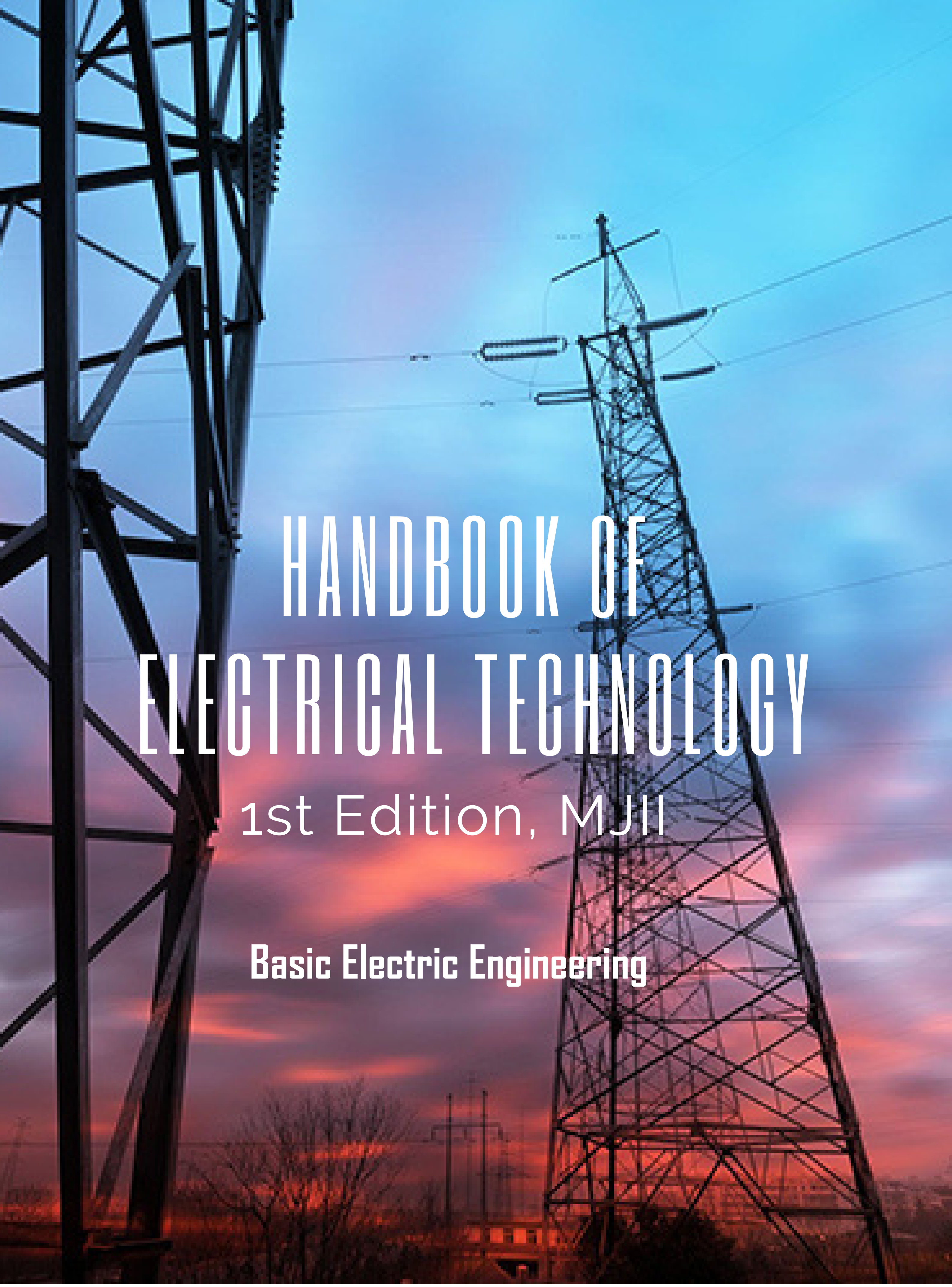

HANDBOOK OF ELECTRICAL TECHNOLOGY

1st Edition, MJII

Basic Electric Engineering

TUTORIAL / EXERCISES

ELECTRICAL TECHNOLOGY

Course Rationale:

This is a fundamental course in Electronic Engineering and lays the foundation for any engineering programme.

Course Synopsis:

This course focuses on the behaviours of passive elements in circuits with AC power supplies. Students will be exposed to the measurements of current, voltage and power of electric circuits with AC voltage source. The course also includes basic concept and application of transformer and the fundamental knowledge of three-phase power system.

Course Learning Outcomes

After completing the course, students should be able to:

1. Explain basic concept for AC electric circuits, transformer and three-phase system.
2. Analyze current, voltage, impedance, power, power factor, phase relationship between current and voltage for basic AC electrical circuit, transformer and three-phase system.
3. Show the ability to perform experiments.
4. Work collaboratively in a team during practical session and demonstrate skill of communication through written assignment or oral presentation.

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INDEKS

UNIT 1: INTRODUCTION TO AC SYSTEM

1.0 INTRODUCTION TO AC SYSTEM

An alternating electrical signal is a voltage or current waveform that changes consistently with time. In other words, it changes instantaneously with time. Both current and voltage have magnitude as well as positive and negative polarity.

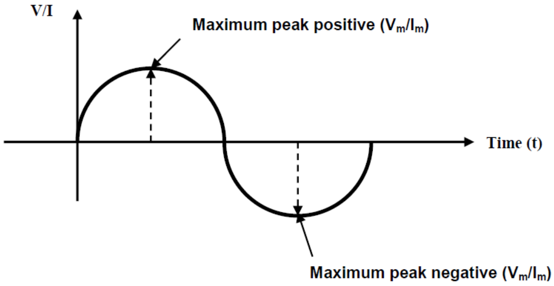


Figure 1: Alternating voltage v(t) or alternating current I(t) changes polarity over time.

An alternating voltage is the one that changes polarity at certain rate, *v(t) = f(t)*, and also an alternating current is the one that changes direction at certain rate, *i(t) = f(t)* as shown in the Figure 1. The sinusoidal waveform is most common and fundamental type compared to the other types of repetitive waveform. The sine wave is a periodic type of waveform that repeats at fixed intervals.

SUB-TOPIC :	1.1 AC System 1.2 The Sine wave 1.3 Sinusoidal voltage source 1.4 Voltage and current values of sine waves 1.5 Angular measurement of a sine wave.	1.6 The sine wave formula 1.7 Introduction to Phasors 1.8 Analysis of AC Circuit 1.9 Superimposed DC and AC voltages.
LEARNING OUTCOME :	After completing this lesson student should be able to: 1. Describe the characteristics of a sinusoidal waveform including its general format, average value, and effective value. 2. Differentiate the expressions in time-domain and phasor-domain 3. Determine the phase relationship between two sinusoidal waveforms of the same frequency. 4. Calculate simple ac circuits using basic circuit laws (Ohm's Law, Kirchhoff's Law, etc.)	

1.1 SUMMARY

1. The sine wave is a time varying, periodic waveform.

2. Alternating current changes direction in response to changes in the polarity of the source voltage.

3. One cycle of an alternating sine wave consists of a positive alternation and negative alternation.

4. Two common sources of sine waves are the electromagnetic ac generator and the electronic oscillator circuit.

5. A full cycle of a sine wave is 360°, or 2π radians. A half-cycle is 180°, or π radian. A quarter-cycle is 90°, or π/2 radian.

6. A sinusoidal voltage can be generated by a conductor rotating in a magnetic field.

7. Phase angle is the difference in degrees or radians between a given sine wave and a reference sine wave.

8. The angular position of a phasor represents the angle of the sine wave with respect to 0° reference, and the length or magnitude of a phasor represents the amplitude.

9. Conversion of sine wave values are summarized in Table 1.0.

Table 1.0: Conversion of Sine Wave

To change from	To	Multiply By
Peak	rms	0.707
Peak	Peak-to-peak	2
Peak	Average	0.637
rms	Peak	1.414
Peak-to-peak	Peak	0.5
Average	Peak	1.57

10. Ohm's law states that the voltage *v* across a resistor is directly proportional to the current *i* flowing through the resistor.

That is,

$$v \propto i$$

Ohm defined the constant of proportionality for a resistor to be the resistance, *R*.

$$v = iR$$

11. Kirchhoff's current law (KCL) states that the algebraic sum of current entering a node (or a closed boundary) is zero or the sum of currents entering a node is equal to the- sum of currents leaving the node. Mathematically, KCL implies that

$$\sum_{n=1}^{N} i_n = 0$$

where N is the number of branches connected to the node and i_n is the *n*th current entering or leaving the node.

12. Kirchhoff's voltage law (KVL) states that the algebraic sum of all voltages around a closed loop (or path) is zero or the sum of voltage drops is equal to the sum of voltage rises. Mathematically, KVL implies that

$$\sum_{m=1}^{M} v_m = 0$$

where M is the number of voltages in the loop and v_m is the *m*th voltage.

1.2 TUTORIAL

1. Sketch (i) 5 sin 754t and (ii) –7.6 sin 436t with the horizontal axis,
   a) in radians
   b) in degrees
   c) in second

2. Refer to Q1.1. Calculate the average and effective values if the sinusoidal waveform in (i) and (ii) is the current waveforms.

3. A sinusoidal voltage with a maximum amplitude of 150 V and an amplitude of 15 V at t = 0 second. Determine the voltage expression $v(t)$ for one complete cycle taken in 1 ms. Sketch the waveform.

4. Given the sinusoid 5 sin(4πt - 60°), calculate its amplitude, phase, angular frequency, period, and frequency.

5. Refer to waveform in Figure Q1.5, determine the frequency (f), angular frequency (ω), and write the current expression i(t). Calculate the instantaneous value for t = 2 ms.

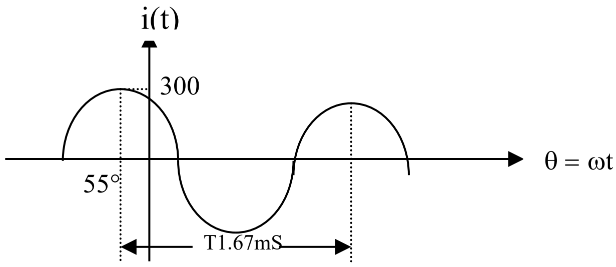


Figure Q1.5

6. Given $v(t)$ = 8 cos (8t + 40°)V
   i) Calculate the period, T
   ii) State the phase relation between the voltage and current i(t) = 6 cos (8t - 80°) A. Sketch both waveforms.

