



18

alternating current

18.1 Characteristics of alternating currents

18.2 The transformer

18.3 Rectification with a diode

Learning Outcomes

Candidates should be able to:

- (a) show an understanding of and use the terms period, frequency, peak value and root-mean-square (r.m.s.) value as applied to an alternating current or voltage
- (b) deduce that the mean power in a resistive load is half the maximum (peak) power for a sinusoidal alternating current
- (c) represent an alternating current or an alternating voltage by an equation of the form $x = x_0 \sin \omega t$
- (d) distinguish between r.m.s. and peak values and recall and solve problems using the relationship $I_{rms} = I_0 / \sqrt{2}$ for the sinusoidal case
- (e) show an understanding of the principle of operation of a simple iron-core transformer and recall and solve problems using $N_s / N_p = V_s / V_p = I_p / I_s$ for an ideal transformer
- (f) explain the use of a single diode for the half-wave rectification of an alternating current.

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18.1**Characteristics of alternating currents****MCQs****[2012(18.1).Q21]**

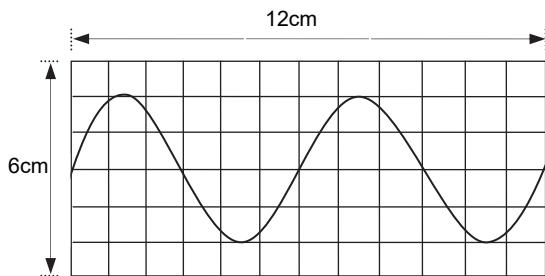
Water from a reservoir is fed to the turbine of a hydroelectric system at a rate of 500 kg s^{-1} . The reservoir is 300 m above the level of the turbine. The electrical output from the generator driven by the turbine is 200 A at a potential difference of 6000 V.

What is the efficiency of the system?

- | | |
|----------------|----------------|
| A 8.0 % | B 8.2 % |
| C 80 % | D 82 % |

[Teachers' Comment] A common incorrect answer was C. Candidates must use $g = 9.81 \text{ m s}^{-2}$ and not 10 m s^{-2} .

1. An oscilloscope is adjusted so that its Y sensitivity is 3 V cm^{-1} and its time-base is 0.1 ms cm^{-1} . The trace on the screen is as shown in the diagram below.



What are the correct values for the peak voltage and the frequency of the supply?

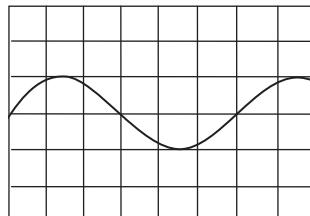
	Peak voltage / V	Frequency
(A)	6	1.67
(B)	6	0.67
(C)	12	1.67
(D)	12	0.67

2. A sinusoidal alternating supply is connected across the terminals of a resistor causing energy to be dissipated at a mean rate P . An ideal diode is inserted in the circuit in series with the resistor. What is the new mean rate of energy dissipation?

(A) zero

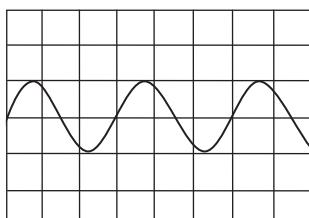
(C) $\frac{1}{2}P$ (B) P $\frac{1}{\sqrt{2}}P$

3. The diagram below shows the waveform obtained when the output of a generator is connected to a cathode ray oscilloscope.

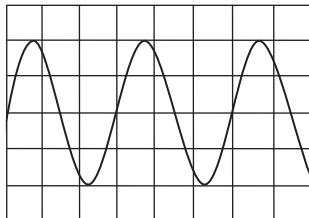


Which one of the following best represents the output when the speed of rotation of the generator is doubled and no adjustment is made to the oscilloscope?

