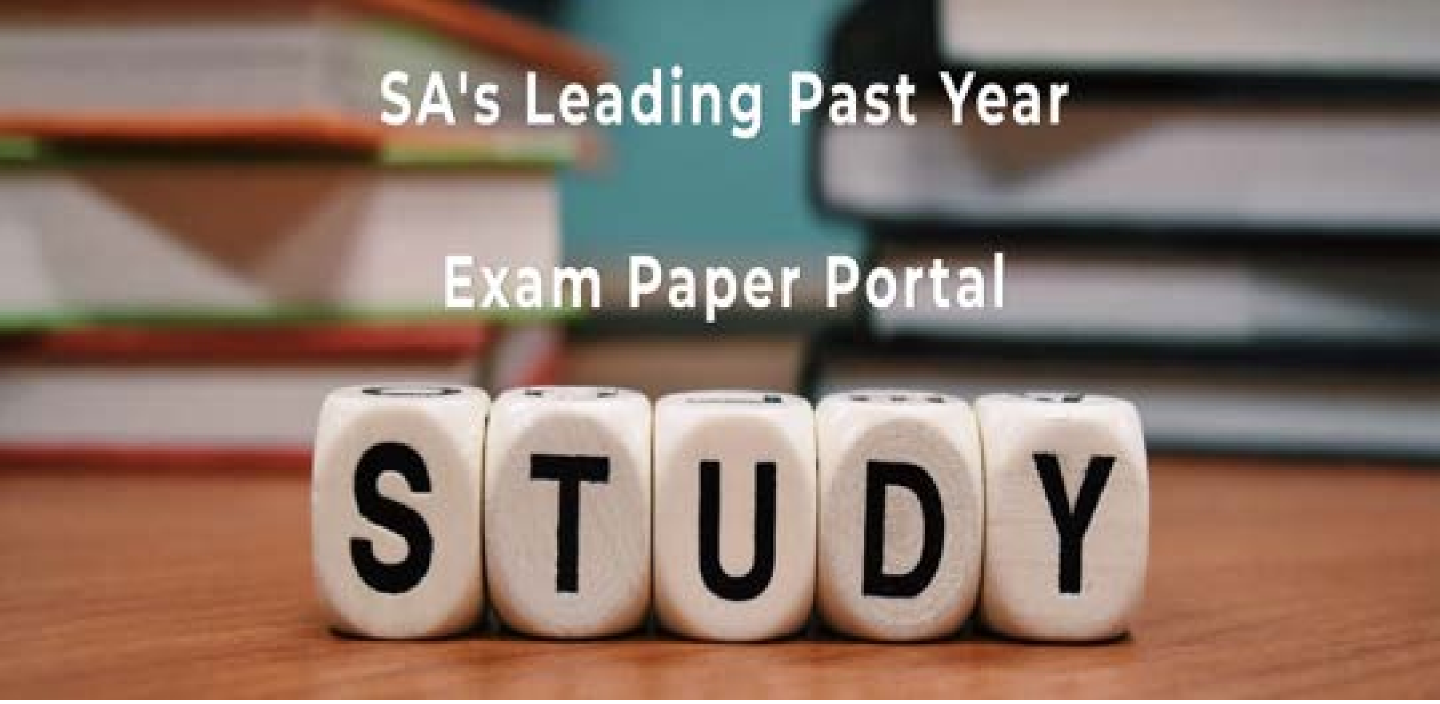
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GRADE 12

ELECTRICAL TECHNOLOGY: POWER SYSTEMS

NOVEMBER 2022

MARKS: 200

TIME: 3 hours

This question paper consists of 16 pages and a 2-page formula sheet.

INSTRUCTIONS AND INFORMATION

1. This question paper consists of SEVEN questions.

2. Answer ALL the questions.

3. Sketches and diagrams must be large, neat and FULLY LABELLED.

4. Show ALL calculations and round off answers correctly to TWO decimal places.

5. Number the answers correctly according to the numbering system used in this question paper

6. You may use a non-programmable calculator.

7. Calculations must include:

   7.1 Formulae and manipulations where needed

   7.2 Correct replacement of values

   7.3 Correct answer and relevant units where applicable

8. A formula sheet is attached at the end of this question paper.

9. Write neatly and legibly.

QUESTION 1: MULTIPLE-CHOICE QUESTIONS

Various options are provided as possible answers to the following questions. Choose the answer and write only the letter (A–D) next to the question numbers (1.1 to 1.15) in the ANSWER BOOK, e.g. 1.16 D.

1.1 A/An … is an occurrence when a serious or unexpected dangerous situation occurs that requires immediate attention.

A evacuation procedure
B non-critical incident
C critical incident
D unsafe condition (1)

1.2 The total opposition against the flow of alternating current in an RLC circuit is the ...

A inductive reactance.
B impedance.
C capacitive reactance.
D inductance. (1)

1.3 When decreasing frequency to below resonance in a series RLC resonance circuit, the …

A impedance increases and the circuit becomes inductive.
B voltage drop across the inductor and capacitor increases.
C impedance decreases and the circuit becomes capacitive.
D impedance increases and the circuit becomes capacitive. (1)

1.4 The opposition to AC current flow caused by a capacitor will increase when the ...

A capacitance is decreased.
B frequency is increased.
C voltage is decreased.
D current is increased. (1)

1.5 An advantage of a three-phase system is that …

A it is available everywhere.
B it is suitable for most residential applications.
C the appliances are cheaper.
D it is more economical. (1)

1.6 Power that is transferred backwards and forwards between the supply and the inductor or capacitor without doing any work is known as ... power.

A apparent
B reactive
C real
D active (1)

1.7 In an electric power system, a load with a low power factor draws ... current from the supply compared with a load with a high power factor.