7. State the phase relation for the waveforms below:

a) $v(t) = 4 \sin(\omega t + 50°)$ V ; $i(t) = 5 \sin(\omega t + 60°)$ A

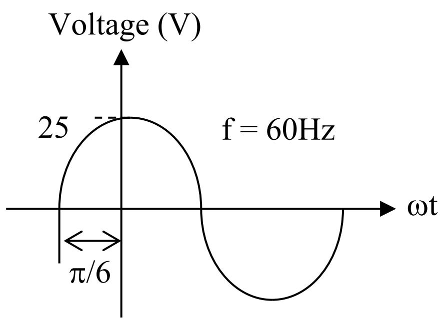
b) $v(t) = 25 \sin(\omega t - 80°)$ V ; $i(t) = 5\times10^{-3} \sin(\omega t - 10°)$ A

c) $v(t) = 2 \cos(\omega t - 30°)$ V ; $i(t) = 5 \sin(\omega t + 60°)$ A

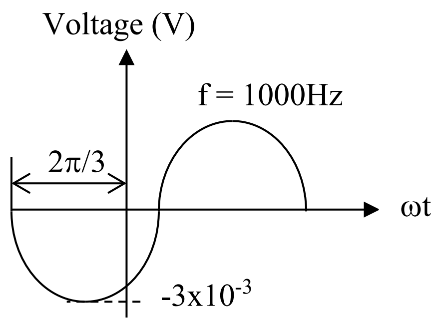
d) $v(t) = -1 \sin(\omega t + 20°)$ V ; $i(t) = 10 \sin(\omega t - 70°)$ A

e) $v(t) = -4 \cos(\omega t + 90°)$ V ; $i(t) = -2 \sin(\omega t + 10°)$ A

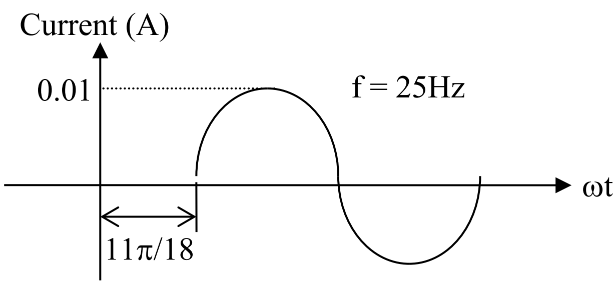
8. Write the expression for the waveforms given below and state the angle in degrees.



(a)



(b)



(c)

9. Refer to waveform in Figure Q1.9 below:
   i) $v_1(t)$ and $v_2(t)$ are waveforms having the same frequency. Write the expressions $v_1(t)$ and $v_2(t)$ in time-domain and in phasors diagram representation.
   ii) Draw the phasors diagram representation for both $v_1(t)$ and $v_2(t)$ and conclude for both graphs.

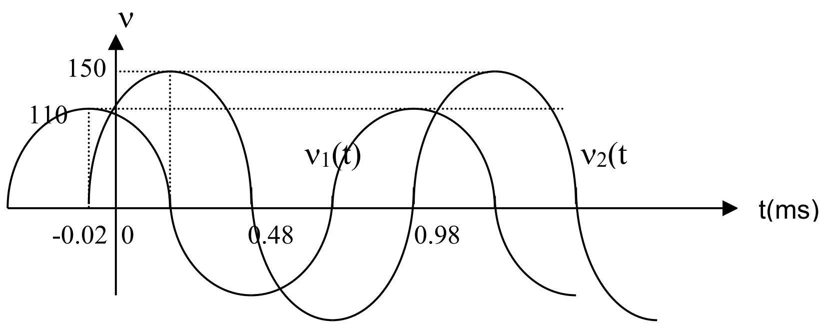


Figure Q1.9

10. Determine the phasor representation for the time-domain functions below:-
    i) $i(t) = 142 \sin(\omega t + 50°)$ mA
    ii) $i(t) = 0.35 \sin(167t - 40°)$ A
    iii) $v(t) = 300 \sin(\omega t - 90°)$ V
    iv) $v(t) = 142 \sin(377t + 90°)$ V
    v) $i(t) = 66 \cos \omega t$ A
    vi) $v(t) = 360 \sin(754t - 120°)$ V

11. Determine the time-domain function for the phasors representation below:-
    i) $I = 48 \angle 25°$A
    ii) $V = 200 \angle 0°$ V
    iii) $I = 8 \angle 120°$A
    iv) $V = 50 \angle 90°$ V
    v) $I = 1600 \angle -120°$ A
    vi) $V = 42.4 \angle -180°$ V

12. Given in time-domain, $i_1(t) = 5\sqrt{2}\sin(\omega t - 30°)$A; $i_2(t) = 14.14\sin(\omega t + 60°)$A. Determine $i_1(t) + i_2(t)$.

13. A sine wave with rms value of 10.6 V is riding on a dc level of 24 V. What are the maximum and minimum values of resulting waveform?

14. Calculate the values of v_1, v_2 and i_3 for the circuit in Figure Q1.14.

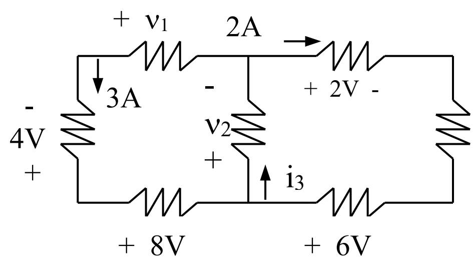


Figure Q1.14

UNIT 2: RC CIRCUIT

2.0 RC CIRCUIT

When a sinusoidal signal is applied to a series RC circuit, each resulting voltage drop and the current in the circuit are also sinusoidal and have the same frequency as the applied voltages. The capacitance causes a phase shift between the voltages and current as shown in Figure 2.1.

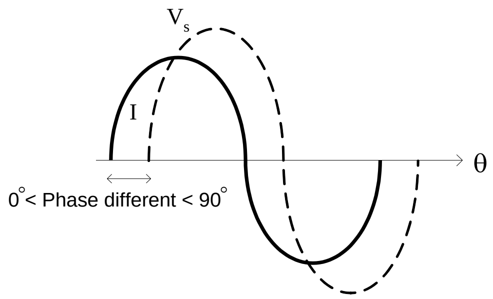


Figure 2.1: Vs versus I if both resistor and capacitor exist in a circuit

To explain this, consider the RC circuit with a sinusoidal voltage source shown in Figure 2.2. The amplitudes and the phase relationships of the voltages and current depend on the values of the resistance and the capacitive reactance.

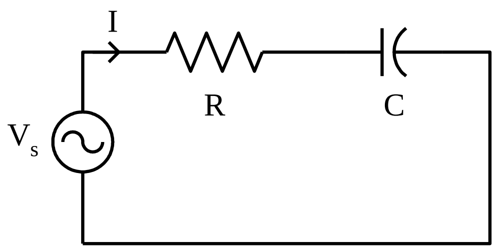


Figure 2.2: RC Circuit

SUB-TOPIC :	2.1 Sinusoidal response of RC circuits. 2.2 Impedance and phase angle of series RC circuits. 2.3 Analysis of series RC circuits. 2.4 Impedance and phase angle of parallel RC circuits. 2.5 Analysis of parallel RC circuits. 2.6 Combination of series and parallel RC circuits. 2.7 Power in RC circuits.
LEARNING OUTCOME :	After completing this lesson, students should be able to: 1. Define the terms of impedance, conductance, susceptance, and admittance of RC circuits. 2. Determine the phase relationship between current and voltage of RC circuit. 3. Analyze simple RC circuits using basic circuit law (Ohm's Law, Kirchhoff's Law, etc.) 4. Determine power and power factor in RC circuits.

2.1 SUMMARY

1. When sinusoidal voltage is applied to an RC circuit, the current and all voltage drops are also sine waves.

2. Total currents in an RC circuit always leads the source voltage.

3. For resistance, the voltage across it is in phase with the current through it.

4. In capacitor, the current leads the voltage by 90°.

5. The impedance of RC circuit is the ratio of source voltage, V_s to total current I_{tot}, i.e.

$$Z_{tot} = \frac{V_S}{I_{tot}}$$

6. In an RC circuit, part of the power is resistive (Real Power) and reactive (Reactive Power).

7. Power factor of an RC circuit is the ratio of real power, P to Apparent Power, S, i.e.

$$cos\theta = \frac{P}{S}$$

   Where θ is the angle between the current and voltage of the circuit and can be calculated as:

$$\theta = tan^{-1}\left(\frac{X_C}{R}\right)$$

8. In an RC circuit, the power factor is said to be leading because the phase angle, θ of total current, I_{tot} lead the source voltage, V_s.

2.2 TUTORIAL

1. For each circuit in Figure Q2.1, write the phasor expression for the impedance in both rectangular form and polar form.

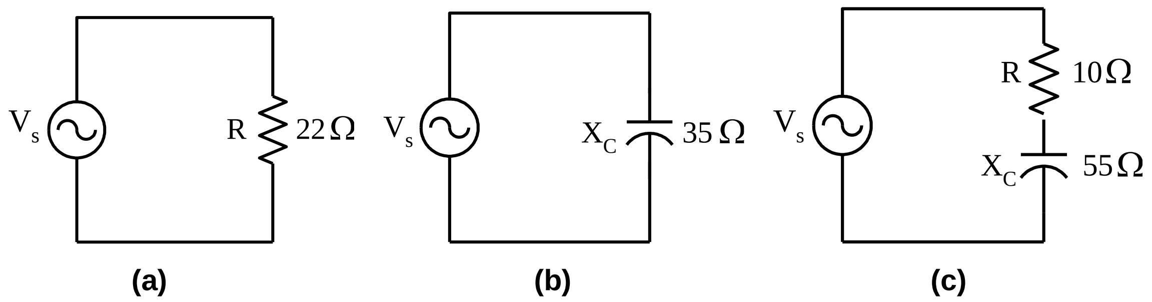


Figure Q2.1

2. Determine the values of R and X_C in a series RC circuit for the following values of total impedance:

   (a) Z = 33 – j 50 Ω

   (b) Z = 300∠-25º Ω

3. A voltage of10 V at 1.5 kHz is applied across a resistor of 2.2 kΩ and capacitor 0.022µF. Determine the current and draw the phasor diagram showing the relation between source voltage and current.

4. For the circuit in Figure Q2.4, determine the value of current at each branch then draw the current phase diagram.

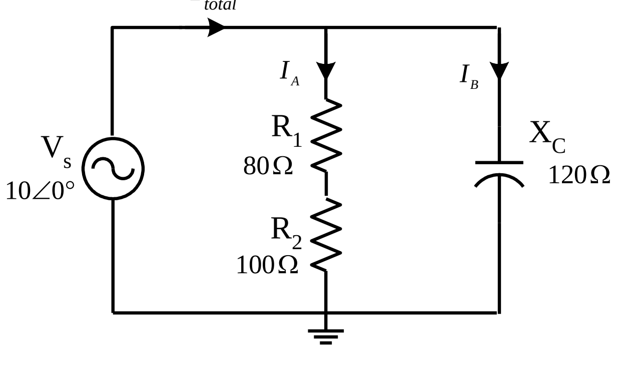


Figure Q2.4

5. For the circuit in Figure Q2.5, draw the phasor diagram showing the voltage across the resistor and capacitor and the total current. Indicate the phase angle.

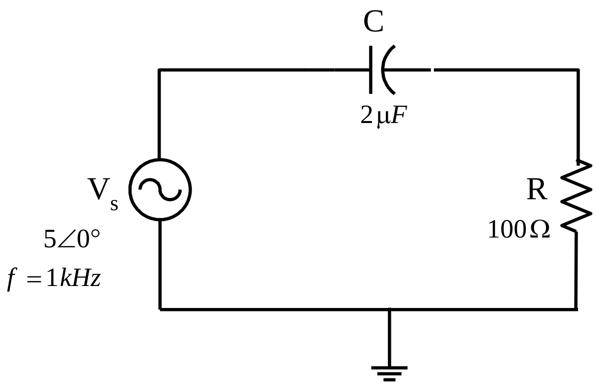


Figure Q2.5

6. Repeat problem 5 for the circuit in Figure Q2.5, using frequency,f=2kHz.

7. The current in Figure Q2.7 is expressed in polar form as I = 0.2∠0º mA. Determine the source voltage expressed in polar form, and draw the phasor diagram showing the relation between source voltage and current.