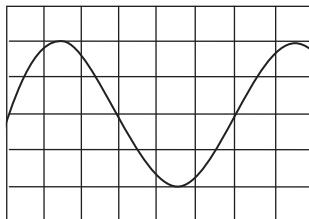
(A)



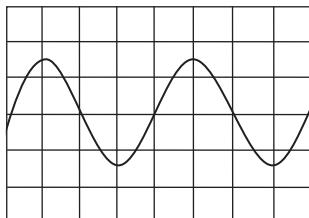
(B)



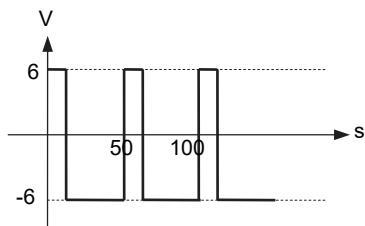
(C)



(D)

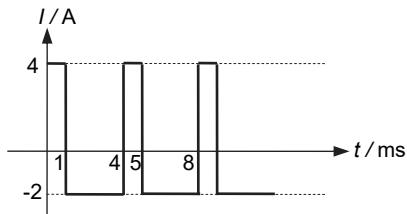


4. The figure below shows the variation of output voltage with time for an alternating supply. This supply is connected to a pure resistor of resistance 3.0Ω .



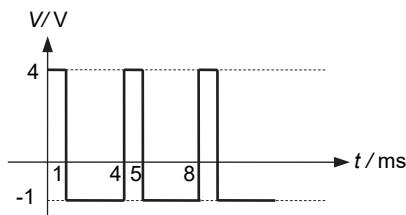
The power dissipated in the resistor is

5. The figure below shows the variation with time of a periodic current.



What is the root mean square value of the current?

6. The voltage V of an a.c. source varying with time t as shown in the figure is applied across a resistor of resistance $2.0\ \Omega$.



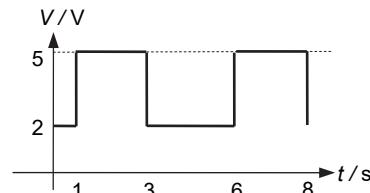
The r.m.s. current I_{rms} through the resistor is

7. A direct current of 10 A flowing through a heating coil produces a power output of P . What is the new power output in the same heating coil by an alternating current with a peak value of 10 A?

- (A) $\frac{1}{4}P$ (B) $\frac{1}{2}P$
 (C) P (D) $2P$

8. When a light bulb is connected across an a.c. source of peak voltage 170 V, the power dissipated is 40 W. Two such light bulbs are now connected in series to the electrical mains of 220 V r.m.s. What would be the total power dissipated?

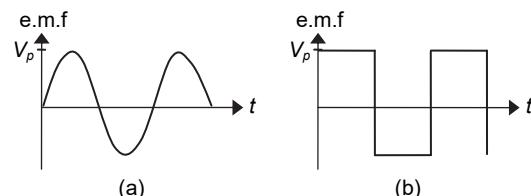
9. What is the mean power dissipated in a resistor of $5.0\text{ k}\Omega$ when the potential difference signal shown below is connected across it?



- 10.** A sinusoidal current of root-mean-square value I is passed through a resistor R with a diode connected in series with it. The average rate of heat dissipated in R is

- (A) $0.25 I^2 R$ (B) $0.50 I^2 R$
 (C) $0.71 I^2 R$ (D) $1.41 I^2 R$

- 11.** A signal generator produces either (a) a sinusoidal or (b) a square wave with the same peak value of e.m.f as shown below:



When the signals are applied to a resistor, determine the ratio of

Mean power of case (a)

Mean power of case (b)

- (A) $\frac{1}{4}$ (B) $\frac{1}{2}$
 (C) $\frac{1}{\sqrt{2}}$ (D) 1

- 13.** An a.c. supply is connected to a resistor. When the peak value of the e.m.f of the supply is V_0 and the frequency is f , the mean power dissipated in the resistor is P . The supply frequency is then changed to $2f$, the peak value of the e.m.f. remaining as V_0 . What is now the mean power in the resistor?

14. A steady current I dissipates a certain power in a variable resistor. The resistance has to be halved to obtain the same power when a sinusoidal alternating current is used. What is the r.m.s. value of the alternating current?

