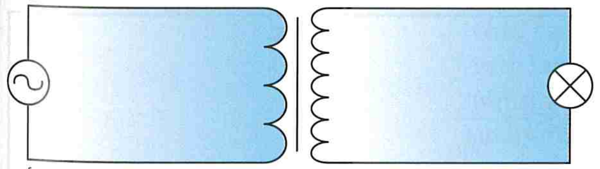
The turns rule

For an ideal transformer, with no power losses, the ratio of the turns on each coil equals the ratio of the primary and secondary voltages. That is

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

where V_s = secondary voltage (V), V_p = primary voltage (V), N_s = turns on the secondary coil and N_p = turns on the primary coil.

A step-up transformer is a transformer that increases voltage, so N_s/N_p is more than 1. A step-down transformer is a transformer that decreases voltage, so N_s/N_p is less than 1. Figure 9.9 shows a simple circuit diagram for a transformer, with the symbols for an ac supply, a step-up transformer and a bulb.



from AQA paper Jan 2011

Figure 9.9

You already know that E depends on the number of turns on the coil. The induced e.m.f. is given by

$$\varepsilon = -N\frac{d\phi}{dt}$$

The rate of flux change $\frac{d\phi}{dt}$ in the core of the transformer is the same for both coils, but the number of turns N is different, so the induced e.m.f. is different in the secondary coil, and depends on the ratio of N_s to N_p.

Transformers cannot increase the power output of the supply. In an ideal transformer, with no power losses, the power input to the transformer must be equal to the power output. Therefore we can write the following equation:

$$V_pI_p = V_sI_s$$

where V_s = secondary voltage (V), V_p = primary voltage (V), I_s = current in the secondary coil (A) and I_p = current in the primary coil (A).

This means that a transformer that reduces the output voltage compared to the input voltage has a larger current in the secondary coil compared to the primary coil.

EXAMPLE

Step-down transformer

A step-down transformer has 2500 turns on the primary coil. It transforms mains voltage, 230 V ac, into a 12 V ac supply.

1 Calculate the number of turns on the secondary coil.

Answer

Rearranging the equation $\frac{V_s}{V_p} = \frac{N_s}{N_p}$ gives

$$N_s = N_p \times \frac{V_s}{V_p}$$

$$= 2500 \times \frac{12\text{ V}}{230\text{ V}}$$

$$= 130\text{ turns}$$

2 When the current in the secondary coil is 1.5 A, what is the current in the primary coil? Assume that the transformer is 100% efficient.

Answer

Rearranging the equation $V_pI_p = V_sI_s$ gives

$$I_p = \frac{V_s}{V_p} \times I_s$$

$$= \frac{12\text{ V}}{230\text{ V}} \times 1.5\text{ A}$$

$$= 0.078\text{ A}$$

Transformer efficiency

Transformers can be very efficient, but they are never 100% efficient. The efficiency of a transformer is calculated using this equation:

$$\text{efficiency} = \frac{V_sI_s}{V_pI_p}$$

where V_s = secondary voltage (V), V_p = primary voltage (V), I_s = current in the secondary coil (A) and I_p = current in the primary coil (A).

EXAMPLE

Efficiency of a transformer

The efficiency of a mains transformer is 90%. The mains supply is 230 V ac and the output of the transformer is 12 V ac. Calculate the current in the secondary coil when the current in the primary coil is 0.5 A.

Answer

Use the equation for efficiency and substitute the values known:

$$\text{efficiency} = \frac{V_sI_s}{V_pI_p}$$

$$0.9 = \frac{12\text{ V} \times I_s}{230\text{ V} \times 0.5\text{ A}}$$

Rearranging to make I_s the subject gives

$$I_s = \frac{0.9 \times 230\text{ V} \times 0.5\text{ A}}{12\text{ V}}$$

$$= 8.6\text{ A}$$

Energy losses in transformers

Energy losses in transformers occur because of the following effects:

- Heat is produced in the copper wires of the primary coil and secondary coil when a current flows. Using low-resistance wire reduces these losses. This is particularly important for the secondary coil of a step-down transformer, because the current is larger in the secondary coil compared to the primary coil. A thicker wire is often used in the secondary coil of a step-down transformer.
- Some magnetic flux produced by the primary coil does not pass through the iron core, which means the flux linkage to the secondary coil is not 100%. This can be reduced by designing the transformer with coils close to each other or wound on top of each other, which improves the flux linkage.
- There is an effect called *hysteresis*. Some energy is lost as heat every time the direction of the magnetic field changes because energy is needed to realign the magnetic domains in the core. This is reduced by using a soft magnetic material such as iron, rather than steel which needs more energy to demagnetise and magnetise.
- Eddy currents form in the iron core due to the continuously changing flux. These currents heat the core up, increasing energy losses. Eddy currents are reduced by making the core using laminated sheets separated by thin layers of insulation. Eddy currents are discussed in more detail below.

Eddy currents in transformers

In Chapter 8, you learnt that eddy currents are created in metal sheets when there is a change in magnetic flux. In the core of a transformer, the alternating supply creates alternating magnetic flux changes, and these create eddy currents. Eddy currents flow in loops, in a direction that opposes the magnetic flux changes that cause them. The result is that eddy currents in the iron core will reduce the e.m.f. induced in the secondary coil. In a core made from solid iron, eddy currents could become large enough to melt the core, because the resistance of the iron core is very low. To prevent these problems, the core is built from very thin laminations, or layers, of metal (Figure 9.10). The eddy currents are smaller when there are thin laminations, because the induced voltage drives the current round longer paths – so the resistance to flow increases. The laminations are insulated from each other, for example using layers of insulating varnish.

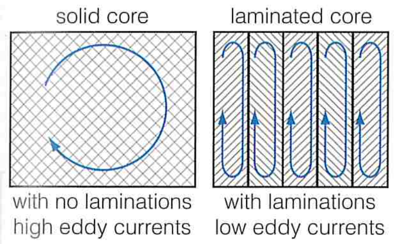


Figure 9.10 Eddy currents are reduced by building the core from thin, insulated layers of iron.

Transmission of electrical power

Energy losses due to the heating of transmission lines in the National Grid can be very significant because electrical energy can be transmitted very long distances from the power stations to the end users. Electricity is transmitted throughout the UK (Figure 9.11), and also between European countries – for example, between the UK, France and the Netherlands.

Transformers are used to step up the voltage generated in power stations. Since power transmitted is equal to the product $V \times I$, stepping up the voltage in transmission lines reduces the current. Smaller currents have a smaller heating effect on the power lines, so reducing the current in transmission lines reduces energy losses to the surroundings.

Power stations generate electrical energy at a potential of about 25 kV. This voltage is stepped up using transformers shortly after it leaves the power station and is transmitted using transmission lines operating at 275 kV and 400 kV. Overhead transmission lines are supported using the familiar large steel pylons. Transformers in substations step down the voltage for distribution of electricity to the end user. Distribution lines operate at 132 kV, with cables supported on smaller steel pylons. Wooden poles are used to support power lines operating at 11 kV and 33 kV.

Calculating power losses in transmission lines

Power losses in the National Grid total about 3% of demand, and mainly occur in the generator transformers, overhead lines, underground cables and grid supply transformers. Two-thirds of the losses in the National Grid occur in the overhead lines of the transmission system. However, the percentage losses in power lines in the distribution system are bigger than in transmission lines because the voltage is stepped down, so currents in the power lines are larger. Losses in the distribution system can reach as much as 15%.

Power losses are calculated using $P = I^2R$. Because the power losses are proportional to the square of the current, doubling the current quadruples the power losses. Power cables are made from aluminium supported by steel cores, and the low resistance of these cables reduces losses in power lines, since losses are proportional to R.

Step-down transformers in distribution systems are made more efficient by using thicker wire in the secondary coil. The current is higher in the secondary coil of step-down transformers, so I^2R losses due to the heating of the secondary coil can be significant. Reducing the resistance of the secondary coil reduces I^2R losses.

