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Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

NATIONAL SENIOR CERTIFICATE

GRADE 12

ELECTRICAL TECHNOLOGY: POWER SYSTEMS

NOVEMBER 2023

MARKS: 200

TIME: 3 hours

This question paper consists of 17 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 The following can be considered as dangerous practices:
- A The use (or misuse) of power tools
 - B The incorrect use and handling of hand tools
 - C The etching of printed circuit boards
 - D All the above-mentioned (1)
- 1.2 ... is the reference quantity in a parallel RLC circuit.
- A Current
 - B Resistance
 - C Reactance
 - D Voltage (1)
- 1.3 The reactance of a ... must be equal for a circuit to resonate.
- A resistor and an inductor
 - B resistor and a capacitor
 - C capacitor and an inductor
 - D transducer and a capacitor (1)
- 1.4 The following condition is common to both series and parallel resonance:
- A The impedance is minimum.
 - B The current is maximum.
 - C The bandwidth is affected by its quality factor.
 - D The Q-factor depends on voltage amplification. (1)
- 1.5 The voltage generated at power stations in South Africa is stepped up to ... for transmission over long distances.
- A 22 kV
 - B 40 kV
 - C 110 kV
 - D 220 kV (1)
- 1.6 ... establish how much electricity must be generated throughout South Africa.
- A Municipalities
 - B Substations
 - C Control centres
 - D Intermediate substations (1)

- 1.7 A ... indicates whether a load is more inductive or more capacitive.
- A wattmeter
 - B power factor meter
 - C kilowatt-hour meter
 - D voltmeter
- (1)
- 1.8 In a three-phase core-type transformer the ...
- A core hides the major part of the windings.
 - B core is enclosed by the windings.
 - C windings are enclosed by the core.
 - D core has 5 limbs.
- (1)
- 1.9 When a load is connected, the primary phase current of a step-down transformer is ... the secondary phase current.
- A higher than
 - B equal to
 - C lower than
 - D $\sqrt{3}$ times
- (1)
- 1.10 When starting an induction motor, the slip ... as the motor picks up speed.
- A is minimum and increases
 - B increases exponentially
 - C is maximum and decreases
 - D remains constant
- (1)
- 1.11 ... are electromagnetically operated switches that provide a safe and convenient means of connecting and interrupting circuits.
- A Key switches
 - B Stop buttons
 - C Start buttons
 - D Contactors
- (1)
- 1.12 An automatic star-delta motor starter reduces the starting current by ...
- A reducing the voltage across the motor coils to phase voltage.
 - B maintaining the voltage across the motor coils to line voltage.
 - C increasing the voltage across the motor coils to $\sqrt{3}$ times the line voltage.
 - D dividing the line current.
- (1)

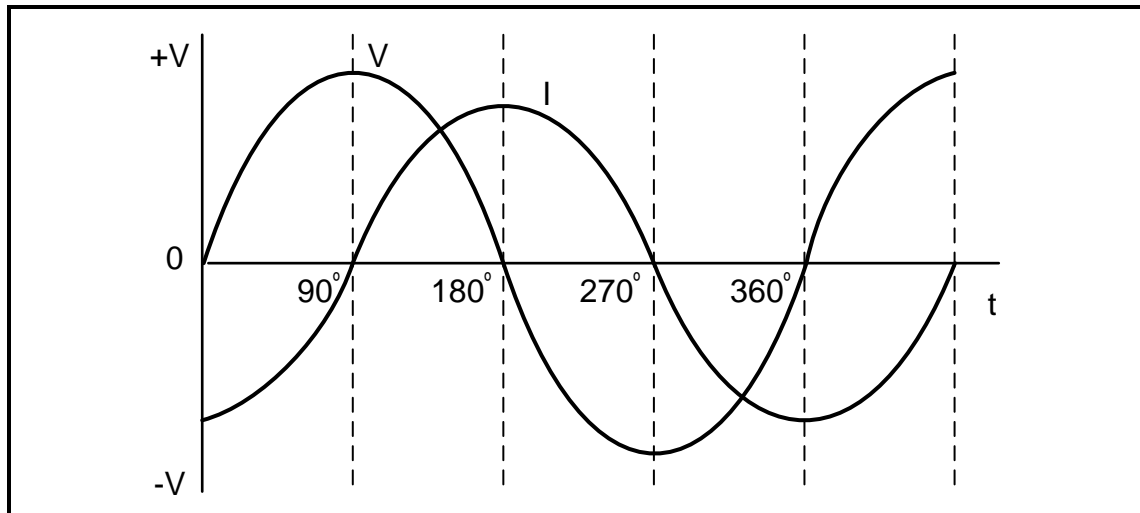
- 1.13 A semiconductor device that uses light to transmit a signal between two circuits that are electrically isolated is called a ...
A switch.
B sensor.
C opto-coupler.
D strain gauge. (1)
- 1.14 The ... is used to dissipate excessive regenerative energy, with reference to VSD.
A filter
B inverter
C converter
D braking resistor (1)
- 1.15 A system that performs many functions digitally to reduce the amount of wiring in a motor starter circuit is called a ... system.
A soft-wired
B hard-wired
C thick-wired
D compact-wired (1)
- [15]**

