Confidential

basic education

Department:
Basic Education
REPUBLIC OF SOUTH AFRICA

NATIONAL SENIOR CERTIFICATE

GRADE 12

ELECTRICAL TECHNOLOGY: POWER SYSTEMS

NOVEMBER 2024

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 disastrous event, resulting from the use of plant and machinery, or from activities at a workplace, is known as a/an …

A minor incident.
B major incident.
C accident.
D risk. (1)

1.2 The impedance in a RLC series circuit, is minimum when the …

A inductive reactance equals the capacitive reactance.
B inductive reactance is greater than the capacitive reactance.
C capacitive reactance is greater than the inductive reactance. (1)
D resistance is maximum.

1.3 In a pure capacitive circuit that is connected to an AC supply, the …

A voltage leads the current by 90°.
B current leads the voltage by 90°.
C voltage and current are in phase.
D current leads the voltage by 180°. *(1)*

1.4 The quality factor of an RLC parallel circuit is … to the bandwidth.

A inversely proportional
B directly proportional
C equal
D not related (1)

1.5 … is transferred backwards and forwards between the supply, inductor or capacitor and performs no real work.

A Apparent power
B Real power
C Reactive power
D True power (1)

1.6 The purpose of the neutral conductor in a three-phase AC system is to …

A carry the highest voltage.
B provide a return path for unbalanced currents.
C be used for phase shifting.
D carry current in a balanced system. (1)

1.7 The purpose of a power factor meter in an electrical system is to …

A measure the energy.
B measure the voltage difference between phases.
C monitor harmonics in the current.
D indicate the phase relationship between voltage and current. (1)

1.8 A … configuration is used extensively as step-down transformers in distribution systems where a four-wire system is required.

A star-star
B star-delta
C delta-delta
D delta-star (1)

1.9 If there is an earth fault in one of the phases of a three-phase transformer, the difference in voltage between phases will activate the …

A Buchholtz relay.
B restricted earth-fault relay.
C balanced earth-fault relay.
D standby earth-fault relay. (1)

1.10 When a three-phase induction motor is connected to a three-phase AC supply, a rotating magnetic field is set up in the …

A rotor.
B stator.
C armature.
D commutator. (1)

1.11 In a three-phase forward-reverse motor-starter control circuit, the … contacts of each contactor prevent the forward and reverse contactors from being energised at the same time.

A N/O
B latching
C hold-in
D N/C interlocking (1)

1.12 In an automatic sequence starter control circuit, the start button of motor 2 is replaced by a … to energise the contactor of the second motor after a pre-determined time period.

A N/O contact of an ON-delay timer
B N/C contact of an ON-delay timer
C N/O retain contact of MC_1
D N/C interlocking contact of MC_2 (1)

1.13 A ladder logic diagram in PLC software is executed from …

A right to left and top to bottom.
B left to right and top to bottom.
C left to right and bottom to top.
D right to left and bottom to top. (1)

1.14 A device that is used to provide a delay in the operation of a PLC's program is known as a …

A transistor.
B relay.
C contactor.
D timer. (1)

1.15 During the process of regenerative braking, a braking resistor is connected in the circuit to …

A decrease the charging rate of the capacitors.
B prevent the charging of the capacitors.
C dissipate the excessive regenerative energy.
D reduce the supply to the motor. (1)
[15]

QUESTION 2: OCCUPATIONAL HEALTH AND SAFETY

2.1 Define the term *workplace* with reference to the Occupational Health and Safety Act, 1993 (Act 85 of 1993). (2)

2.2 Name TWO human rights in the workplace. (2)

2.3 Explain why poor ventilation is an unsafe condition in a workshop. (2)

2.4 State TWO types of victimisation by an employer that are forbidden. (2)

2.5 Explain why a person should not interfere with equipment in the workshop that is provided for safety. (2)
[10]

QUESTION 3: RLC CIRCUITS

3.1 Explain the following terms with reference to RLC circuits:

3.1.1 Inductive reactance (2)

3.1.2 Bandwidth (2)

3.2 FIGURE 3.2 below shows an RLC series circuit with a variable frequency supply. Answer the questions that follow.

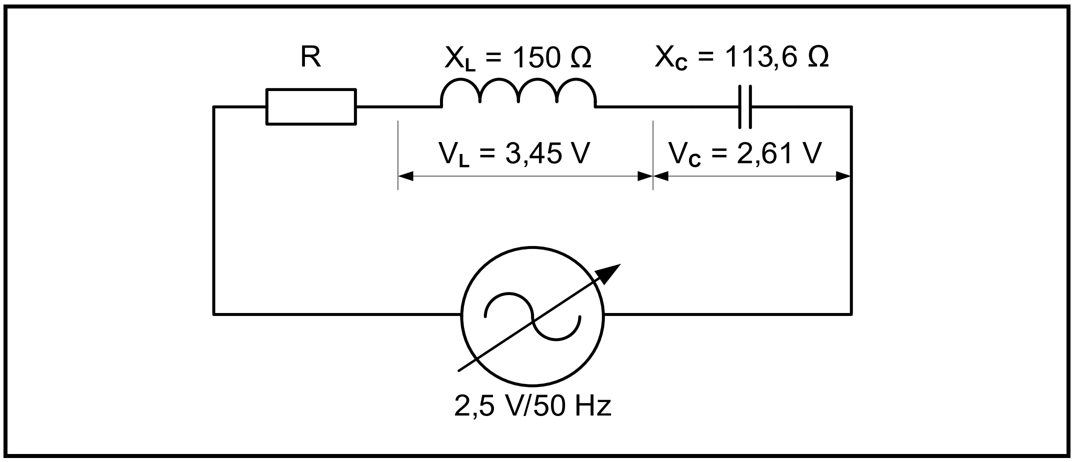


FIGURE 3.2: RLC SERIES CIRCUIT

Given:

