basic education

Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

SENIOR CERTIFICATE EXAMINATIONS/ NATIONAL SENIOR CERTIFICATE EXAMINATIONS

ELECTRICAL TECHNOLOGY: POWER SYSTEMS

2023

MARKS: 200

TIME: 3 hours

This question paper consists of 20 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 critical incident causes …

A damage to equipment. External repair services are required.
B a person to sustain a sudden and severe physical injury. External medical services are required.
C a person to sustain a physical injury. External medical services are not required.
D a person to get a mental disturbance. A restful recovery is required. (1)

1.2 The … is the term used for the ratio of the applied voltage to the resulting circuit current where the applied voltage is the resultant of V_R, V_C and V_L in an RLC circuit.

A reactance
B resistance
C impedance
D phase angle (1)

1.3 The current through a capacitor in an RLC parallel circuit will … when the frequency increases.

A remain the same
B decrease
C increase
D be zero (1)

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

A two currents are available in star connections.
B a neutral point is available in delta connections.
C phase balancing and load distribution are possible.
D two voltages are available in delta connections. (1)

1.5 The ratio of real power to apparent power is known as the …

A reactive power.
B phase angle.
C efficiency.
D power factor. (1)

1.6 The correct method to connect a wattmeter is by connecting the voltage coil in … with the load.

A parallel and the current coil in series
B series and the current coil in series
C parallel and the current coil in parallel
D series and the current coil in parallel (1)

1.7 The construction of a three-phase shell-type transformer is described as a core with …

A three limbs and the coils are wound around all three limbs.
B five limbs and the coils are wound around the three middle limbs.
C five limbs and the coils are wound around all five limbs.
D three limbs and the coils are wound around the outside two limbs. (1)

1.8 A delta-star transformer with a primary line voltage of 2 200 V and a secondary line voltage of 381 V has a turns ratio of …

A 6 **:** 1
B 1 **:** 10
C 1 **:** 6
D 10 **:** 1 (1)

1.9 … are the main causes of heat generation inside transformers with laminated cores.

A Hysteresis losses
B Copper losses
C Eddy current losses
D Stray losses (1)

1.10 Power in an induction motor is transferred from the …

A rotor to the stator through mutual induction.
B stator to the rotor through slip rings.
C stator to the rotor through mutual induction.
D rotor to the stator through self-induction. (1)

1.11 At the moment of starting an induction motor, the … is at maximum and decreases as the motor's speed increases.

A slip
B rotor speed
C full-load speed
D momentum (1)

1.12 The start-up current in an automatic star-delta motor starter is reduced because the …

A line voltage in star is lower than the line voltage in delta.
B phase voltage in delta is lower than the phase voltage in star.
C line voltage in delta is lower than the line voltage in star.
D phase voltage in star is lower than the phase voltage in delta. (1)

1.13 A semiconductor device that uses light to transfer an electrical signal between circuits or elements of a circuit is called a/an …

A diode.
B opto-coupler.
C transistor.
D switch. (1)

1.14 An example of an output on a PLC is a …

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

1.15 The part of a VSD that converts DC back to AC is the …

A filter.
B inverter.
C converter.
D rectifier. (1)
[15]

QUESTION 2: OCCUPATIONAL HEALTH AND SAFETY

2.1 State the purpose of the Occupational Health and Safety Act, 1993 (Act 85 of 1993). (3)

2.2 Explain how an *unsafe act* can reduce the rate of production at the work place. (2)

2.3 Explain the term *high impact; low probability* with reference to risk analysis. (2)

2.4 State TWO recommended procedures to stop bleeding in an emergency. (2)

2.5 State ONE procedure to follow for personal protection when administering the procedures mentioned in QUESTION 2.4. (1)
[10]

QUESTION 3: RLC CIRCUITS

3.1 Describe what is meant by the term *in phase* with reference to the relationship between the applied voltage and current in an RLC circuit connected to an AC supply. (3)

3.2 Refer to the AC waveforms in FIGURE 3.2 below and draw the phasor diagram that represents them.

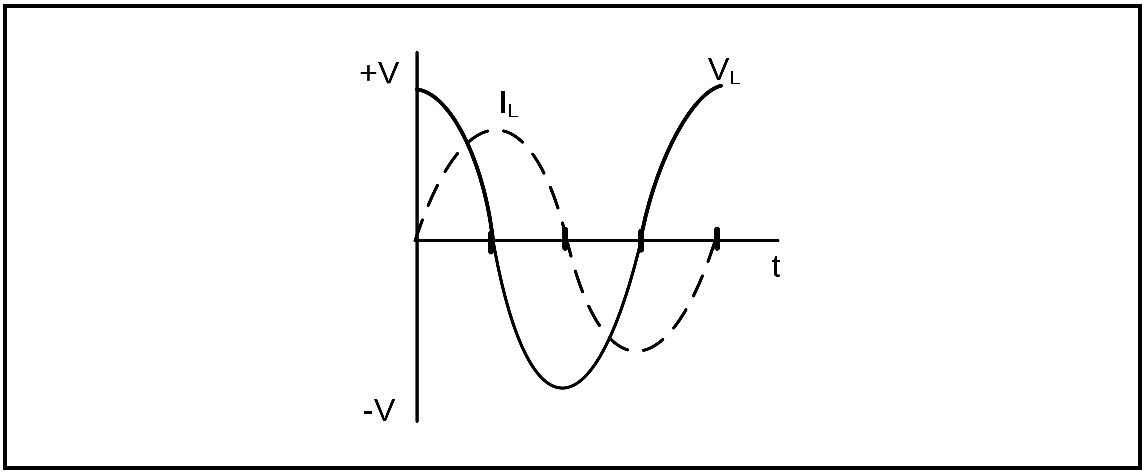

FIGURE 3.2: CURRENT AND VOLTAGE WAVEFORMS (3)