- (A) $\frac{1}{2}I$ (B) $\sqrt{\frac{1}{2}}I$
 (C) I (D) $\sqrt{2}I$

15. A sinusoidal current of peak value I_0 dissipates power in a resistor at a mean rate P . What are the values for the mean current in the resistor and the maximum instantaneous power dissipated?

	Mean current	Maximum power
(A)	$\frac{I_0}{\sqrt{2}}$	$2P$
(B)	$\frac{I_0}{\sqrt{2}}$	$\sqrt{2}P$
(C)	0	$2P$
(D)	0	$\sqrt{2}P$

16. An alternating current I/A varies with time t/s according to the equation

$$I = 5\sin(100\omega t)$$

What is the mean power developed by the current in a resistive load of $10\ \Omega$?

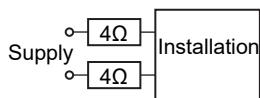
17. A direct current of 10 A flowing through a heating coil produces a certain power P . What is the new power produced in the same heating coil by an alternating current of 10 A peak value?

- (A) $\frac{1}{2}P$ (B) $\frac{1}{\sqrt{2}}P$
 (C) P (D) $2P$



Questions – 18.1

1. (i) Define the *peak value* and *root-mean-square* value of a sinusoidal alternating current. State the mathematical relation between them.
- (ii) Electrical cables connecting a generator supplying 5000 kW of electrical power to a high voltage installation is shown below in the figure below. The total resistance of the cables is 8Ω .



What will be the maximum power output of the installation if used on

- (1) a 50 kV direct supply,
 - (2) an alternating supply with a peak voltage of 50 kV?
- (iii) Explain why the transmission of electrical energy in national distribution systems is carried out with alternating current and with a high voltage.



2. (i) Distinguish between the peak value and root-mean-square value of an alternating current.

- (ii) Given that V_{rms} of the sinusoidal alternating current shown in Fig. 1 is $\frac{V_0}{\sqrt{2}}$, find V_{rms} of the voltages shown in Fig. 2 and Fig. 3. Show your workings clearly.

(Note: no marks will be awarded for simply stating the V_{rms})

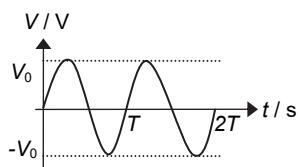


Fig. 1

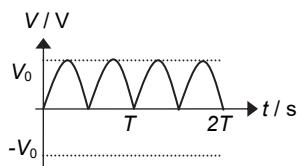


Fig. 2

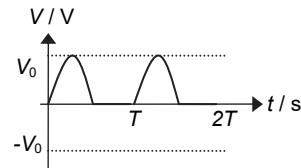


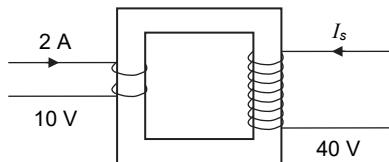
Fig. 3



18.2 The transformer

MCQs

1. A transformer has a turn ratio of 1:4. If the electrical energy is converted to heat in the windings and the core at the rate of 4 W, what is the current in the secondary?



- (A) 0.1 A (B) 0.4 A
 (C) 0.5 A (D) 0.8 A

2. A transformer, connected to a 240 V power supply, light a set of four 12 V, 24 W lamps to their normal brightness. Given that these lamps are connected in parallel to the secondary coil, what is the current in the primary coil, assuming no losses?

- (A) 0.20 A (B) 0.40 A
 (C) 0.80 A (D) 2.0 A

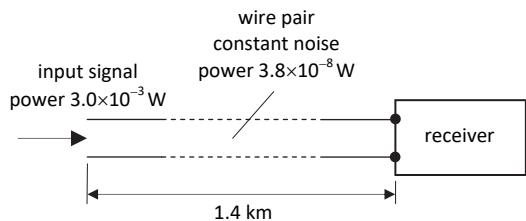
3. The ratio of turns of the primary coil to the secondary coil is 10:1. The primary voltage and current are 20 V and 3 A respectively. The efficiency of the transformer is 0.9. Which statement is wrong?
- (A) The secondary voltage is 2 V.
 (B) The output power is 60 W.
 (C) The secondary current is 27 A.
 (D) Energy lost is 6 W.

