

EXAMINATION INTERNAL VERIFICATION FORM (2017-2018)

MODULE :	PSDE5027 Power and Machines	LEVEL:	5
PROGRAMME :	BSc (hons) Electrical and Electronic Engineering	TERM OF EXAM: (SPRING OR SUMMER)	Summer
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2.			

INTERNAL VERIFIER PLEASE TICK TO INDICATE THAT THE EXAMINATION:

✓	Conforms to the assessment pattern described in the module syllabus
✓	Tests the module learning outcome(s) appropriately

SIGNATURES OF FINAL APPROVAL:	SIGNATURE	DATE
INTERNAL VERIFIER: I confirm that this version of the exam paper is ready to be sent to the external examiner		6/03/2018
EXAM AUTHOR: I confirm that internal verifier and external examiner approval have been received and that this version of the exam paper is ready for printing.		

**UNIVERSITY OF WALES:
TRINITY SAINT DAVID**



**PRIFYSGOL CYMRU:
Y DRINDOD DEWI SANT**

LOCATION: COLEG SIR GAR

LLEOLIAD: COLEG SIR GAR

LEVEL 5

LEFEL 5

**EXAMINATION PERIOD
MAY 2018**

**CYFNOD ARHOLIADAU
MAI 2018**

BSc ELECTRICAL AND ELECTRONIC ENGINEERING

MODULE CODE: PSDE5027

POWER AND MACHINES

TIME: 2 HOURS

ANSWER THREE QUESTIONS OUT OF FOUR

TOTAL MARKS = 102

NUMBER OF PAGES = 5

Equipment or materials required – Calculators are permitted

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QUESTION 1

- (a) Draw the per-phase equivalent circuit of a transformer referred to the secondary and explain the meaning of each circuit parameter. [8 marks]
- (b) Draw the phasor diagram for the circuit of part (a) with the transformer secondary terminal voltage as the reference phasor and a lagging power factor ϕ_2 . [4 marks]
- (c) Explain the meaning of the “percentage regulation” of a transformer and provide an approximate equation for it in terms of the secondary equivalent circuit parameters from part (a) which includes lagging and leading power factors. [5 marks]
- (d) When a short-circuit test was carried out on a 380:110V (50Hz) transformer, the total per-phase resistance and reactance referred to the secondary were found to be 0.08Ω and 0.42Ω respectively. If the transformer is rated at 2.8KVA, calculate:
- (i) Full-load secondary current [2 marks]
- (ii) Percentage regulation under full-load with power factors of:
- Unity
 - 0.75 lagging
 - 0.88 leading
- [9 marks]
- (e) When an open-circuit test is carried out on the transformer of part (d), the iron losses were found to be 35W. Calculate the copper losses of this transformer under full-load with a lagging power factor of 0.85 and hence determine the efficiency of the transformer with this load. [6 marks]

Total for this question is 34 marks

QUESTION 2

- (a) Draw the circuit diagram of a 4 stage rotor resistance starter for a wound rotor induction motor and explain the starting process by means of torque-speed graphs. [12 marks]
- (b) A two-pole, delta connected three-phase induction motor is fed from a 440V, 50Hz supply and runs at 2875rpm under full load. The standstill rotor impedance per-phase is $0.5 + j 1.34 \Omega$. The effective stator to rotor turns ratio is 1.6:1 and the stator impedance and magnetic losses may be neglected.
- (i) With the aid of an equivalent circuit diagram for the rotor, derive an expression for the per-phase torque at any value of fractional slip, neglecting stator impedance. [14 marks]
- (ii) Calculate the total full-load torque. [8 marks]

Total for this question is 34 marks

QUESTION 3

- (a) Draw a diagram that represents a separately excited DC motor controlled by a DC drive, coupled to a mechanical system having a constant load torque T_L , a moment of inertia J and a coefficient of viscous friction B . The motor has an armature resistance of R_a , an armature inductance of L_a and a back EMF of E_a .

[6 marks]

- (b) If the field supply of the above motor is held constant, write out the electrical and mechanical dynamic equations for the system together with the proportional relationships.

[6 marks]

- (c) A separately excited DC motor is driving a hoist with a constant load of 120Nm at a constant speed. The viscous friction of the system is 0.015Nm/rad/s. The armature is connected to a 230V DC supply and the field current is held constant at its rated value. The motor has the following parameters $R_a = 0.45\Omega$, $K_b = 0.75V/\text{rad/s}$. L_a is large and can be ignored under steady state conditions.

- (i) Derive the steady-state torque equations for the motor and the load, sketch the equations as lines on a torque-versus-angular-speed graph and add suitable labels.

[12 marks]

- (ii) Calculate the steady state speed, back EMF, motor torque and current together with the standstill torque, standstill current and no load speed.