EXAMPLE

Transmission line

A power transmission line in a factory operates at 25 kV. The power input to the cable is 750 kW.

1 Calculate the current in the transmission line.

Answer

Rearranging the equation P = VI for power gives

$$I = \frac{P}{V} = \frac{750 \times 10^3 \text{ W}}{25 \times 10^3 \text{ V}}$$

$$= 30 \text{ A}$$

2 The resistance of the cable is 40 Ω. Calculate the power supplied by the cable.

Answer

Use the equation power supplied = input power − power losses

power losses = $I^2R = (30\text{ A})^2 \times 40\,\Omega = 36$ kW

power supplied = 750 kW − 36 kW = 714 kW (710 kW 2sf)

3 Calculate the efficiency of the transmission line.

Use the equation for efficiency and substitute the values known:

$$\text{efficiency} = \frac{P_{out}}{P_{in}} = \frac{714 \text{ kW}}{750 \text{ kW}} \times 100 = 95.2\% \text{ (95\% 2sf)}$$

TEST YOURSELF

5 Explain why:

a) transformers do not work using dc

b) the iron core of a transformer is laminated

c) a thicker wire is used in the secondary coil of a step-down transformer.

6 a) Calculate the turns ratio for a transformer that steps up a 25 kV input to an output of 132 kV.

b) The transformer in part (a) is 90% efficient, and it has a current of 40 A flowing in the primary coil. Calculate the power output in the secondary coil.

c) Calculate the current in the secondary coil.

7 A step-up transformer transforms the input voltage, 12 V ac, into a 48 V ac supply.

a) If the primary coil has 200 turns, calculate the number of turns on the secondary coil.

b) When the current in the primary coil is 2.4 A, what is the current in the secondary coil? Assume that the transformer is 100% efficient.

8 A transformer is 95% efficient. The transformer uses mains voltage, 230 V ac, and the output voltage is 6 V ac. Calculate the current in the primary coil if the current in the secondary coil is 4.8 A.

Practice questions

1 The r.m.s. voltage from a power supply with a peak voltage of 6 V is:

A 3.0 V   **C** 4.2 V

B 0.12 V   **D** 0.85 V

Use the information in Figure 9.12 about the voltage waveform from an ac power supply to answer questions 2, 3 and 4.