QUESTION 2: OCCUPATIONAL HEALTH AND SAFETY

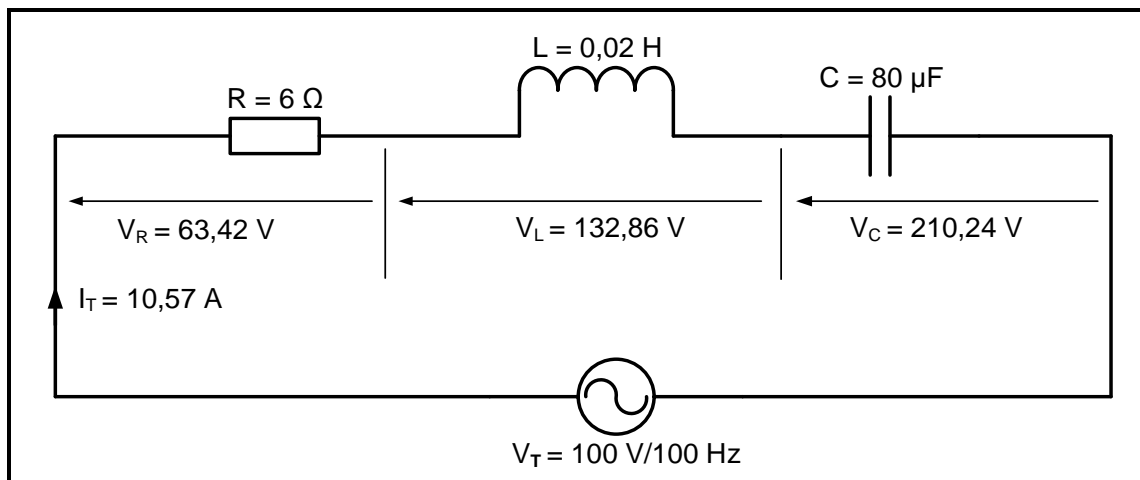
- 2.1 Name TWO incidents arising out of activities of people at the workplace that must be reported to the health and safety inspector. (2)
- 2.2 Define the term *danger* with reference to the Occupational Health and Safety Act, 1993 (Act 85 of 1993). (2)
- 2.3 Explain why the location of the emergency master switch is important for safety in and around the workshop. (2)
- 2.4 State TWO effects a third-degree burn has on a person's body. (2)
- 2.5 Name TWO first-aid steps to take after a person has been shocked by an electric current. (2)
- [10]**

QUESTION 3: RLC CIRCUITS

- 3.1 State the relationship between inductive reactance and frequency. (1)
- 3.2 Refer to FIGURE 3.2 below and state the phase relationship between the current and voltage waveforms.

**FIGURE 3.2: CURRENT AND VOLTAGE WAVEFORMS**

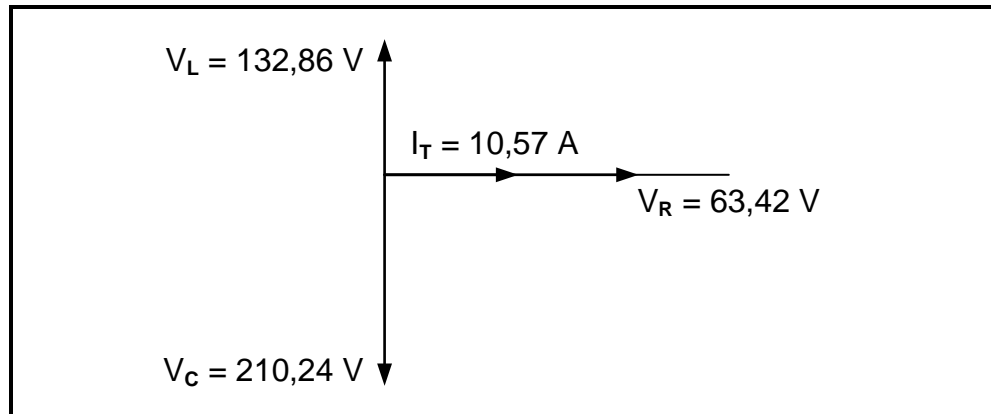
- 3.3 FIGURE 3.3 below shows an RLC series circuit which consists of a resistor with a resistance of $6\ \Omega$, an inductor with an inductance of $0,02\ \text{H}$ and a capacitor with a capacitance of $80\ \mu\text{F}$, which are all connected across an alternating supply of $100\ \text{V}/100\ \text{Hz}$.