3.3 Name TWO applications of resonance as applicable to tuned circuits. (2)

3.4 Identify the graphs below.

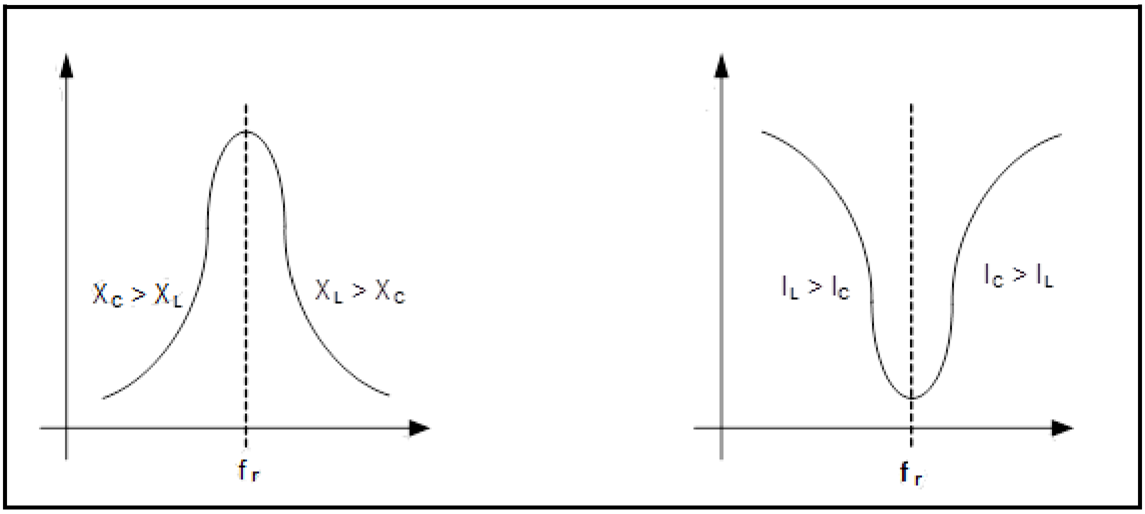

FIGURE 3.4(a) **FIGURE 3.4(b)**

3.4.1 FIGURE 3.4(a) (1)

3.4.2 FIGURE 3.4(b) (1)

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

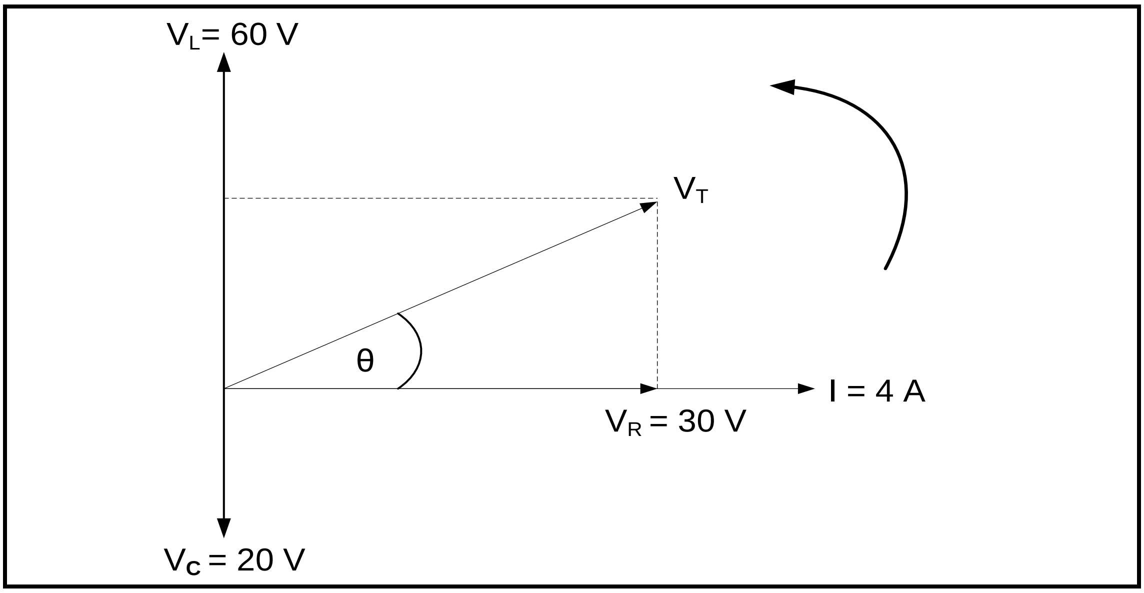

FIGURE 3.5: PHASOR DIAGRAM

Given:

V_L = 60 V
V_C = 20 V
V_R = 30 V
I = 4 A
f = 60 Hz

3.5.1 Calculate the value of the supply voltage. (3)

3.5.2 Calculate the phase angle. (3)

3.5.3 State whether the phase angle is leading or lagging. (1)

3.6 Refer to FIGURE 3.6 below and answer the questions that follow.

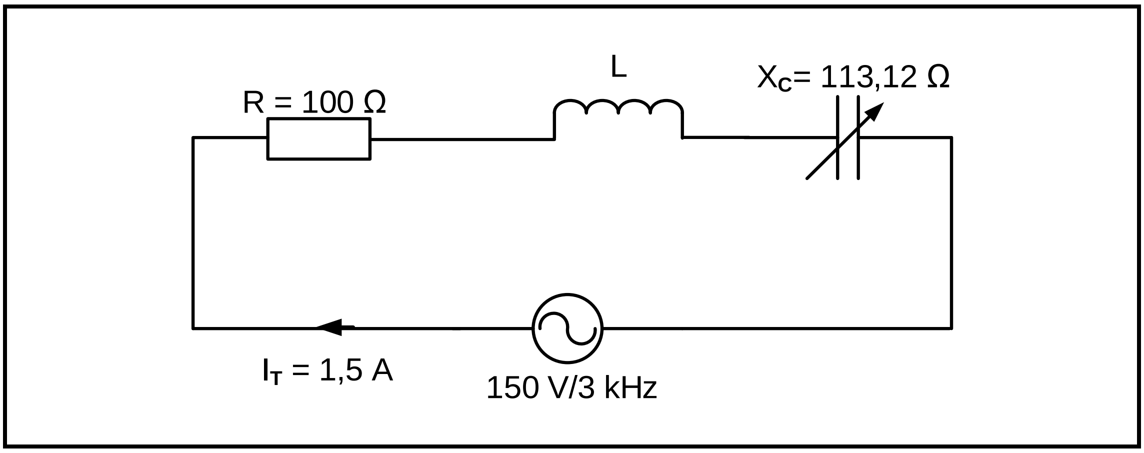

FIGURE 3.6: RLC SERIES CIRCUIT

Given:

R = 100 Ω
X_C = 113,12 Ω
V_T = 150 V
I_T = 1,5 A
f = 3 kHz

3.6.1 Calculate the value of the inductance for the circuit to resonate at 3 kHz. (3)

3.6.2 Calculate the Q-factor of the circuit at resonance. (3)

3.6.3 Calculate the bandwidth of the circuit. (3)

3.6.4 Explain how the value of the total current would be influenced if R is halved when the circuit is at resonance. (1)

3.7 Refer to FIGURE 3.7 below and answer the questions that follow.

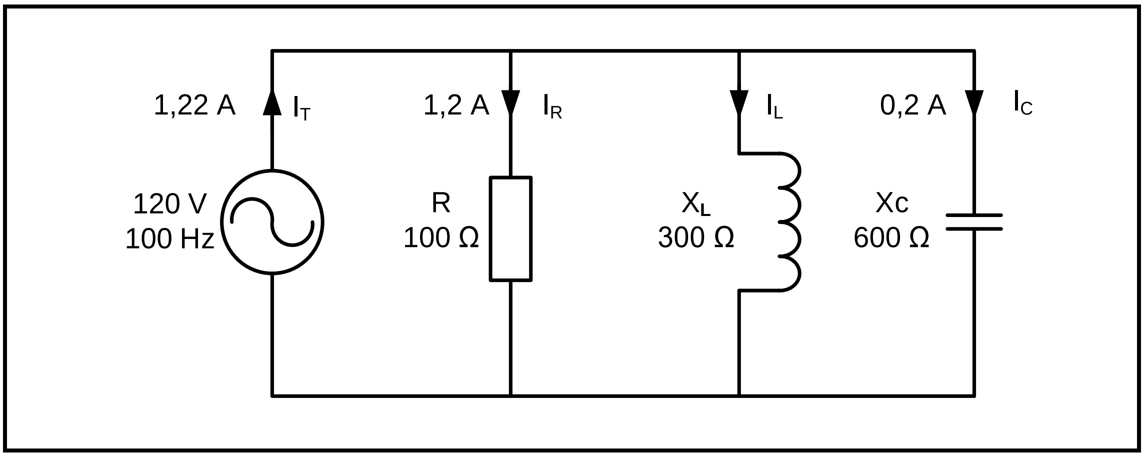

FIGURE 3.7: RLC PARALLEL CIRCUIT DIAGRAM

Given:

V_T = 120 V
I_R = 1,2 A
I_C = 0,2 A
I_T = 1,22 A
f = 100 Hz
R = 100 Ω
X_C = 600 Ω
X_L = 300 Ω

3.7.1 Calculate the current through the inductor. (3)

3.7.2 Calculate the value of the active power. (3)

3.7.3 State, with a reason, if the circuit is capacitive or inductive. (2)
[35]

QUESTION 4: THREE-PHASE AC GENERATION

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

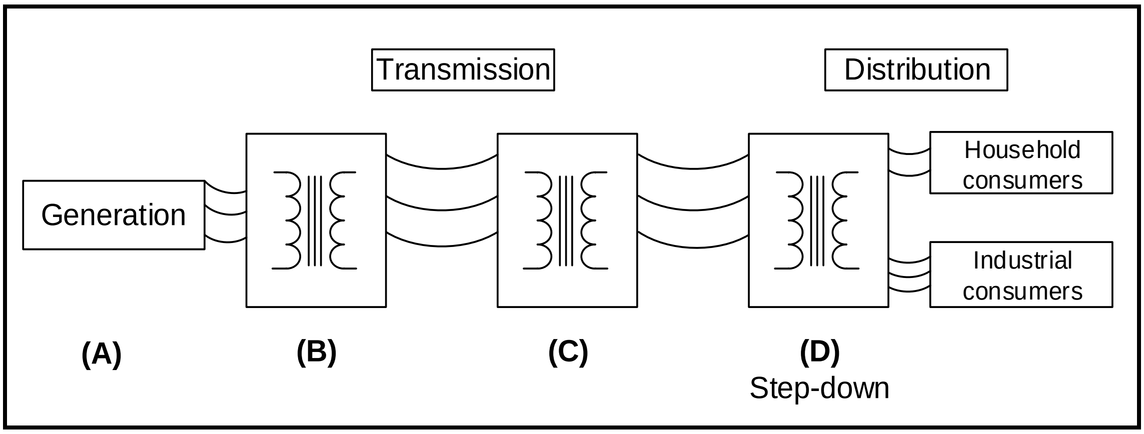

FIGURE 4.1: THE NATIONAL POWER GRID

4.1.1 State whether the following are step-up or step-down transformers:

(a) Transformer at **(B)** (1)

(b) Transformer at **(C)** (1)

4.1.2 Name the expected voltage provided to the following consumers after transformer **(D)**:

(a) Household (1)

(b) Industrial (1)

4.1.3 Explain why both household and industrial loads can be powered by transformer **(D)**. (2)

4.1.4 Explain why transformer **(B)** reduces copper losses in the transmission lines. (2)

4.1.5 Draw a neatly labelled waveform generated at **(A)** in FIGURE 4.1 above. (4)

4.2 A three-phase star-connected generator delivers power to a balanced three-phase star-connected load with a line voltage of 400 V. The load has a phase impedance of 75 Ω per phase and a power factor of 0,8 lagging.