[10 marks]

Total for this question is 34 marks

QUESTION 4

- (a) Briefly explain the difference between the representation of short and medium length transmission lines and draw the per-phase equivalent circuit for each to support your explanation. [11 marks]
- (b) A 3-phase, 50 Hz, short transmission line supplies a 2.5 MW, 11 kV, 0.85 lagging power factor load. The series impedance of the line is $6 + j9\Omega$ per phase. The receiving-end voltage may be assumed to be constant at 11 kV.
- (i) Calculate the sending-end voltage. Draw the per-phase equivalent circuit to support the calculation. [13 marks]
- (ii) A capacitor bank is to be connected at the receiving-end of the line for the purpose of power factor improvement.
- a. Calculate the required line-to-neutral capacitance of the capacitor bank if the power factor at the receiving-end is to be improved to 0.95 lagging. Draw a phasor diagram to aid the calculation. [8 marks]
- b. Calculate the current in the transmission line after power factor improvement. [2 marks]

Total for this question is 34 marks

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BSc ELECTRICAL AND ELECTRONIC ENGINEERING

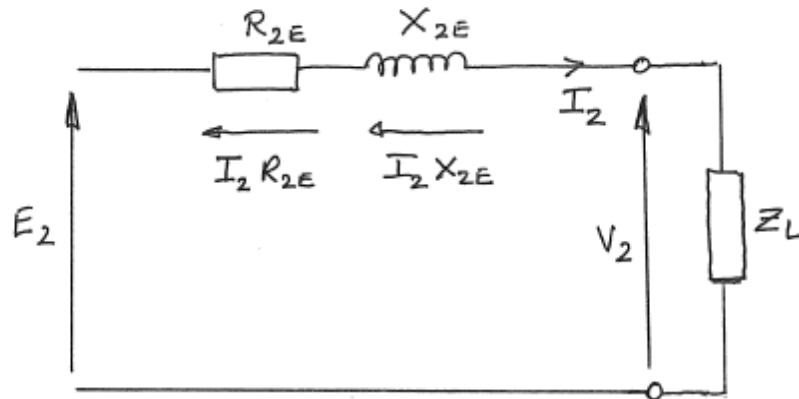
MODULE CODE: PSDE5027

POWER AND MACHINES

MAIN SOLUTIONS

QUESTION 1

(a) An equivalent circuit for the transformer is shown below:



[4 marks]

Where

V_2 = secondary terminal voltage

E_2 = no-load secondary terminal voltage

R_{2E} = total primary and secondary winding resistance referred to the secondary

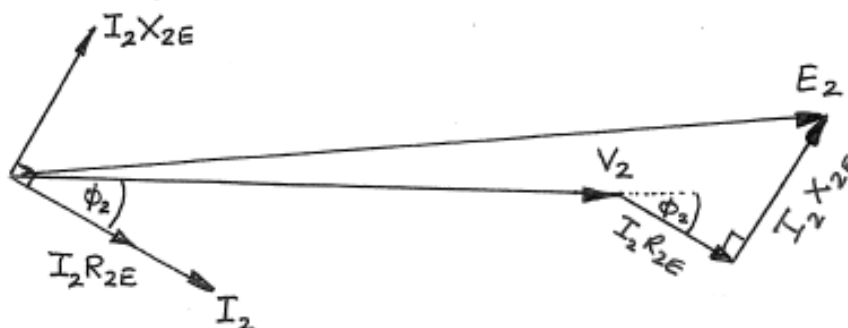
X_{2E} = total primary and secondary winding reactance referred to the secondary

Z_L = load impedance

I_2 = secondary current

[4 marks]

(b) With lagging power factor $\cos \phi_2$



[4 marks]

QUESTION 1 continued

(c)

Defined as the change in the output terminal voltage V_2 between no-load and full-load for a given power factor. Expressed as a percentage

[2 marks]

$$\% \text{ regulation} = \frac{|E_2| - |V_2|}{|V_2|} \times 100$$

[1 marks]

This approximates to:

$$\% \text{ regulation} = \frac{I_2 \left(R_{2E} \cos \phi_2 \pm X_{2E} \sin \phi_2 \right)}{V_2} \times 100$$

+ for lagging
- for leading

[2 marks]

(d) (i)

$$\begin{aligned} \text{Full load current } I_2 &= \frac{\text{VA rating}}{V_2 \text{ rated}} \\ &= \frac{2800}{110} \\ &= 25.45 \text{ A} \end{aligned}$$

(d) (ii) a. unity power factor

[2 marks]

$$\begin{aligned} \cos \phi_2 &= 1 & \phi_2 &= 0 \text{ rads} \\ \sin \phi_2 &= 0 \end{aligned}$$

[1 mark]