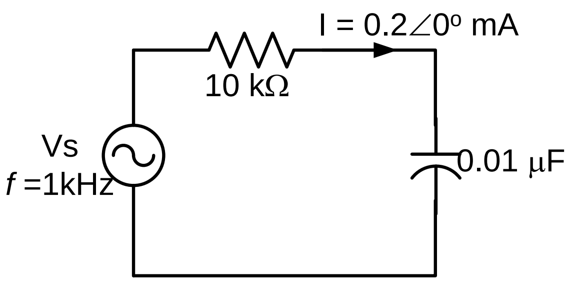


Figure Q2.7

8. For the circuit in Figure Q2.8, determine the following in polar form.

(a) Z (b) I_{total} (c) V_R (d) V_C

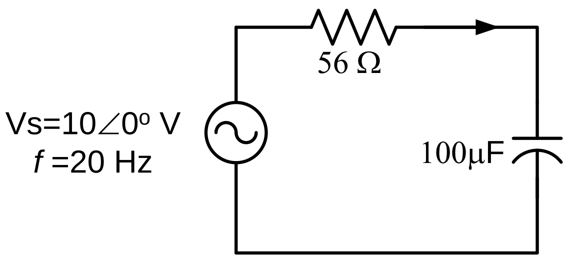


Figure Q2.8

9. Determine the series element or elements that must be installed in the block of Figure Q2.9 to meet the following requirements. True Power = 400 W and there is a leading power factor (I_{total} leads V_S)

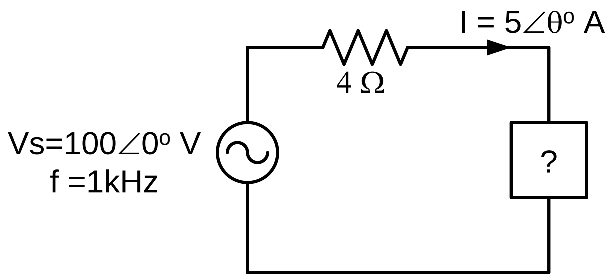


Figure Q2.9

10. For the circuit in Figure Q2.10, determine:

a) total impedance
b) total current
c) phase angle

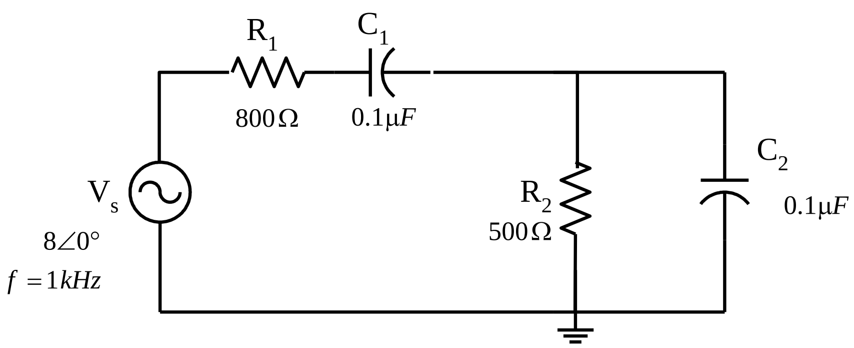


Figure Q2.10

11. In a series RC circuit, the True Power is 3 W, and the Reactive Power is 3.5 VAR. Determine the Apparent Power in polar form and rectangular form.

12. In a certain RC circuit, the True Power is 15 W and the Apparent Power is 45.54∠70.8°. Determine the Reactive Power and then draw the power triangle showing the True Power,P, Reactive Power,Q and Apparent Power,S.

13. Refer to Q12, what is the power factor of the circuit.

14. For the circuit in Figure Q2.14, find the True Power, the Reactive Power and the Apparent Power.

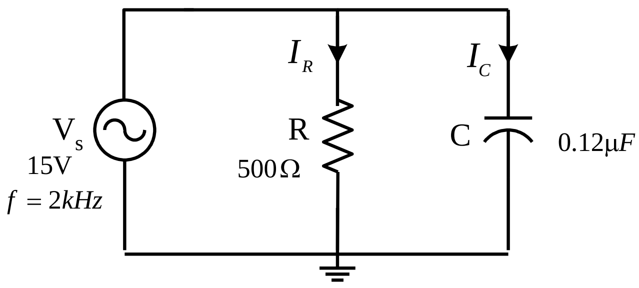


Figure Q2.14

15. Refer to Q14, draw the power triangle and find the power factor of the circuit.

UNIT 3: RL CIRCUIT

3.0 RL CIRCUIT

When a sinusoidal voltage is applied to a circuit consisting of resistor, *R* connected in series or parallel with inductor, *L,* the current flowing through the circuit, *I* and the voltages across the resistor and inductor, V_R and V_L respectively are also in a form of sinusoidal and have the same frequency as the source voltage as shown in Figure 3.1.

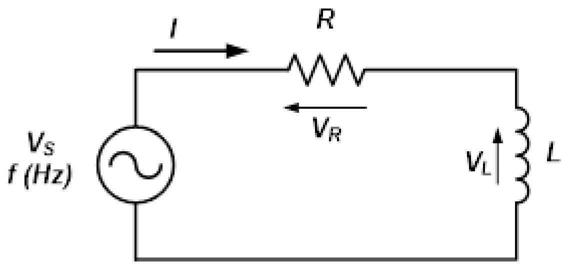


Figure 3.1: RL Circuit

The inductance causes a phase shift between the voltage and the current that depends on the relative values of the resistance and the inductive reactance as shown in Figure 3.2.

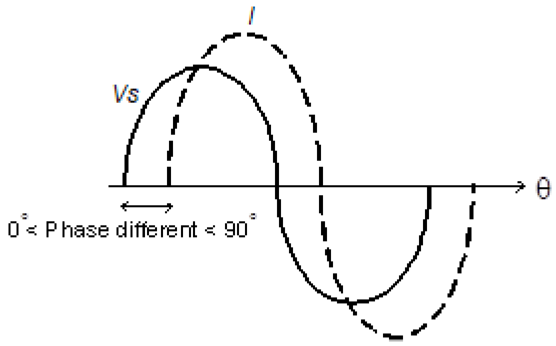


Figure 3.2: Vs versus I if both resistor and inductor exist in a circuit

SUB-TOPIC :	3.1 Sinusoidal response of RL circuits. 3.2 Impedance and phase angle of series RL Circuits. 3.3 Analysis of series RL circuits. 3.4 Impedance and phase angle of parallel RL circuits. 3.5 Analysis of parallel RL Circuits. 3.6 Combination of series and parallel RL circuits. 3.7 Power in RL circuits.
LEARNING OUTCOME :	After completing this lesson, students should be able to : 1. Define the terms of impedance, conductance, susceptance and admittance of RL circuits. 2. Determine the phase relationship between current and voltage of RL circuit. 3. Analyze simple RL circuits using basic circuit law. 4. Determine power and power factor in RL circuits.

3.1 SUMMARY

1. When sinusoidal voltage is applied to an RL circuit, the current and all voltage drops are also sine waves.

2. Total currents in an RL circuit always lags the source voltage.

3. For resistance, the voltage across it is in phase with the current through it.

4. In inductor, the current lags the voltage by 90°.

5. The impedance of RL circuit is the ratio of source voltage, V_S to total current I_{tot}, i.e.

$$Z_{tot} = \frac{V_S}{I_{tot}}$$

6. In an RL circuit, part of the power is resistive (real power) and part reactive (reactive power).

7. Power factor of an RL circuit is the ratio of real power, P to apparent power, S, i.e.

$$cos\theta = \frac{P}{S}$$

Where θ is the angle between the current and voltage of the circuit and can be calculated as:

$$\theta = tan^{-1}\left(\frac{X_L}{R}\right)$$

8. In an RL circuit, the power factor is said to be lagging because the phase angle, θ of total current, I_{tot} lag the source voltage, V_S.

9. Power factor of a series RL circuit can be increased by placing the capacitor across the series RL.

3.2 TUTORIAL

1. In Figure Q3.1, determine the impedance at each of the following frequencies:
   (a) 100 Hz (b) 500 Hz (c) 1 kHz (d) 2 kHz

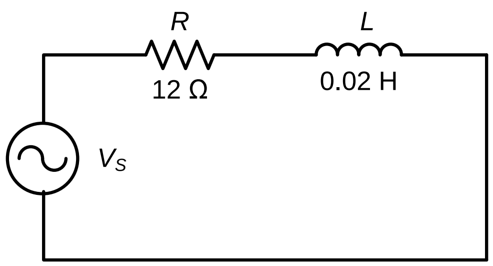


Figure Q3.1

2. Determine the value of R and X_L in a series RL circuit for the following values of impedance and phase angle.
   a) Z = 20 Ω, θ = 45°
   b) Z = 500Ω, θ = 35°
   c) Z = 2.5 kΩ, θ = 72.5°
   d) Z = 998 Ω, θ = 45°

3. A coil having a resistance of 10Ω and an inductance of 0.2H is connected to a 100 V, 50Hz supply. Calculate (a) the impedance of the coil, (b) the reactance of the coil, (c) the current taken and (d) the phase difference between the current and the voltage.

4. A choke coil connected across a 250 V, 50 Hz supply takes a current of 10 A at 0.8 power factor lag. What will be the power taken by the choke when it is connected across a 200 V, 25 Hz supply.

5. An impedance coil takes 480 W of power and 5 A from a 120-V, 50 Hz source. Calculate:
   a) Power factor of the circuit
   b) The impedance, resistance and reactance of the coil and
   c) Phase angle between current and voltage

6. A coil takes the 2.5 A when connected across 200 V, 50 Hz mains. The power consumed by the coil is found to be 400 W. Find the inductance and the power factor of the coil.

7. Determine the impedance, voltage across the total resistance and total inductance, phase angle, total real power, total reactive power and power factor of Figure Q3.7. Repeat the question if the frequency of the source is increased to 1 kHz.