**FIGURE 3.3: RLC SERIES CIRCUIT**

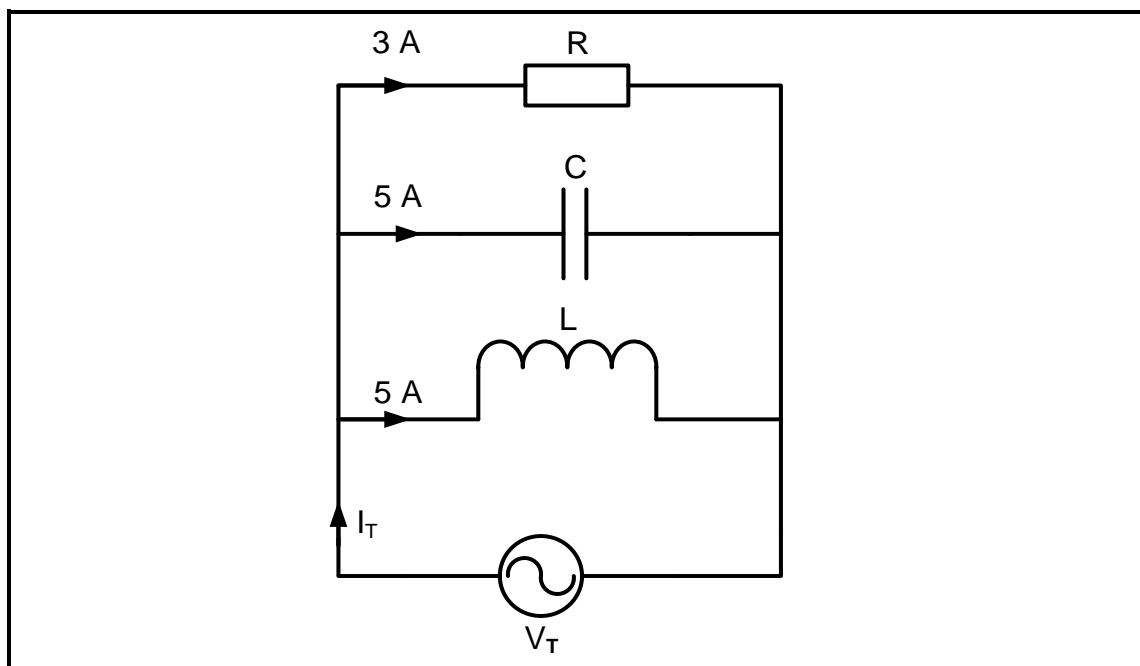
Given:

R	$=$	$6\ \Omega$
L	$=$	$0,02\ \text{H}$
C	$=$	$80\ \mu\text{F}$
V_R	$=$	$63,42\ \text{V}$
V_C	$=$	$210,24\ \text{V}$
V_L	$=$	$132,86\ \text{V}$
V_T	$=$	$100\ \text{V}$
I_T	$=$	$10,57\ \text{A}$
f	$=$	$100\ \text{Hz}$

- 3.3.1 State whether the supply current is leading or lagging the supply voltage. Motivate your answer. (2)
- 3.3.2 Redraw and complete the phasor diagram of the circuit diagram in FIGURE 3.3 below in the ANSWER BOOK.

**FIGURE 3.3.2: PHASOR DIAGRAM**

- 3.3.3 Prove that the resultant of V_R , V_L and V_C equals the supply voltage. (3)
- 3.3.4 Calculate the frequency at which the circuit will resonate. (3)
- 3.4 Refer to FIGURE 3.4 below and answer the questions that follow.

**FIGURE 3.4: CIRCUIT DIAGRAM**

- 3.4.1 Calculate the total current of the circuit. (3)
- 3.4.2 Calculate the phase angle. (3)
- 3.4.3 Draw a fully labelled phasor diagram for the circuit in FIGURE 3.4 above in the ANSWER BOOK. (4)

- 3.5 A series circuit consists of a resistor with a resistance of 30 ohms, an inductor with an inductance of 10 mH and a capacitor with a capacitive reactance of 300 ohms. This combination is connected across an alternating supply of 30 V and resonates at a frequency of 4,77 kHz.

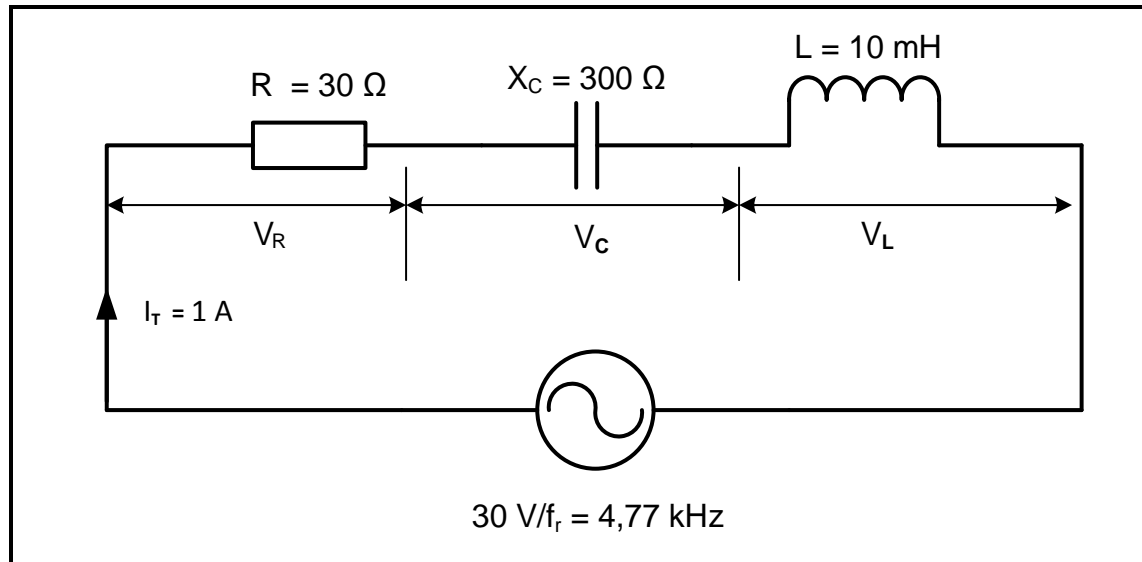


FIGURE 3.5: RESONANCE RLC SERIES CIRCUIT

Given:

$$\begin{aligned}
 R &= 30 \, \Omega \\
 X_c &= 300 \, \Omega \\
 L &= 10 \, \text{mH} \\
 V_T &= 30 \, \text{V} \\
 f_r &= 4,77 \, \text{kHz} \\
 I_T &= 1 \, \text{A}
 \end{aligned}$$