A less
B the same
C no
D more (1)

1.8 When comparing three-phase transformers to single-phase transformers, a ...

A single-phase transformer has higher efficiency.
B three-phase transformer is used in all homes.
C three-phase transformer can power both single- and three-phase loads.
D single-phase transformer uses three windings. (1)

1.9 A Buchholz relay will activate and isolate the transformer from the supply when ...

A a severe fault causes a large amount of gas forming inside the oil of a transformer.
B the load becomes an open circuit.
C a small fault causes a small amount of gas forming inside the oil of the transformer.
D a small fault causes the top float inside the relay to activate the alarm. (1)

1.10 An advantage of a three-phase motor over a single-phase motor is that a three-phase motor ...

A has a lower starting torque.
B is less efficient.
C has more moving parts.
D requires less maintenance. (1)

1.11 Refer to the typical speed versus the torque characteristic curve of a three-phase induction motor. The breakdown torque is … the full-load torque.

A higher than
B equal to
C lower than
D 50% of (1)

1.12 A three-phase motor with 18 poles has ... pole pairs per phase.

A 6
B 3
C 9
D 4 (1)

1.13 A … is an example of an output device in a PLC system that could automatically switch on a high-current motor.

A switch
B sensor
C relay
D strain gauge (1)

1.14 In pulse width modulation (PWM), longer ON-times create a ... output wavelength.

A high frequency output with a short
B low frequency output with a long
C high frequency output with a long
D low frequency output with a short (1)

1.15 Braking that occurs when the load on the motor rotates faster than the motor is known as ... braking.

A regenerative
B vector
C transistor
D variable frequency (1)
[15]

QUESTION 2: OCCUPATIONAL HEALTH AND SAFETY

2.1 State TWO human rights in the workplace that ensure that the dignity of the employer is not infringed. (2)

2.2 State TWO evacuation steps to be followed when an emergency alarm is sounded in a workshop. (2)

2.3 Explain why the misuse of equipment in a workshop could cause a health or safety threat. (2)

2.4 Refer to victimisation and state TWO actions by the employer that are forbidden. (2)

2.5 State TWO types of risk analysis reports done by the health and safety representative. (2)
[10]

QUESTION 3: RLC CIRCUITS

3.1 Explain the term *inductance* with reference to RLC circuits connected to an AC supply. (2)

3.2 Draw the phasor diagrams for FIGURES 3.2.1 and 3.2.2 in the ANSWER BOOK.

3.2.1

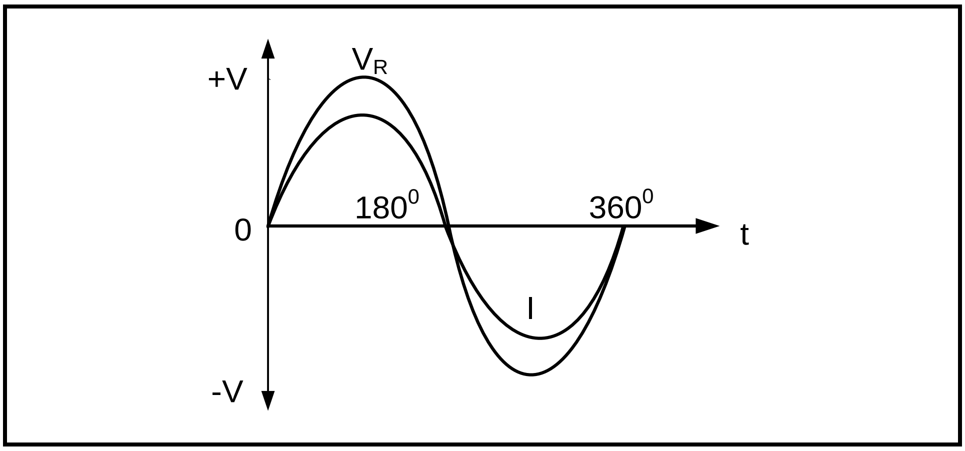

FIGURE 3.2.1: VOLTAGE AND CURRENT WAVEFORMS (2)

3.2.2

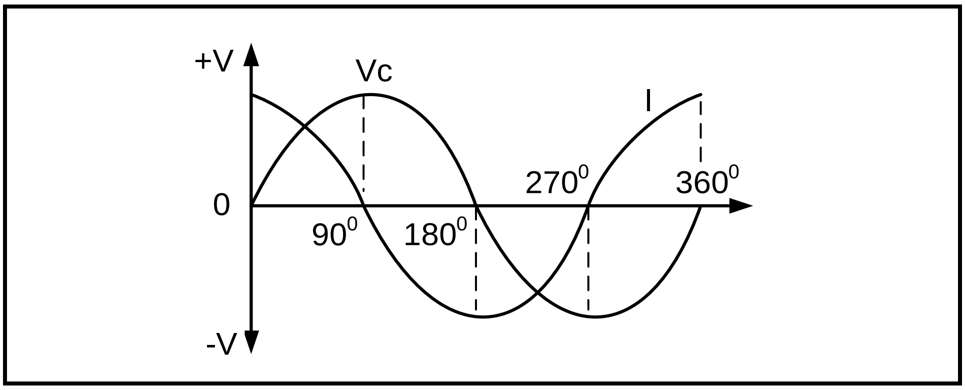

FIGURE 3.2.2: VOLTAGE AND CURRENT WAVEFORMS (2)

3.3 A series RLC circuit with a resistance of 25 Ω, an inductive reactance of 94 Ω and a capacitive reactance of 13 Ω is connected across a 150 V/60 Hz AC supply. Answer the questions that follow.