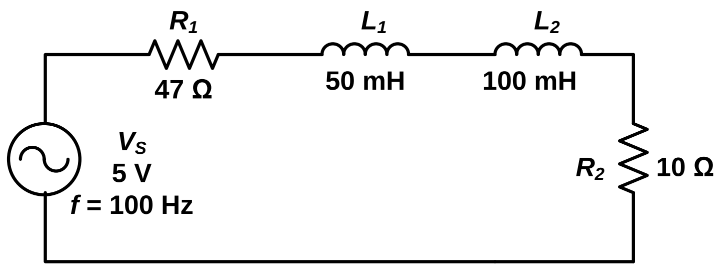


Figure Q3.7

8. Calculate the total current in Figure Q3.8. Draw a phasor diagram. Show the proper phase relationships.

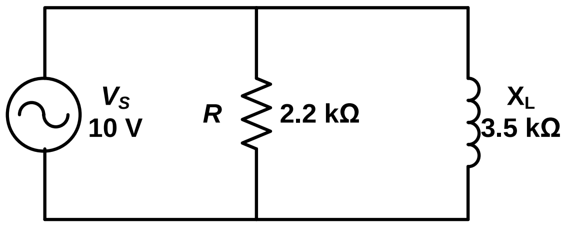


Figure Q3.8

9. Determine the following quantities in Figure Q3.9.

(a) Z (b) I_R (c) I_L (d) I_{tot} (e) θ

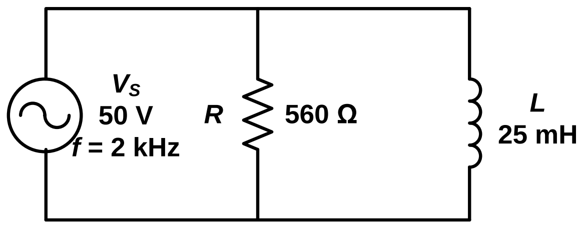


Figure Q3.9

10. Consider a circuit shown in Figure Q3.10.
    a) Determine the voltage across each element.
    b) Find the current in each branch and the total current.
    c) Determine the real power, reactive power and apparent power. Draw the power triangle.
    d) What is the power factor of the circuit?

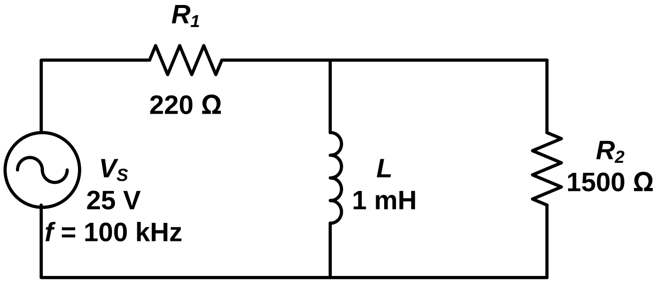


Figure Q3.10

UNIT 4: RLC CIRCUIT

4.0 RLC CIRCUIT

Instead of analysing each passive element separately, we can combine all three together into a series RLC circuit. The analysis of a **series RLC circuit** is the same as that for the individual series RL and RC circuits in the previous chapter. However, this time we need to consider the magnitudes of both X_L and X_C to find the overall circuit reactance.

SUB-TOPIC :	4.1 Impedance, analysis of series RLC circuits. 4.2 Series resonance. 4.3 Impedance, analysis of parallel RLC circuits. 4.4 Parallel resonance. 4.5 Power in RLC circuits.
LEARNING OUTCOME :	After completing this lesson, students should be able to: 1. Define the terms of impedance, conductance, susceptance, and admittance of RLC circuits. 2. Determine the phase relationship between current and voltage of RLC circuit. 3. Analyze simple RLC circuits using basic circuit law. 4. Determine power and power factor in RLC circuits. 5. Analyze RLC circuits at resonance.

4.1 SUMMARY

1. The total reactance for series RLC is either $X_L – X_C$ or $X_C – X_L$.

2. The circuit in a series RLC circuit is said to be predominantly inductive if $X_L > X_C$. At this condition, the total current lags the source voltage.

3. When $X_C > X_L$, the series RLC circuit is predominantly capacitive, thus the total current is leads the source voltage.

4. In series RLC resonance, the magnitude of X_L and X_C are equal. The impedance at resonance is equal to resistance of the circuit.

5. For parallel RLC circuit, when $X_L > X_C$, I_C will dominate and the total current leads the source voltage. If $X_C > X_L$, I_L will dominate and the total current lags the source voltage.

6. In order to draw phasor diagram for both series and parallel RLC circuits, there are three main points to be followed i.e.,
   (a) Take voltage (for parallel) or current (for series) as reference.
   (b) The resistor voltage is in phase with the resistor current.
   (c) The inductor current lags the inductor voltage by 90°.
   (d) The capacitor current leads the capacitor voltage by 90°.

4.2 TUTORIAL

1. A certain series RLC circuit has the following values: R = 10Ω, C = 0.047μF, and L = 5mH. Determine the impedance in polar form. What is the net reactance? The source frequency is 5kHz.

2. For the Figure Q4.2, determine the current I_{tot}, the power factor, the voltage across each element, the total real power, the total reactive power and the total apparent power. Draw a phasor diagram showing all the voltages and current, the impedance triangle of the circuit and the power triangle. Is the circuit predominantly inductive or predominantly capacitive?

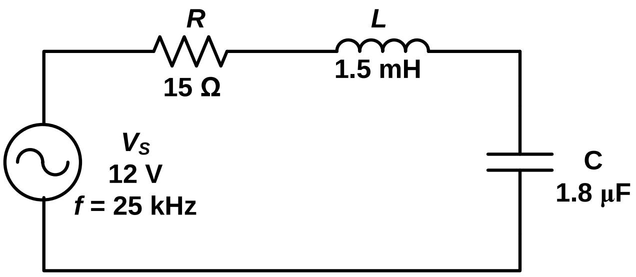


Figure Q4.2

3. (a) Repeat the question Q2, for Figure Q4.3.

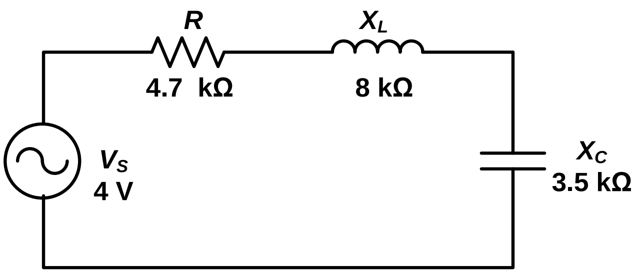


Figure Q4.3

(b) If the frequency of the source voltage is doubled from the value that produces the indicated reactance, how does the impedance change?

4. Consider the series resonant circuit shown in Figure Q4.4.

   (a) Compute the resonant frequency, the bandwidth, and the half-power frequencies.

   (b) Determine the voltage across *R* at resonance.

   (c) Find X_L, X_C, Z and I at resonant frequency.

   (d) Sketch a phasor diagram at resonance.

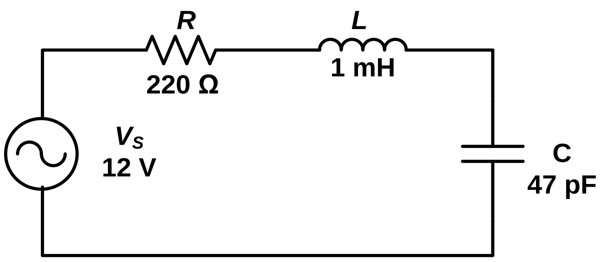


Figure Q4.4

5. A certain series resonant circuit has a maximum current of 50 mA and a V_L of 100 V. The source voltage is 10 V. What is Z? What are X_L and X_C.

6. For the RLC circuit in Figure Q4.6, determine the resonant frequency and the cutoff frequencies. What is the value of the current at the half-power points?

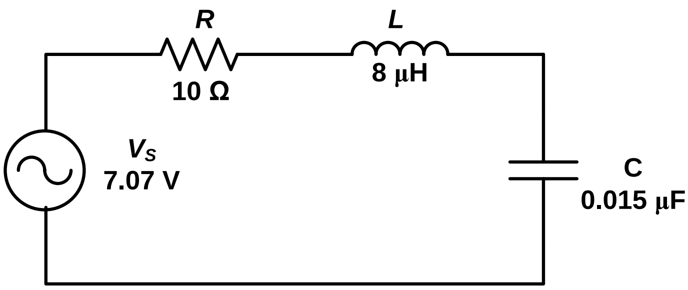


Figure Q4.6

7. At the resonant frequency f_r = 1 MHz, a series resonant circuit with R = 50 Ω has V_R = 2 V and V_L = 20 V. Determine the values of L and C. What is the value of V_C?

8. For each circuit shown in Figure Q4.8,

   (a) Find the total impedance of the circuit.
   (b) Is the circuit capacitive or inductive? Explain.
   (c) Find all currents and voltages
   (d) Draw a phasor diagram showing all the currents and voltages.
   (e) Calculate Real Power, Reactive Power, and Apparent Power. Draw Power Triangle.

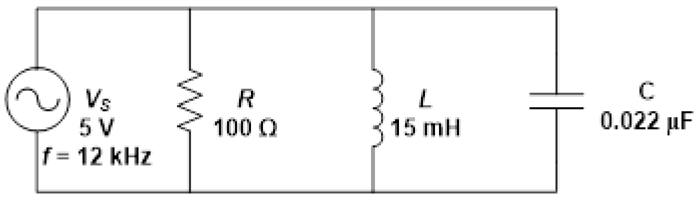


Figure Q4.8

9. For the circuit in Figure Q4.9, find the current through each component and the voltage across each component.

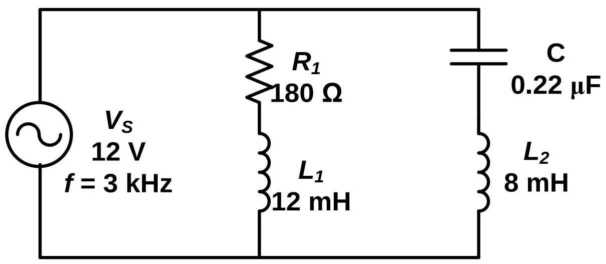


Figure Q4.9

10. A parallel RLC circuit has R = 5 kΩ, L = 8 mH, and C = 60 μF. Determine:

    (a) the resonant frequency
    (b) the bandwidth
    (c) the quality factor

11. A parallel resonance circuit has a resistance of 2 kΩ and half-power of 86 kHz and 90 kHz. Determine

    (a) the capacitance
    (b) the inductance
    (c) the resonant frequency
    (d) the bandwidth
    (e) the quality factor

12. For the circuit shown in Figure Q4.12, calculate the resonant frequency, the quality factor and the bandwidth. If the circuit is supplied by the source voltage of 10 V, determine branch currents at resonance. Draw a phasor diagram at resonance.

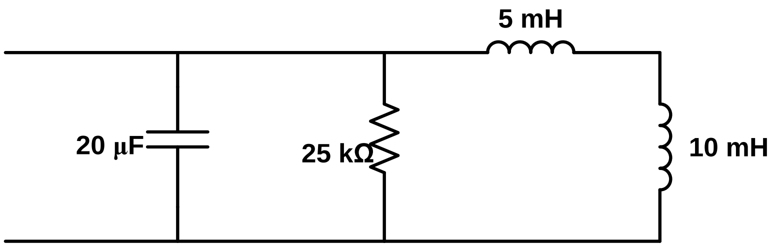


Figure Q4.12

UNIT 5: TRANSFORMER

5.0 TRANSFORMER

A basic transformer consists of two windings coupled by a magnetic core so that there is a mutual inductance for the transfer of power from one winding to the other. Figure 5.1 shows the schematic of a basic transformer. As shown, one coil is called primary winding and the other is secondary winding. The voltage source is connected to the primary winding and the second coil is connected to a load. It is common to refer the source voltage as the primary and the induced voltage as the secondary.