- 3.5.1 Calculate the Q-factor of the circuit. (3)
- 3.5.2 Calculate the bandwidth of the circuit. (3)
- 3.5.3 Calculate the voltage drop across the inductor. (3)
- 3.5.4 Explain why the voltage across the inductor is greater than the value of the supply voltage. (2)
- [35]**

QUESTION 4: THREE-PHASE AC GENERATION

- 4.1 Explain the following terms with reference to three-phase systems:
- 4.1.1 Efficiency (2)
 - 4.1.2 Power factor correction (2)
- 4.2 Name TWO advantages of power factor correction to the supplier. (2)
- 4.3 Differentiate between *power transmission* and *power distribution*. (4)
- 4.4 An alternator delivers power to a three-phase delta-connected load at 400 V. The output power is 5 kW with a power factor of 0,85.
- Given:
- $V_L = 400 \text{ V}$
 $P = 5 \text{ kW}$
 $\text{pf} = 0,85$
- Calculate the:
- 4.4.1 Line current (3)
 - 4.4.2 Apparent power (3)
 - 4.4.3 Reactive power (5)
 - 4.4.4 Draw a phasor diagram of the supply indicating the correct phase sequence of line voltages and the angle between voltages. (5)

- 4.5 FIGURE 4.5 below shows the diagram of an analogue wattmeter connected to a phase of a three-phase star-connected system. Answer the questions that follow.

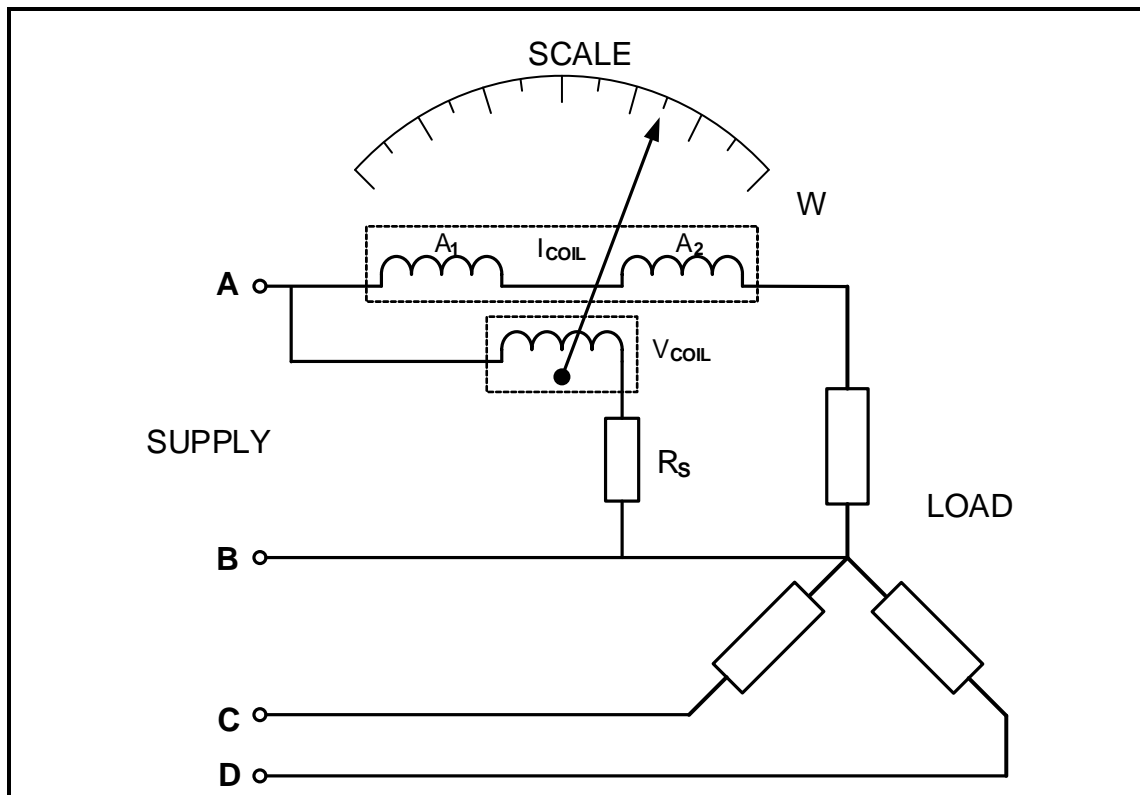


FIGURE 4.5: ANALOGUE WATTMETER

- 4.5.1 Name TWO methods used to measure the total power of a three-phase system. (2)
- 4.5.2 Label the terminals at **A** and **B**. (2)
- 4.5.3 Differentiate between a *wattmeter* and a *kilowatt-hour meter*. (3)
- 4.6 Explain what a reading of 0,9 on a power factor meter means with reference to the following:
- 4.6.1 The load (1)
- 4.6.2 The supply (1)
- [35]**

QUESTION 5: THREE-PHASE TRANSFORMERS

- 5.1 Name TWO parts of the cooling system in three-phase transformers. (2)
- 5.2 Name the type of loss that contributes the most to heat in three-phase transformers. (1)
- 5.3 State ONE application of a star-delta transformer in a transmission network. (1)
- 5.4 State how eddy current losses are reduced in transformers. (1)
- 5.5 Explain why heat should be dissipated in transformers. (2)
- 5.6 Name the cooling method preferred for very large transformers of several hundred MVA (megavolt ampere). (1)
- 5.7 State the function of the Buchholz relay in a transformer. (1)
- 5.8 A 100 kVA three-phase delta-star transformer with a transformer ratio of 48 : 1 delivers power to an industrial load. The primary line voltage is 11 kV and the total losses in the transformer are given as 5 kW. The load operates at a power factor of 0,9.

