THE PAPUA NEW GUINEA UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL & COMMUNICATION ENGINEERING

BACHELOR OF ENGINEERING IN ELECTRICAL ENGINEERING YEAR 4 –POWER (BEEP 4)

EE462: ADVANCED ELECTRIC MACHINES AND DRIVES SECOND

SEMESTER EXAMINATION – 2021

TIME ALLOWED: 3 HOURS

INFORMATION FOR STUDENTS

1. You have **TEN (10)** minutes to read the paper.
   You must **NOT** begin writing during this time.

2. All answers must be written in the **ANSWER BOOK** supplied. **COMPLETE THE DETAILS REQUIRED ON THE FRONT COVER OF YOUR ANSWER BOOK. DO THIS NOW!**

3. Drawing instruments and calculators are allowed.

4. Attempt **ALL** questions.

5. The total number of marks for the paper is **100.** All questions carry equal marks

6. If anyone is found cheating in the Examinations, the penalties specified by the University shall apply.

QUESTION ONE **(20)**

A 230V, 6 pole, 30 hp, Y-connected three-phase induction motor operating at a rated frequency of 60 Hz develops its full-load torque at a rated slip of 2.7% with a rotor mass moment of inertia (J_M) of 0.4 kg.m^2.

This motor has the following per phase steady-steady equivalent parameters when operated at 60Hz and 230V;

Stator resistance:	R_s	=	0.294 Ω
Stator reactance	X_s	=	15.981 Ω
Stator leakage reactance:	X_{ls}	=	0.524 Ω
Stator inductance	L_s	=	0.0424 H
Rotor resistance	R_r	=	0.156 Ω
Rotor reactance	X_r	=	15.736 Ω
Rotor leakage reactance	X_{lr}	=	0.279 Ω
Rotor inductance	L_r	=	0.0417 H
Magnetizing reactance	X_m	=	15.457 Ω
Magnetizing inductance	L_m	=	0.041 H

This motor can be represented by the per phase equivalent circuit diagram in Figure 1 with rotor quantities referred to the stator side.

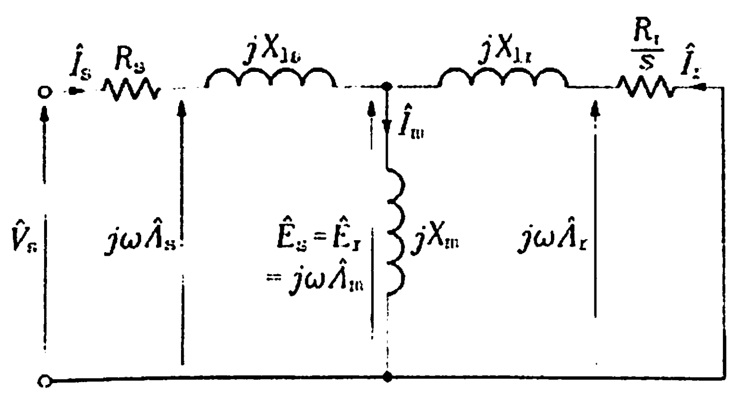

Figure 1: Per-phase equivalent circuit of the induction motor with rotor parameters referred to the stator side.

The per-phase equivalent circuit in Figure 1 can be further approximated by an approximate equivalent circuit shown in Figure 2.

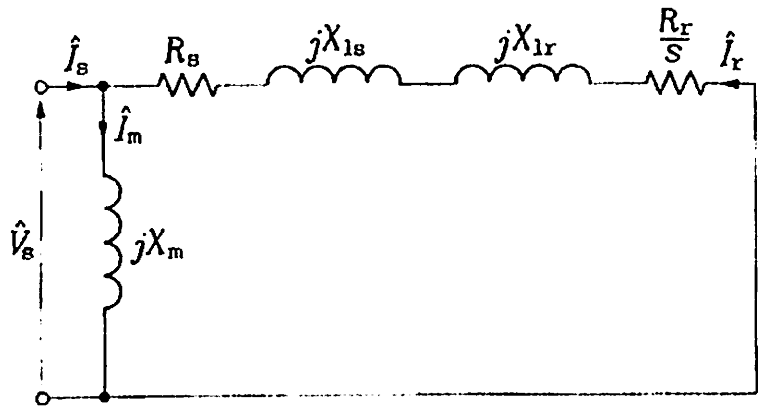

Figure 2: Approximate per-phase equivalent circuit of the induction motor.

(A) Based on the equivalent circuit diagram of Figure 2, determine the following for this motor;

- **(i)** The starting current
- **(ii)** The starting torque
- **(iii)** The pull-out torque
- **(iv)** The critical slip
- **(v)** The equivalent load resistance

(B) The motor defined above is to be operated under 50Hz rated frequency. Determine the following under this condition

- **(i)** The rated speed of the motor
- **(ii)** Stator current under rated condition
- **(iii)** Rotor current under rated condition
- **(iv)** The pull-out torque
- **(v)** The critical slip
- **(vi)** The equivalent load resistance

QUESTION TWO **(20)**

(A) Compare your answers to part (A)(iii) and part (B)(iv) of Question One and determine how the torque varies with the change in frequency.