QUESTION 1 continued

(d) (ii) a.

$$\begin{aligned}
 \% \text{ regulation} &= \frac{25.45 \times (0.08 \times 1 + 0.42 \times 0) \times 100}{110} \\
 &= 0.0185 \times 100 \\
 &= 1.85 \%
 \end{aligned}$$

[2 marks]

(d) (ii) b. 0.75 lagging power factor

$$\begin{aligned}
 \cos \phi_2 &= 0.75 & \phi_2 &= 0.7227 \text{ rad} \\
 \sin \phi_2 &= 0.661 \\
 \% \text{ regulation} &= \frac{25.45 \times (0.08 \times 0.75 + 0.42 \times 0.661) \times 100}{110} \\
 &= 7.81 \%
 \end{aligned}$$

[3 marks]

(d) (iii) c. 0.88 leading power factor

$$\begin{aligned}
 \cos \phi_2 &= 0.88 & \phi_2 &= 0.4949 \text{ rad} \\
 \sin \phi_2 &= 0.47497 \\
 \% \text{ regulation} &= \frac{25.45 \times (0.08 \times 0.88 - 0.42 \times 0.47497) \times 100}{110} \\
 &= -2.987 \%
 \end{aligned}$$

Negative regulation means that $V_2 > E_2$

[3 marks]

QUESTION 1 continued

(e)

$$\text{Copper losses} = |I_2|^2 R_{2E} \quad [1 \text{ mark}]$$

$$= 25.45^2 \times 0.08$$

$$= 51.82 \text{ W} \quad [1 \text{ mark}]$$

$$\% \text{ efficiency} = \frac{\text{output VA} \times \text{power factor} \times 100}{\text{output VA} \times \text{power factor} + \text{iron loss} + \text{copper loss}} \quad [2 \text{ marks}]$$

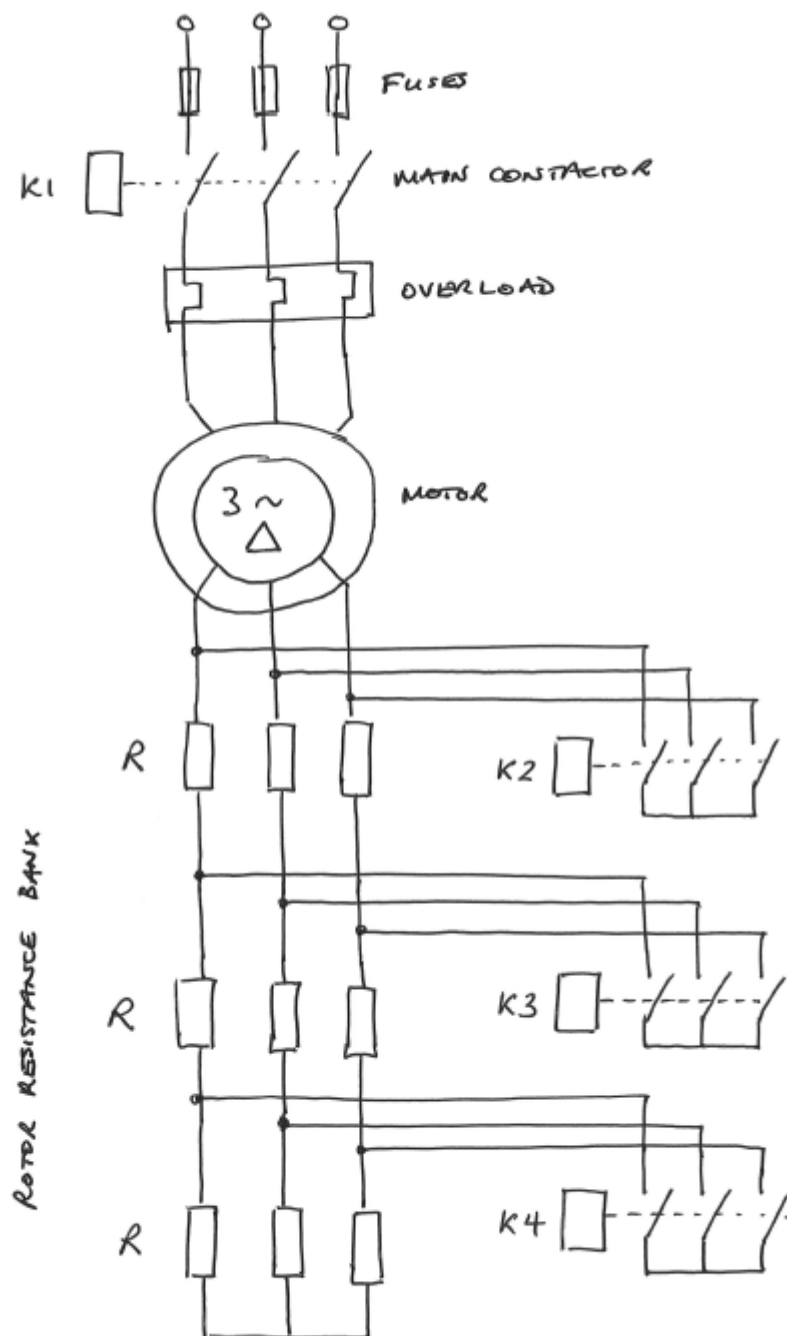
$$= \frac{2800 \times 0.85 \times 100}{2800 \times 0.85 + 35 + 51.82} \quad [1 \text{ mark}]$$