X_L = 150 Ω
X_C = 113,6 Ω
V_T = 2,5 V
V_L = 3,45 V
V_C = 2,61 V

3.2.1 State whether the circuit represented in FIGURE 3.2 has a leading or a lagging power factor. (1)

3.2.2 Calculate the current through the inductor. (3)

3.2.3 Calculate the value of the inductor. (3)

3.2.4 Calculate the value of resistor R if the impedance Z = 106,42 Ω. (3)

3.2.5 Complete the phasor diagram in FIGURE 3.2.5 below in your ANSWER BOOK.

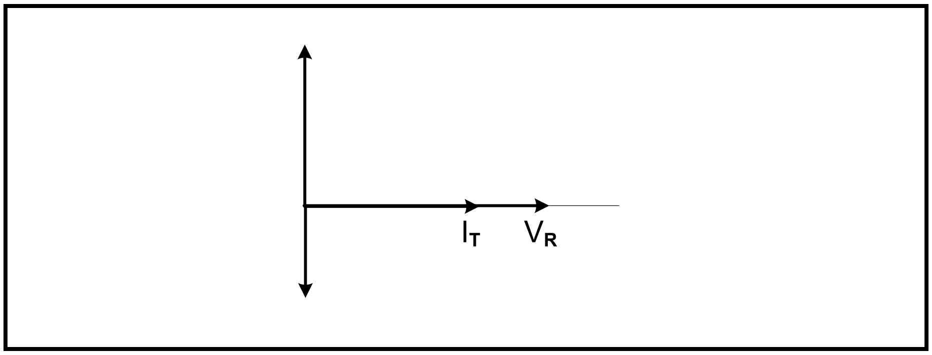


FIGURE 3.2.5: PHASOR DIAGRAM (4)

3.2.6 After decreasing the frequency, the current increased slightly. Explain why this happened. (3)

3.3 FIGURE 3.3 below shows an RLC parallel circuit and its impedance vs frequency response curve. Answer the questions that follow.

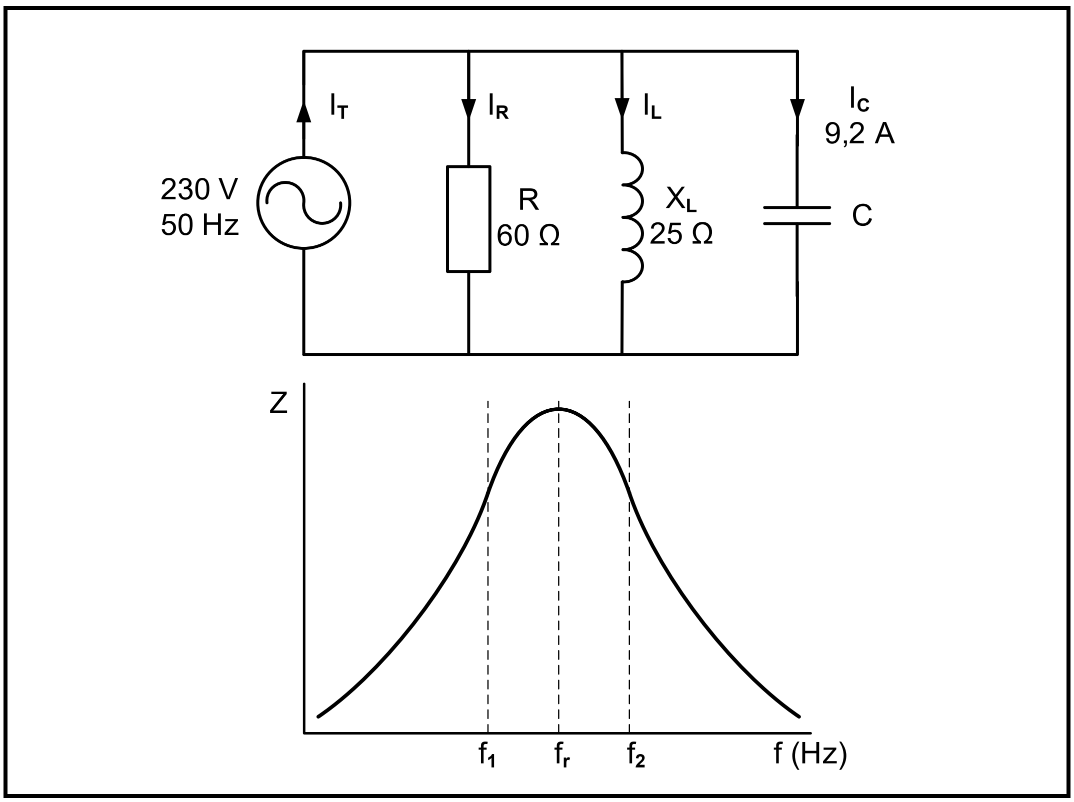


FIGURE 3.3: RLC PARALLEL CIRCUIT AND FREQUENCY RESPONSE CURVE

Given:

V_T = 230 V
I_C = 9,2 A
R = 60 Ω
X_L = 25 Ω
f = 50 Hz

3.3.1 Calculate the current through the resistor. (3)

3.3.2 Calculate the capacitive reactance. (3)

3.3.3 Determine the total current. Give a reason for your answer. (2)

3.3.4 Calculate the Q-factor of the circuit (3)

3.3.5 Calculate the bandwidth of the circuit (3)
[35]

QUESTION 4: THREE-PHASE AC GENERATION

4.1 State TWO advantages of three-phase systems. (2)

4.2 Refer to electricity generation at power stations in South Africa and answer the following questions:

4.2.1 State the voltage AND frequency at which electricity is generated in South Africa. (2)

4.2.2 Name TWO energy sources, other than coal, used for electricity generation in South Africa. (2)

4.2.3 Explain the transmission process with reference to voltages in the national grid. (3)

4.3 FIGURE 4.3 below shows the coil connection in a balanced three-phase generator. Answer the questions that follow.

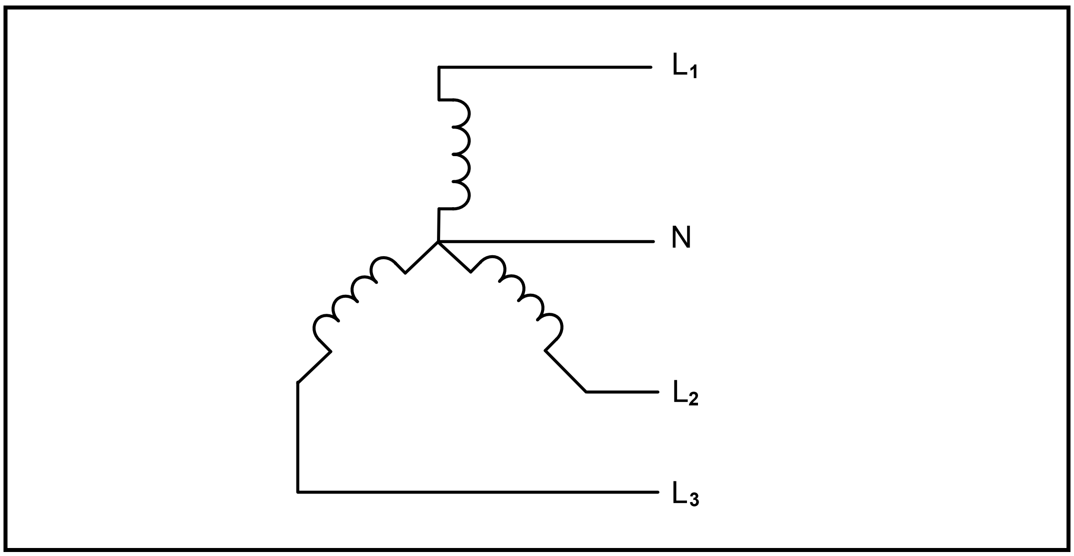


FIGURE 4.3: THREE-PHASE GENERATOR

4.3.1 Identify the configuration of the coils in FIGURE 4.3 above. (1)

4.3.2 Draw the voltage waveforms of a three-phase AC generator. (4)

4.4 FIGURE 4.4 below shows a balanced three-phase load powered by a three-phase alternator. The alternator provides a line voltage of 400 V to the load with a power factor of 0,85. The apparent power of the system is 14 kVA. Answer the questions that follow.

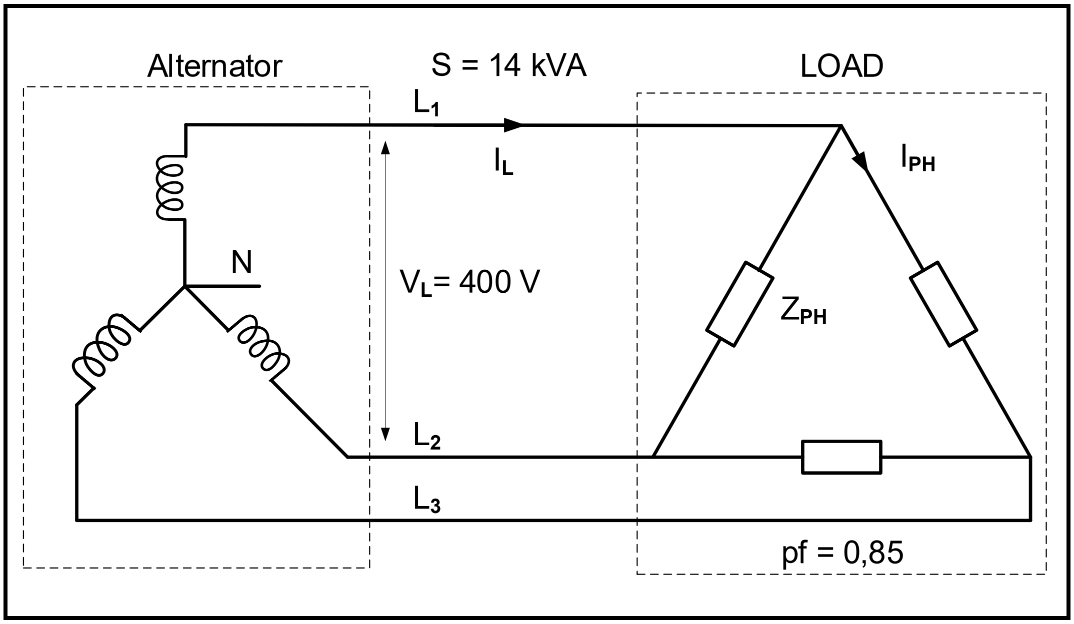


FIGURE 4.4: THREE-PHASE SYSTEM

Given:

V_L = 400 V
S = 14 kVA
pf = 0,85

Calculate the:

4.4.1 Active power (3)

4.4.2 Line current (3)

4.4.3 Phase current (3)

4.4.4 Phase impedance (3)

4.4.5 Phase angle (3)

4.5 FIGURE 4.5 below shows how a three-phase supply is connected to a three-phase load.

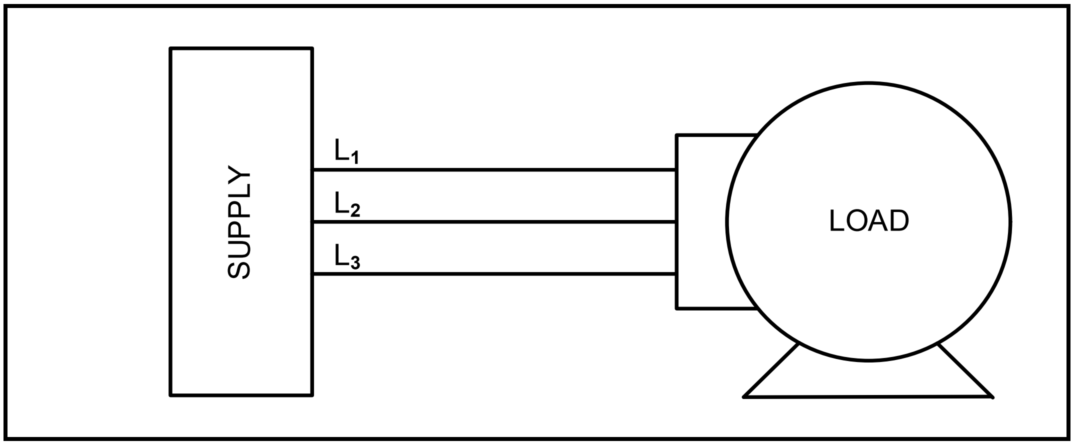


FIGURE 4.5: THREE-PHASE SYSTEM

4.5.1 State ONE method, other than capacitors, used for power factor correction. (1)

4.5.2 Redraw FIGURE 4.5 above and show how a three-phase power factor correcting capacitor bank will be connected to this system. (3)

4.5.3 State the preferred wattmeter method that would be used to measure the total power of the load. Motivate your answer. (2)

[35]

QUESTION 5: THREE-PHASE TRANSFORMERS

5.1 Explain the function of transformers with reference to voltage and current. (2)

5.2 Briefly describe the principle on which a transformer operates. (2)

5.3 Refer to FIGURE 5.3 below and answer the questions that follow.

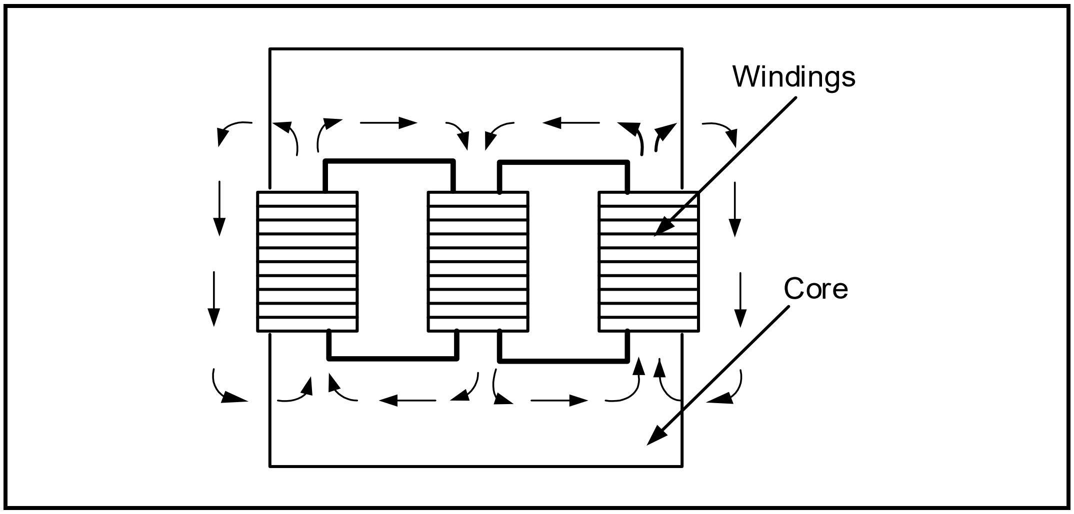


FIGURE 5.3: THREE-PHASE TRANSFORMER

5.3.1 Identify the type of core construction in FIGURE 5.3 above. (1)

5.3.2 Explain the purpose of the laminated iron-core in a transformer. (2)

5.3.3 Compare the construction of a three-phase transformer with reference to a core-type and a shell-type transformer. (2)

5.3.4 Describe how hysteresis losses occur in the iron core of a transformer. (3)

5.4 FIGURE 5.4 below shows a 200 kVA three-phase transformer. The primary line voltage is 6 kV and the secondary line voltage is 380 V with 80 turns on the secondary side.

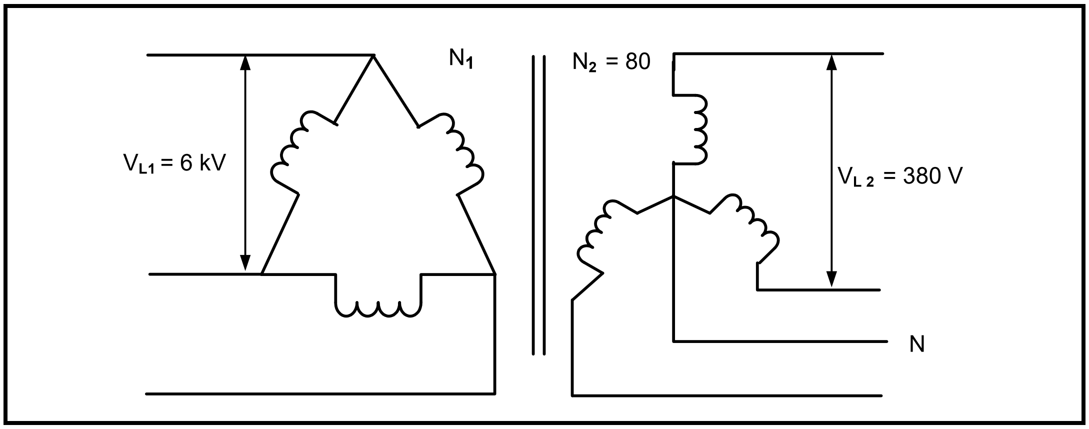


FIGURE 5.4: THREE-PHASE TRANSFORMER

Given:

S	= 200 kVA
V_{L1}	= 6 kV
V_{L2}	= 380 V
N_2	= 80

Calculate the following:

5.4.1 Secondary phase voltage (3)

5.4.2 Number of primary turns (3)

5.4.3 Turns ratio (3)

5.4.4 Supply current at full load (3)

5.5 State TWO common defects which are likely to occur in transformers due to overloading. (2)

5.6 FIGURE 5.6 below shows the schematic diagram of a transformer. Answer the questions that follow.

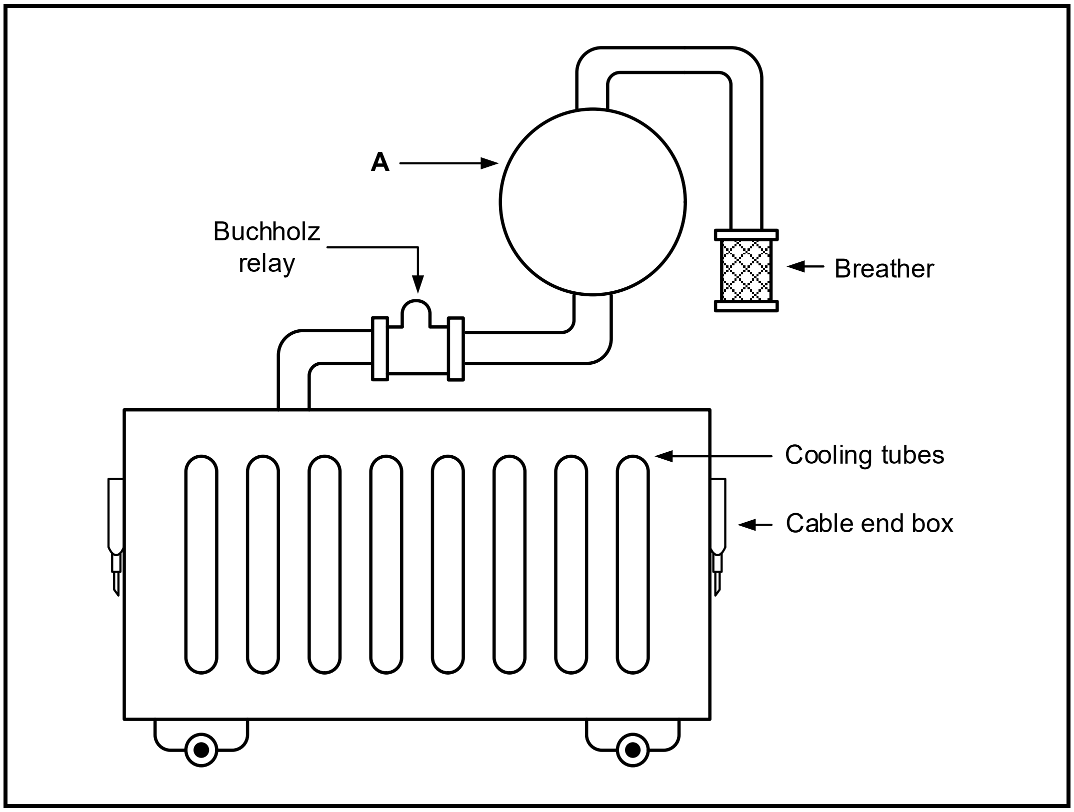


FIGURE 5.6: TRANSFORMER

5.6.1	Identify component **A** in FIGURE 5.6 above.	(1)
5.6.2	State ONE function of the dielectric oil in a transformer besides providing insulation between the windings and case.	(1)
5.6.3	Briefly describe the function of the Buchholz relay in an oil-immersed transformer.	(2) **[30]**

QUESTION 6: THREE-PHASE MOTORS AND STARTERS

6.1 State TWO typical applications (uses) of a three-phase induction motor in a workshop. (2)

6.2 FIGURE 6.2 below shows the terminal box of a three-phase induction motor and an insulation resistance tester indicating a reading of 100 kΩ. Answer the questions that follow.

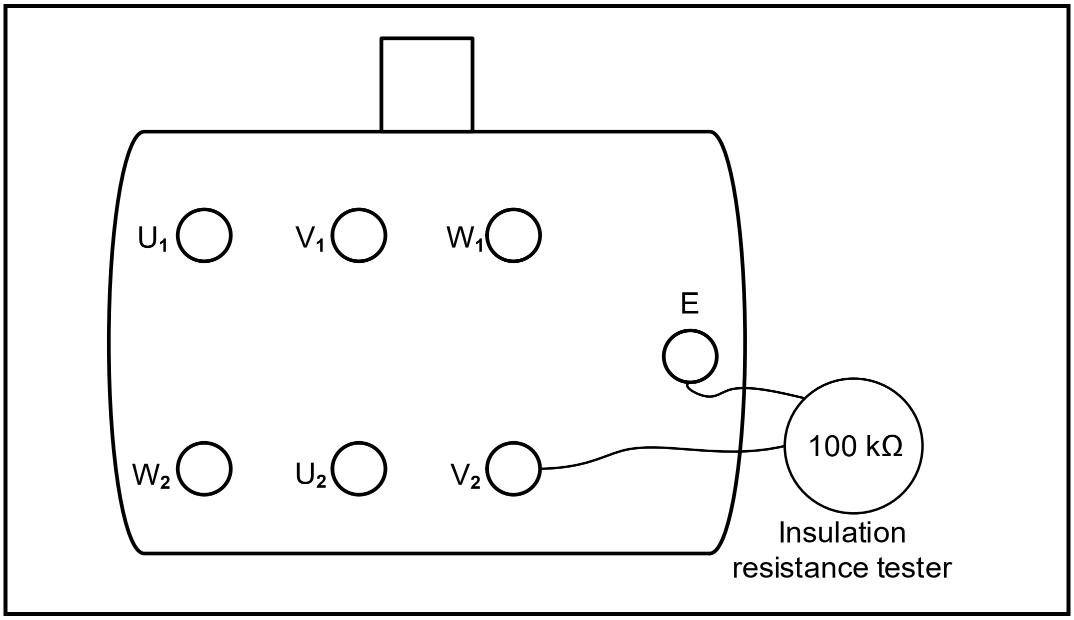


FIGURE 6.2: TERMINAL BOX

6.2.1 State why this motor is NOT safe for use. (1)

6.2.2 Explain the danger of the fault in FIGURE 6.2 above when the motor is powered. (1)

6.2.3 Redraw the terminals of the coils in your ANSWER BOOK and indicate how you would place the connecting plates/bars to connect this motor in delta. (3)

6.3 A three-phase induction motor with six poles is connected to a 400 V/50 Hz supply. The motor experiences a slip of 6% at full load.