Given:

S	=	100 kVA
TR	=	48 : 1
V_{L1}	=	11 000 V
Losses	=	5 kW
pf	=	0,9

Calculate the:

- 5.8.1 Primary line current (3)
- 5.8.2 Secondary phase voltage (3)
- 5.8.3 Active (true) power (3)
- 5.8.4 Draw a diagrammatic representation of the transformer coils. (7)
- 5.8.5 Determine whether it is a step-down or step-up transformer. Motivate your answer. (2)
- 5.9 Explain, with a reason, the relationship between voltage and current of a step-down transformer. (3)

[30]

QUESTION 6: THREE-PHASE MOTORS AND STARTERS

6.1 Name TWO parts of a stator with reference to induction motors (2)

6.2 FIGURE 6.2 below shows the name plate of an induction motor. Answer the questions that follow.

S/N	MO85SA26Z
V	400 V
I_{FL}	5 A
η	85%
P	2,5 kW
n_s	
$n_{(full\ load)}$	1 250 r/min
f	50 Hz
p	2
slip	

FIGURE 6.2: NAME PLATE

6.2.1 Motivate why this nameplate belongs to a three-phase motor. (1)

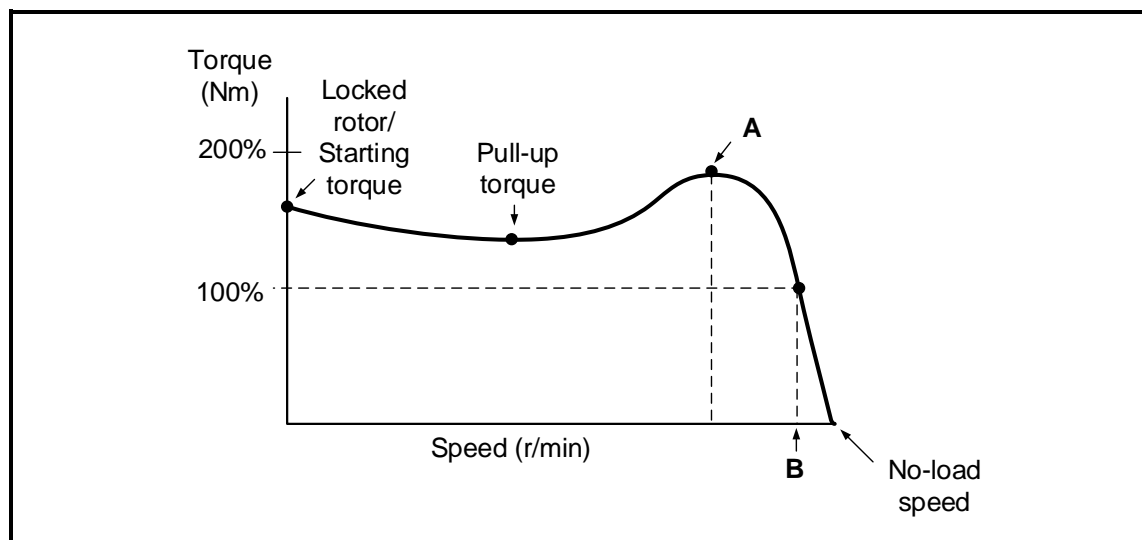
6.2.2 Identify the efficiency of the motor. (1)

6.2.3 Calculate the synchronous speed of the motor. (3)

6.2.4 Calculate the slip in r/min. (3)

6.3 Explain how power in a three-phase induction motor is transferred from the stator to the rotor. (4)

6.4 FIGURE 6.4 below shows the speed vs torque curve of an induction motor. Answer the questions that follow.

**FIGURE 6.4: SPEED VS TORQUE CURVE**

- 6.4.1 Write down the labels for **A** and **B** in the ANSWER BOOK. (2)
- 6.4.2 State how the speed and torque of the motor in FIGURE 6.4 are affected when increasing the load beyond the full-load value. (2)
- 6.4.3 State when the motor represented in FIGURE 6.4 will stall. (1)