(B) Assuming that the difference in voltage drop across the stator and rotor resistance is negligible, the stator flux can be considered only as a function of frequency which is approximately equal to the supply voltage divided by radian frequency. Thus determine how the stator flux changes with change in frequency experienced by the motor when operated under different rated frequencies stated in Question One.

(C) **(i)** Explain why it is important to maintain constant Volts/Hertz (CVH)

(ii) To maintain CHV operation for the motor in Question One, the stator voltage is adjusted according to the following rule:

$$V_s = \begin{cases} (V_{s,rat} - V_{s,0})\dfrac{f}{f_{rat}} + V_{s,0} & for \quad f < f_{rat} \\ V_{s,rat} & for \quad f \geq f_{rat} \end{cases},$$

Where $V_{s,rat}$ and f_{rat} are the rated stator voltage and supply frequency respectively. $V_{s,0}$ is the rms value of the stator voltage at zero frequency.

- Sketch a graphical illustration of the above rule as the frequency increases
- A CVH drive system with slip compensation is shown in Figure 3. Using this diagram briefly describe how CVH operation is achieved.

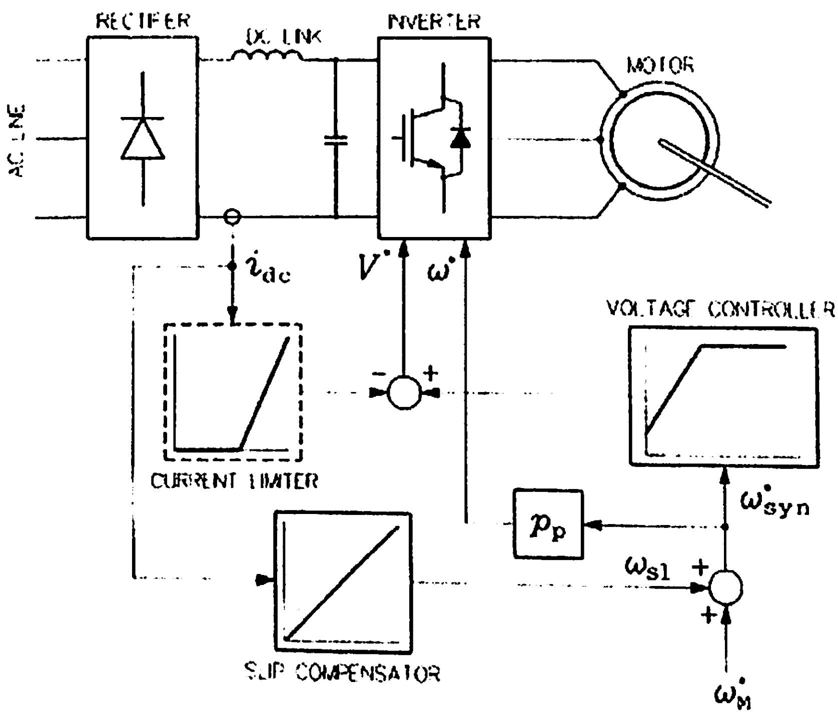

Figure 3: CVH drive system with slip compensation

QUESTION THREE **(20)**

To analyse the behaviour of the motor given in Question for scalar method of control, it is convenient to transform the per-phase equivalent circuit of Figure 1 into a "Two-Inductance Equivalent Circuit".

(A) Draw a Two-Inductance Γ-model of the induction motor represented by the per-phase equivalent circuit of Figure 1. All equivalent circuit parameters must be appropriately labelled.

(B) Assuming the motor in Question One is to be operated at 50 Hz rated frequency, determine the following Γ-model parameters referred to the stator side;

- **(i)** The transformation coefficient,
- **(ii)** The magnetizing inductance,
- **(iii)** The magnetizing reactance
- **(iv)** The leakage inductance
- **(v)** The total leakage reactance
- **(vi)** The rotor time constant
- **(vii)** The rotor current. Use the appropriate value of the flux calculated in Question Two (B)
- **(viii)** Calculate the torque developed
- **(ix)** The critical slip

QUESTION FOUR **(20)**

(A) Considering that the value of the stator and rotor currents obtained in Question One (B) (ii) and (iii) respectively are rms values, and considering phase "a" as the reference phase obtain;

- **(i)** The per-phase stator phase currents ($i_{s,s}$, $i_{b,s}$ $i_{c,s}$) in time domain form
- **(ii)** The per-phase rotor current currents ($i_{a,r}$, $i_{b,r}$ $i_{c,r}$) in time domain form
- **(iii)** Perform abc to dq transformation of the stator and rotor phase currents in the stationary frame
- **(iv)** Obtain the current space vectors for the stator and rotor currents respectively

(v) By calculation; show that the magnitude of the space vector for the stator and rotor currents are $1.5\sqrt{2}$ times rms value of phase currents and 1.5 times the maximum value of the stator and rotor current phasors

(B) Using the stator and rotor current vectors obtained in part A (iv), determine;

(i) The rated rms value of the stator flux
(ii) The rated rms value of the rotor flux
(iii) The torque developed

QUESTION FIVE **(20)**

Using the current space vectors for the stator and rotor obtained in Question Four (A) (iv); perform dq to abc transformation to obtain;

(A) The stator phase currents
(B) The rotor phase currents