Given:

$R = 25\ \Omega$
$X_C = 13\ \Omega$
$X_L = 94\ \Omega$
$V_T = 150\ V$
$f = 60\ Hz$

3.3.1 Calculate the impedance of the circuit. (3)

3.3.2 Calculate the phase angle of the circuit. (3)

3.3.3 Calculate the value of the inductor. (3)

3.3.4 Explain what is meant by a *lagging power factor*. (1)

3.3.5 Explain why the current and the voltage waveforms are in phase in a series RLC resonance circuit. (2)

3.4 Refer to FIGURE 3.4 and answer the questions that follow.

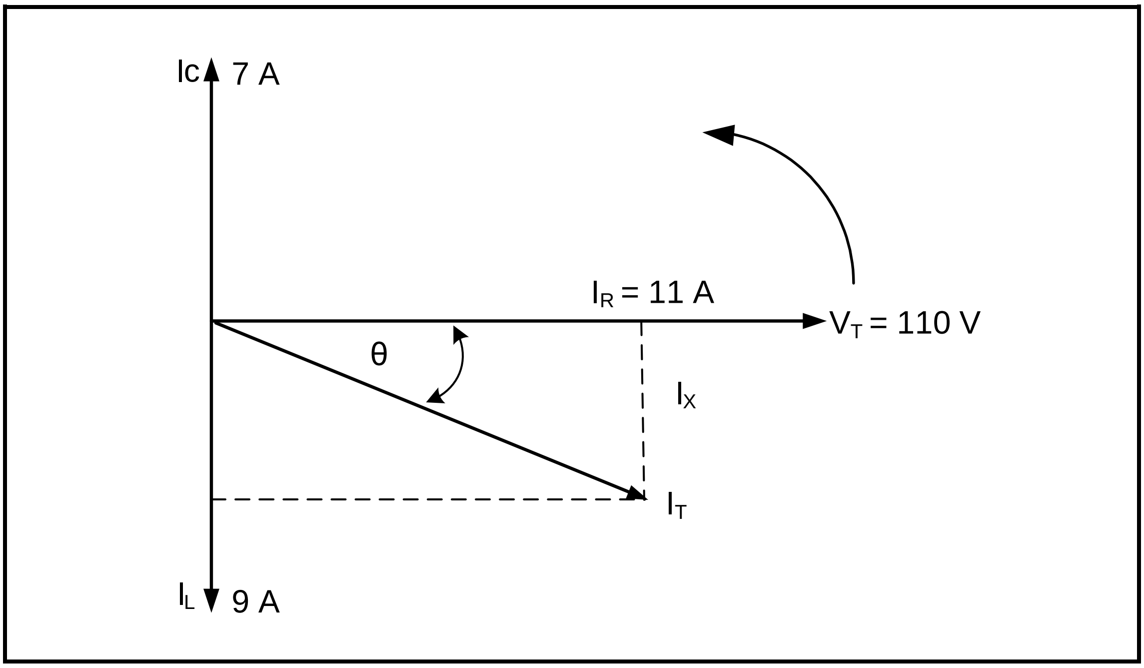

FIGURE 3.4: PARALLEL RLC PHASOR DIAGRAM

Given:

I_L = 9 A
I_C = 7 A
I_R = 11 A
V_T = 110 V

3.4.1 Calculate the total current. (3)

3.4.2 Calculate the power factor. (3)

3.4.3 Calculate the total power. (3)

3.4.4 State, with a reason, whether the circuit has a leading or lagging power factor. (2)

3.5 Refer to FIGURE 3.5 and answer the questions that follow.

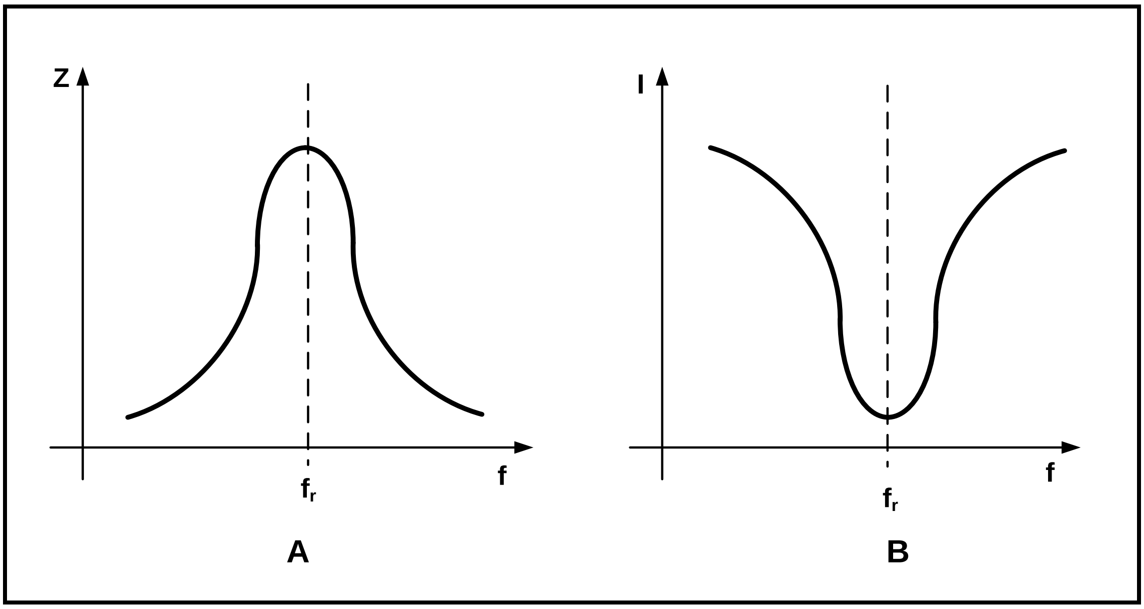

FIGURE 3.5: IMPEDANCE AND CURRENT RESPONSE CURVES

3.5.1 Name the circuit that produces the response at **A** and **B** in FIGURE 3.5. (2)

3.5.2 Discuss the difference between the *impedance* and *current* at resonant frequency. (2)

3.5.3 Describe what happens to impedance when the frequency increases in FIGURE 3.5 **A**. (2)
[35]

QUESTION 4: THREE-PHASE AC GENERATION

4.1 Refer to FIGURE 4.1 and answer the questions that follow.

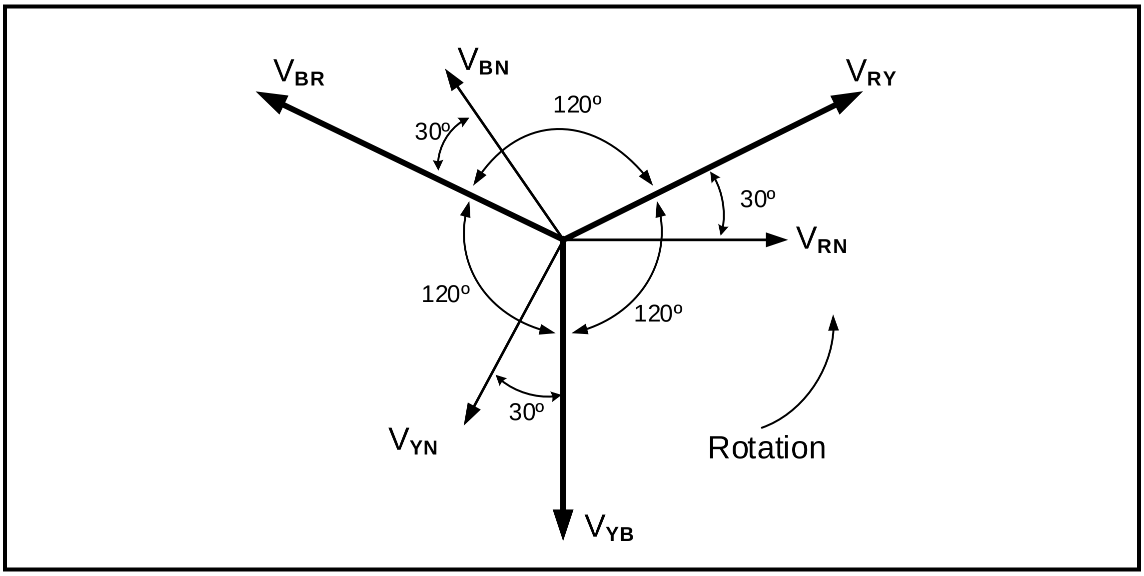

FIGURE 4.1: THREE-PHASE PHASOR DIAGRAM

4.1.1 State whether the phasor diagram represents positive phase sequence or negative phase sequence. Motivate your answer. (2)

4.1.2 Determine whether phasor V_{RN} represents a line voltage or a phase voltage. Motivate your answer. (2)

4.2 Explain the term *active power.* (1)

4.3 Explain the effect of stepping up the voltage in transmission lines. (2)

4.4 Draw a diagrammatic representation of a four-wire three-phase star-connected system. (4)

4.5 Refer to voltages and explain what happens in the distribution stage of the national power grid. (3)

4.6 A balanced three-phase load is connected in delta to a three-phase star-connected alternator. The load draws a current of 15 A from the 400 V supply. The load has a power factor of 0,85. Answer the questions that follow.

Given:

I_L = 15 A
V_L = 400 V
pf = 0,85

Calculate the:

4.6.1 Phase current of the load (3)

4.6.2 Impedance of the load (3)

4.6.3 Phase angle (3)

4.6.4 Active power (3)

4.6.5 Draw a diagram of a power-factor correcting-capacitor bank connected to the three-phase supply in FIGURE 4.6.5.

FIGURE 4.6.5: THREE-PHASE SUPPLY (3)