$$= 96.48 \% \quad [1 \text{ mark}]$$

Total for this question is 34 marks

QUESTION 2

(a)



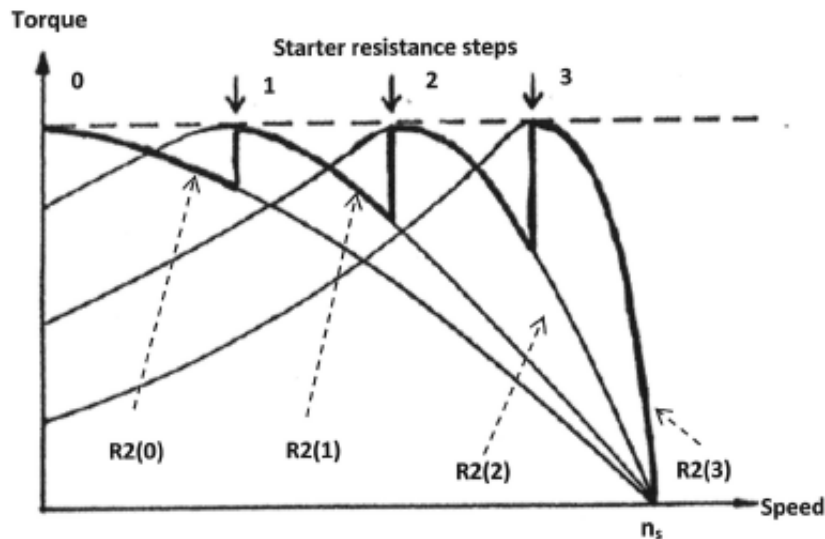
FOUR STAGE
SEQUENCE:

$K1 \rightarrow K4 \rightarrow K3 \rightarrow K2$

[6 marks]

QUESTION 2 continued

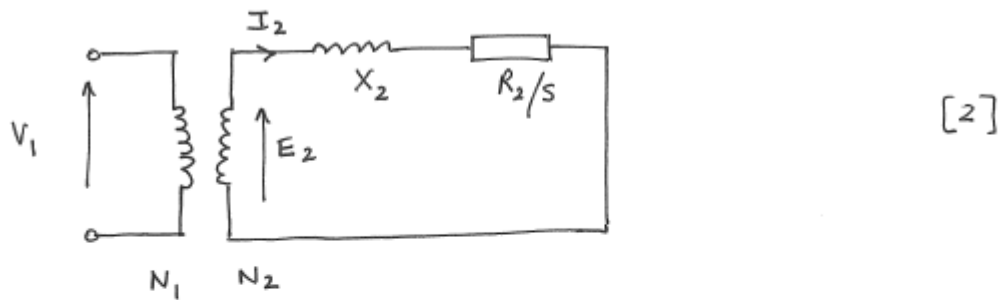
There are four stages in starting the machines. When contactor K1 energises, the full resistance $R_2(0)$ is applied to the rotor. Then in 3 steps, the external resistors are shorted out as shown below.



The largest resistance is $R_2(0)$ and this reduces to $R_2(1)$, $R_2(2)$ and $R_2(3)$ in 3 steps as shown above and n_s is the synchronous speed. The rotor circuit resistance may be altered in the wound rotor induction motor by means of the starter. The motor is started with a resistance of $R_2(0)$ in series with each of the rotor coils. As the motor speed increases, the resistance is reduced to $R_2(1)$ at step 1. As the motor speed increases further, the resistance is reduced to $R_2(2)$ at step 3. Finally, at step 3, the resistance is reduced to $R_2(3)$ which is the actual resistance of the rotor coils themselves with no external resistance i.e. slip rings are shorted out. The motor then runs normally.