4. The function of a transformer is to convert
- (A) An alternating voltage to a direct voltage.
 (B) A direct voltage to an alternating voltage.
 (C) One direct voltage to another direct voltage of a different magnitude.
 (D) One alternating voltage to another alternating voltage of a different magnitude.

Questions – 18.2

[2012(18.2).Q12]

- (a) Wire pairs used for the transmission of telephone signals are subject to cross-linking.
- (i) Explain what is meant by *cross-linking*. [1]
- (ii) Suggest why cross-linking in coaxial cables is much less than in wire pairs. [2]
- (b) A wire pair has a length of 1.4 km and is connected to a receiver, as illustrated in the figure below.

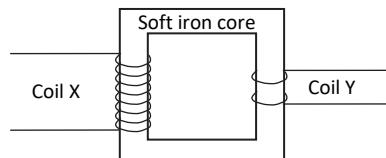


The constant noise power in the wire pair is 3.8×10^{-8} W. For an input signal to the wire pair of 3.0×10^{-3} W, the signal-to-noise ratio at the receiver is 25 dB.

Calculate the attenuation per unit length for the wire pair. [4]

- [Teachers' Comment]**
- (a) (i) Cross-linking was frequently confused with noise.
- (ii) A common misunderstanding was to attribute shielding of the core to the insulator surrounding the core, without mentioning the outer braid. The fact that the outer braid is earthed was mentioned in a small minority of scripts.
- (b) This type of calculation is becoming more familiar to candidates but they do need to apply caution. Amplification and attenuation are frequently confused. A significant number of calculations started by assuming that the attenuation along the wire pair is 25dB. The most usual correct method was to determine the minimum signal power at the receiver and then to calculate the attenuation in the wire pair.

1. The figure below shows 2 coils X and Y wound on a soft-iron core.

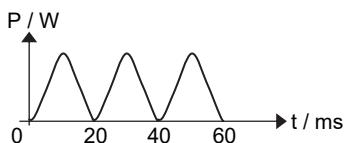


- (a) Magnetic flux links X and Y when there is a current in X. What happens in coil Y when the magnetic flux in the core changes? State a law that justifies your answer.



- (b) (i) The input of coil X is now connected to a 240 V mains supply, the current from which changes direction 100 times per second. The output of coil Y is connected to a 12 V, 3 A light bulb. The bulb lights with full intensity. Use energy considerations to calculate the current in coil X. Assume that the efficiency of energy transfer between the two coils is 100%.
- (ii) Suggest what would happen to the light bulb if a source supplying a constant 240 V were substituted for the mains supply. Give a reason for your answer.

2. A graph of the power input to a transformer (assumed to be ideal) is shown in the figure below.



The transformer has a turns ratio of $\frac{N_s}{N_p} = 10$ and

the sinusoidal input voltage has a value of 6.0 V r.m.s. For the transformer, showing your working clearly, calculate

- (i) the r.m.s. output voltage
- (ii) the mean power output
- (iii) the r.m.s. value of the input current
- (iv) the r.m.s. value of the output current
- (v) The output power is transmitted to a second

transformer with turns ratio $\frac{N_s}{N_p} = \frac{1}{10}$ via

connecting wires of total resistance 1Ω . Find the input power to the second transformer.

3. A power station needs to deliver 20.0 MW of power to a city 10.0 km away. This power is generated at 16.0 kV and then stepped up to 240 kV using a transformer before transmission. The total resistance of the transmission cables is $20.0\text{ k}\Omega$. The station loses \$0.10 for every kWh of electrical power lost. (Note: $1.0\text{ kWh}=3.6\text{ MJ}$)

- (i) Show the power lost during transmission is 139 kW and hence determine the amount of money lost by the station in one day if power is delivered at 240 kV.