4.7 FIGURE 4.7 shows three wattmeters connected to a balanced three-phase load. Answer the questions that follow.

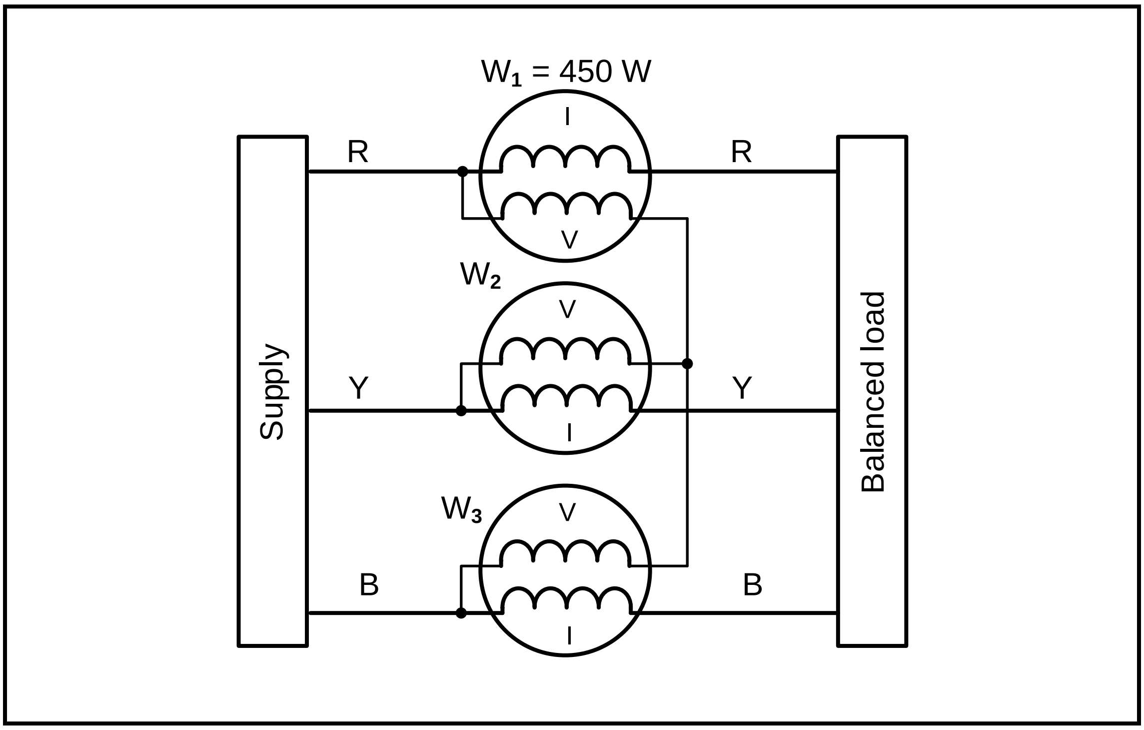

FIGURE 4.7: THREE-WATTMETER METHOD

4.7.1 State TWO advantages of using the three-wattmeter method. (2)

4.7.2 State ONE disadvantage of using the three-wattmeter method. (1)

4.7.3 Calculate the total power if the reading on W_1 = 450 W. (3)
[35]

QUESTION 5: THREE-PHASE TRANSFORMERS

5.1 Explain the principle of *mutual induction* with reference to transformers. (3)

5.2 Single-phase transformers can be used to create a three-phase transformer unit. Answer the questions that follow.

5.2.1 List THREE characteristics of single-phase transformers that must be identical. (3)

5.2.2 Name the connection on the secondary side of a three-phase transformer that will create a neutral point. (1)

5.3 Discuss the main contributing factors for the following losses in transformers:

5.3.1 Copper losses (2)

5.3.2 Iron losses (2)

5.4 Describe how insulation failure is controlled in dry-type transformers. (2)

5.5 Differentiate between *shell-type* and *core-type transformers* with reference to the core. (2)

5.6 Describe how a balanced earth-fault relay protects a three-phase transformer. (3)

5.7 FIGURE 5.7 below shows a 200 kW delta-connected load with a power factor of 0,8 which is connected to a delta-star transformer. The primary line voltage is 6 kV and the secondary line voltage is 400 V.

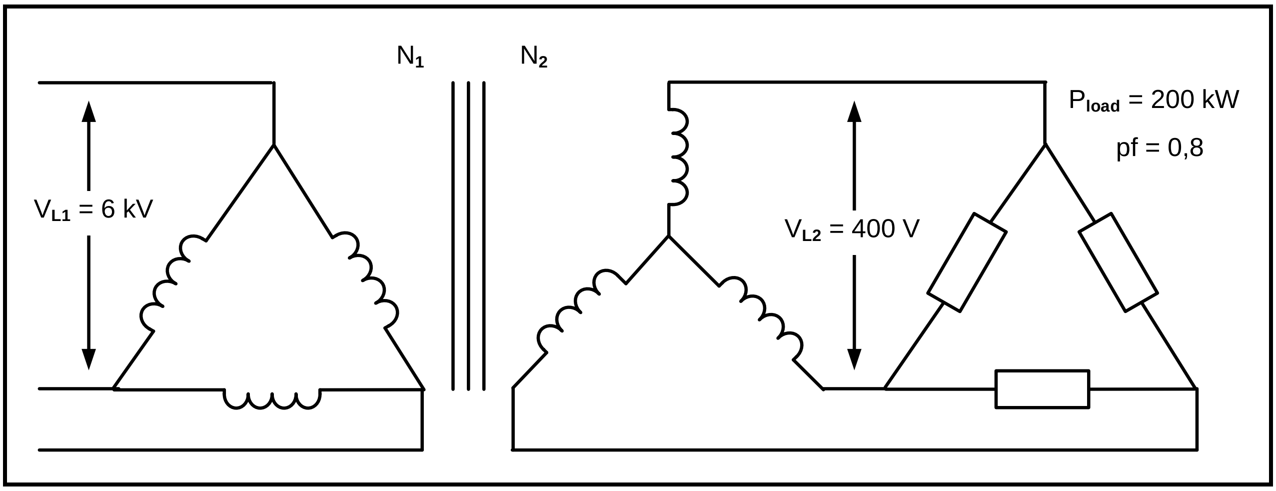

FIGURE 5.7: THREE-PHASE TRANSFORMER

Given:

P_{load} = 200 kW
pf = 0,8
V_{L1} = 6 kV
V_{L2} = 400 V

Calculate the:

5.7.1 Secondary line current (3)

5.7.2 Secondary phase current (3)

5.7.3 Apparent power (3)

5.7.4 Primary line current (3)
[30]

QUESTION 6: THREE-PHASE MOTORS AND STARTERS

6.1 Name the TWO types of rotor construction used in induction motors. (2)

6.2 Refer to the speed of induction motors and answer the questions that follow.

6.2.1 Explain the difference between *rated speed* and *full-load speed*. (2)

6.2.2 Calculate the synchronous speed of a three-phase motor with four pole pairs per phase that are connected to a 400 V/50 Hz supply. (3)

6.2.3 Calculate the percentage slip if the rotor turns at 725 r/min (rpm). (3)

6.3 Name TWO mechanical inspections that could be carried out on the rotor and bearings of a motor. (2)

6.4 A three-phase delta-connected motor draws a line current of 5 A from a 380 V/50 Hz supply. The phase angle is 20°.

Given:
I_L = 5 A
V_L = 380 V
θ = 20°

Calculate the:

6.4.1 Input power (3)

6.4.2 Reactive power (3)

6.4.3 Output power if the motor is 90% efficient (3)

6.5 FIGURE 6.5 shows the terminal box of a three-phase motor. Redraw the terminal box in the ANSWER BOOK and indicate how the motor can be connected in delta.