Given:

$f = 50$ Hz
$V_L = 400$ V
Slip $= 6\%$

Calculate the:

6.3.1 Pole pairs per phase (3)

6.3.2 Synchronous speed (3)

6.3.3 Rotor speed (3)

6.4 FIGURE 6.4 below shows the control circuit of an automatic star-delta motor starter with contactor T set to 5 seconds. Answer the questions that follow.

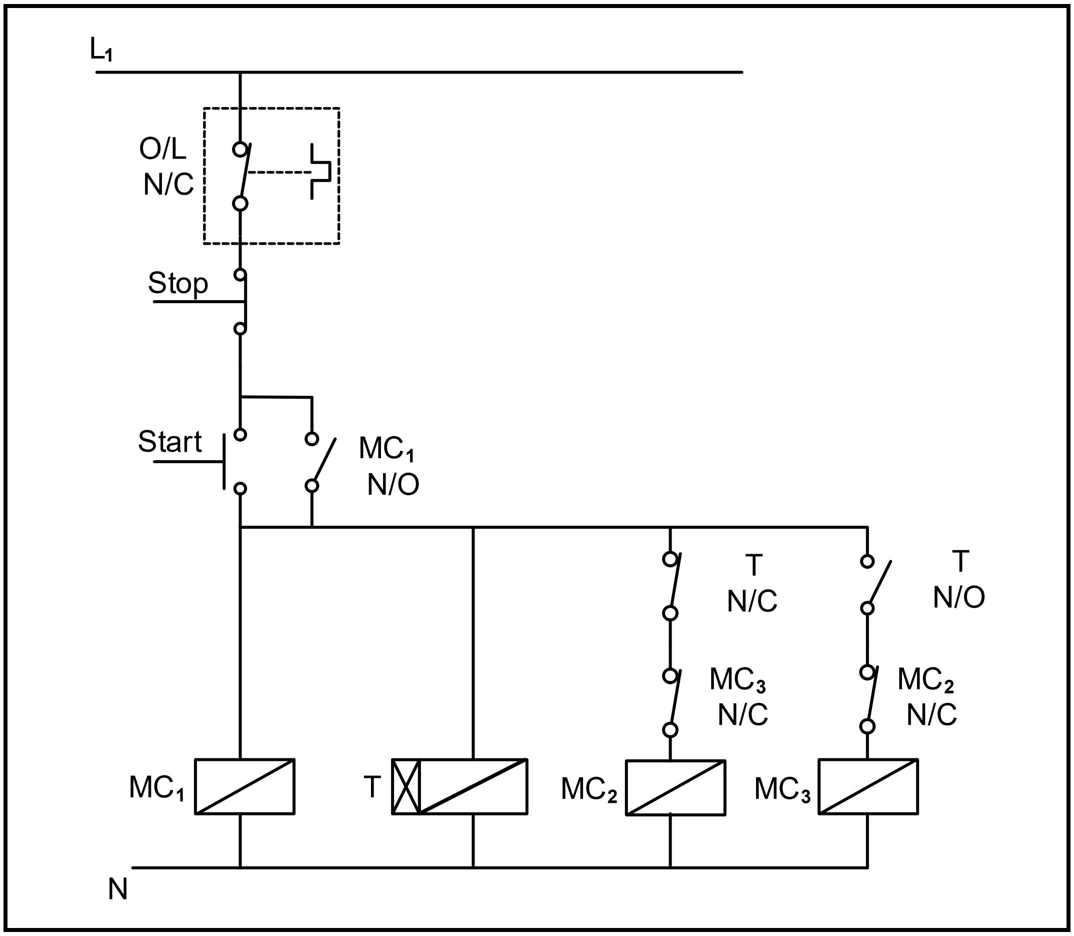


FIGURE 6.4: AUTOMATIC STAR-DELTA CONTROL CIRCUIT

6.4.1 State the function of MC_1N/O. (1)

6.4.2 Explain the function of contactor T. (2)

6.4.3 Explain why it is safe to assume that MC_2 will be the contactor connecting the motor coils in star in the main circuit. (2)

6.4.4 Describe the operation of the circuit 5 seconds after the start button is pressed. (3)

6.5 The name plate of a three-phase induction motor indicates that it is able to power a 30 kW mechanical load when connected to a 400 V supply. The motor has a power factor of 0,87. The total losses were determined as 5 kW.

Given:

P_{OUT} = 30 kW
V_L = 400 V
pf = 0,87
losses = 5 kW

Calculate the:

6.5.1 Efficiency (3)

6.5.2 Line current (3)

6.5.3 Reactive power (5)
[35]

QUESTION 7: PROGRAMMABLE LOGIC CONTROLLERS (PLCs)