- (ii) Explain quantitatively why it is more economical to transmit electricity at 240 kV instead of 16.0 kV.
- (iii) State the turns ratio of the transformer required.



4. A generator at the utility supply company is specified as "240 V_{rms} , 50 Hz a.c." and it produces I_{rms} of 6.00 A. The voltage is stepped up to 2700 V_{rms} by an ideal transformer and transmitted a long distance through a power line of total resistance 30.0Ω .

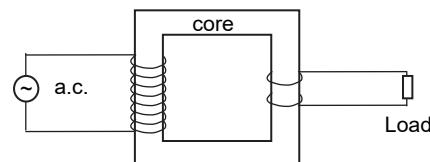
- (a) Find the turn ratio $\frac{N_s}{N_p}$ of the transformer.
- (b) On the same axes given below, sketch two waveforms of the supply voltage, before and after the voltage has been stepped up by the transformer. Label your graphs and add numerical values to the axes where appropriate.



- (c) Determine the percentage of power lost in the transmission line.
- (d) What percentage of the original power would be lost in the transmission line if the voltage has not been stepped up?
- (e) Suggest a way to reduce the power lost in the transmission line in part (c).



5. The figure below shows a simple iron-cored transformer. The primary coil is connected to a 120 V a.c. power supply and the output voltage across the load in the secondary coil is 60 V a.c.



- (i) State Faraday's law of electromagnetic induction and use the law to explain why a transformer will operate for an a.c. input but not for a d.c. input.

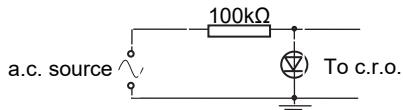
- (ii) Sketch a graph to show how the power dissipated in the resistor varies with time over one cycle of the alternating output voltage.
- (iii) Calculate the efficiency of the transformer if the r.m.s current in the primary and secondary coils are 2.5 A and 4.0 A respectively.
- (iv) State 3 reasons why you would expect this efficiency to be less than 100%.

18.3

Rectification with a diode

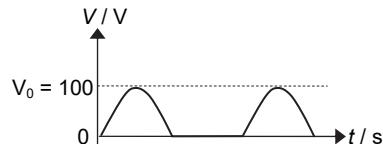
MCQs

1. In the circuit below, the waveform across the diode shown on the screen of a cathode ray oscilloscope should be



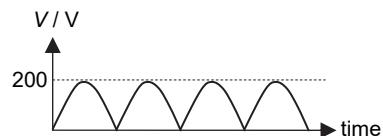
- (A)
- (B)
- (C)
- (D)

2. The half-wave rectification of an alternating sinusoidal voltage of amplitude 100 V gives the waveform as shown in the figure. The r.m.s. value of the rectified voltage is



- (A) 125 V
- (B) 150 V
- (C) 171 V
- (D) 1100 V

3. Full wave rectification of a sinusoidally alternating voltage of amplitude 200 V gives the waveform as shown in the diagram.

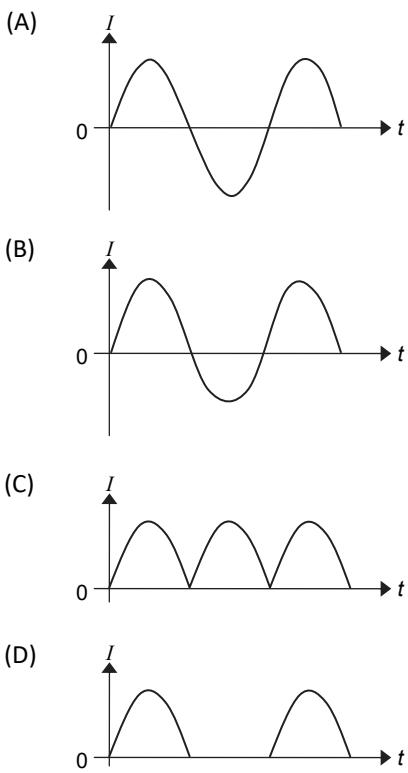
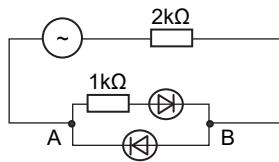


The r.m.s value of the rectified voltage is

- (A) 0 V
- (B) 70 V
- (C) 100 V
- (D) 141 V



4. Which of the following graphs best represents the variation with time t of the current I through the segment AB in the circuit below?



