



higher education & training

Department:
Higher Education and Training
REPUBLIC OF SOUTH AFRICA

MARKING GUIDELINE

NATIONAL CERTIFICATE

ELECTROTECHNICS N6

3 December 2024

This marking guideline consists of 10 pages.

QUESTION 1: DC MACHINES

1.1 It is working at maximum efficiency when the constant losses✓ and the armature copper losses are equal.✓ (2)

1.2

- Armature copper loss
- Interpole copper loss
- Series winding copper loss
- Brush resistance loss
- Compensating winding copper loss (Any 3 × 1) (3)

1.3 The speed of a DC motor increases with an increase of armature voltage✓ but not in direct proportion.✓ (2)

1.4 1.4.1 The output power

$$\begin{aligned}P_{motor} &= (W - P) \times 9,81 \times \pi D n \\&= (35 - 10) \times 9,81 \times \pi \times \frac{40}{100} \times \frac{950}{60} \checkmark \\&= 4\,879,679 \text{ W } \checkmark\end{aligned} \quad (2)$$

1.4.2 The efficiency

$$P_{motor \text{ input}} = V_{motor} \cdot I_{motor} = 200 \times 30 \checkmark = 6\,000 \text{ W } \checkmark$$

$$\% \text{ Efficiency} = \frac{P_{motor \text{ output}}}{P_{motor \text{ input}}} \times 100\%$$

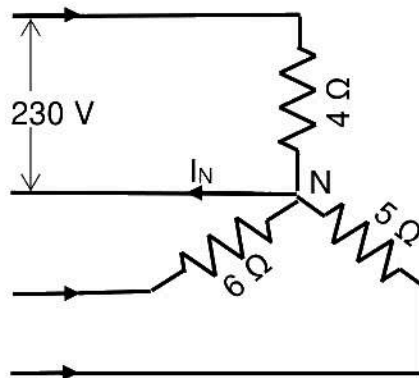
$$= \frac{4\,879,679}{6\,000} \times 100\% \checkmark$$

$$= 81,328\% \checkmark$$

(4)
[13]

QUESTION 2: AC CIRCUIT THEORY

2.1 GIVEN: A 3-phase, star-connected system



2.1.1 The current flowing in each phase

$$I_{R4\Omega} = \frac{V}{R_4} = \frac{230}{4} \checkmark = 57,5 \text{ A} \checkmark$$

$$I_{R5\Omega} = \frac{V}{R_5} = \frac{230}{5} \checkmark = 46 \text{ A} \checkmark$$

$$I_{R6\Omega} = \frac{V}{R_6} = \frac{230}{6} \checkmark = 38,333 \text{ A} \checkmark$$

(6)

2.1.2 The neutral current

$$I_{X-comp} = I_{R5\Omega} \cos 30^\circ - I_{R6\Omega} \cos 30^\circ$$

$$= 46 \cos 30^\circ - 38,333 \cos 30^\circ \checkmark$$

$$= 6,64 \text{ A} \checkmark$$

$$I_{Y-comp} = I_{R4\Omega} - I_{R5\Omega} \sin 30^\circ - I_{R6\Omega} \sin 30^\circ$$

$$= 57,5 - 46 \sin 30^\circ - 38,333 \sin 30^\circ \checkmark$$

$$= 15,334 \text{ A} \checkmark$$

$$I_N = \sqrt{I_{X-comp}^2 + I_{Y-comp}^2}$$

$$= \sqrt{6,64^2 + 15,334^2} \checkmark$$

$$= 16,71 \text{ A} \checkmark$$

(6)

2.1.3 The total power absorbed

$$P = P_{R4\Omega} + P_{R5\Omega} + P_{R6\Omega} = 230(57,5 + 46 + 38,333) \checkmark$$

$$= 32\,621,59 \text{ W} \checkmark$$

(2)

2.2 A 3-phase balanced load is an electrical circuit in which the loads connected across three phases, are identical. ✓

QUESTION 3: TRANSFORMERS

- 3.1
- Star-delta
 - Delta-star
 - Star-star
 - Delta-delta

(4)