7.1 Refer to the programmed scan cycle of a PLC and answer the questions that follow.

7.1.1 State the TWO steps, other than the process scan, of a programmed scan cycle. (2)

7.1.2 Explain the *process scan*. (3)

7.2 Refer to FIGURE 7.2 below of the symbol of a logic gate and answer the questions that follow.

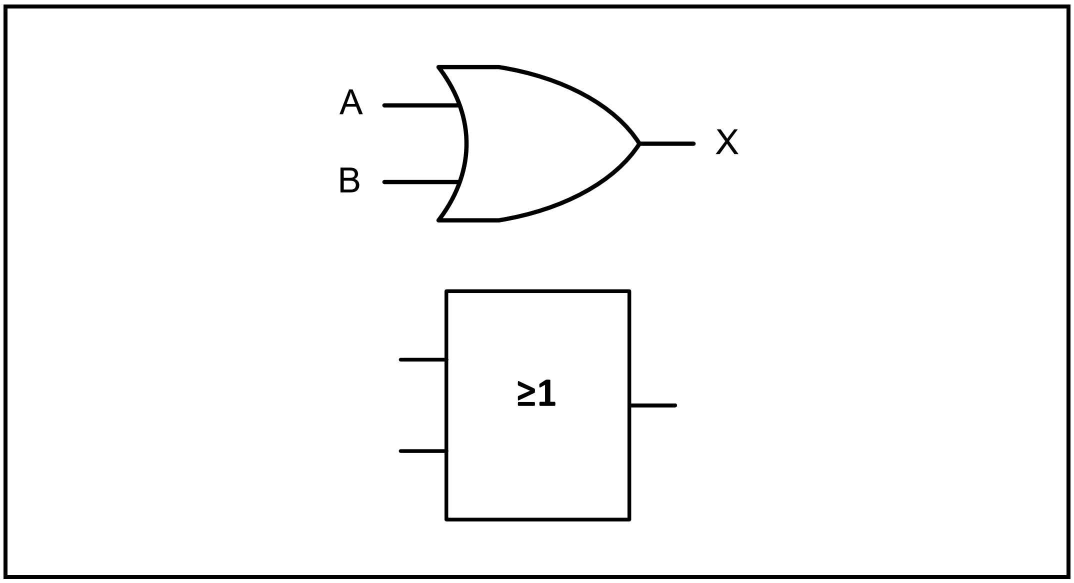


FIGURE 7.2: LOGIC GATE

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

7.2.2 Draw the ladder logic of this logic gate. (3)

7.2.3 Complete the truth table in FIGURE 7.2.3 below by writing down only the state of the output in the ANSWER BOOK.

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

FIGURE 7.2.3: TRUTH TABLE (4)

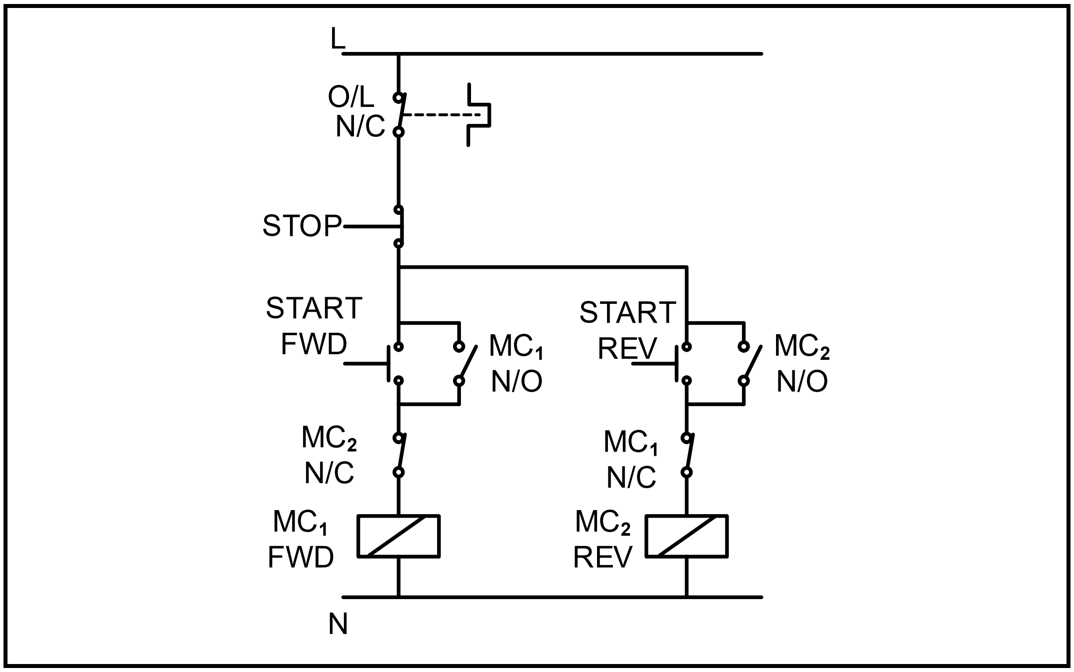
7.3 Refer to inputs on a PLC and answer the questions that follow.

7.3.1 Name TWO categories of input devices. (2)

7.3.2 Name TWO applications (uses) of a level sensor. (2)

7.3.3 Differentiate between the application of an *inductive proximity sensor* and a *capacitive proximity sensor*. (4)

7.4 FIGURE 7.4 below shows the relay diagram of a forward-reverse motor starter. Redraw and complete the PLC ladder logic diagram in FIGURE 7.4.1 that will execute the same function in a PLC system in the ANSWER BOOK.



(8)