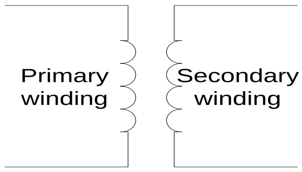


Figure 5.1: Basic schematic of transformer

SUB-TOPIC :	5.1 The basic transformer. 5.2 Basic operation of a transformer. 5.3 Ideal transformer. 5.4 Step up transformer. 5.5 Step down transformer. 5.6 Isolation transformer. 5.7 Reflected load. 5.8 Impedance matching. 5.9 Polarity. 5.10 Practical transformer. 5.11 Transformer rating. 5.12 Transformer efficiency. 5.13 Types of transformers.
LEARNING OUTCOME :	After completing this lesson, students should be able to : 1. Identify the basic structure of a transformer. 2. Explain the basic principle of operation of a transformer. 3. Explain how a step-up and step-down transformer works. 4. Identify the different types of transformer application.

5.1 SUMMARY

1. A normal transformer consists of two or more coils that are magnetically coupled on a common core.

2. When current in one coil changes, voltage is induced in the other coil.

3. The primary is the winding connected to the source and the secondary is the winding connected to the load.

4. The number of turns in the primary and the number of turns in the secondary determine the turn ratio; a = $\frac{N_1}{N_2}$.

5. A transformer in which the secondary voltage is greater than the primary voltage is called step up transformer.

6. A transformer in which the secondary voltage is less than the primary voltage is called step down transformer.

7. A load across the secondary winding of a transformer appears to the source as a reflected load having a value dependent on a^2.

8. Certain transformers can match a load resistance to a source resistance to achieve maximum power transfer to the load by selecting the proper turn ratio.

9. Conversion of electrical energy in a transformer result in losses due to winding resistance (copper loss), hysteresis and eddy current loss (core loss).

10. Auto-transformers have a common primary and secondary winding.

11. Instrument transformers are intended for the purposes of measurement.

5.2 TUTORIAL

1. What is the turn ratio of a transformer having 250 primary turns and 1000 secondary turns?

2. A certain transformer has 250 turns in its primary winding. In order to double the voltage, how many turns must be in the secondary winding?

3. To step 240 V ac up to 720 V, what must the turn ratio be?

4. The primary winding of a transformer has 120 V ac across it. What is the secondary voltage if the turn ratio is 5?

5. To step 720 V ac down to 240 V, what must the turn ratio be?

6. The primary winding of a transformer has 1200 V ac across it. What is the secondary voltage if the turn ratio is 0.2?

7. Determine I_s in Figure Q5.7. What is the value of R_L?

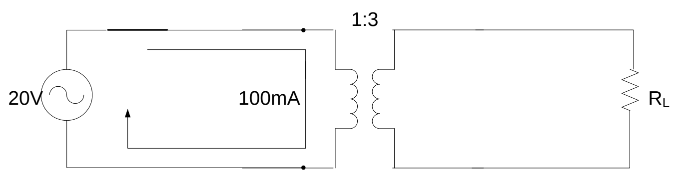


Figure Q5.7

8. Determine the following quantities in Figure Q5.8.
   a) primary current
   b) secondary current
   c) secondary voltage
   d) power in the load

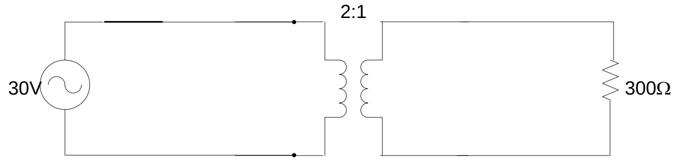


Figure Q5.8

9. What is the load resistance as seen by the source in Figure Q5.9?

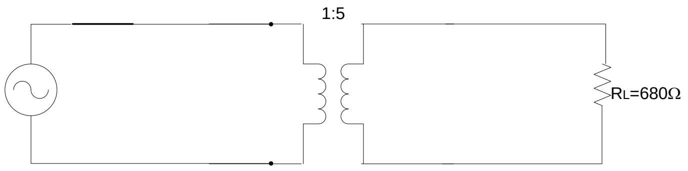


Figure Q5.9

10. What must the turn ratio be in Figure Q5.10 in order to reflect 300Ω into the primary circuit?

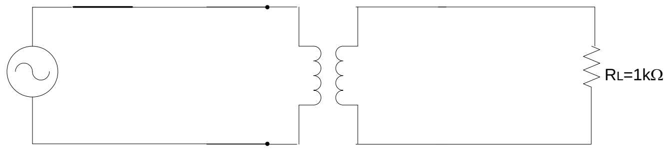


Figure Q5.10

11. For the circuit in Figure 5.11, find the turn ratio required to deliver maximum power to the 4Ω speaker.

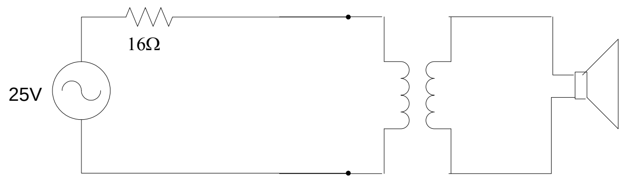


Figure Q5.11

12. In Figure 5.11, what is the maximum power that can be delivered to the 4Ω speaker?

13. In a certain transformer, the input power to the primary is 100W. If 5.5W are lost in the winding resistances, what is the output power to the load, neglecting any other losses?

14. What is the efficiency of transformer in Q5.13?

15. A certain transformer is rated at 5kVA, 2400/120 V at 50 Hz.

    (a) What is the turn ratio if the 120V is the secondary voltage?
    (b) What is the current rating of the secondary if 2400V is the primary voltage?
    (c) What is the current rating of the primary winding if 2400V is the primary voltage?

UNIT 6: BALANCED THREE PHASE SYSTEM

6.0 BALANCED THREE-PHASE

The three-phase system has three live wire and one returns the path. The three-phase system is use for transmitting a large amount of power. The three-phase system divided mainly into two types. One is a balanced three-phase system and another one is an unbalanced three-phase system.

The balance system is one in which the load are equally distributed in all the three phases of the system. The magnitude of voltage remains same in all the three phases and separated by an angle of 120º. In the unbalance system, the magnitude of voltage in all the three phases becomes different.

SUB-TOPIC :	6.1 Advantages of three-phase system. 6.2 Generation of single phase. 6.3 Generation of two-phase winding. 6.4 Generation of three-phase winding. 6.5 Types of three-phase connection. 6.6 Voltage and current in three phase system 6.7 Three phase load. 6.8 Three phase source/load analysis. 6.9 Measurement of three-phase power.
LEARNING OUTCOME :	After completing this lesson, students should be able to : 1. Have the understanding of the generation of three phase e.m.f's. 2. Identify the star and delta connection. 3. Identify the difference between line voltages and phase voltages; line currents and `phase currents. 4. Identify the relationship between line voltages and phase voltages in the star and delta connection. 5. Identify the difference between line currents and phase currents in the star and delta connection. 6. Calculate the voltages and currents in star and delta connection source and balanced load. 7. Calculate the power in a three-phase system.

6.1 SUMMARY

1. A simple three phase generator consists of three conductive loops separated by 120^0.

2. Advantages of three phase system over single-phase systems are smaller copper cross section for the same power delivered to the load, constant power delivered to the load.

3. Three-phase system can be connected either in star or delta. Star connection, sometimes called a wye connection and a delta connection is sometimes called mesh connection.

4. The voltage across the components of the load is termed phase voltage. The voltage between each pair of the lines are termed as line voltage

5. Current flow thru the components of the load is termed phase current. The current that flow in each pair of the lines are termed as line current

6. In star connection, line current = phase current and line voltage = √3 phase voltage

7. In star connection, line voltage leads phase voltage by 30^0

8. In delta connection, line voltage = phase voltage and line current = √3 phase current

9. In delta connection, line current lags phase current by 30^0

10. A balanced load is one in which all impedances are equal

11. Power is measured in a three phase load using either the one wattmeter method (balanced load), two wattmeter method (balanced and unbalanced load) and three wattmeter method (unbalanced load)

6.2 TUTORIAL

1. Determine the line voltages in Figure Q6.1.

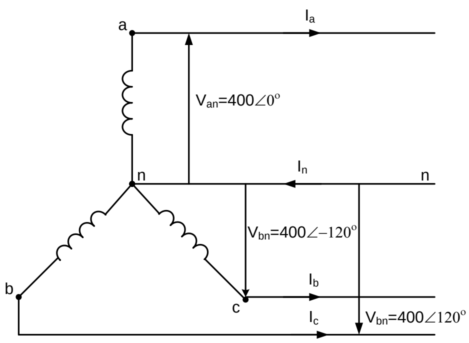


Figure Q6.1

2. Determine the line current in Figure Q6.2

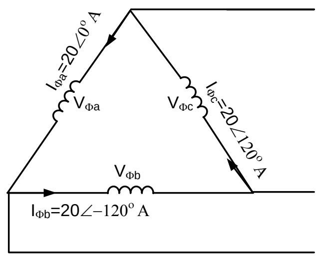


Figure Q6.2

3. A three-phase generator 240 volt/phase is supplying to a Y-connected load each of impedance $40\angle 25\ ^o\ \Omega$ is shown in Figure Q6.3. Determine the following:

   (a) Load current and line current in each phase

   (b) Neutral current

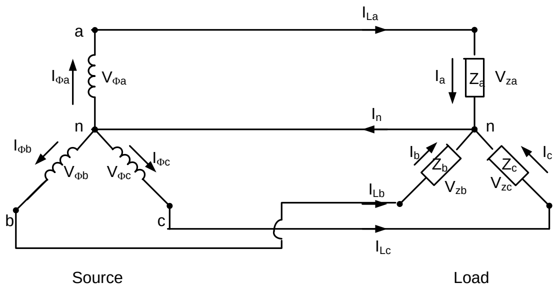


Figure Q6.3

4. A three phase supply 415 volt Y-connected is supplying to a Δ-connected load each of impedance $60\angle 40^o$ is shown in Figure Q6.4. Determine the load voltages and load currents. Draw the phasor diagram.

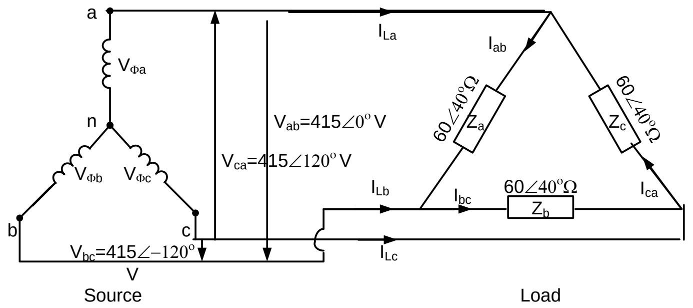


Figure Q6.4

5. Determine the current and voltages in the balanced load of impedance 60+j20Ω and the magnitude of the line voltages in Figure Q6.5.