- 3.2 Given: A single-phase transformer
- $S = 650 \text{ kVA}$ $\eta_{\max} = 95\%$
 $\text{pf} = 0,8 \text{ lagging}$ $k = 85\%$

- 3.2.1 The iron loss at maximum efficiency

Method 1

$$\eta_{\max} = \frac{k \cdot S \cdot \cos \theta}{k \cdot S \cdot \cos \theta + 2P_o} \times 100\%$$

$$0,95 = \frac{0,85 \times 650 \times 0,8}{(0,85 \times 650 \times 0,8) + 2P_o} = \frac{442}{442 + 2P_o} \checkmark$$

$$2P_o = \frac{442}{0,95} - 442 = 23,263 \checkmark$$

$$P_o = \frac{23,263}{2} \checkmark = 11,632 \text{ kW} \checkmark$$

OR

Method 2

$$k = \sqrt{\frac{P_o}{P_{sc}}}$$

$$\therefore P_o = k^2 \cdot P_{sc} = 0,85^2 \times P_{sc} = 0,723P_{sc} \checkmark$$

$$\eta_{\max} = \frac{k \cdot S \cdot \cos \theta}{k \cdot S \cdot \cos \theta + P_o + k^2 \cdot P_{sc}} \times 100\%$$

$$0,95 = \frac{0,85 \times 650 \times 0,8}{(0,85 \times 650 \times 0,8) + 0,723P_{sc} + 0,85^2P_{sc}} \checkmark$$

$$0,95 = \frac{442}{442 + 1,446P_{sc}}$$

$$1,446P_{sc} = \frac{442}{0,95} - 442 = 23,263$$

$$P_{sc} = \frac{23,263}{1,446} = 16,088 \text{ kW} \checkmark$$

$$P_o = k^2 \cdot P_{sc} = 0,85^2 \times 16,088 = 11,624 \text{ kW} \checkmark$$

(4)

3.2.2 The copper loss at maximum efficiency

$$k = \sqrt{\frac{P_o}{P_{sc}}}$$

$$P_{sc} = \frac{P_o}{k^2} = \frac{11,624}{0,85^2} \checkmark = 16,089 \text{ kW} \checkmark \quad (2)$$

3.2.3 The copper loss at full load

$$P_{sc} = \frac{P_{sc}}{k} = \frac{16,089}{0,85} = 18,928 \text{ kW} \checkmark \quad (1)$$

3.2.4 The full-load efficiency

$$\begin{aligned} \eta_{max} &= \frac{S \cdot \cos \theta}{S \cdot \cos \theta + P_o + P_{sc}} \times 100\% \\ &= \frac{650 \times 0,8}{(650 \times 0,8) + 11,624 + 16,089} \times 100 \checkmark \\ &= 94,94\% \checkmark \end{aligned} \quad (2)$$

[13]

QUESTION 4: AC MACHINES - GENERATORS

4.1 Armature reaction is the influence of the stator ampere-turns $\checkmark$ on the value and distribution of the magnetic flux $\checkmark$ in the air gaps between the poles and stator core. $\checkmark$ (3)

4.2 Given: A three-phase, star-connected alternator
 $V_L = 3\,600 \text{ V}$ slots/pole/phase = 3
 $f = 50 \text{ Hz}$ $Z/\text{slot} = 20$
 $N = 500 \text{ r/min}$ $K_d = 0,96$

4.2.1 The number of poles

$$f = \frac{N \cdot p}{60}$$

$$\begin{aligned} p &= \frac{60 f}{N} = \frac{60 \times 50}{500} = 6 \text{ pairs} \checkmark \\ \therefore \text{number of poles} &= 6 \times 2 = 12 \checkmark \end{aligned} \quad (2)$$

4.2.2 The useful flux per pole

$$E_L = \frac{V_L}{\sqrt{3}} = \frac{3\,600}{\sqrt{3}} = 2\,078,461\text{ V} \checkmark$$

n = Number of slots per pole/phase

Number of slots per pole = $n \times \text{phase} \checkmark = 3 \times 3 = 9 \checkmark$