FIGURE 7.4: FORWARD-REVERSE CONTROL CIRCUIT

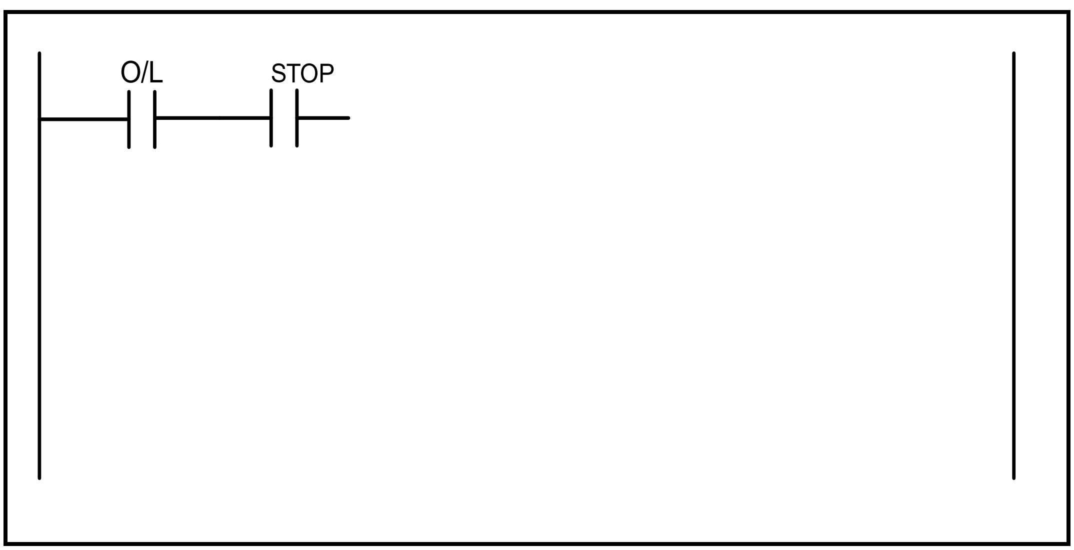


FIGURE 7.4.1: PLC LADDER LOGIC DIAGRAM

7.5 FIGURE 7.5 below shows a variable frequency drive (VFD) circuit. Study the circuit and answer the questions that follow.

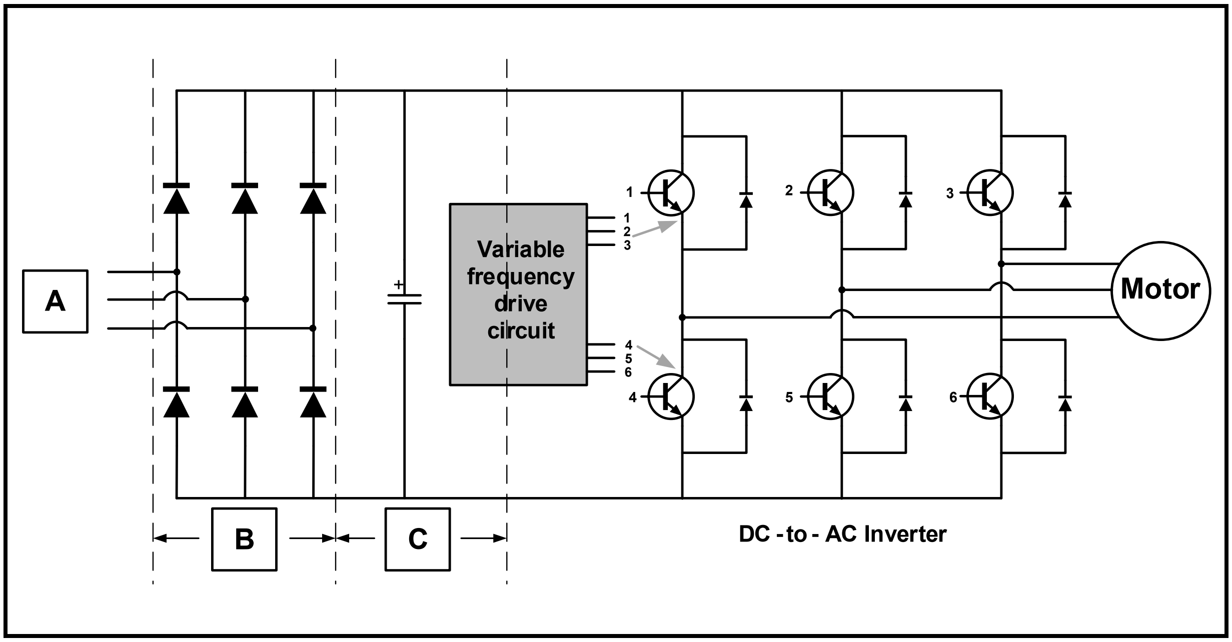


FIGURE 7.5: VARIABLE FREQUENCY DRIVE (VFD) CIRCUIT

7.5.1	Label blocks **A**, **B** and **C**.	(3)
7.5.2	State TWO types of motors used with a VSD.	(2)
7.5.3	Explain the function of the DC-to-AC inverter.	(3)
7.5.4	Explain pulse width modulation (PWM) when referring to VSD.	(3) **[40]**

TOTAL: 200

FORMULA SHEET

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

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** $S(P_{app}) = \sqrt{3}\, V_L\, I_L$ $Q(P_r) = \sqrt{3}\, V_L\, I_L \text{Sin}\, \theta$ $P = \sqrt{3}\, V_L\, I_L\, \text{Cos}\, \theta$ $\text{Cos}\, \theta = \frac{P}{S}$ $\frac{V_{PH(1)}}{V_{PH(2)}} = \frac{N_1}{N_2} = \frac{I_{PH(2)}}{I_{PH(1)}}$ Turns ratio: $TR = \frac{N_1}{N_2}$	**STAR** $V_L = \sqrt{3}\, V_{PH}$ $I_L = I_{PH}$ **DELTA** $V_L = V_{PH}$ $I_L = \sqrt{3}\, I_{PH}$ **POWER** $S(P_{app}) = \sqrt{3}\, V_L\, I_L$ $Q(P_r) = \sqrt{3}\, V_L\, I_L \text{Sin}\, \theta$ $P = \sqrt{3}\, V_L\, I_L\, \text{Cos}\, \theta$ $P = \sqrt{3}\, V_L\, I_L\, \text{Cos}\, \theta\, \eta$ $\text{Cos}\, \theta = \frac{P}{S}$ **EFFICIENCY** $\eta = \frac{P_{IN} - \text{losses}}{P_{IN}} \times 100$ $\eta = \frac{P_{OUT}}{P_{OUT} + \text{losses}} \times 100$ $\eta = \frac{P_{OUT}}{P_{IN}} \times 100$ **SPEED** (pole pairs) $p = \frac{\text{poles per phase}}{2}$ $n_s = \frac{60 \times f}{p}$ Per unit slip $= \frac{n_s - n_r}{n_s}$ % Slip $= \frac{n_s - n_r}{n_s} \times 100$ $n_r = n_s(1 - \%\ \text{slip})$ Slip $= n_s - n_r$