6.5 FIGURE 6.5 below shows the control circuit of a forward-reverse motor starter. Answer the questions that follow.

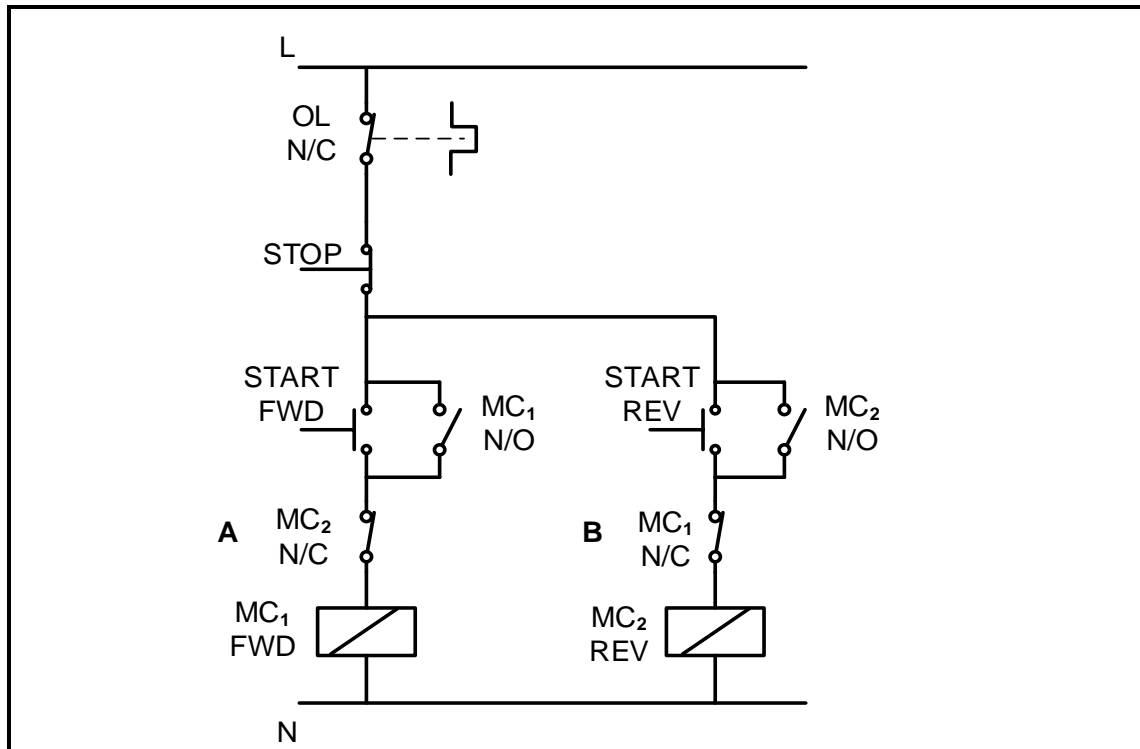


FIGURE 6.5: FORWARD-REVERSE CONTROL CIRCUIT

- 6.5.1 State the purpose of contacts **A** and **B**. (1)
- 6.5.2 Explain the function of MC₂N/O. (2)
- 6.5.3 Explain how the operation of the circuit will be affected if MC₁N/O becomes faulty and permanently closed. (3)

- 6.6 A 5 kW three-phase delta-connected motor is connected to a 400 V/50 Hz supply. When operating at full load, the motor draws 8,59 A from the supply.

Given:

$$\begin{aligned} P &= 5 \text{ kW} \\ V_L &= 400 \text{ V} \\ I_L &= 8,59 \text{ A} \end{aligned}$$

Calculate the following:

- 6.6.1 The phase current of the motor (3)
- 6.6.2 The power factor of the motor (4)
- 6.6.3 The output power if the motor is 90% efficient (3)
- [35]**

QUESTION 7: PROGRAMMABLE LOGIC CONTROLLERS (PLCs)

7.1 Explain the advantages of PLC systems with regard to the following:

7.1.1 Space (2)

7.1.2 Flexibility (2)

7.2 FIGURE 7.2 below shows the ladder logic of a logic gate. Answer the questions that follow.

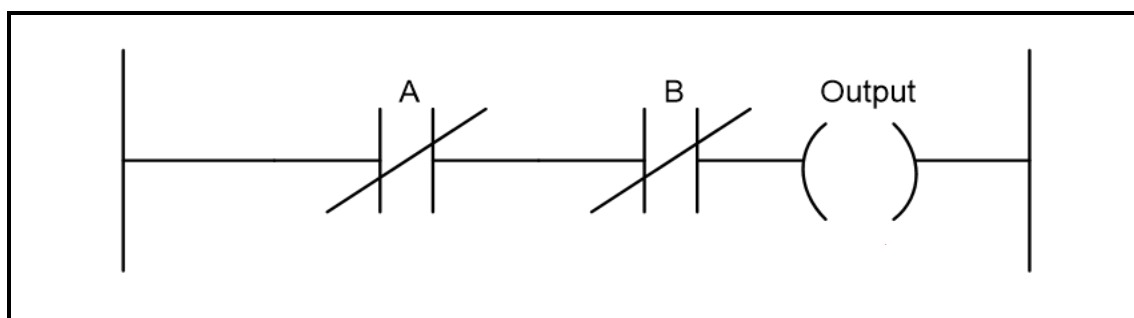


FIGURE 7.2: LADDER LOGIC

7.2.1 Name the logic gate represented in FIGURE 7.2 above. (1)

7.2.2 Draw the equivalent logic gate symbol of FIGURE 7.2 above. (3)

7.2.3 FIGURE 7.2.3 below shows two input states of the circuit in FIGURE 7.2. Complete the truth table in FIGURE 7.2.3 by writing down only the state of the output in the ANSWER BOOK.