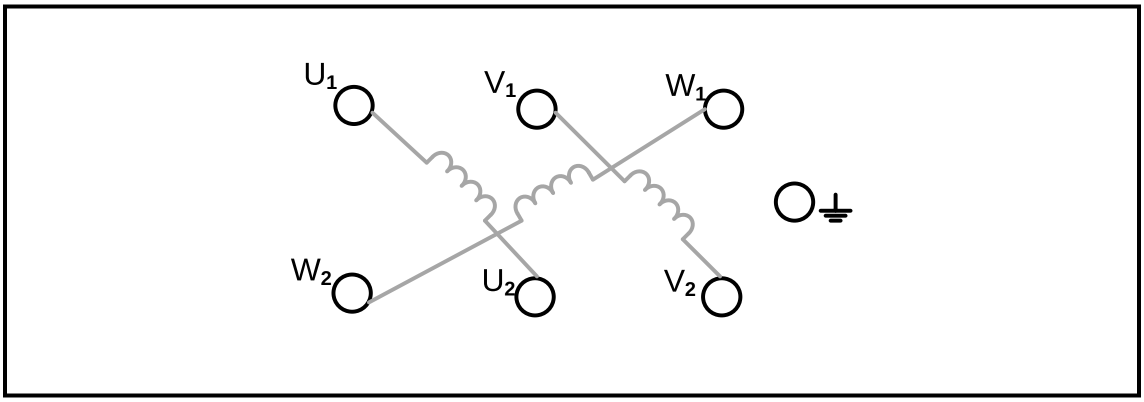

FIGURE 6.5: TERMINAL BOX (3)

6.6 FIGURE 6.6 shows the control circuit of an automatic star-delta starter. Answer the questions that follow.

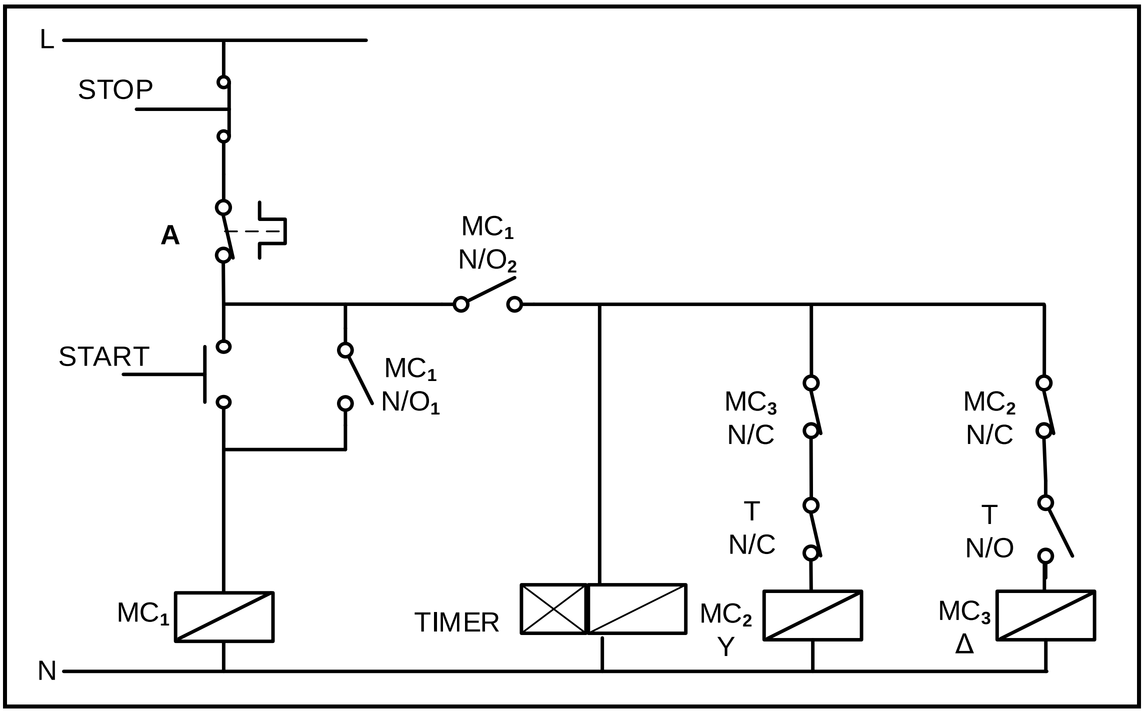

FIGURE 6.6: AUTOMATIC STAR-DELTA STARTER

6.6.1 Identify component **A**. (1)

6.6.2 Explain the purpose of MC_1N/O_2. (3)

6.6.3 Explain the importance of interlocking in this circuit. (2)

6.6.4 Describe the operation of the circuit after the timer has timed through. (5)

[35]

QUESTION 7: PROGRAMMABLE LOGIC CONTROLLERS (PLCs)