Number of slots per pole = Number of slots/Number of poles

Number of slots = Number of slots per pole $\times$ Number of poles $\checkmark$

$$= 9 \times 12$$

$$= 108 \checkmark$$

Z = Total conductors in series per phase

$$= (108 \times 20) / 3 \checkmark$$

$$= 720 \checkmark$$

$$E = 2k_f k_d k_p f \Phi Z$$

$$\Phi = \frac{E}{2k_f k_d k_p f Z}$$

$$\Phi = \frac{2\,078,461}{2 \times 1,11 \times 0,96 \times 1 \times 50 \times 720} \checkmark$$

$$\Phi = 0,027\,090\text{ Wb} \checkmark$$

(9)

4.3 Distribution factor – is the ratio of the actual EMF $\checkmark$ obtained to the EMF that would be concentrated in one slot. $\checkmark$

(2)

[16]

QUESTION 5: AC MACHINES – SYNCHRONOUS MOTORS

5.1 The V-curves of a synchronous motor shows how the armature current $\checkmark$ varies with the field current $\checkmark$ when the input is kept constant. $\checkmark$

(3)

5.2 Given: A three-phase, star-connected synchronous motor
 $S = 7\,000\text{ VA}$ $P = 5,5\text{ kW}$
 $V = 450\text{ V}$ $Z_s = (0,35 + j3,5)\text{ ohms/phase}$

5.2.1 The power factor

$$\cos \theta = \frac{P}{S} = \frac{5\,500}{7\,000} = 0,786\text{ leading} \checkmark$$

(1)

5.2.2 The phase current

Method 1

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

$$\therefore I_L = \frac{P}{\sqrt{3} \cdot V_L \cdot \cos \theta}$$

$$= \frac{5\,500}{\sqrt{3} \times 450 \times 0,786} \checkmark$$

$$= 8,978 \text{ A} \checkmark$$

Method 2

$$S = \sqrt{3} \cdot V_L \cdot I_L$$

$$\therefore I_L = \frac{S}{\sqrt{3} \cdot V_L} = \frac{7\,000}{\sqrt{3} \times 450} \checkmark$$

$$= 8,981 \text{ A} \checkmark$$

(2)

5.2.3 The EMF to which the machine is excited

$$\cos \theta = 0,786$$

$$\therefore \theta = \cos^{-1} 0,786 = 38,187^\circ \checkmark$$

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{450}{\sqrt{3}} = 259,808 \text{ V} \checkmark$$

Method 1

$$Z_S = R_a + jX_S = 0,35 + j3,5$$

$$= 3,517 \angle 84,289^\circ \checkmark$$

$$E_r = IZ_S$$

$$= 8,981 \angle 38,187^\circ$$

$$\times 3,517 \angle 84,289^\circ$$

$$= 31,586 \angle 122,476^\circ \text{ V} \checkmark$$

Method 2

$$IR_a = 8,981 \times 0,35$$

$$= 3,143 \text{ V} \checkmark$$

$$IX_S = 8,981 \times 3,5$$

$$= 31,434 \text{ V} \checkmark$$

$$E_{ph} = E_r - V_{ph}$$

$$= 31,586 \angle 122,476^\circ - 259,808 \angle 0^\circ$$

$$= 278,048 \angle 174,501^\circ \text{ V} \checkmark$$

OR

$$E_{ph} = V_{PH} + IR_a + IX_S$$

$$= 259,808 \angle -38,187^\circ + 3,143 \angle 180^\circ + 31,434 \angle -90^\circ$$

$$= 278,051 \angle -43,687^\circ \text{ V} \checkmark$$

$$E_L = \sqrt{3} \cdot E_{ph} = \sqrt{3} \times 278,048$$

$$= 481,593 \text{ V} \checkmark$$

$$E_L = \sqrt{3} \cdot E_{ph} = \sqrt{3} \times 278,051$$

$$= 481,598 \text{ V} \checkmark$$

(6)