A	B	OUTPUT
0	0	(W)
0	1	(X)

FIGURE 7.2.3: TRUTH TABLE

(2)

7.3 Refer to inputs on a PLC and answer the questions that follow.

7.3.1 Name the type of proximity sensor that utilises an electrostatic field (e-field) to sense proximity. (1)

7.3.2 Explain the purpose of a light sensor in an automated garage door system. (2)

7.3.3 Explain how a temperature sensor is used to prevent a mining drill from breaking. (3)

7.4 Refer to the outputs on a PLC and answer the questions that follow.

7.4.1 State the function of a timer in PLC systems. (2)

7.4.2 Explain why contactors are used on the output of a PLC when controlling high-current three-phase loads. (2)

7.5 Refer to FIGURE 7.5 below and answer the questions that follow.

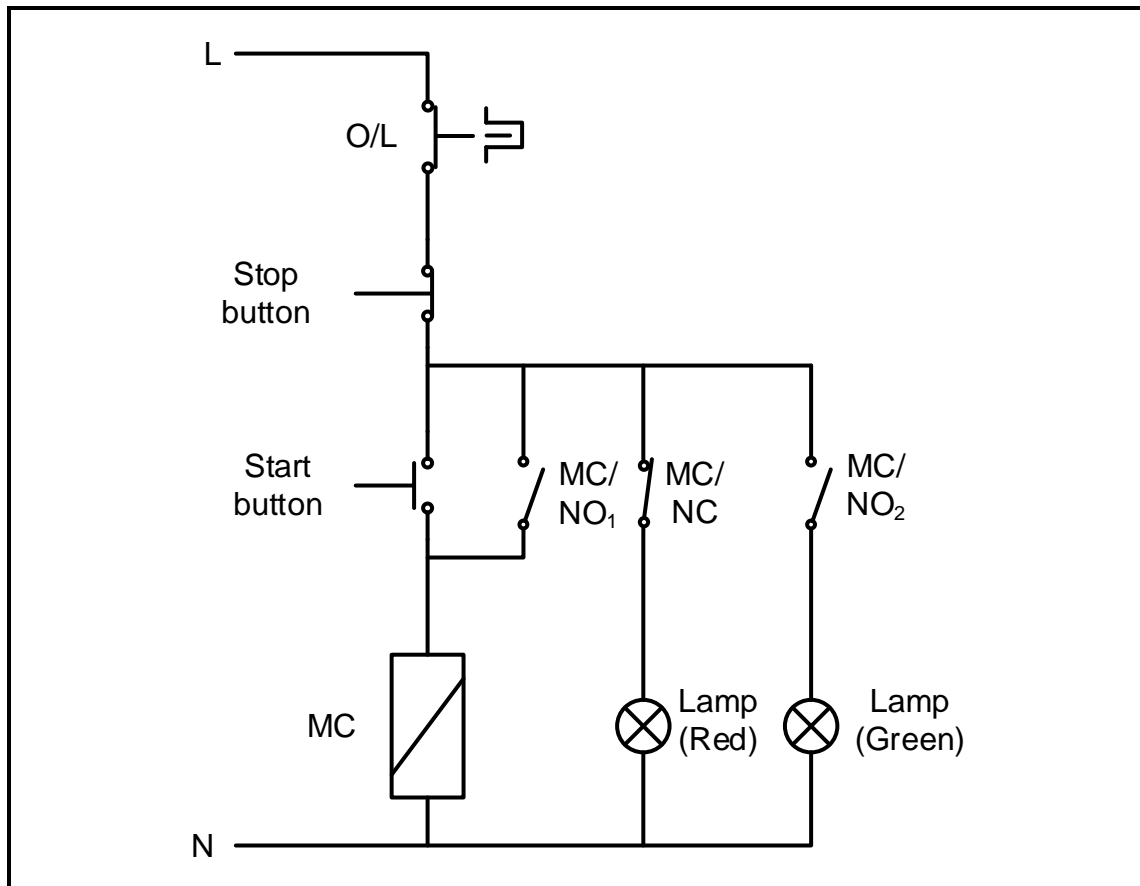


FIGURE 7.5: CONTROL CIRCUIT

7.5.1 Draw the PLC ladder logic diagram that will execute the same function in a PLC system. (9)

7.5.2 State the conditions of the red and green lamps after the start button is pressed and released. (2)

7.5.3 Describe the function of the MC contactor that is connected in series with the start pushbutton. (2)

- 7.6 FIGURE 7.6 below shows the basic block diagram of a variable speed drive. Answer the questions that follow.