7.1 Easy fault finding is one of the advantages of hard wiring. Explain why. (2)

7.2 Refer to sensors as input devices to a PLC and answer the questions that follow.

7.2.1 Explain the term *sensor*. (2)

7.2.2 Explain what the PLC does after receiving data from a temperature sensor as an input device. (2)

7.2.3 State TWO applications of temperature sensors. (2)

7.3 Refer to FIGURE 7.3 and answer the questions that follow.

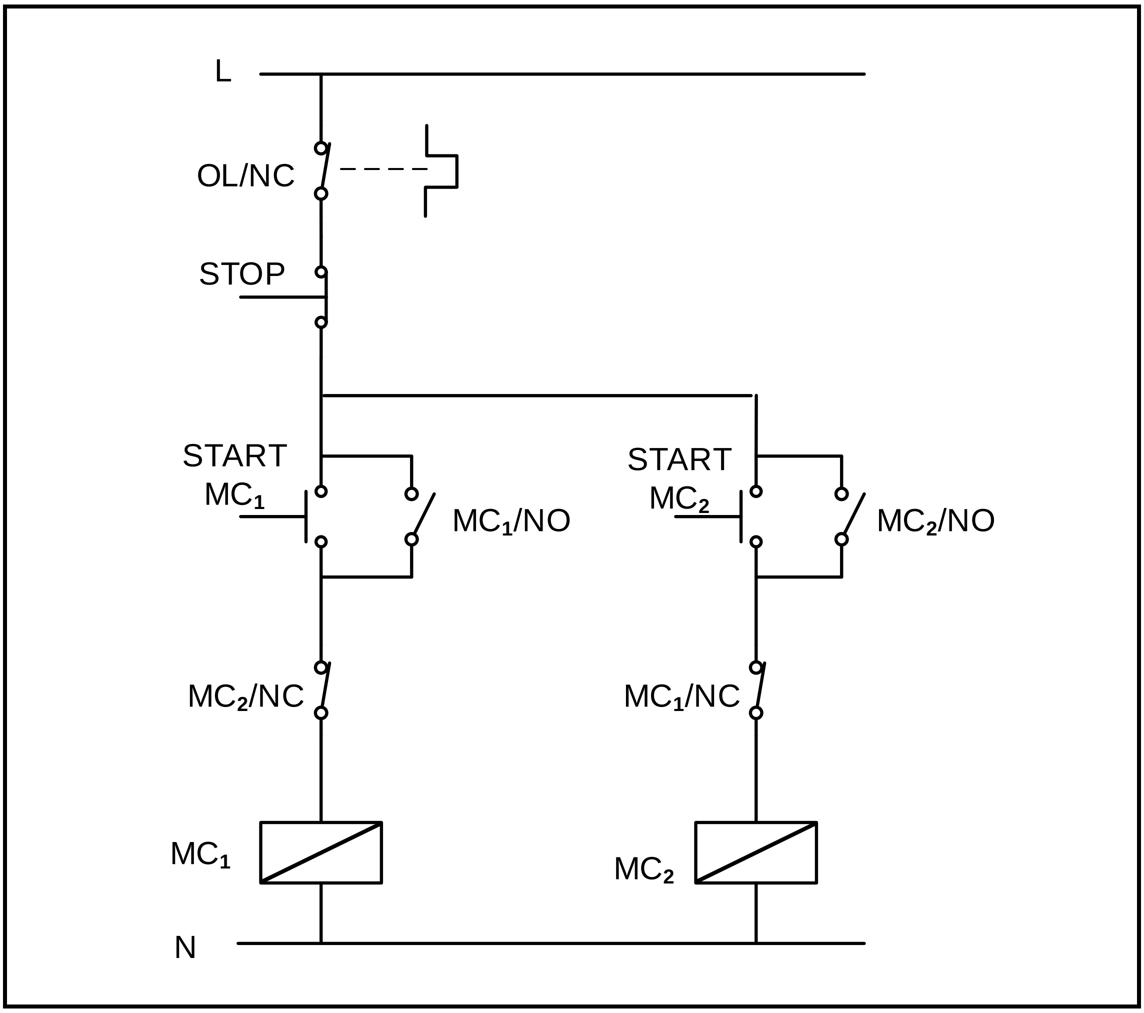

FIGURE 7.3: CONTROL CIRCUIT

7.3.1 Identify the control circuit in FIGURE 7.3. (1)

7.3.2 Explain *latching* with reference to motor control circuits. (3)

7.3.3 Redraw and complete the ladder logic diagram in FIGURE 7.3.3 in the ANSWER BOOK to execute the same function as in FIGURE 7.3.

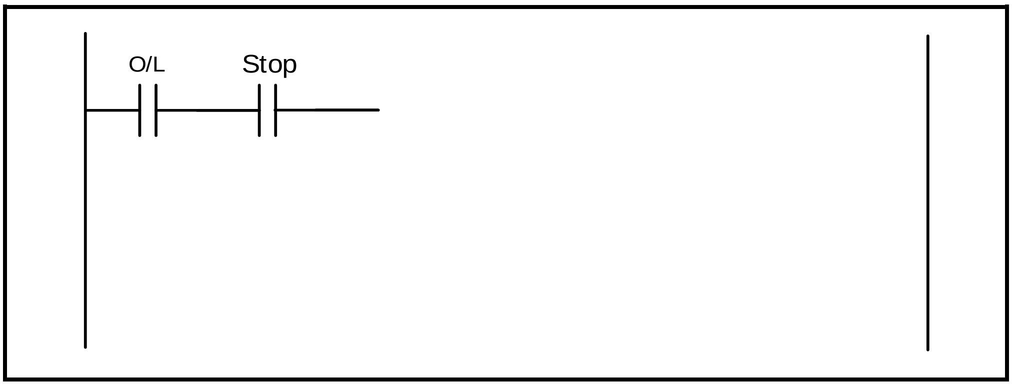

FIGURE 7.3.3: LADDER LOGIC DIAGRAM (8)

7.4 Draw a ladder logic diagram with two outputs, each controlled by two inputs. Input 1 and input 2 must be closed for output 1 to be high. Either input 3 or input 4 or both must be closed for output 2 to be high. (6)