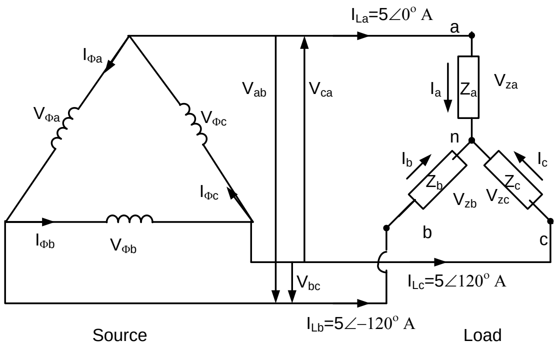


Figure Q6.5

6. Determine the load currents, I_{ab}, I_{bc} and I_{ca} and the magnitude of the line current as given in Figure Q6.6.

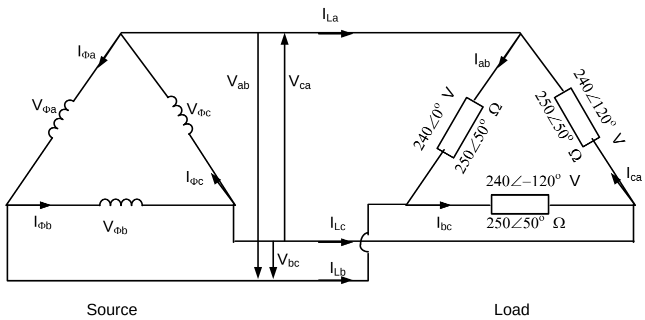


Figure Q6.6

7. If the power in each phase of a balanced three phase load is 1500 W. What is the total power for circuit connection in Figure Q6.6?

8. Find the total power in Figure Q6.8

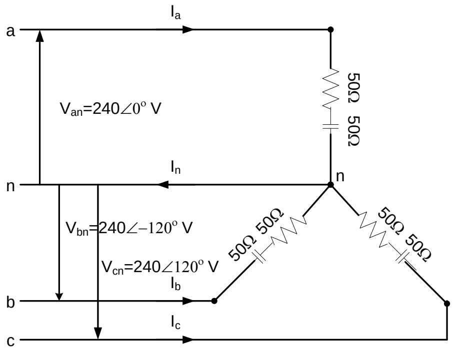


Figure Q6.8

9. What is the reading for each wattmeter using the three-wattmeter method for Figure Q6.8?

10. Using a two-wattmeter method for Figure Q6.8, what is the reading for each wattmeter?

MOCK EXAM QUESTION

Answer **ALL** questions.

Question 1

a. A sine wave with peak voltage 8 V_p is repeated in 4 cycles. The total period for 4 cycles is $12ms$.

i. In your own words, define period,(T) and Frequency,(f)

ii. Find V_{pp} and the period,(T) for one (1) cycle of sine wave

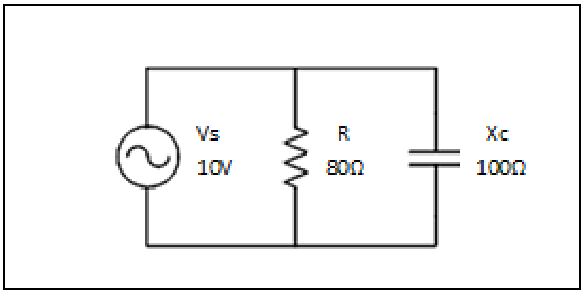


Figure 1

b. Refer to Figure 1, answer the following question.

i. Express the total impedance, (Z_T) in rectangular and polar form.

ii. Illustrate and label the impedance phasor diagram based on the value in question 1c (i).

Question 2

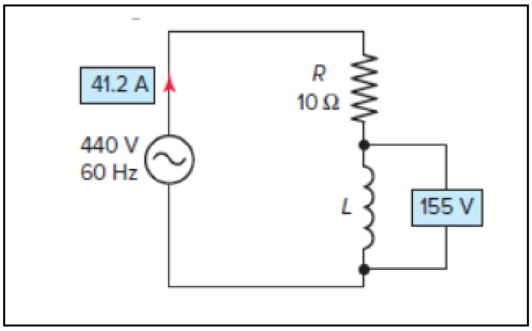


Figure 2

a. Referring to Figure 2, find

i. the value of reactive inductance, X_L and inductance, L

ii. the total impedance, Z in polar form

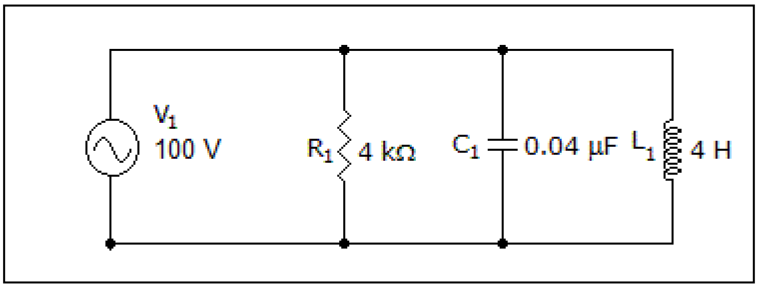


Figure 3

b. Referring to Figure 3 for a parallel resonance RLC circuit. Identify

i. the resonance frequency, f_r

ii. reactance at resonance, X_L and X_C

iii. the total impedance, Z_T

Question 3

a. Various methods are used for measurement of three phase power in three phase circuit on the basis of number of wattmeter used.

i. Give **two(2)** methods to measure power in a three phase circuit.
ii. If the system comprises of a fan, a heater and a refrigerator, with unbalanced power each phase, suggest a method to measure the power. Justify your answer.

b. Three coils each having a resistance of 10Ω and inductance of 6.28Ω are connected in delta to a 3-phase, $50Hz$ supply and the line voltage being $500V$.

i. Find the phase impedance, (Z_{phase}) and phase voltage, $\left(V_{phase}\right)$ for Δ-connection
ii. Find the line current, (I_{line})
iii. Illustrate phase currents in a phasor diagram

Question 4

A 50KVA, 2000V/100V, 50Hz single-phase step down transformer has 100 secondary turns. Applying the knowledge you have learned,

i. interpret in your own words the difference between steps up and step down in term of number of turns and ratio.

ii. compute the current,(I_1) secondary current, (I_2) and the number of primary turns, (N_1)

Question 5

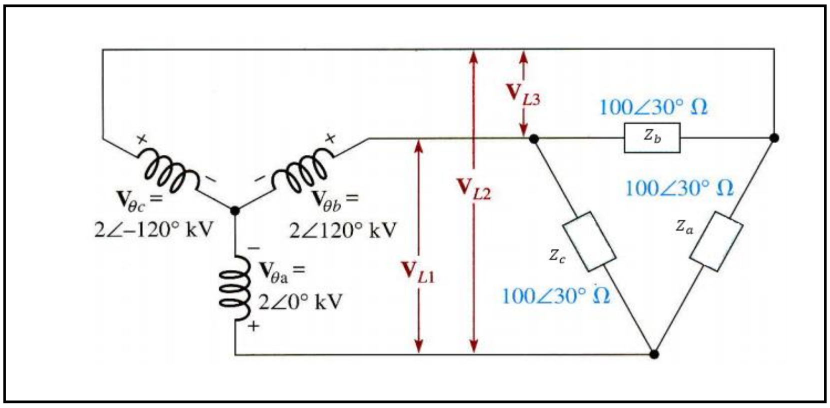


Figure 4.

Refer to Figure 4, answer the following question.

i. Determine the load voltages (V_{Za}, V_{Zb}, V_{Zc}) and the load currents (I_{Za}, I_{Zb}, I_{Zc}) flow in the system shown in Figure 4.

ii. Sketch the phasor diagram showing all load voltages and load currents.

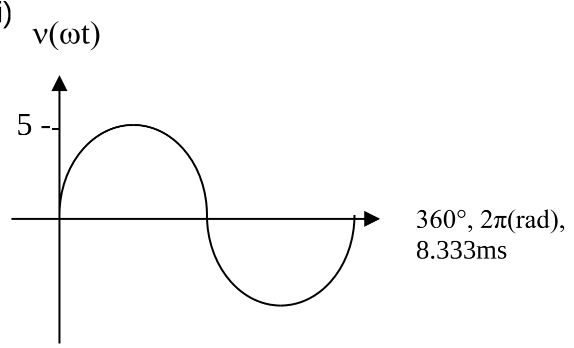
QUESTIONS END

ANSWER SECTION

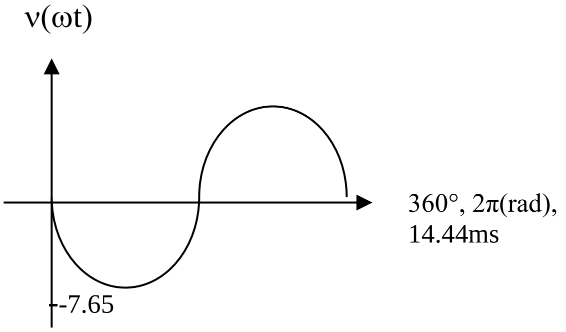
ANSWER UNIT 1: INTRODUCTION TO AC SYSTEM

1.0 ANSWER

1. (i)



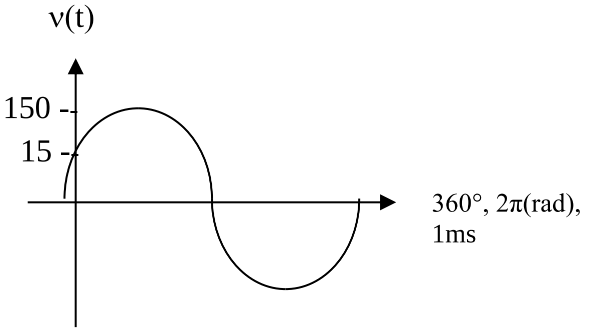
(ii)



2. (i) $I_{avg} = 3.185A$; $I_{rms} = 3.535A$

   (ii) $I_{avg} = 4.841A$; $I_{rms} = 5.373A$

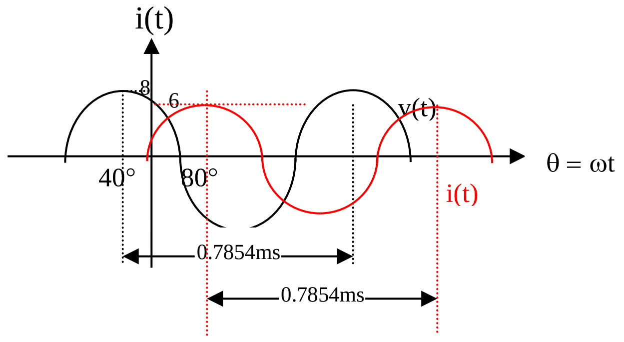
3. $V(t) = 150\sin(6.28kt + 5.74°)V$



4. Amplitude = 5A; Phase = -60°; Angular frequency, $\omega = 12.57\ rad/sec$; Frequency, $f = 2Hz$; Period, $T = 0.5s$

5. Angular frequency, $\omega = 3762.4\ rad/sec$; Frequency, $f = 598.8Hz$;
$i(t) = 300\cos(3762.4t + 55°)\,A$
$i(2m) = -176.9A$

6. (i) T=0.7854s
(ii) v(t) leads i(t) by 120°

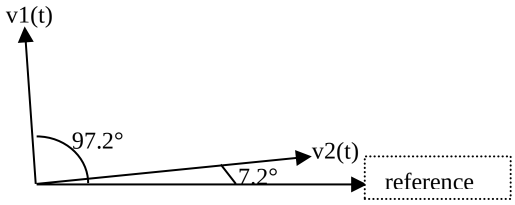


7. (a) i(t) leads v(t) by 10°
(b) i(t) leads v(t) by 70°
(c) i(t) is in phase with v(t)
(d) v(t) leads i(t) by 90°
(e) v(t) leads i(t) by 170°