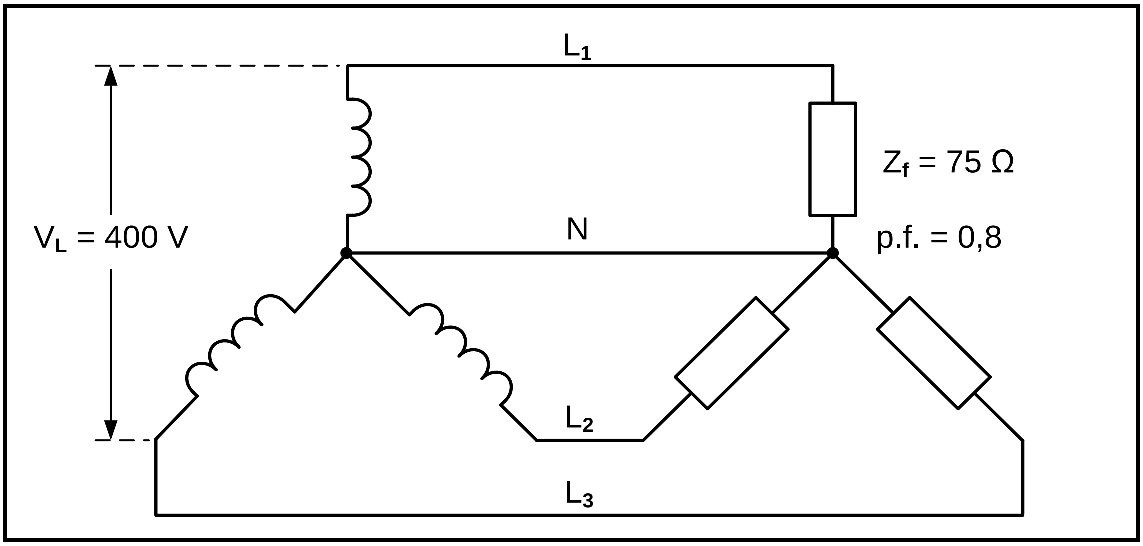

FIGURE 4.2: THREE-PHASE SYSTEM

Given:

V_L = 400 V
Z_{ph} = 75 Ω
p.f. = 0,8

Calculate the:

4.2.1 Phase voltage across the load (3)

4.2.2 Phase current through the load (3)

4.2.3 True power (4)

4.2.4 Phase angle (3)

4.2.5 Reactive power (3)

Answer the following questions:

4.2.6 State why this is an inductive load. (1)

4.2.7 Explain how the power factor of this system can be improved. (2)

4.2.8 Explain the effect that an improved power factor would have on a system. (2)

4.2.9 State TWO advantages of an improved power factor to the consumer. (2)
[35]

QUESTION 5: THREE-PHASE TRANSFORMERS

5.1 Name the process used by transformers to transfer energy from the primary winding to the secondary winding. (1)

5.2 Explain how an alternating magnetic field is created in the primary winding of a transformer. (3)

5.3 List THREE properties that must be identical in single-phase transformers so that they can be used as a three-phase transformer unit. (3)

5.4 Explain where delta-delta transformers are mainly used. Give a reason for the answer. (2)

5.5 A three-phase transformer unit can be obtained by two methods: either by using single-phase transformers and connecting them as a three-phase unit or by a pre-manufactured three-phase transformer.

Compare the two methods and state which method:

5.5.1 Is more expensive (1)

5.5.2 Has a higher efficiency (1)

5.5.3 Uses thicker-sized conductors (1)

5.6 Transformers generate a lot of heat during normal operation and therefore need cooling systems. Answer the following questions:

5.6.1 With reference to cooling, transformers are divided into two categories. Name the TWO categories. (2)

5.6.2 Name TWO cooling methods used in transformers. (2)

5.6.3 Name the protective device that monitors gas formation in high-power transformers. (1)

5.7 FIGURE 5.7 below shows a three-phase delta-star transformer.

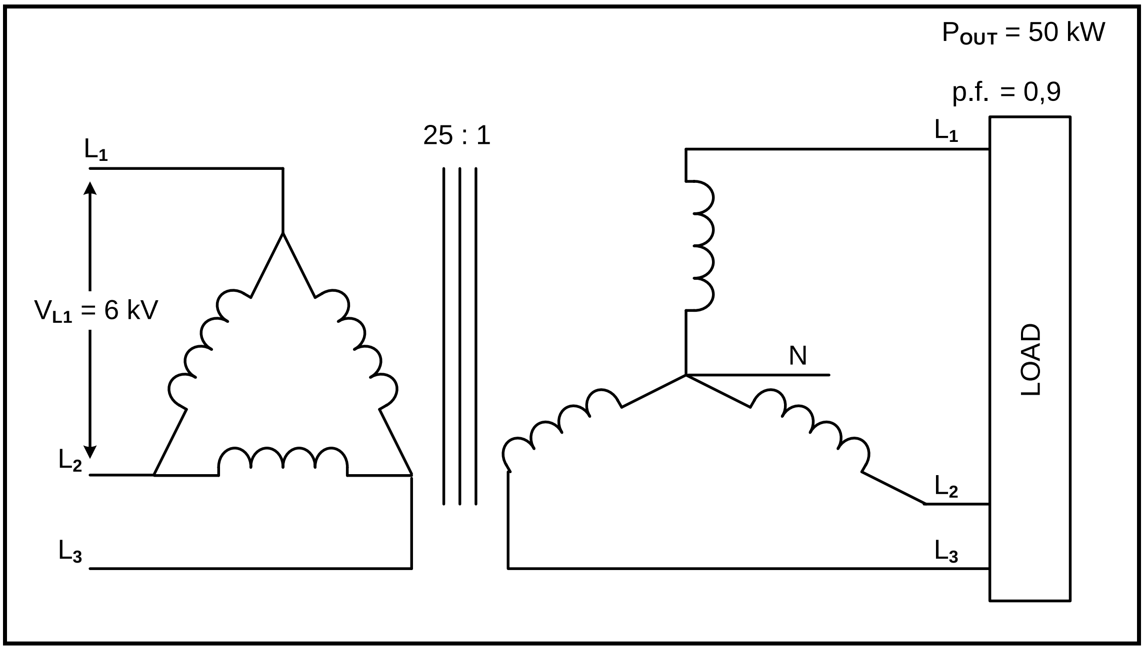

FIGURE 5.7: THREE-PHASE DELTA-STAR TRANSFORMER

Given:

V_{L1}	=	6 kV
TR	=	25 **:** 1
P_{OUT}	=	50 kW
p.f.	=	0,9

Use the data in FIGURE 5.7 to calculate the following:

5.7.1 Secondary phase voltage (3)

5.7.2 Secondary line voltage (3)

5.7.3 Apparent power (3)

5.7.4 Primary line current (4)
[30]

QUESTION 6: THREE-PHASE MOTORS AND STARTERS

6.1 Name THREE parts of a cage rotor. (3)

6.2 Refer to FIGURE 6.2 below and answer the questions that follow.

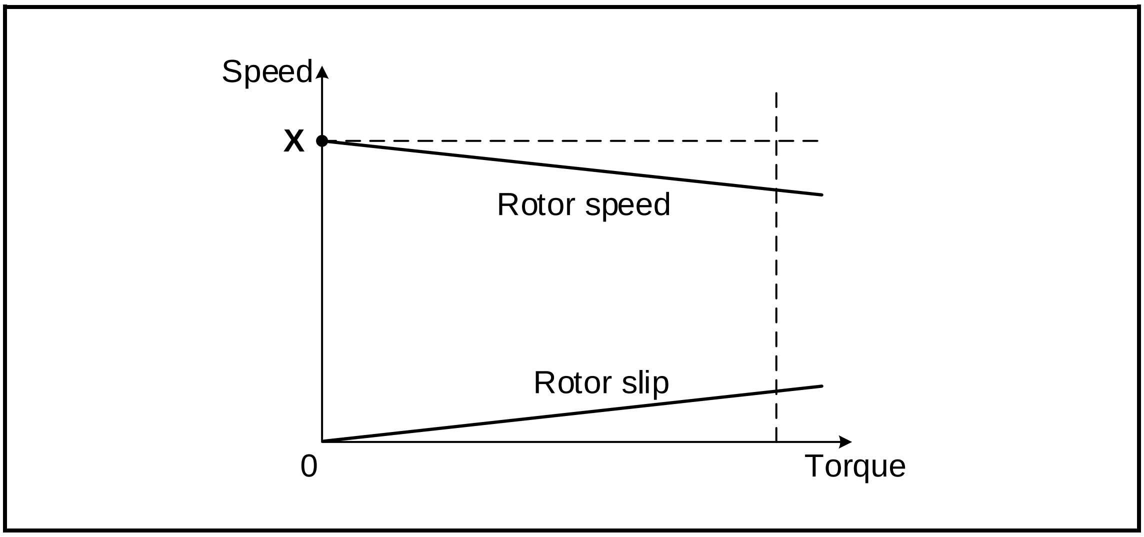

FIGURE 6.2: ROTOR SPEED AND SLIP

6.2.1 Identify point **X**. (1)

6.2.2 Define the term *rotor slip*. (2)

6.2.3 Explain why the torque is zero when the rotor speed is at point **X**. (2)

6.3 A three-phase induction motor with four pole pairs per phase is connected to a 400V/50 Hz supply. Calculate the following:

Given:

p = 4
f = 50 Hz

6.3.1 Synchronous speed (3)

6.3.2 Rotor speed if the slip is 5% (3)

6.4 A factory has added an additional three-phase induction motor to their system. The existing motor is a 75 kW three-phase induction motor with a power factor of 0,8. The new induction motor is a 50 kW three-phase induction motor with a power factor of 0,9. Refer to FIGURE 6.4 below and answer the questions that follow.

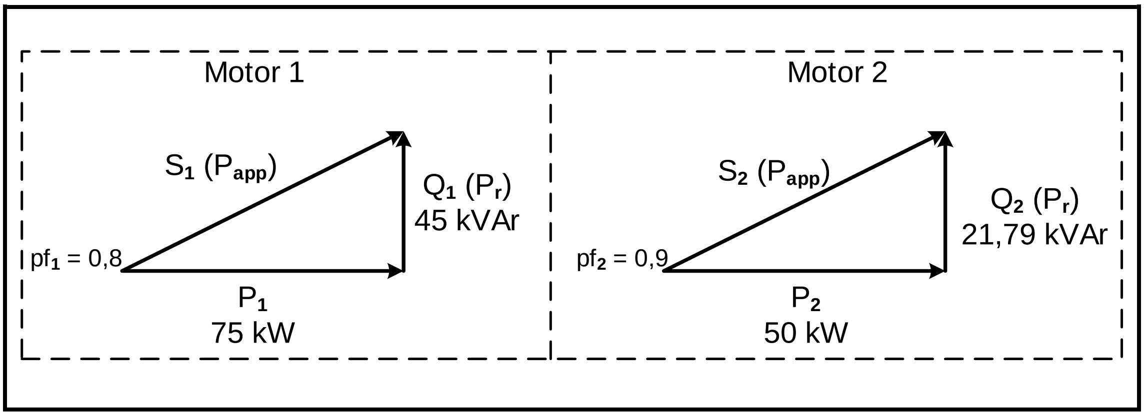

FIGURE 6.4: POWER TRIANGLES

Given:

P_1 = 75 kW
pf_1 = 0,8
Q_1 = 45 kVAr
P_2 = 50 kW
pf_2 = 0,9
Q_2 = 21,79 kVAr

Calculate the:

6.4.1 Combined true power of the two motors (3)

6.4.2 Combined reactive power of the two motors (3)

6.4.3 Apparent power after Motor 2 was added to the system (3)

6.4.4 Power factor of the system after Motor 2 was added (3)

6.5 Refer to FIGURE 6.5 below and answer the questions that follow.

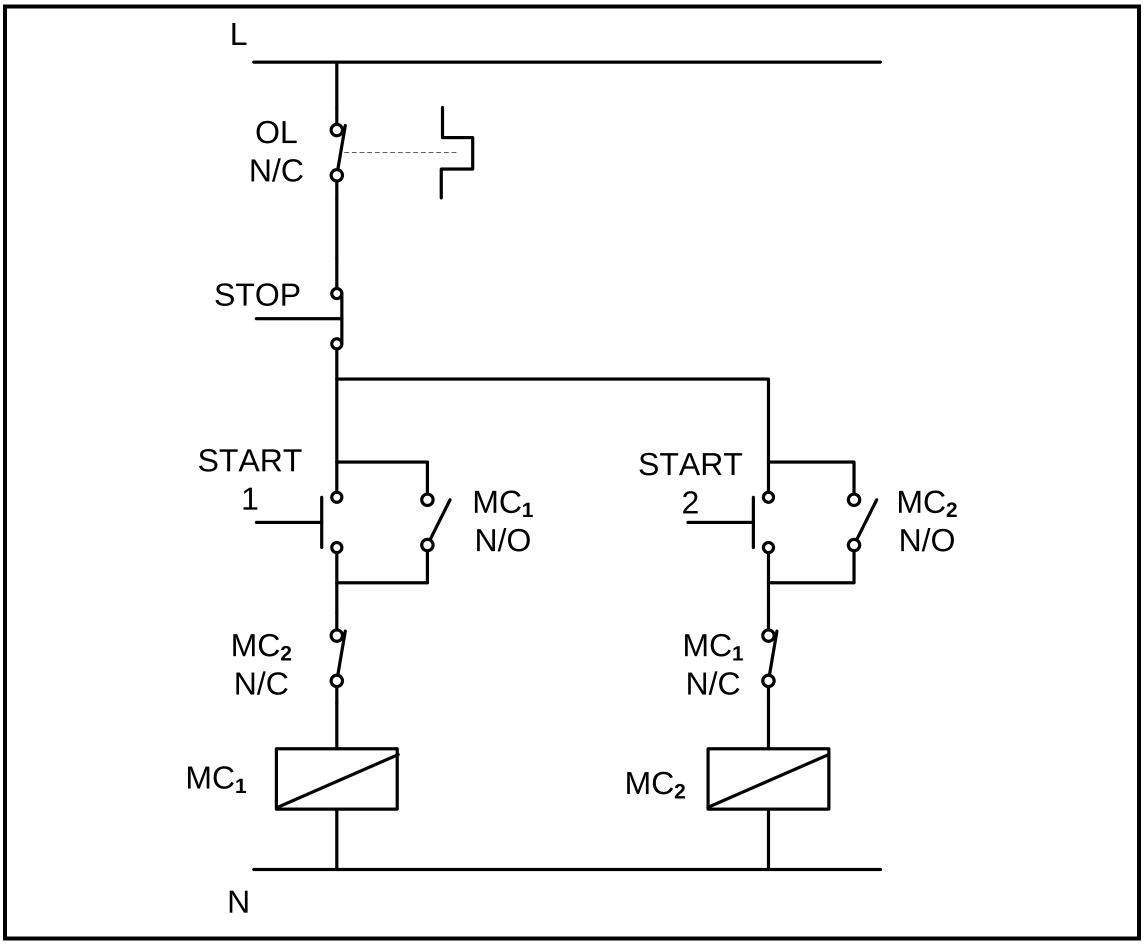

FIGURE 6.5: MOTOR CONTROL CIRCUIT

6.5.1 Name the contacts that create the interlocking function in the circuit above. (2)

6.5.2 Explain why a normally closed contact of the overload is used and not a normally open contact. (3)

6.5.3 Referring to the control mechanisms in the control circuit, explain why MC_2 cannot be energised at the same time as MC_1. (2)

6.5.4 Explain how the operation of the circuit will be affected when MC_1 N/O is faulty and permanently open. (2)

[35]

QUESTION 7: PROGRAMMABLE LOGIC CONTROLLERS (PLCs)