[6 marks]

(b) (i) Equivalent circuit neglecting stator impedance



$$|E_2| = \frac{N_2}{N_1} |V_1| \quad [1]$$

$$\text{Rotor impedance } |Z_2| = \sqrt{\left(\frac{R_2}{s}\right)^2 + X_2^2} \quad [1]$$

$$\text{Rotor current } |I_2| = \frac{|E_2|}{\sqrt{\frac{R_2^2}{s^2} + X_2^2}} \quad [1]$$

$$= \frac{s |E_2|}{\sqrt{R_2^2 + s^2 X_2^2}} \quad [1]$$

$$\begin{aligned} \text{Rotor power lost} &= |I_2|^2 R_2 \\ &= \frac{s^2 |E_2|^2 R_2}{(R_2^2 + s^2 X_2^2)} \end{aligned} \quad [1]$$

$$\text{But rotor power} = 2\pi n_R T \quad [1]$$

$$\text{and } n_R = (1-s)n_s \quad [1]$$

$$\begin{aligned} \therefore \text{Rotor power} &= 2\pi (1-s)n_s T \\ &= 2\pi n_s T - 2\pi s n_s T \end{aligned} \quad [1]$$

QUESTION 2 (b) continued

The term $2\pi n_s T$ is the stator power [1]

the term $2\pi s n_s T$ is the power lost in the rotor [1]

$$\therefore 2\pi s n_s T = \frac{s^2 |E_2|^2 R_2}{(R_2^2 + s^2 X_2^2)} \quad [1]$$

$$\therefore T = \frac{1}{2\pi n_s} \frac{s |E_2|^2 R_2}{(R_2^2 + s^2 X_2^2)} \quad [1]$$

[14 marks]

(b)

(ii) $R_2 = 0.5 \Omega$

$X_2 = 1.34 \Omega$

$\frac{N_1}{N_2} = 1.6$

$V_1 = 440 \text{ V}$

$n_s = 50 \text{ rps}$

$n_r = \frac{2875}{60} = 47.92$

[1 mark]

$s = \frac{50 - 47.92}{50} = 0.042$

[1 mark]

$$\begin{aligned} |E_2| &= \frac{N_2}{N_1} |V_1| \\ &= \frac{1}{1.6} \times 440 = 275 \text{ V} \end{aligned}$$

[1 mark]

$$T = \frac{1}{2\pi \times 50} \times \frac{0.042 \times 275^2 \times 0.5}{(0.5^2 + 0.042^2 \times 1.34^2)} \quad [2 \text{ marks}]$$

$$= \frac{1588.13}{100\pi \times 0.253}$$

$$= 19.98 \text{ Nm} \quad [2 \text{ marks}]$$

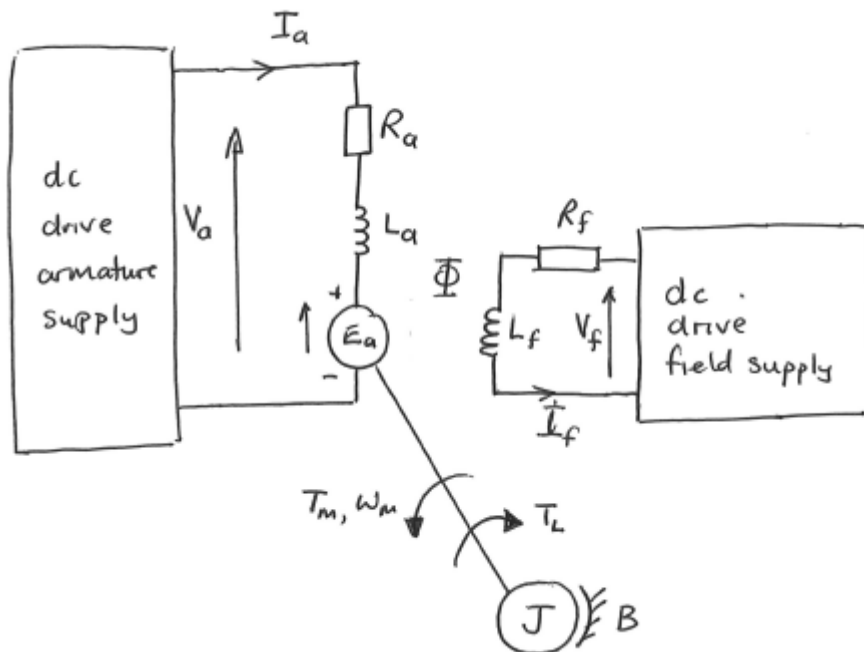
$$\therefore \text{Total torque} = 3 \times 19.98 = 59.94 \text{ Nm} \quad [1 \text{ mark}]$$

Total for this question is 34 marks

QUESTION 3

(a)

The armature is represented on the left of the diagram below and the field is the left. The mechanical load is shown connected to the back EMF. The field produces a constant total flux of Φ .