(A)



(B)



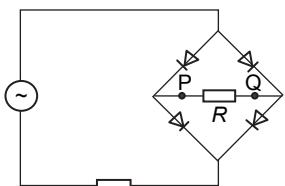
(C)



(D)



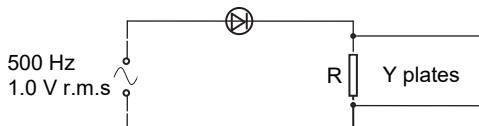
5. The circuit below shows a connection of four ideal rectifiers with a sinusoidal alternating voltage applied to it. The terminals P and Q are joined by a load resistor.



Which of the following traces would be seen on a cathode-ray-oscilloscope (CRO) connected across PQ?

Questions – 18.3

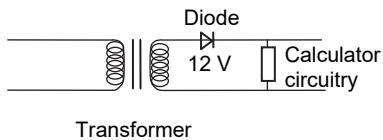
1. The figure below is the circuit diagram for a half-wave rectifier. The supply to the rectifier is a 500 Hz, 1.0 V r.m.s. sinusoidal signal. The diode may be assumed to be ideal. The Y-plate sensitivity and time-base of the cathode-ray oscilloscope are set at 0.5 V cm^{-1} and 0.50 ms cm^{-1} respectively.



Sketch a full-scale diagram to show the waveform observed on the cathode ray oscilloscope.

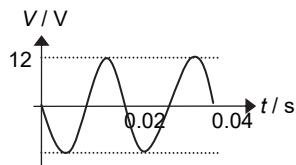


2. A desk-top calculator is being operated from a 240 V .r.m.s mains supply. The calculator has a transformer device to change the 240 V r.m.s. supply to a voltage of peak value of about 12 V in the calculator. Prior to current entry to the calculator circuitry, a diode is connected between the secondary coil of the transformer and the calculator circuitry. The diode forms part of the rectifier circuit. A diagram of the system is shown below in the figure below.



The diode allows current to pass through it when the voltage drop across it is at least 0.7 V.

The graph below shows the input voltage to the calculator prior to half-wave rectification.



- What is meant by the root-mean-square (r.m.s) value of an alternating voltage?
- Sketch a graph showing the voltage against time across the calculator circuitry for the input voltage shown over 2 cycles. Label the maximum potential difference across the calculator circuitry on your sketch.

- (iii) State and explain one disadvantage of a half-wave rectifier when used in the above application.





Answer keys:

18.1

MCQs

2012(18.1).Q21 D

1. A

2. C

3. B

4. B

5. B

6. A

7. B

8. B

9. C

10. B

11. B

12. C

13. A

14. D

15. C

16. A

17. A

Questions

1. (ii)(1) 4920 kW

(ii)(2) 4840 kW

2. (ii) $V_{rms} = \sqrt{\frac{2A}{T}}$,

$$V_{rms} = \frac{V_0}{\sqrt{2}}, \quad V_{rms} = \frac{V_0}{2}$$

18.2

MCQs

1. B

2. B

3. B

4. B

5. D

Questions

2012(18.2).Q12

(b) 17 dB km⁻¹

1. (b)(i) 0.15 A

2. (i) 60 V

(ii) 27 W

(iii) 4.5 A

(iv) 0.45 A

(v) 24.975 W

3. (i) \$333

(ii) \$75000

(iii) 1:15 or 15:1

4. (a) $\frac{45}{4}$

(b) 339 V, 3820 V

(c) 0.59 %

(d) 75 %

5. (iii) 80 %

18.3

MCQs

1. D

2. B

3. D

4. B

5. B