7.1 State TWO disadvantages of a relay control system in comparison with PLC control systems. (2)

7.2 Explain why a soft-wired system is cheaper to implement than a hardwired system. (2)

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

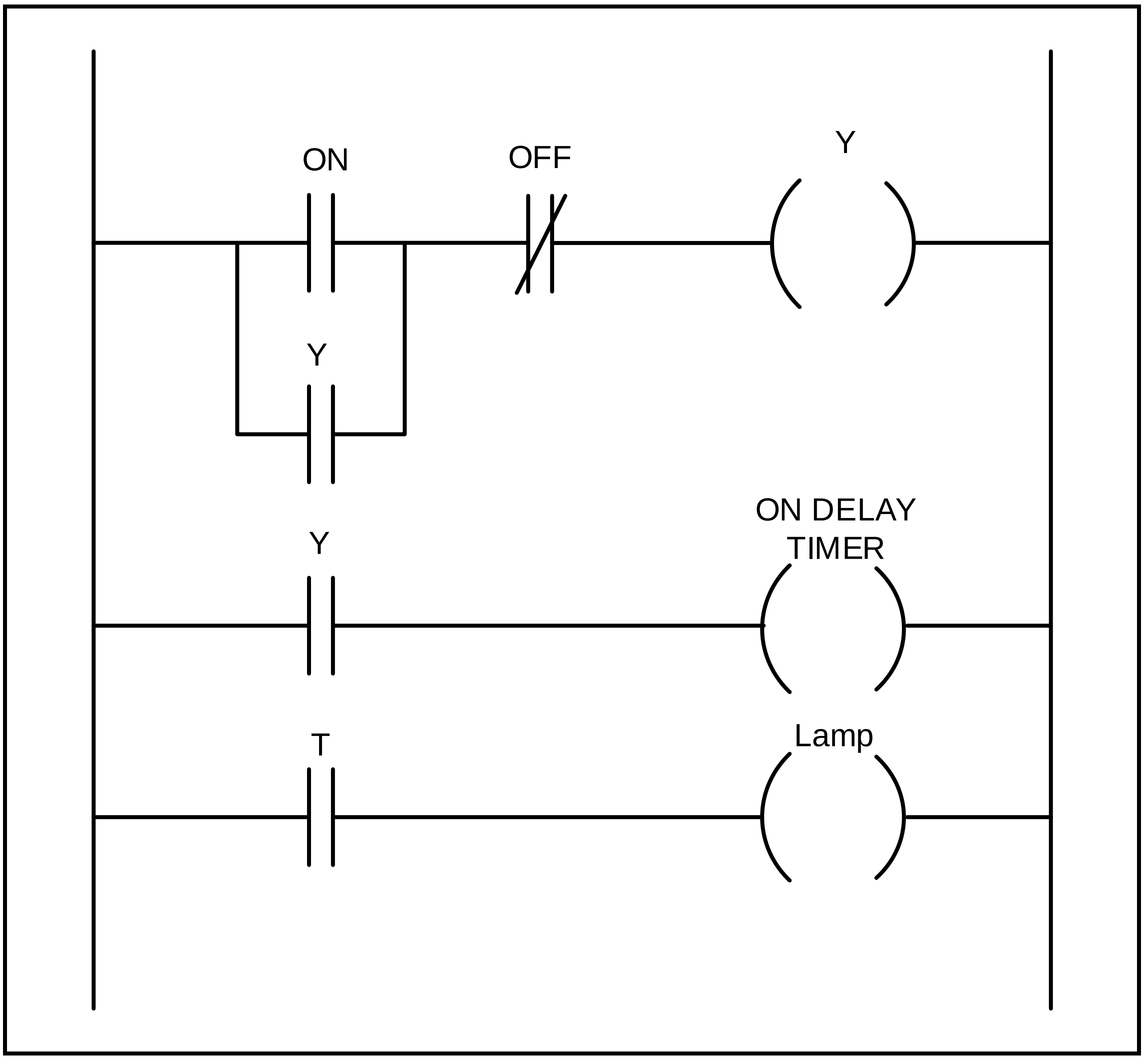

FIGURE 7.3

7.3.1 Explain the function of the timer in FIGURE 7.3. (2)

7.3.2 Describe the operation of the program in FIGURE 7.3. (5)

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

7.4.1 Differentiate between a *relay* and a *contactor*. (4)

7.4.2 Explain how an OFF delay timer creates the time delay when de-energised. (2)

7.5 Refer to proximity sensors as input devices on a PLC and answer the questions that follow.

7.5.1 State TWO applications of the proximity sensor. (2)

7.5.2 Name TWO types of proximity sensors. (2)

7.6 Refer to FIGURE 7.6 below and answer the questions that follow.

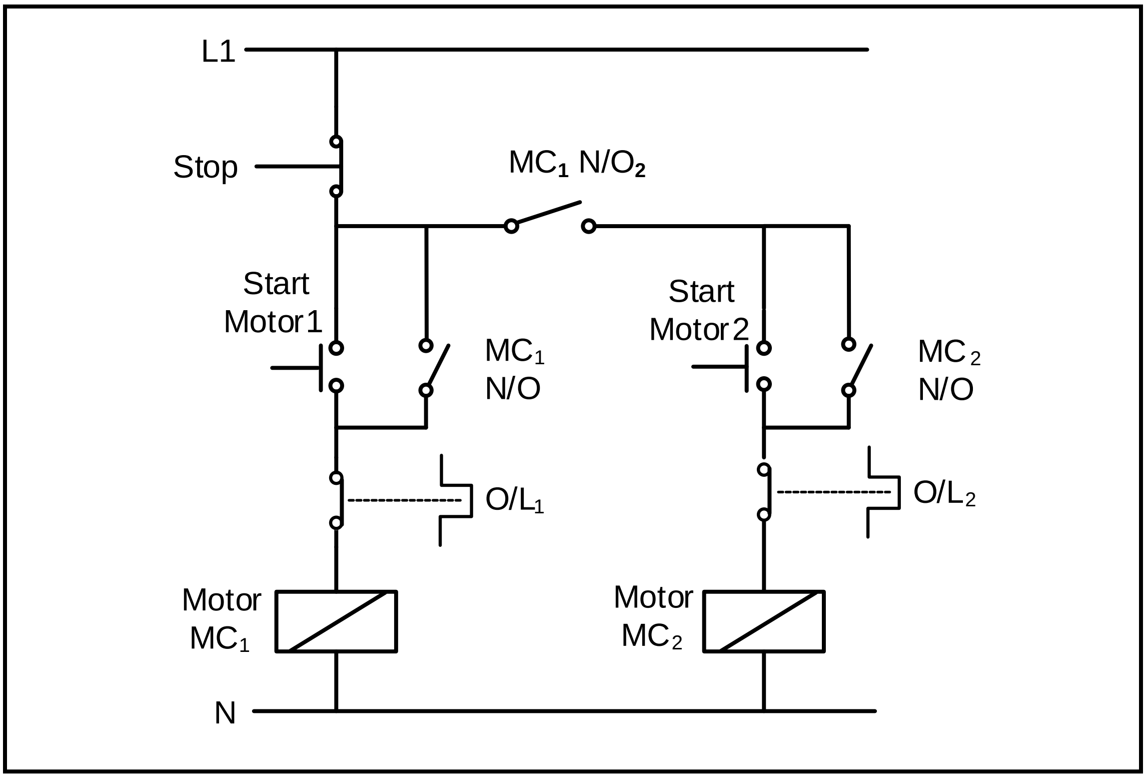

FIGURE 7.6: MANUAL SEQUENCE STARTER WITHOUT A TIMER

7.6.1 Redraw in the ANSWER BOOK and complete the ladder logic diagram for FIGURE 7.6.1 below that executes the same function as the one in FIGURE 7.6.

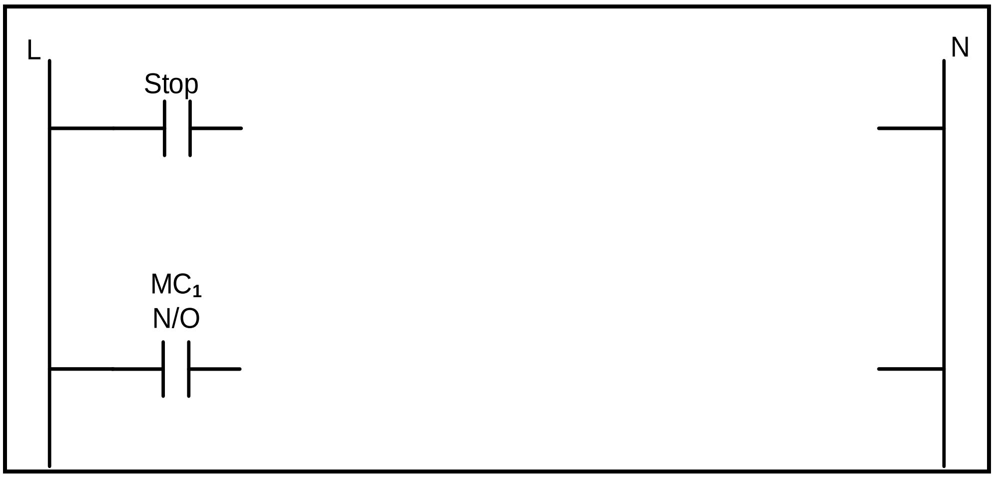

FIGURE 7.6.1 (8)