5.2.4 The load angle in electrical degrees

Method 1

$$\alpha = 180^\circ - 161,373^\circ \\ = 18,627^\circ \quad \checkmark$$

Method 2

$$\alpha = 56,815^\circ - 38,187^\circ \\ = 18,628^\circ \quad \checkmark$$

(1)
[13]

QUESTION 6: AC MACHINES – INDUCTION MOTORS

- 6.1 Given: A 3-phase, 50-Hz induction motor
 $p = 8$ -pole $T_{MAX} = 185 \text{ Nm}$
 $R_r = 0,3 \, \Omega$ $S_{MAX} = 5\%$
 $N = 360 \text{ r/min}$

The torque developed by the rotor

$$N_s = \frac{60f}{p} = \frac{60 \times 50}{8} = 375 \text{ r/min} = 6,25 \text{ r/s} \quad \checkmark$$

$$S_{fractional} = \frac{N_s - N}{N_s} = \frac{375 - 360}{375} = 0,04 \quad \checkmark$$

$$R_2 = SX_0 \therefore X_0 = \frac{R_2}{S} = \frac{0,3}{0,04} = 7,5 \, \Omega \quad \checkmark$$

$$T_{MAXIMUM} = \frac{3 \cdot S \cdot E_0^2}{2 \cdot \pi \cdot N (R_2^2 + [S \cdot X_0]^2)} \\ = \frac{3 \times 0,04 \times E_0^2}{2 \times \pi \times \frac{360}{60} \times (0,3^2 + [0,04 \times 7,5]^2)} \quad \checkmark \\ = 0,017 \, 684 \times E_0^2$$

$$\therefore E_0 = \sqrt{\frac{T_{max}}{0,017 \, 684}} = \sqrt{\frac{185}{0,017 \, 684}} \quad \checkmark = 102,281 \text{ V} \quad \checkmark$$

$$T_{START} = \frac{3 \cdot S \cdot E_0^2}{2 \cdot \pi \cdot n (R_2^2 + [S \cdot X_0]^2)} \quad \checkmark \\ = \frac{3 \times 0,05 \times (102,281)^2}{2 \times \pi \times 6,25 \times (0,3^2 + [0,05 \times 7,5]^2)} \quad \checkmark = 173,267 \text{ Nm} \quad \checkmark$$

(9)

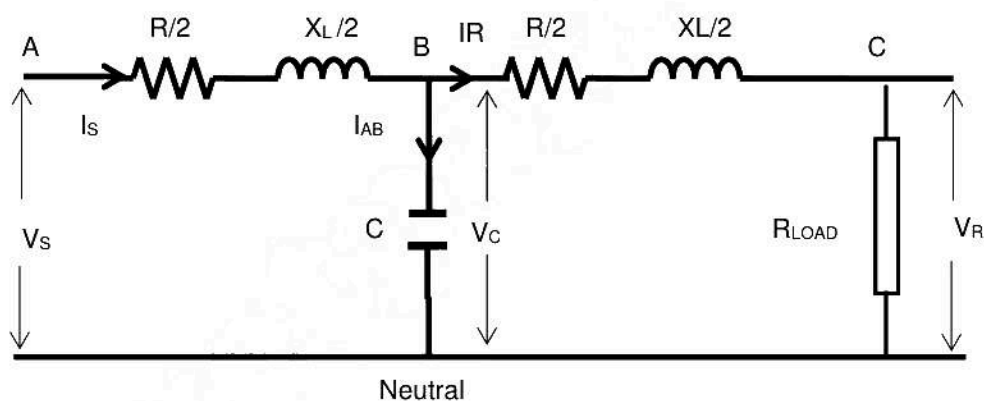
- 6.2 Slip is the difference between the speed of the rotating field✓ and the actual speed or the rotor.✓ (2)
- 6.3
- Actual measurement of motor speed
 - Comparing rotor and stator supply frequencies
 - Stroboscopic method
- (3)
- 6.4 6.4.1 Decreases
6.4.2 Increases

