(University of Choice)

MASINDE MULIRO UNIVERSITY OF SCIENCE AND TECHNOLOGY (MMUST)

MAIN CAMPUS

UNIVERSITY EXAMINATIONS 2022/2023 ACADEMIC YEAR

FIFTH YEAR FIRST SEMESTER EXAMINATIONS

FOR THE DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL AND COMMUNICATION ENGINEERING

COURSE CODE: ECE 513E

COURSE TITLE: ELECTRICAL MACHINES DRIVES AND INDUSTRIAL APPLICATIONS

DATE: 16TH DECEMBER, 2022 TIME: 12: 00 PM – 2:00 PM

INSTRUCTIONS TO CANDIDATES

ANSWER QUESTION ONE AND ANY OTHER TWO QUESTIONS.
QUESTION ONE CARRIES 30 MARKS AND ALL OTHERS 20 MARKS EACH.

TIME: 2 Hours

MMUST observes ZERO tolerance to examination cheating

Question 1 (30 Marks)

(a) A 750 hp, 250 V, 1200 r/min dc motor is connected to a 208V, 3-phase, 60 Hz line using a 3-phase bridge converter as shown in Fig 1. The full-load armature current is 2500 A and the armature resistance is 4 m Ω.

i. The required firing angle α and internally generated e.m.f E_0 under rated full load conditions. (4 marks)

ii. The firing angle required so that the motor develops its rated torque at 400 r/min (4 marks)

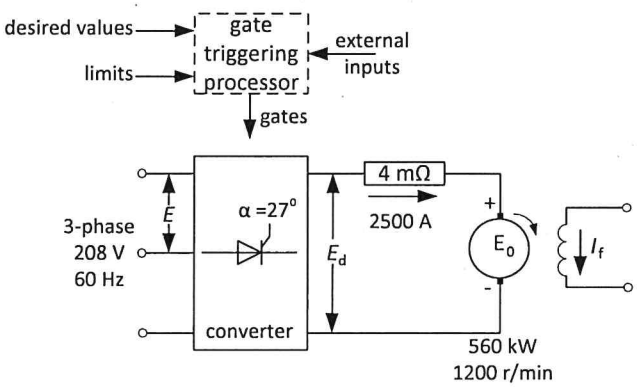

Figure 1: D.C. motor with 3 phase bridge

(b) With the aid of a circuit layout sketch briefly explain the operation of a rectifier -inverter system with *line commutation* as would be used to control a wound rotor induction motor. (5 marks)

(c) An industrial process requires variable speed and constant torque as in shown in fig. 2.

i. Briefly describe the process using words. (3 marks)

ii. Suggest and justify what a suitable drive system should be able to do to meet the process, in your proposed system, sketch and describe the type of motor and it's characteristic/s that is/are suitable. (6 marks)

(d) Fig. 3 shows a 6.1 Hz operating mode (applied to stator) of a 1 kW, 4-pole, 1740 r/min induction motor. The motor has a nominal rating of 416 V 3-phase, 60 Hz but is designed to run over a broad range of speeds, including zero speed, by varying the stator frequency. In this mode we assume that the torque is held constant at its rated value. Furthermore, the flux in the air gap is held constant with a peak flux density $B_{peak} = 0.8$ T. The peak voltage induced in each rotor bar under rated conditions is known to be 100 mV and the corresponding peak current is 250 A. It is also known that the current lags 4o behind the voltage and so the current axis lies 4o behind the flux axis.

i. Find the slip speed, S (r/min) at rated conditions. (2 marks)

ii. Determine the synchronous speed n_s when the stator is supplied with 6.1 Hz . (2 marks)