2 The peak-to-peak voltage shown in Figure 9.12 is:

A 128 V   **C** 90.5 V

B 64 V   **D** 45.3 V

3 The r.m.s. voltage of the signal shown in Figure 9.12 is:

A 128 V   **C** 90.5 V

B 64 V   **D** 45.3 V

4 The frequency of the ac power supply shown in Figure 9.12 is:

A 0.2 Hz   **C** 0.1 Hz

B 200 Hz   **D** 100 Hz

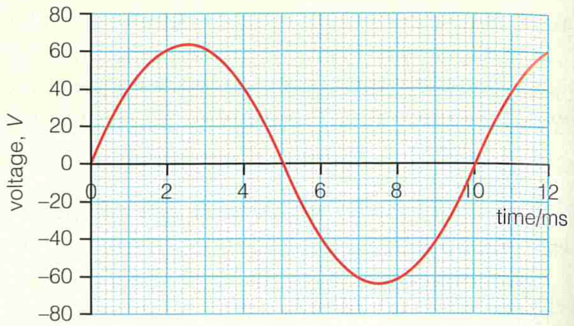


Figure 9.12

5 Which of the waveforms in Figure 9.13 shows a 4.24 V r.m.s. voltage?

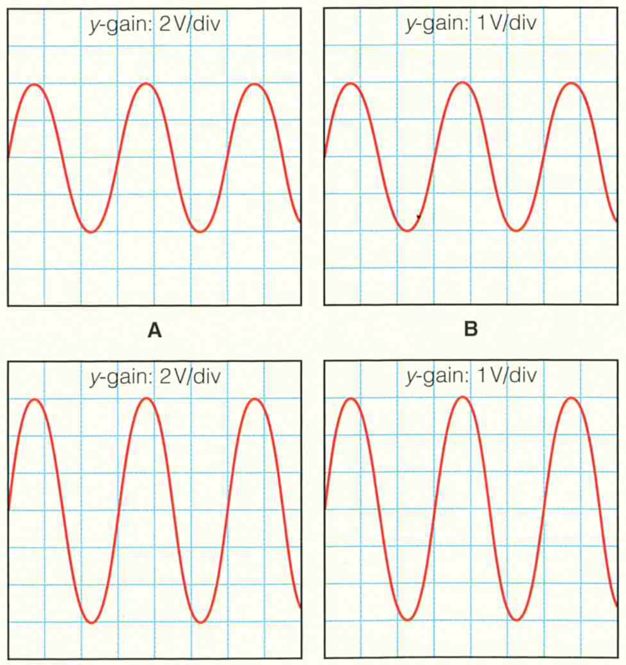


Figure 9.13

6 A transformer has 1500 turns on the primary coil and 600 turns on the secondary coil. The transformer uses 230 V ac mains supply, and draws a current of 0.4 A in normal use. If the efficiency of the transformer is 85%, what is the current in the secondary coil, when the secondary voltage is 92 V?

A 0.65 A   **C** 0.85 A

B 1.00 A   **D** 0.14 A

7 The primary coil of a step-down transformer uses an ac mains supply. The secondary coil is connected to a phone charger. Which line A–D in the table correctly describes the potential difference and current in the secondary coil in relation to the primary coil?

	Secondary current/primary current	Secondary p.d./primary p.d.
A	>1	>1
B	>1	<1
C	<1	>1
D	<1	<1

8 Which of these does not reduce the efficiency of a transformer?

A heating of the primary and secondary coils

B eddy currents in the iron core

C leakage of magnetic flux from the primary coil

D insulation between the primary and secondary coils

9 The National Grid transmits electrical power from power stations using transmission lines. Substations link transmission lines to distribution systems that distribute electrical power to the final users. Which line A–D in the table correctly describes the arrangement of step-up and step-down transformers in the National Grid?

	Transformers in power stations	Transformers in substations
A	Step-up	Step-down
B	Step-up	Step-up
C	Step-down	Step-down
D	Step-down	Step-up

10 A cable, 4 cm^2 in cross-section and of resistivity $5 \times 10^{-8}\,\Omega$ m, carries a current of 2500 A. The power loss per km is:

A 391 W   **C** 391 kW

B 781 W   **D** 781 kW

11 An alternating voltage from a signal generator is displayed on an oscilloscope screen with the following settings: timebase, 25 ms per division; and y-sensitivity, 3 V per division. The waveform of the voltage signal is shown in Figure 9.14.

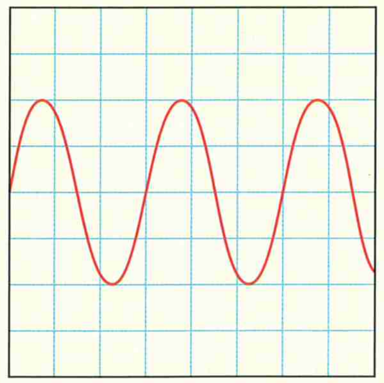


Figure 9.14

Calculate:

a) the peak-to-peak voltage of the signal *(1)*

b) the r.m.s. voltage *(1)*

c) the time period of the signal *(1)*

d) the frequency of the signal. *(2)*

Make a sketch copy of the trace on the oscilloscope screen.

e) On your copy, sketch the dc voltage signal that would produce the same power dissipation in a resistor, of resistance *R*, equivalent to that produced by the signal generator. *(2)*

12 Domestic electricity in the USA is delivered with a peak value of 170 V and a frequency of 60 Hz.

a) State what is meant by the 'peak value' and show how this value is related to the root mean square (r.m.s.) value. *(2)*

b) Calculate the r.m.s. voltage. *(2)*

c) A light bulb is connected to the mains supply in the USA and draws an r.m.s. current of 0.50 A. Calculate the mean power of the bulb. *(1)*

d) Using a suitable set of axes, sketch the voltage waveform of mains electricity in the USA. Include suitable numerical scales on your sketch graph. *(4)*

13 A student is using an oscilloscope to measure the voltage from a range of different voltage sources. She connects the voltage sources to the *y*-input of the oscilloscope. The *y*-gain of the oscilloscope is set to 0.5 V/div, and the timebase is set to 4 ms/div. The screen of the oscilloscope is divided into a 10 × 10 grid as shown in Figure 9.15.