[6 marks]

(b)

For constant flux k_b is the machine constant in $V/\text{rad/s}$ or N_m/A

$$E_a = k_b \omega_m \quad \text{--- (1)} \quad \text{and} \quad T_m = k_b I_a \quad \text{--- (2)}$$

[2 marks]

Electrical dynamic equation

$$V_a = E_a + I_a R_a + L_a \frac{dI_a}{dt} \quad \text{--- (3)}$$

[2 marks]

Mechanical dynamic equation

$$T_m = T_L + B \omega_m + J \frac{d\omega_m}{dt} \quad \text{--- (4)}$$

[2 marks]

QUESTION 3 continued

(c) under steady state $\frac{dI_a}{dt} = 0$, $\frac{d\omega_m}{dt} = 0$ [1 mark]

$\therefore$ (4) becomes

$$T_m = T_L + B \omega_m \quad [1 \text{ mark}]$$

$$\therefore T_m = 120 + 0.015 \omega_m \quad \text{--- (5)} \quad [1 \text{ mark}]$$

This is the load equation

and (3) becomes

$$V_a = E_a + I_a R_a \quad [1 \text{ mark}]$$

using (1) and (2)

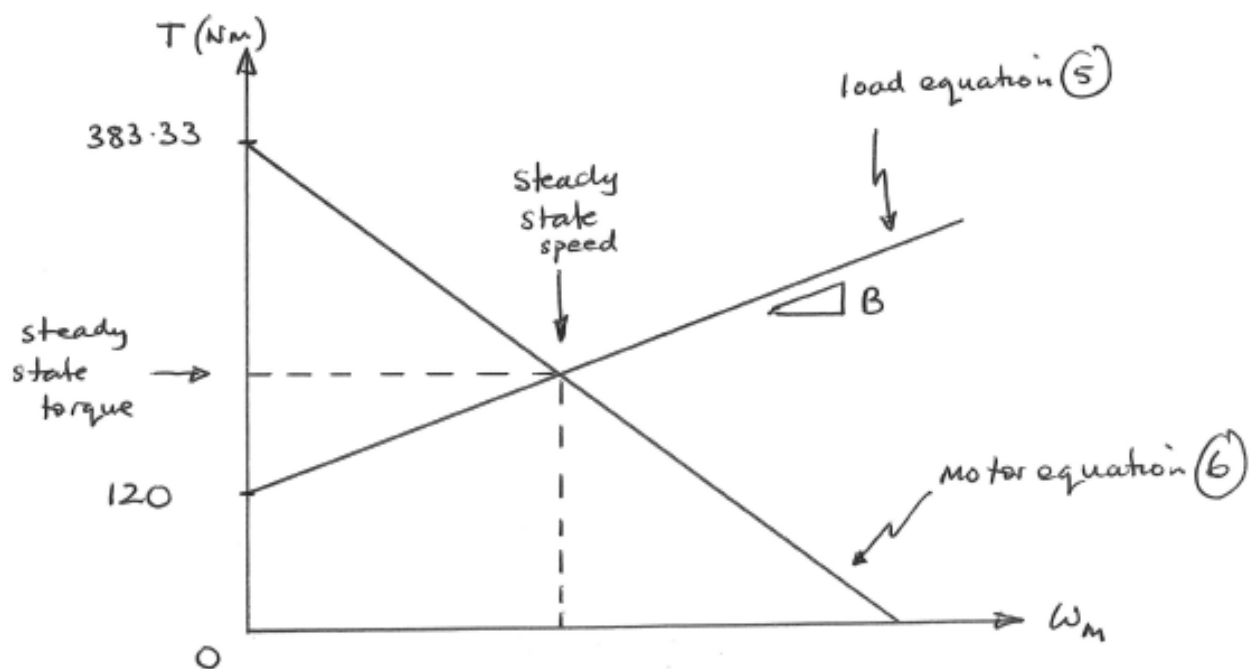
$$V_a = K_b \omega_m + \frac{T_m}{K_b} R_a \quad [1 \text{ mark}]$$

$$230 = 0.75 \omega_m + \frac{T_m \times 0.45}{0.75}$$

$$230 = 0.75 \omega_m + 0.6 T_m$$

$$T_m = 383.33 - 1.25 \omega_m \quad \text{--- (6)} \quad [2 \text{ mark}]$$

This is the motor equation



[5 marks]

QUESTION 3 continued

Equating (5) and (6)

$$120 + 0.15 \omega_m = 383.33 - 1.25 \omega_m$$

[1 mark]

$$(1.25 + 0.15) \omega_m = 383.33 - 120$$

$$\omega_m = \frac{263.33}{1.40}$$

$$= 188.1 \text{ rad/s}$$

[2 marks]

$$\therefore E_a = 0.75 \times 188.1$$

[1 mark]

$$= 141.07 \text{ V}$$

$$T_m = 120 + 0.015 \times 188.1$$

[1 mark]

$$= 122.82 \text{ Nm}$$

$$I_a = \frac{T_m}{K_b} = \frac{122.82}{0.75}$$

[1 mark]

$$= 163.762 \text{ A}$$

@ $\omega_m = 0$, using (6)