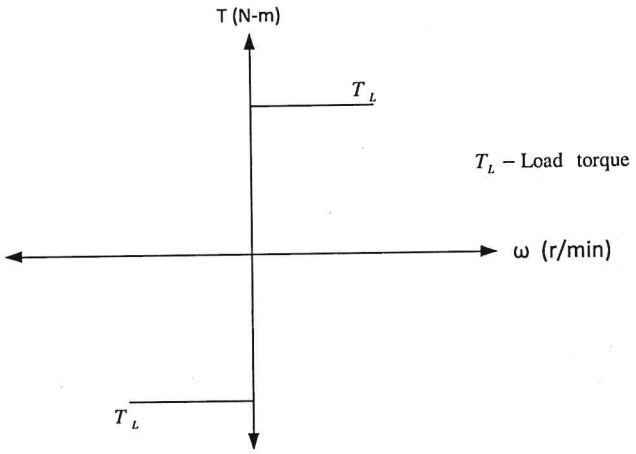

Figure 2: Variable speed constant torque characteristic

iii. Noting that in order to produce full load torque at 6.1 Hz, the slip speed must be maintained equal to that at rated conditions in item (i) above, determine rotor speed at 6.1 Hz. (2 marks)

iv. Determine the e.m.f induced in the stator E_ϕ at 6.1 Hz. (2 marks)

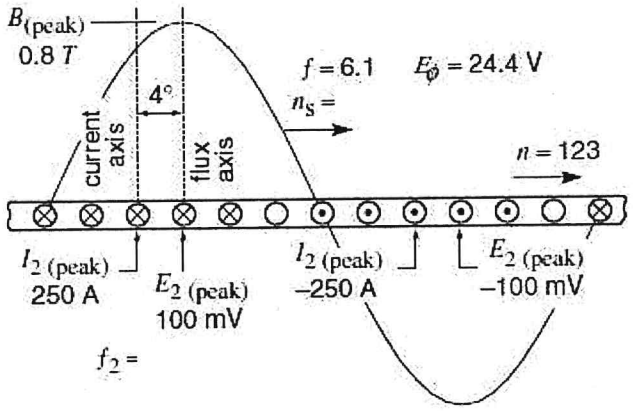

Figure 3: Variable speed constant torque characteristic

Question 2 (20 Marks)

(a) An industrial drive has to develop the torque-speed characteristic given in Fig. 4. A dc shunt motor is used, powered by two converters operating back-to-back. The converters function alternately (only one at a time) as shown in fig. 5 with terminals marked 'a' and 'b' as shown. The speed and torque are considered positive when acting clockwise.

i. Determine the operating state of each converter over the 30.5-second operating period (i.e whether it is in rectification or inverting mode) *Fill the table 1 provided appropriately.* (8 marks)

ii. Determine polarity at the d.c. machine terminals over the same operating period. *Fill*