7.6.2 Explain why each overload is connected in series with the contactor coil. (2)

7.6.3 Describe the purpose of the MC_1 N/O_2 contact that is connected in series with Start motor 2. (2)

7.7 Explain *voltage frequency control* with reference to VSD. (2)

7.8 Refer to regenerative braking and answer the questions that follow.

7.8.1 Name TWO examples where this braking method may be used. (2)

7.8.2 Describe *regenerative energy*. (3)
[40]

TOTAL: 200

FORMULA SHEET

RLC CIRCUITS	THREE-PHASE AC GENERATION
$P = V I \cos\theta$	**STAR**
$X_L = 2\pi fL$	$V_L = \sqrt{3}\, V_{PH}$
$X_C = \dfrac{1}{2\pi fC}$	$V_{PH} = I_{PH} Z_{PH}$ $I_L = I_{PH}$
$f_r = \dfrac{1}{2\pi\sqrt{LC}}$ **OR** $f_r = \dfrac{f_1 + f_2}{2}$	**DELTA**
$BW = \dfrac{f_r}{Q}$ **OR** $BW = f_2 - f_1$	$V_L = V_{PH}$
SERIES	$V_{PH} = I_{PH} Z_{PH}$
$V_R = IR$	$I_L = \sqrt{3}\, I_{PH}$
$V_L = IX_L$	**POWER**
$V_C = IX_C$	$S(P_{APP}) = \sqrt{3}\; V_L\, I_L$
$I_T = \dfrac{V_T}{Z}$ **OR** $I_T = I_R = I_C = I_L$	$Q(P_r) = \sqrt{3}\, V_L\, I_L \sin\theta$ $P = \sqrt{3}\; V_L\, I_L \cos\theta$
$Z = \sqrt{R^2 + (X_L - X_C)^2}$	$\cos\theta = pf = \dfrac{P}{S}$
$V_T = \sqrt{V_R{}^2 + (V_L - V_C)^2}$ **OR** $V_T = IZ$	$P_T = P_1 + P_2$
$\cos\theta = \dfrac{R}{Z}$ OR $\cos\theta = \dfrac{V_R}{V_T}$ **OR** $\tan\theta = \dfrac{V_L - V_C}{V_R}$	$Q_T = Q_1 + Q_2$
$Q = \dfrac{X_L}{R} = \dfrac{X_C}{R} = \dfrac{V_L}{V_T} = \dfrac{V_C}{V_T} = \dfrac{1}{R}\sqrt{\dfrac{L}{C}}$	$S = \sqrt{(P_T)^2 + (Q_T)^2}$
PARALLEL	**EFFICIENCY**
$V_T = V_R = V_C = V_L$	
$I_R = \dfrac{V_T}{R}$	$\eta = \dfrac{P_{OUT}}{P_{IN}}\; 100$
$I_C = \dfrac{V_T}{X_C}$	**TWO-WATTMETER METHOD**
$I_L = \dfrac{V_T}{X_L}$	$P_T = P_1 + P_2$
$I_T = \sqrt{I_R^2 + (I_L - I_C)^2}$	$\tan\theta = \sqrt{3}\left(\dfrac{P_1 - P_2}{P_1 + P_2}\right)$
$Z = \dfrac{V_T}{I_T}$	**THREE-WATTMETER METHOD**
$\cos\theta = \dfrac{I_R}{I_T}$	$P_T = P_1 + P_2 + P_3$
$Q = \dfrac{R}{X_L} = \dfrac{R}{X_C}$	

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** $S(P_{APP}) = \sqrt{3}\,V_L\,I_L$ $Q(P_r) = \sqrt{3}\,V_L\,I_L \text{Sin}\,\theta$ $P = \sqrt{3}\,V_L\,I_L\,\text{Cos}\,\theta$ $\text{Cos}\,\theta = \text{pf} = \frac{P}{S}$ $\frac{V_{PH(1)}}{V_{PH(2)}} = \frac{N_1}{N_2} = \frac{I_{PH(2)}}{I_{PH(1)}}$ Turns ratio: $TR = \frac{N_1}{N_2}$ $\eta = \frac{P_{OUT}}{P_{OUT} + \text{losses}}\ 100$	**STAR** $V_L = \sqrt{3}\,V_{PH}$ $I_L = I_{PH}$ **DELTA** $V_L = V_{PH}$ $I_L = \sqrt{3}\,I_{PH}$ **POWER** $S(P_{APP}) = \sqrt{3}\,V_L\,I_L$ $Q(P_r) = \sqrt{3}\,V_L\,I_L\,\text{Sin}\,\theta$ $P = \sqrt{3}\,V_L\,I_L\,\text{Cos}\,\theta$ $P = \sqrt{3}\,V_L\,I_L\,\text{Cos}\,\theta\,\eta$ $\text{Cos}\,\theta = \text{pf} = \frac{P}{S}$ $P_T = P_1 + P_2$ (real power) $Q_T = Q_1 + Q_2$ (reactive power) **EFFICIENCY** $\eta = \frac{P_{IN} - \text{losses}}{P_{IN}}\ 100$ $\eta = \frac{P_{OUT}}{P_{IN}}\ 100$ $n_s = \frac{60\,f}{p}$ Per Unit Slip $= \frac{n_s - n_r}{n_s}$ % Slip $= \frac{n_s - n_r}{n_s}\ 100$ Slip $= n_s - n_r$