(2 × 1) (2)
[16]

QUESTION 7: GENERATION AND DISTRIBUTION OF AC

Given: A 3-phase transmission line

$S = 20 \text{ MW}$	$C = 0,08 \text{ mF/km}$	$L = 100 \text{ km}$
$V_L = 110 \text{ kV}$	$R = 0,2 \text{ } \Omega/\text{phase/km}$	$X_L = 0,4 \text{ } \Omega/\text{phase/km}$
$f = 50 \text{ Hz}$	$\text{pf} = 0,9 \text{ lagging}$	



7.1 The sending end current

$$R/2 = (0,2 \times 100)/2 = 10 \, \Omega \checkmark$$

$$\frac{X_L}{2} = \frac{0,4 \times 100}{2} = 20 \, \Omega \checkmark$$

$$X_C = \frac{1}{2\pi f C} = \frac{1}{2\pi \times 50 \times 0,08 \times 10^{-3}} \times 100 = 3\,978,874 \, \Omega \checkmark$$

$$V_R = V_L/\sqrt{3} = 110\,000/\sqrt{3} = 63\,508,53 \angle 0^\circ \text{ V}$$

Method 1

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

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

$$= 20 \times 10^6 / \sqrt{3} \times 110\,000 \times 0,9$$

$$= 116,636 \angle -25,842^\circ \text{ A} \checkmark$$

Method 2

$$S = \frac{P}{\cos \theta} = \frac{20 \times 10^6}{0,9} = 22,222 \text{ MW}$$

$$S = \sqrt{3} \cdot V_L \cdot I_L$$

$$\therefore I_L = S/\sqrt{3} \cdot V_L$$

$$= 22,222 \times 10^6 / \sqrt{3} \times 110 \times 10^3$$

$$= 116,636 \angle -25,842^\circ \text{ A} \checkmark$$

(4)

7.2 The sending end voltage

$$Z_{BC} = Z_{AB} = \frac{R}{2} + \frac{jX_L}{2} = 10 + j20 = 22,361 \angle 63,435^\circ \, \Omega \checkmark$$

$$V_{BC} = I_R \cdot Z_{BC} = 116,636 \angle -25,842^\circ \times 22,361 \angle 63,432^\circ$$

$$= 2\,608,098 \angle 37,59^\circ \text{ V} \checkmark$$

$$V_C = V_{BC} + V_R = 2\,608,098 \angle 37,59^\circ + 63\,508,53 \angle 0^\circ$$

$$= 65\,594,473 \angle 1,39^\circ \text{ V} \checkmark$$

$$I_C = V_C/Z_C = 65\,594,473 \angle 1,39^\circ / 3\,978,874 \angle -90^\circ = 16,486 \angle 91,39^\circ \text{ A} \checkmark$$

$$I_S = I_C + I_R = 16,486 \angle 91,39^\circ + 116,636 \angle -25,842^\circ$$

$$= 110,073 \angle -18,189^\circ \text{ A} \checkmark$$

$$V_{AB} = I_S \cdot Z_{AB} = 110,073 \angle -18,189^\circ \times 22,361 \angle 63,435^\circ$$

$$= 2\,461,342 \angle 45,246^\circ \text{ V} \checkmark$$

$$V_S = V_{AB} + V_C = 2\,461,342 \angle 45,246^\circ + 65\,594,473 \angle 1,39^\circ$$

$$= 67\,390,886 \angle 2,84^\circ \text{ V} \checkmark$$

$$V_L = \sqrt{3} \cdot V_S = \sqrt{3} \times 67\,390,886$$

$$= 116\,724,439 \text{ V} \checkmark$$

(8)

7.3 The power factor

$$\text{Power factor} = \cos(29,556^\circ + 9,291^\circ) = \cos 38,847^\circ = 0,779 \text{ lagging} \checkmark$$

(1)

[13]

TOTAL: 100