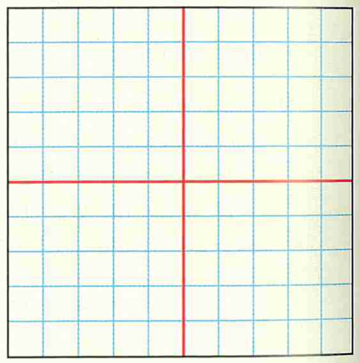


Figure 9.15

a) Copy the diagram twice and draw sketches of the oscilloscope screen illustrating the voltage waveforms of the following sources:

i) 1.5 V cell (battery) *(1)*

ii) UK mains low-voltage ac power supply, 2 V (peak). *(2)*

b) Calculate the r.m.s. voltage of the ac power supply. *(2)*

14 a) Describe how you would use an oscilloscope to compare the output from an ac, 12 V_{rms}, 15 Hz wind turbine and a 12 V dc car battery. You need to consider the quality of your written communication in your answer. *(6)*

b) The car battery is connected to a car headlight bulb and the current is measured to be 2.5 A. Calculate the power of the bulb. *(1)*

c) Calculate the peak power drawn from the wind turbine if it was connected to the same car headlamp, with the same mean power. *(1)*

d) Calculate the peak voltage produced by the wind turbine. *(2)*

15 High-voltage transmission of electrical power in the National Grid can cause large energy losses. Explain how energy losses are minimised when transmitting ac voltage in the National Grid. *(6)*

16 A transformer is used inside a 12 V, 60 W heater, to step down the mains voltage of 230 V.

a) Calculate the turns ratio for the heater's transformer if the output voltage is 12 V r.m.s. when the heater is connected to a mains supply of 230 V r.m.s. State any assumptions you make. *(3)*

b) Calculate the current in the supply lead when the heater is connected to the mains supply and turned on. *(3)*

c) The r.m.s. current flowing in the primary coil is 0.26 A. Calculate the efficiency of the heater's transformer if the r.m.s. output voltage is 11.8 V, and an r.m.s. current of 4.5 A flows in the secondary coil. *(3)*

17 A factory uses a transformer to step down the voltage from 11 kV to 415 V.

a) Calculate the number of turns on the secondary coil if there are 3000 turns on the primary coil. *(3)*

b) A crane with maximum power of 60 kW uses the 415 V ac supply. Calculate the current drawn from the 11 kV supply when the crane works at maximum power, at which point the efficiency of the transformer is 85%. *(3)*

c) State two important causes of energy loss in the transformer and describe how the transformer is designed to reduce these losses. *(4)*

Stretch and challenge

The first question that follows here is a British Physics Olympiad question.

18 A 20 Ω resistor is connected to an ac power supply with a voltage output that varies from 4 V to –2 V at equal time intervals, as shown in Figure 9.16. What is the mean heating power dissipated in the resistor?

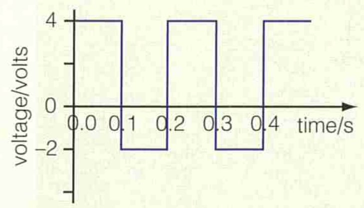


Figure 9.16

A 0.2 W

B 0.5 W

C 0.8 W

D 1.0 W

(BPhO AS Challenge – 2007 Q4)

19 A 'saw tooth' waveform voltage rises from 0 to a maximum value V_0 in a time *t*, at which point it immediately falls to 0 again, before rising once more to the value V_0. Show that the power generated by this voltage through a resistance *R* is the same as would be generated by a dc voltage of $\frac{V_0}{\sqrt{3}}$.