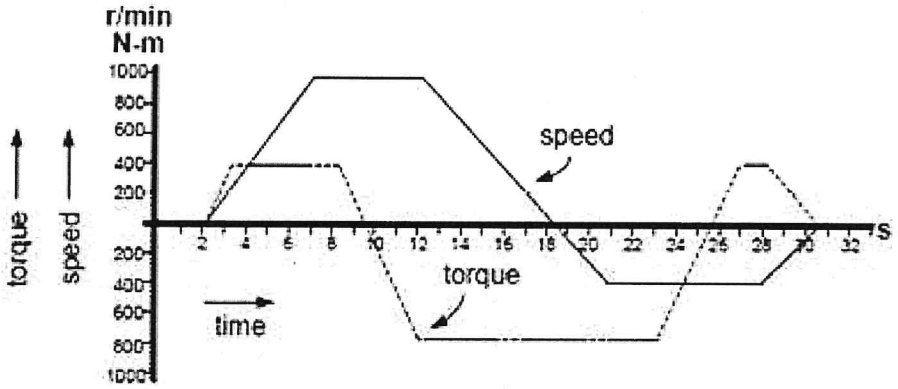

Figure 4: torque/speed characteristic of 4 quadrant drive process

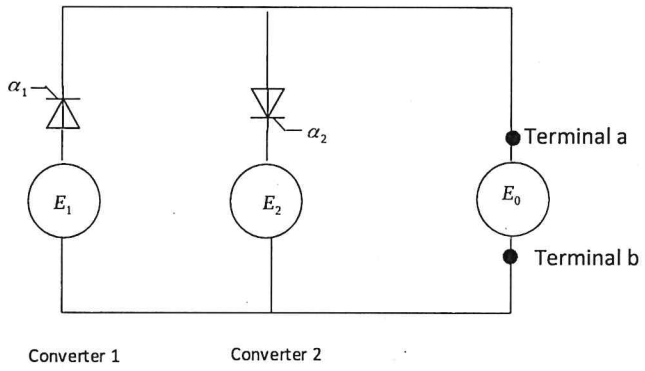

Figure 5: Four quadrant back -to -back converter drive system connection

(b) i. Sketch the equivalent circuit of a 3-phase induction motor (2 marks)

ii. Briefly describe Leakage reactances in your sketch. (1 marks)

iii. Briefly describe magnetizing reactance in your sketch (1 marks)

iv. Briefly describe the slip dependent equivalent resistance in the rotor circuit that represents the active power, P_r transmitted from stator to rotor. (2 marks)

Question 3 (20 Marks)

(a) Explain the volts/hertz principle used in the control of a 3 phase squirrel cage induction motor in terms of the torque speed curve. (4 marks)

(b) A 30 kW , 730 r.p.m., 400 V, 57 A, 50 Hz, 8 pole, 3 phase induction motor is driven by a current-source frequency converter with d.c. current of 73 A and negligible volt drop on the d.c inductance. The efficiency of the motor is 92% and that of the inverter is 99%. Determine

(a) The d.c power input to the motor. (2 marks).

(b) The d.c power input to the inverter. (3 marks).

(c) Derive the e.m.f equation of a d.c motor and explain the significance of back e.m.f. (8

Table 1:

Time interval (sec)	Operating mode(Inverter/Rectifier		d.c machine polarity (+ve/-ve)	
	Converter 1	Converter 2	Terminal a	Terminal b

(d) Explain the working principle of a thyristor. (2 marks).

Question 4

(a) Explain why machine ratings are given in KVA rather than KW (3 marks)

(b) Briefly explain the similarities and difference between a 3-phase transformer and 3-phase induction motor, use appropriate equivalent circuit sketches. (5 marks)

(c) A 30MVA, 15 kV, 60 Hz ac generator has a synchronous reactance of 1.2 pu and a resistance of 0.02 pu. Calculate

i. The base voltage, base power and base impedance of the generator. (3 marks)

ii. The actual value of the synchronous reactance. (2 marks)

iii. The actual winding resistance, per phase. (2 marks)

(d) Explain how the theory of a separately excited d.c machine is exploited to simplify control of a.c machines. (5 marks)

Question 5

(a) With the aid of typical torque -speed characteristic curve of a three phase squirrel cage induction motor operating at fixed voltage and frequency, explain the Four Quadrant operation of a three phase induction motor. (8 marks)

(b) A machine is turning clockwise in quadrant 3. Does it develop a clockwise or counter-clockwise torque? Explain. (3 marks)

(c) Explain the basic difference between a line-commutated and a self-commutated inverter. (3 marks)

(d) A set of balanced three phase currents of a synchronous machine are represented as

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} \cos(\omega_s t) \\ \cos(\omega_s t - 120^\circ) \\ \cos(\omega_s t + 120^\circ) \end{bmatrix}$$

i. Perform a two phase α, β Clarke's orthogonal transformation of the currents using the provided transformation matrix

$$\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

(4 marks)

ii. Perform a Park's $d-q$ transformation of the currents using an absolute rotor angle $\theta = 30°$ with stator phase 'a' axis as reference. (2 marks)