8. (a) $v(t) = 25\sin(377t + 30°)V$
(b) $v(t) = -3x10^{-3}\sin(6283t + 120°)V$
(c) $i(t) = 0.01\sin(157t - 110°)A$

9. (i) $v_1(t) = 110\sin(6283.2t + 97.2°)V$; $V_1 = 77.78 \measuredangle 97.2°$ V
$v_2(t) = 150\sin(6283.2t + 7.2°)V$; $V_2 = 106.05 \measuredangle 7.2°$ V

(ii) $V_1\ leads\ V_2\ by\ 90°$ V



10. (i) $i(t) = 100.4 \measuredangle 50°\ mA$
(ii) $i(t) = 0.25 \measuredangle -40°\ A$
(iii) $v(t) = 212.2 \measuredangle -90°\ V$
(iv) $v(t) = 100.4 \measuredangle 90°\ V$
(v) $i(t) = 46.7 \measuredangle 90°\ A$
(vi) $v(t) = 354.56 \measuredangle -120°\ V$

11. (i) $i(t) = 67.9\sin(\omega t + 25)\ A$
(ii) $v(t) = 282.8\sin(\omega t)\ V$
(iii) $i(t) = 11.3\sin(\omega t + 120)\ A$
(iv) $v(t) = 70.7\sin(\omega t + 90°)\ V$
(v) $i(t) = 2262.7\sin(\omega t - 120°)\ A$
(vi) $v(t) = 60\sin(\omega t - 180°)\ V$

12. $i(t) = 15.8\sin(\omega t + 33.43°)\ A$

13. $V_{max} = 39V$; $V_{min} = 9V$

14. $V_1 = 11V$; $V_2 = 7V$; $I_3 = 5A$

ANSWER UNIT 2: RC CIRCUIT

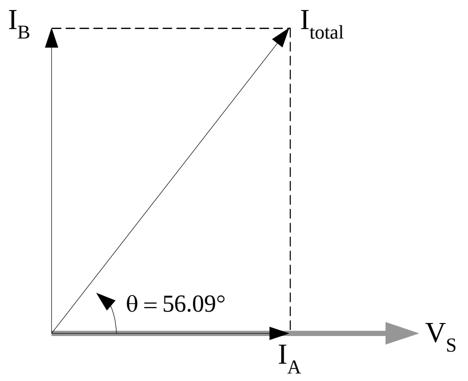
2.0 ANSWER

1. (a) $Z = 22\Omega\ (rectangular\ form)$; $Z = 22 \measuredangle 0°\ \Omega\ (polar\ form)$
   (b) $Z = -j35\Omega\ (rectangular\ form)$; $Z = 35 \measuredangle -90°\ \Omega\ (polar\ form)$
   (c) $Z = 10 - j55\Omega\ (rectangular\ form)$; $Z = 55.9 \measuredangle -79.9°\ \Omega\ (polar\ form)$

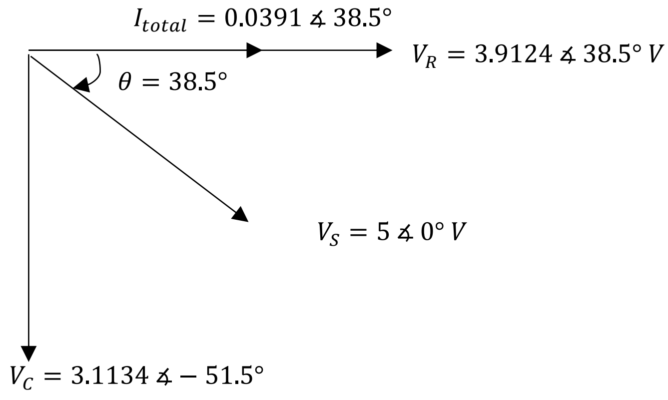
2. (a) $R = 33\Omega$; $X_C = 50\Omega$
   (b) $R = 272\Omega$; $X_C = 127\Omega$

3. $I_{total} = 1.89 \measuredangle 65.5°\ mA$

4. $I_A = 56mA$; $I_B = j83.3\ mA$; $I_{total} = 100.37 \measuredangle 56.09°\ mA$

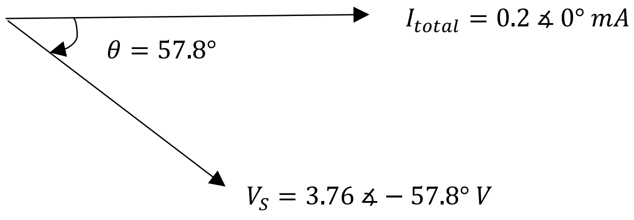


5. $V_R = 3.9124 \measuredangle 38.5°\ V$; $V_C = 3.1134 \measuredangle -51.5°$; $I_{total} = 0.0391 \measuredangle 38.5°$



6. $V_R = 4.6458 \measuredangle 21.7° V$; $V_C = 1.8485 \measuredangle -68.3°$; $I_{total} = 0.0465 \measuredangle 21.7°$

7. $V_S = 3.76 \measuredangle -57.8° V$



8. (a) $Z = 97.3 \measuredangle -54.9° \Omega$
   (b) $I_{total} = 97.3 \measuredangle -54.9° \Omega$
   (c) $V_R = 5.76 \measuredangle 54.9° V$
   (d) $V_C = 8.18 \measuredangle -35.1° V$

9. (i) $R_X = 12\Omega$; $R_X = 13.3\mu F \ (in\ series)$

10. (a) $Z_{total} = 2140 \measuredangle -54.12° \Omega$
    (b) $I_{total} = 3.74 \measuredangle 54.12° mA$
    (c) I_{total} leads V_S by $54.12°$

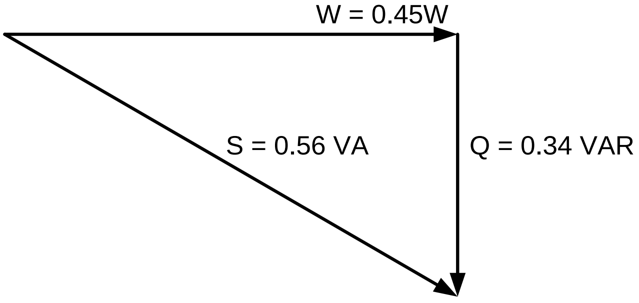
11. $S = 4.61 \measuredangle 49.4° VA \ (polar\ form)$
    $S = 3 + j3.5\ VA \ (rectangular\ form)$

12. $Q = 43\ VA$

13. $PF = 0.33$

14. $P = 0.45\ W$; $Q = 0.34\ VAR$; $S = 0.564\ VA$

15. $PF = 0.79$



ANSWER UNIT 3: RL CIRCUIT

3.0 ANSWER

1. (a) $Z = 17.38\ \Omega$
   (b) $Z = 63.97\ \Omega$
   (c) $Z = 126.24\ \Omega$
   (d) $Z = 251.62\ \Omega$

2. (a) $R = 14.14\ \Omega$; $X_L = 14.14\ \Omega$
   (b) $R = 409.58\ \Omega$; $X_L = 286.79\ \Omega$
   (c) $R = 0.752\ k\Omega$; $X_L = 2.38\ k\Omega$
   (d) $R = 705.7\ \Omega$; $X_L = 705.7\ \Omega$

3. (a) $Z = 63.5\ \Omega$
   (b) $X_L = 62.8\ \Omega$
   (c) $i = 1.575\ A$
   (d) $\theta = 81°$

4. $P = 1753W$;

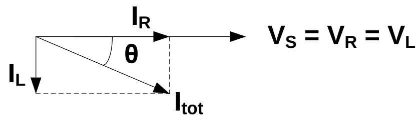
5. (a) $PF = 0.8$;
   (b) $Z = 24\ \Omega$; $R = 19.2\ \Omega$; $X_L = 14.14\ \Omega$
   (c) $\theta = 36.9°$

6. $L = 0.153\ H$; $PF = 0.8\ lag$;

7. For f = 100Hz,
   $Z = 110.14\ \Omega$; $V_{Rtot} = 2.59\ V$; $V_{Ltot} = 4.28\ V$; $\theta = 58.84°$
   $P_{tot} = 4117.5\ mW$; $P_{tot} = 194.26\ mVAR$; $PF = 0.52\ lagging$

   For f = 1000Hz,
   $Z = 944.2\ \Omega$; $V_{Rtot} = 0.302\ V$; $V_{Ltot} = 5\ V$; $\theta = 86.55°$
   $P_{tot} = 1.6\ mW$; $P_{tot} = 26.52\ mVAR$; $PF = 0.06\ lagging$

8. $I = 5.37\ mA$



9. (a) $Z = 274\ \Omega$

(b) $I_R = 89.29\ A$

(c) $I_L = 159.15\ mA$

(d) $I_{total} = 182.5\ mA$

(e) $\theta = 60.71°$

10. (a) $V_{R1} = 7.92\ V$; $V_L = V_{R2} = 20.85\ V$;

(b) $I_{total} = 35.98\ mA$; $I_L = 33.18\ mA$; $I_{R2} = 13.9\ mA$

(c) $P_{total} = 574.62\ mW$; $Q = 691.72\ mVAR$; $S = 899.5\ mVA$

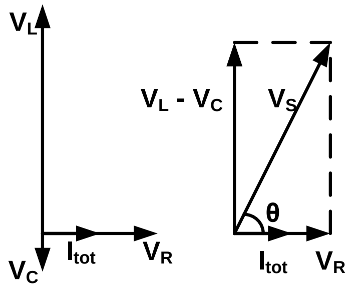
(d) $PF = 0.64\ lagging$

ANSWER UNIT 4: RLC CIRCUIT

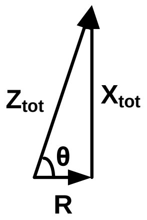
4.0 ANSWER

1. $Z = 520 \measuredangle -88.9° \ \Omega$; $X_{total} = 520 \ \Omega$, capacitive

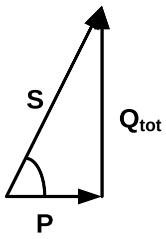
2. $I_{total} = 51.6 \ mA$; $PF = 0.064$; $V_R = 0.774 \ V$; $V_L = 12.16 \ V$
$V_C = 0.183 \ V$; P= $39.93 \ mW$; $Q = 617.93 \ mVAR$;
$S = 619.22 \ mVA, inductive$



Phasor diagram

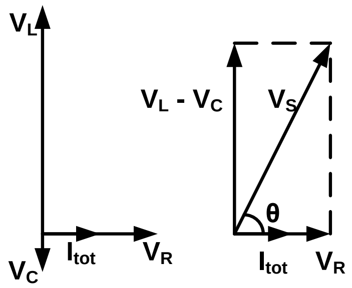


Impedance triangle

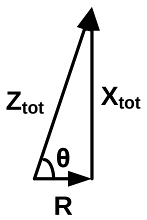


Power triangle

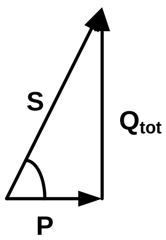
3. (a) $I_{total} = 0.615 \ mA$; $PF = 0.722$; $V_R = 2.89 \ V$; $V_L 4.92 \ V$
$V_C = 2.15 \ V$; P= $1.78 \ mW$; $Q = 1.7 \ mVAR$;
$S = 2.46 \ mVA, inductive$



Phasor diagram



Impedance triangle



Power triangle

(b) When frequency is doubled, the R will remain the same while X_L is double up and X_C decrease twice. This will change the total impedance to increase higher than double value.