[1 mark]

$$\therefore T_m = 383.33 \text{ Nm}$$

$$I_a = \frac{383.33}{0.75} = 511.1 \text{ A}$$

[1 mark]

@ $T_m = 0$, using (6)

$$0 = 383.33 - 1.25 \omega_m$$

$$\therefore \omega_m = \frac{383.33}{1.25} = 306.66 \text{ rad/s}$$

[2 marks]

Total for this question is 34 marks

QUESTION 4

(a)

A short transmission line is one where its length does not exceed 100Km at 50Hz for an overhead line (or 20Km for a cable). The shunt capacitance and leakage may be neglected and the transmission line may be represented as a series impedance as shown in the per-phase equivalent circuit of figure 1 where V_{SN} is the sending-end voltage, V_{RN} is the receiving end voltage and the impedance Z is made up of a resistance and a reactance with line current I .

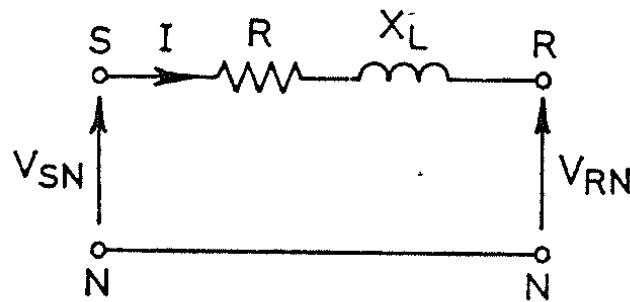
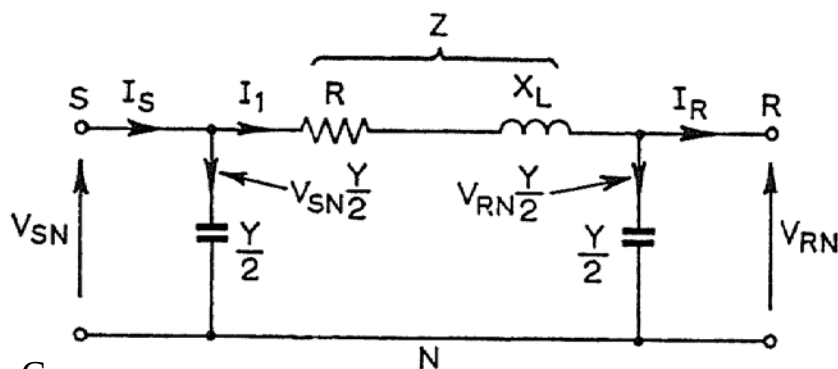


Figure 1

[5 marks]

A medium length transmission line is one where its length is between 100 and 350Km at 50Hz. In this case, the shunt capacitance cannot be neglected and is represented as an admittance Y with half at the sending end and half at the receiving end as shown in the per-phase nominal- π equivalent circuit of figure 2.

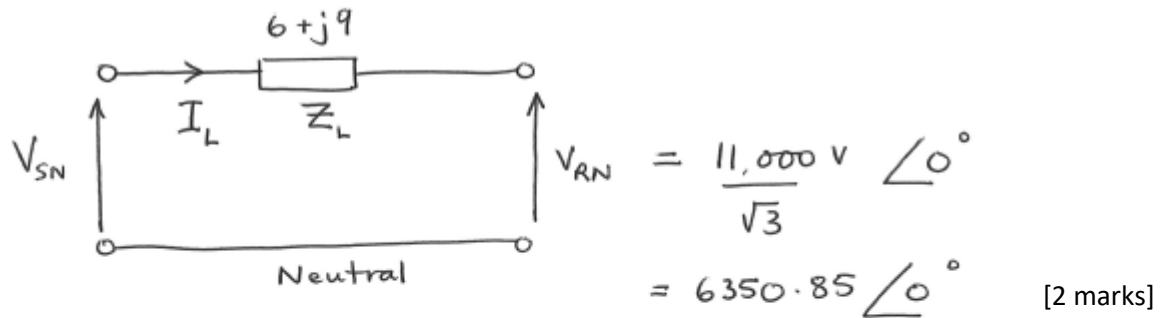


Where $Y = j\omega C$

[6 marks]

QUESTION 4 continued

(b) (i)



$$P = \sqrt{3} |V_L| |I_L| \cos \phi$$

$$\begin{aligned}
 \therefore |I_L| &= \frac{P}{\sqrt{3} |V_L| \cos \phi} \\
 &= \frac{2500,000}{\sqrt{3} \times 11,000 \times 0.85} \\
 &= 154.37 \text{ A}
 \end{aligned}$$