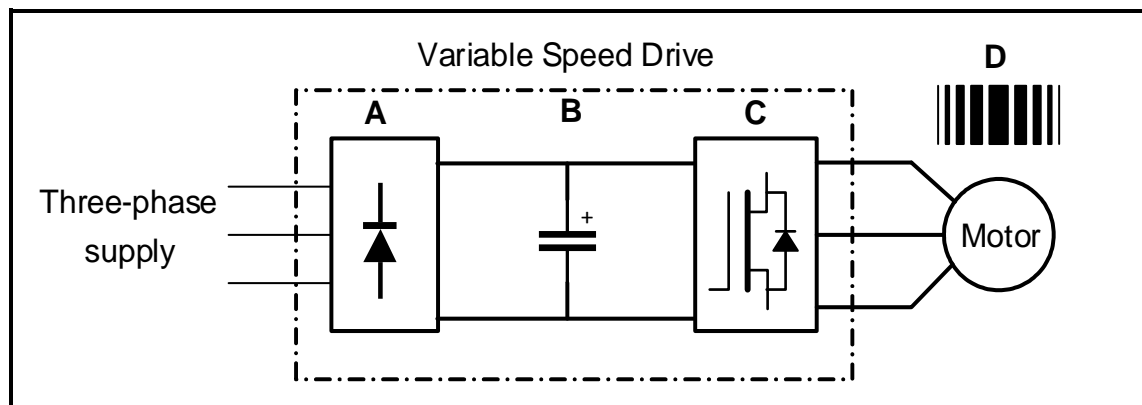


FIGURE 7.6: VARIABLE SPEED DRIVE

- 7.6.1 Name the process that takes place at **C** to generate the output at **D**. (1)
- 7.6.2 State TWO precautions that must be considered in the application of a variable speed drive (VSD). (2)
- 7.6.3 Explain the principle of operation of the VSD. (4)

[40]

TOTAL: 200

FORMULA SHEET

RLC CIRCUITS	THREE-PHASE AC GENERATION
$P = V I \cos \theta$ $X_L = 2\pi fL$ $X_C = \frac{1}{2\pi fC}$ $f_r = \frac{1}{2\pi\sqrt{LC}} \quad \text{OR} \quad f_r = \frac{f_1 + f_2}{2}$ $BW = \frac{f_r}{Q} \quad \text{OR} \quad BW = f_2 - f_1$ SERIES $V_R = IR$ $V_L = IX_L$ $V_C = IX_C$ $I_T = \frac{V_T}{Z} \quad \text{OR} \quad I_T = I_R = I_C = I_L$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$ $V_T = \sqrt{V_R^2 + (V_L - V_C)^2} \quad \text{OR} \quad V_T = IZ$ $\cos \theta = \frac{R}{Z} \quad \text{OR} \quad \cos \theta = \frac{V_R}{V_T}$ $Q = \frac{X_L}{R} = \frac{X_C}{R} = \frac{V_L}{V_T} = \frac{V_C}{V_T} = \frac{1}{R} \sqrt{\frac{L}{C}}$ PARALLEL $V_T = V_R = V_C = V_L$ $I_R = \frac{V_T}{R}$ $I_C = \frac{V_T}{X_C}$ $I_L = \frac{V_T}{X_L}$ $I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$ $Z = \frac{V_T}{I_T}$ $\cos \theta = \frac{I_R}{I_T}$ $Q = \frac{R}{X_L} = \frac{R}{X_C}$	STAR $V_L = \sqrt{3} V_{PH}$ $V_{PH} = I_{PH} Z_{PH}$ $I_L = I_{PH}$ DELTA $V_L = V_{PH}$ $V_{PH} = I_{PH} Z_{PH}$ $I_L = \sqrt{3} I_{PH}$ POWER $S(P_{app}) = \sqrt{3} V_L I_L$ $Q(P_r) = \sqrt{3} V_L I_L \sin \theta$ $P = \sqrt{3} V_L I_L \cos \theta$ $\cos \theta = \frac{P}{S}$ EFFICIENCY $\eta = \frac{P_{OUT}}{P_{IN}} \times 100$ TWO-WATTMETER METHOD $P_T = P_1 + P_2$ $\tan \theta = \sqrt{3} \left(\frac{P_1 - P_2}{P_1 + P_2} \right)$ THREE-WATTMETER METHOD $P_T = P_1 + P_2 + P_3$

THREE-PHASE TRANSFORMERS	THREE-PHASE MOTORS AND STARTERS
STAR $V_L = \sqrt{3} V_{PH}$ $I_L = I_{PH}$ DELTA $V_L = V_{PH}$ $I_L = \sqrt{3} I_{PH}$ POWER $S(P_{app}) = \sqrt{3} V_L I_L$ $Q(P_r) = \sqrt{3} V_L I_L \sin \theta$ $P = \sqrt{3} V_L I_L \cos \theta$ $\cos \theta = \frac{P}{S}$ $\frac{V_{PH(1)}}{V_{PH(2)}} = \frac{N_1}{N_2} = \frac{I_{PH(2)}}{I_{PH(1)}}$ Turns ratio: $TR = \frac{N_1}{N_2}$ $\eta = \frac{P_{OUT}}{P_{OUT} + \text{losses}} \times 100$	STAR $V_L = \sqrt{3} V_{PH}$ $I_L = I_{PH}$ DELTA $V_L = V_{PH}$ $I_L = \sqrt{3} I_{PH}$ POWER $S(P_{app}) = \sqrt{3} V_L I_L$ $Q(P_r) = \sqrt{3} V_L I_L \sin \theta$ $P = \sqrt{3} V_L I_L \cos \theta$ $P = \sqrt{3} V_L I_L \cos \theta \eta$ $\cos \theta = \frac{P}{S}$ EFFICIENCY $\eta = \frac{P_{IN} - \text{losses}}{P_{IN}} \times 100$ $\eta = \frac{P_{OUT}}{P_{IN}} \times 100$ SPEED $n_s = \frac{60 \times f}{p}$ Per unit slip = $\frac{n_s - n_r}{n_s}$ $\% \text{ Slip} = \frac{n_s - n_r}{n_s} \times 100$ $n_r = n_s(1 - \% \text{ slip})$ Slip = $n_s - n_r$