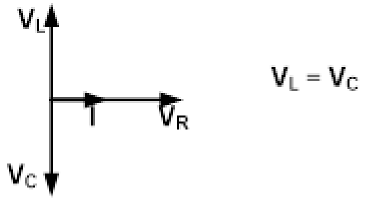
4. (a) $f = 734.13\ kHz$; $BW = 35\ kHz$;

$f_1 = 751.63\ kHz$; $f_2 = 716.63\ kHz$

(b) $V_R = 4V$;

(c) $X_L = X_C = 4.613\ k\Omega$; $Z = 220\ \Omega$; $I = 18.18\ mA$

(d)



5. (a) $Z = 200\ \Omega$;

(b) $X_L = X_C = 2\ k\Omega$

6. $f_r = 459.44\ kHz$; $f_1 = 569.53\ kHz$; $f_2 = 370.63\ kHz$;

$I_{f1} = I_{f1} = 0.5\ A$

7. $L = 79.58\ \mu H$; $C = 0.318\ nF$; $V_C = 20\ V$;

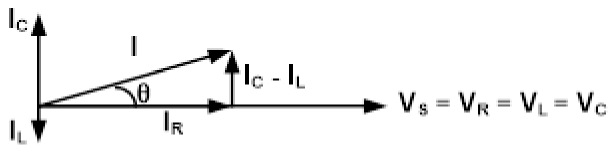
8.

(a) $Z = 100.3\ \Omega$

(b) $capacitive\ since\ X_L > X_C\ , I_C\ will\ dminate\ and\ I_{total}\ leads\ V_S$

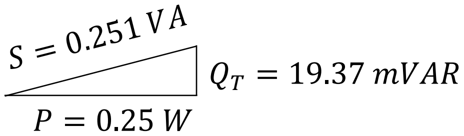
(c) $V_R = V_L = V_C = 5\ V$; $I_R = 0.05\ A$; $I_L = 4.42\ mA$; $I_C = 8.293\ mA$

(d)



(e) $P = 0.25\ W$; $Q_L = 22.1\ mVAR$; $Q_C = 41.47\ mVAR$;

$Q_{total} = 19.37\ mVAR$; $S = 0.251\ VA$



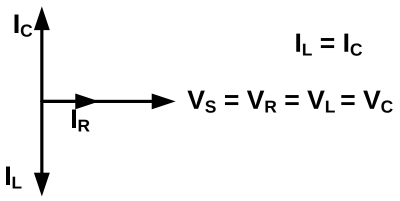
9. $I_{R1L1} = 41.51\ mA$; $I_{CL2} = 132.8\ mA$; $I_{total} = 103.6\ mA$
$V_{R1} = 747\ V$; $V_{L1} = 9.39\ V$; $V_C = 32.02\ V$; $V_{L2} = 20.02\ V$

10. (a) $f_r = 229.72\ Hz$
(b) $BW = 0.531\ Hz$
(c) $Q_r = 433.01$

11. (a) $C = 19.89\ nF$
(b) $L = 164.45\ \mu H$
(c) $f_r = 88\ kHz$
(d) $BW = 4\ kHz$
(e) $Q_r = 22$

12. $f_r = 290.58\ Hz$; $Q_r = 912.86$; $BW = 0.32\ Hz$
$I_L = I_C = 0.365\ A$; $I_R = 0.4\ mA$

Phasor diagram at resonance:



ANSWER UNIT 5: TRANSFORMER

5.0 ANSWER

1. $a = 0.25$
2. $N_2 = 500\ turns$
3. $a = 0.33$
4. $V_2 = 24\ V$
5. $a = 3$;
6. $V_2 = 6000\ V$
7. $I_2 = 33.3\ mA$ $R_L = 1800\ \Omega$;
8. $I_1 = 25\ mA$; $I_2 = 50\ mA$; $V_2 = 15\ V$; $P = 0.75\ W$
9. $R' = 27.2\ \Omega$;
10. $a = 0.55$
11. $a = 2$
12. $P = 19.5\ W$
13. $P_{out} = 94.5\ W$
14. $\zeta = 94.5\%$
15. (a) $a = 20$
    (b) $I_2 = 41.7\ A$
    (c) $I_1 = 2.08\ A$

ANSWER UNIT 6: BALANCED THREE-PHASE SYSTEM

6.0 ANSWER

1. $V_{ab} = 692.4 \measuredangle 30° \, V$; $V_{bc} = 692.4 \measuredangle 90° \, V$; $V_{ab} = 692.4 \measuredangle 150° \, V$

2. $I_{ab} = 34.64 \measuredangle -30° \, A$; $I_{bc} = 34.64 \measuredangle -150° \, A$; $I_{ca} = 34.64 \measuredangle 90° \, A$

3. (a) $I_{za} = 6 \measuredangle -25° \, A$; $I_{zb} = 6 \measuredangle -145° \, A$; $I_{zc} = 6 \measuredangle 95° \, A$

   $I_L = I_{phase}$

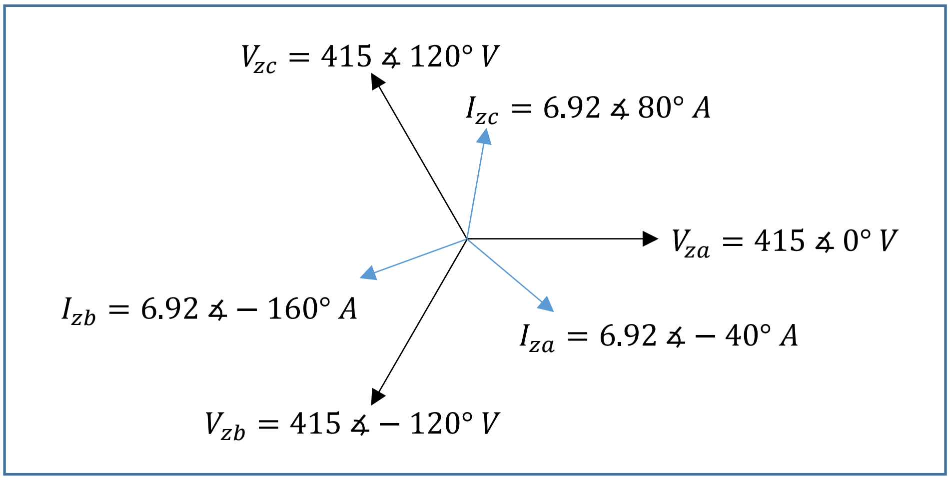
   (b) $I_N = 0 \, A$

4. $V_{za} = V_{ab} = 415 \measuredangle 0° \, V$

   $V_{zb} = V_{bc} = 415 \measuredangle -120° \, V$

   $V_{zc} = V_{ca} = 415 \measuredangle 120° \, V$

   $I_{za} = 6.92 \measuredangle -40° \, A$; $I_{zb} = 6.92 \measuredangle -160° \, A$; $I_{zc} = 6.92 \measuredangle 80° \, A$



Phasor diagram

5. $I_{za} = I_{La} = 5 \measuredangle 0° \, A$; $I_{zb} = I_{Lb} = 5 \measuredangle -120° \, A$; $I_{zc} = I_{Lc} = 5 \measuredangle 120° \, A$

   $V_{za} = V_{an} = 316 \measuredangle 18° \, V$;

   $V_{zb} = V_{bn} = 316 \measuredangle -101.6° \, V$;

   $V_{zc} = V_{cn} = 316 \measuredangle 138.4° \, V$

   $V_L = 8.66 \, V$

6. $P = 0.96 \measuredangle -50° \ A$; $I_{bc} = 0.96 \measuredangle -170° \ A$; $I_{ca} = 0.96 \measuredangle \ 70° \ A$

7. $P_{total} = 4500W$

8. $P_{total} = 1726W$

9. $W_1 = 576 \ W$; $W_2 = 576 \ W$; $W_3 = 576 \ W$

10. $W_1 = 1361 \ W$; $W_2 = 365 \ W$

ANSWER : MOCK EXAM

Question 1:

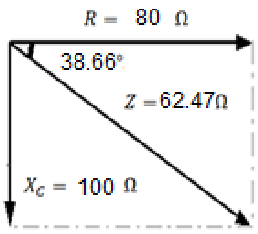
a. i. Period, T can de defined as the time required foa a sine wave to make complete full cycle.

Frequency, f can be defined as number of cycles that a sine wave completes in one second.

ii. $V_{pp} = 16\,V$; $T = 3ms$

b. i. $Z_T = 48.78 - j39.02\ \Omega$; $Z_T = 62.47\measuredangle - 38.66°\ \Omega$

ii.



Question 2:

a. i. $X_L = 3.76\Omega$; $L = 9.97mH$

ii. $Z = 10.68 \measuredangle 20.61\Omega$

b. i. $f_r = 397.89\ Hz$

ii. $X_L = 10k\Omega$; $X_C = 10k\Omega$

iii. $Z_T = R = 4k\Omega$

Question 3

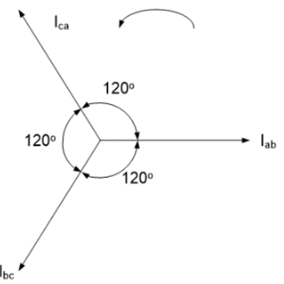
a. i. One Wattmeter method, Two Wattmeter method, Three Wattmeter method

ii. Two or Three Wattmeter method because the system is unbalanced system.

b. i. $Z_{phase} = 11.8\Omega$; $V_{phase} = 500V$

ii. $I_{line} = 73.39A$

iii.



Question 4

i. - Step up transformer : Number of turns in primary < turns in secondary

Turns ratio will be < 1

- Step down transformer : Number of turns in primary > turns in secondary

Turns ratio will be > 1

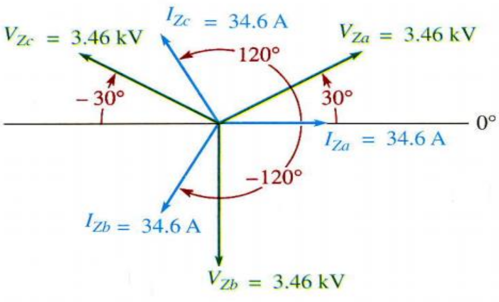
ii. $I_1 = 25A$; $I_2 = 500A$; $N = 2000\ turns$

Question 5

i. $V_{za} = 3.46\measuredangle 30° kV$; $V_{zb} = 3.46\measuredangle -90° kV$; $V_{zc} = 3.46\measuredangle 150° kV$

$I_{za} = 34.6\measuredangle 0°\ A$; $I_{zb} = 34.6\measuredangle -120°\ A$; $I_{zc} = 34.6\measuredangle 120°\ A$

ii.



ANSWERS END