[2 marks]

$$\begin{aligned}
 \phi &= \cos^{-1}(0.85) \\
 &= 31.79^\circ \text{ lagging}
 \end{aligned}$$

$$\therefore I_L = 154.37 \angle -31.79^\circ$$

[2 marks]

$$\begin{aligned}
 Z_L &= 6 + j9 \\
 &= 10.82 \angle 56.31^\circ
 \end{aligned}$$

$$\begin{aligned}
 |Z_L| &= \sqrt{6^2 + 9^2} \\
 \angle Z_L &= \tan^{-1}\left(\frac{9}{6}\right)
 \end{aligned}$$

[2 marks]

Using Kirchhoff's Law

$$V_{SN} = V_{RN} + I_L Z_L$$

[1 mark]

$$\begin{aligned}
 &= 6350.85 \angle 0^\circ + 154.37 \angle -31.79^\circ \\
 &\quad \times 10.82 \angle 56.31^\circ
 \end{aligned}$$

QUESTION 4 continued

$$\begin{aligned}
 &= 6350.85 \angle 0^\circ + 1670.28 \angle 24.52^\circ \\
 &= 6350.85 + 1670.28 \cos(24.52) \\
 &\quad + j 1670.28 \sin(24.52) \\
 &= 6350.85 + 1519.65 + j 693.18 \\
 &= 7870.5 + j 693.18
 \end{aligned}$$

[2 marks]

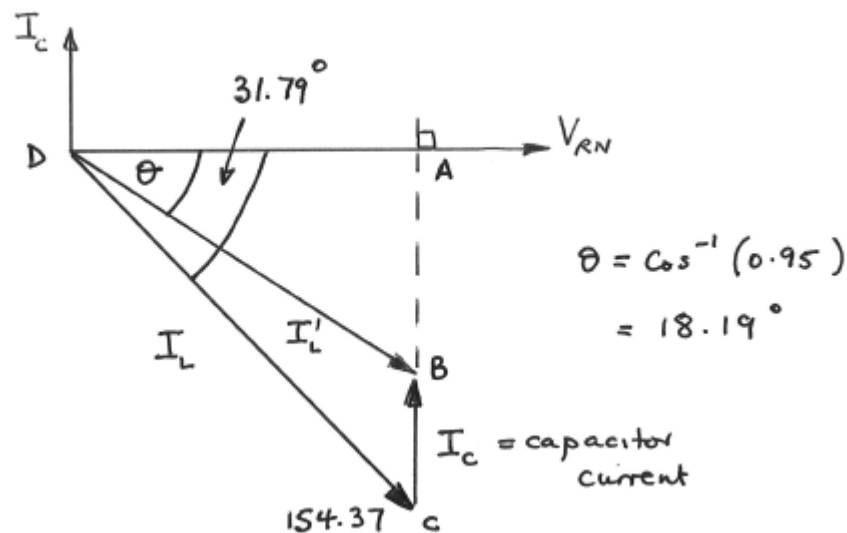
$$\begin{aligned}
 |V_{SN}| &= \sqrt{7870.5^2 + 693.18^2} = 7900.97 \text{ V} \\
 \angle V_{SN} &= \tan^{-1}(693.18/7870.5) = 5.03^\circ
 \end{aligned}$$

$$V_{SN} = 7900.97 \angle 5.03^\circ \text{ for phase voltage}$$

$$\text{or } V_s = 13684.88 \angle 5.03^\circ \text{ for line voltage}$$

[2 marks]

(b) (ii) a.



[3 marks]

QUESTION 4 continued

For the diagram

$$AC = 154.37 \sin(31.79) = 81.32$$

$$AD = 154.37 \cos(31.79) = 131.21$$

$$AB = 131.21 \tan(18.19) = 43.11$$

[2 marks]

$$\begin{aligned} BC &= |I_c| = AC - AB \\ &= 81.32 - 43.11 \end{aligned}$$

$$|I_c| = 38.21 \text{ A}$$

[1 mark]

$$\text{Since } X_c = \frac{|V_{RN}|}{|I_c|} = \frac{1}{\omega C}$$

[1 mark]

$$\therefore C = \frac{|I_c|}{\omega |V_{RN}|} = \frac{38.21}{2\pi \times 50 \times 6350.85}$$

$$C = 19.15 \mu\text{F}$$

[1 mark]

(b) (ii) b.

$$|I'_L| = BD$$

$$= \frac{AD}{\cos \theta}$$

$$= \frac{131.21}{0.95}$$

$$= 138.12 \text{ A}$$

$$\therefore I'_L = 138.12 \angle -18.19^\circ$$

[2 marks]

Total for this question is 34 marks