7.5 Refer to PLCs and explain the concept *marker*. (2)

7.6 FIGURE 7.6 is a block diagram of a VSD. Answer the questions that follow.

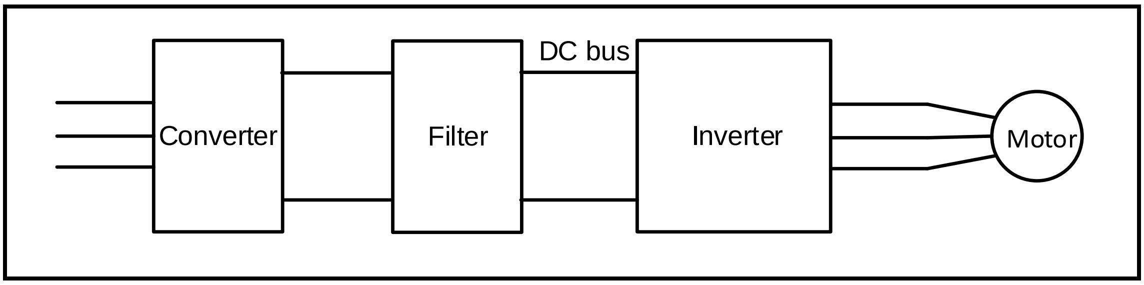

FIGURE 7.6: BLOCK DIAGRAM OF A VARIABLE SPEED DRIVE

7.6.1 Explain how the converter achieves its function. (2)

7.6.2 State the purpose of the filter. (2)

7.6.3 Describe the principle of operation of the inverter stage. (4)

7.6.4 State TWO advantages of using VSDs over conventional motor drives. (2)

7.7 Give TWO examples where regenerative energy can be reused. (2)
[40]

TOTAL: 200

FORMULA SHEET

RLC CIRCUITS

$P = V \times I \times \cos\theta$

$X_L = 2\pi fL$

$X_C = \dfrac{1}{2\pi fC}$

$f_r = \dfrac{1}{2\pi\sqrt{LC}}$ **OR** $f_r = \dfrac{f_1 + f_2}{2}$

$BW = \dfrac{f_r}{Q}$ **OR** $BW = f_2 - f_1$

SERIES

$V_R = IR$

$V_L = I\,X_L$

$V_C = I\,X_C$

$I_T = \dfrac{V_T}{Z}$ **OR** $I_T = I_R = I_C = I_L$

$Z = \sqrt{R^2 + (X_L - X_C)^2}$

$V_T = \sqrt{V_R{}^2 + (V_L - V_C)^2}$ **OR** $V_T = IZ$

$\cos\theta = \dfrac{R}{Z}$ **OR** $\cos\theta = \dfrac{V_R}{V_T}$

$Q = \dfrac{X_L}{R} = \dfrac{X_C}{R} = \dfrac{V_L}{V_T} = \dfrac{V_C}{V_T} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$

PARALLEL

$V_T = V_R = V_L = V_C$

$I_R = \dfrac{V_T}{R}$

$I_C = \dfrac{V_T}{X_C}$

$I_L = \dfrac{V_T}{X_L}$

$I_T = \sqrt{I_R{}^2 + (I_L - I_C)^2}$

$Z = \dfrac{V_T}{I_T}$

$\cos\theta = \dfrac{I_R}{I_T}$

$Q = \dfrac{R}{X_L} = \dfrac{R}{X_C} = \dfrac{I_L}{I_T} = \dfrac{I_C}{I_T}$

THREE-PHASE AC GENERATION

STAR

$V_L = \sqrt{3}\,V_{PH}$

$V_{PH} = I_{PH} \times Z_{PH}$

$I_L = I_{PH}$

DELTA

$V_L = V_{PH}$

$V_{PH} = I_{PH} \times Z_{PH}$

$I_L = \sqrt{3}\,I_{PH}$

POWER

$S\ (P_{app}) = \sqrt{3} \times V_L \times I_L$

$Q\ (P_r) = \sqrt{3} \times V_L \times I_L \times \sin\theta$

$P = \sqrt{3} \times V_L \times I_L \cos\theta$

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

EFFICIENCY

$\eta = \dfrac{\text{output power}}{\text{input power}} \times 100$

TWO-WATTMETER METHOD

$P_T = P_1 + P_2$

$\tan\theta = \sqrt{3}\left(\dfrac{P_1 - P_2}{P_1 + P_2}\right)$

THREE-WATTMETER METHOD

$P_T = P_1 + P_2 + P_3$

THREE-PHASE TRANSFORMERS	THREE-PHASE MOTORS AND STARTERS
STAR	**STAR**
$V_L = \sqrt{3}\, V_{PH}$ and $I_L = I_{PH}$	$V_L = \sqrt{3}\, V_{PH}$ and $I_L = I_{PH}$
DELTA	**DELTA**
$I_L = \sqrt{3}\, I_{PH}$ and $V_L = V_{PH}$	$I_L = \sqrt{3}\, I_{PH}$ and $V_L = V_{PH}$
POWER	**POWER**
$S\ (P_{app}) = \sqrt{3} \times V_L \times I_L$	$S\ (P_{app}) = \sqrt{3} \times V_L \times I_L$
$Q\ (P_r) = \sqrt{3} \times V_L \times I_L \times \operatorname{Sin}\theta$	$Q\ (P_r) = \sqrt{3} \times V_L \times I_L \times \operatorname{Sin}\theta$
$P = \sqrt{3} \times V_L \times I_L \operatorname{Cos}\theta$	$P = \sqrt{3} \times V_L \times I_L \operatorname{Cos}\theta$
$\operatorname{Cos}\theta = \frac{P}{S}$	$P = \sqrt{3} \times V_L \times I_L \operatorname{Cos}\theta \times \eta$
$\frac{V_{ph(1)}}{V_{ph(2)}} = \frac{N_1}{N_2} = \frac{I_{ph(2)}}{I_{ph(1)}}$	$\operatorname{Cos}\theta = \frac{P}{S}$
Transformer ratio: $TR = \frac{N_1}{N_2}$	**EFFICIENCY**
$\eta = \frac{P_{OUT}}{P_{OUT} + \text{copper losses} + \text{core losses}} \times 100$	$\eta = \frac{\text{output power}}{\text{input power}} \times 100$
	$n_s = \frac{60 \times f}{p}$
	$\%\ \text{slip} = \frac{n_s - n_r}{n_s} \times 100$
	$\text{Per unit slip} = \frac{n_s - n_r}{n_s}$
	$\text{Slip} = n_s - n_r$