Name and Surname: ______________________________

Q1 : ...40...

Q2 : ...40...

Q3 : ...25...

TOTAL : ...105...

Middle East Technical University
Electrical and Electronics Engineering Department

EE 462

Second Midterm Exam

Duration: 100 min. 21 May 2007

SOLUTIONS

Q1 (40 pts) A separately excited dc machine is supplied from a controlled dc supply which has bidirectional power transfer capability (Fig.1).

DC Motor data

$200 = K \cdot 133.\bar{3}$

Rated armature voltage : 200 V

Rated output power : 10 hp

$\Rightarrow K = 1.5$ //

$R_a = 1.0$ ohm

Magnetization characteristic : 200 V at 133.3 rad/s at set value of field current

(assume it is linear)

$E_a\Big|_{100\,rad/s} = \frac{100}{133.3} \times 200 = 150\ V$ //

Load Characteristic

$T_e\Big|_{100\,rad/s} = 0.2 \times 100 + 30 = 50\ Nm$ //

$T_l = 0.2\ w + 30$

In the steady-state

where, T_l in Nm and w in rad/s

$T_e = T_l = K I_a \Rightarrow I_a = 50/1.5 = 33.3\ A$ //

Speed / torque characteristics of the Constant Speed Drive (CSD) and its load are as given in Figure 2. The loci of the operating point during regenerative braking and reversing are also marked on the same diagram.

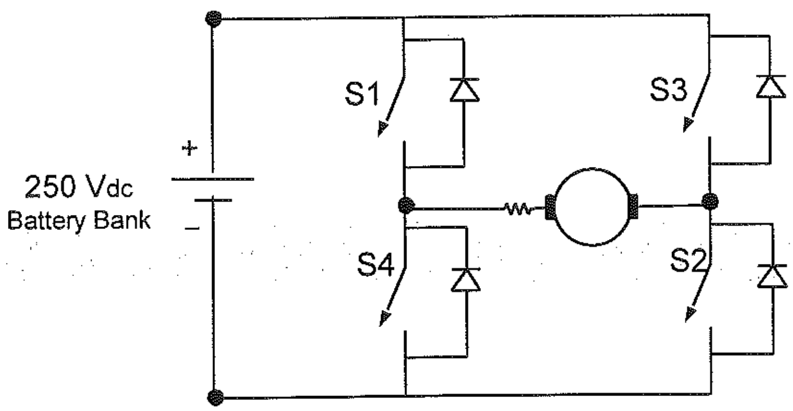


Fig.1. 4-Q DC Motor Drive

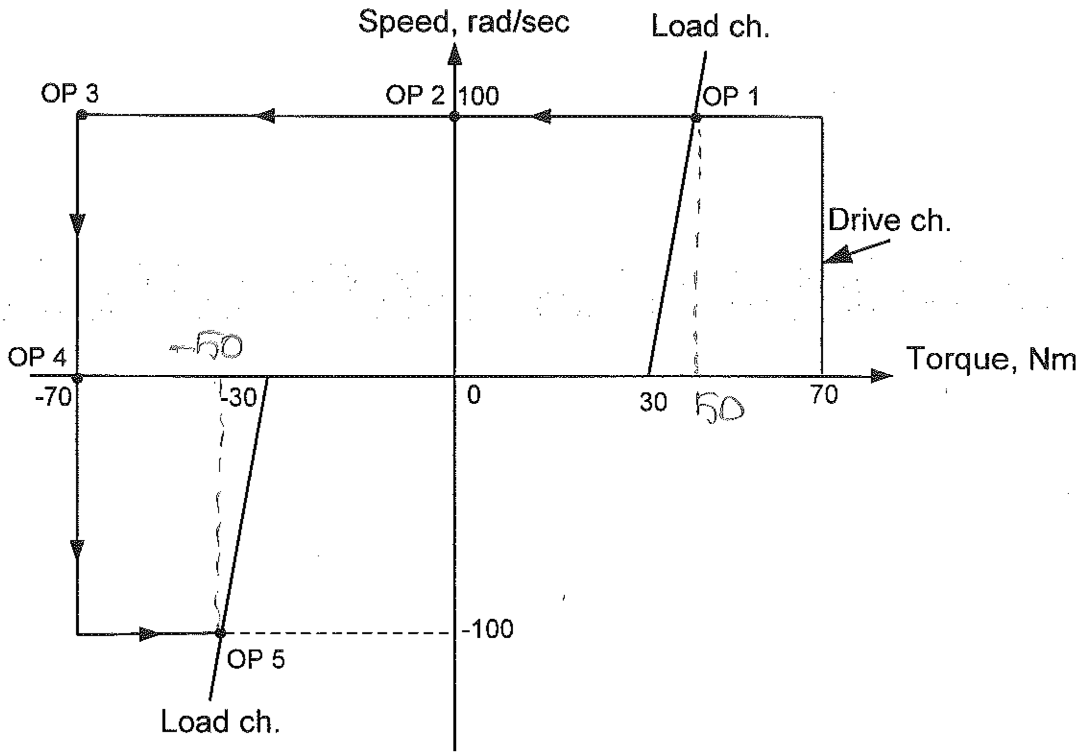


Fig 2. Loci of the operating point during regenerative braking and reversing

A. Calculate:

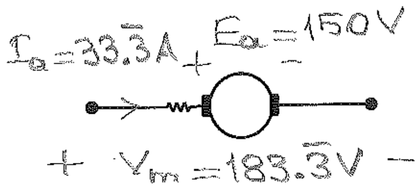
Applied motor voltage V_m, armature current I_a, induced armature emf E_a, and duty ratio of chopper circuit D at points from OP 1 to OP 5, and mark them on the associated armature circuit diagram.

i. point OP 1

$V_m = E_a + R_a I_a$

$= 150 + 1.0 \times 33.\bar{3}$

$= 183.\bar{3}\ V$ //



$D = \frac{183.\bar{3}}{250}$

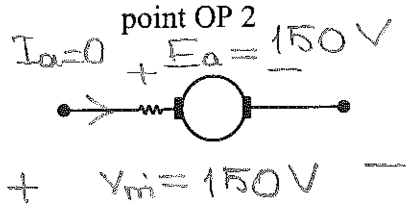
$D = 0.7\bar{3}$ //

4 pts each

ii. point OP 2

$T_e = 0$

$\Rightarrow I_a = 0$



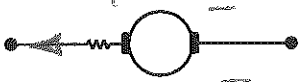
$D = \frac{150}{250}$

$D = 0.6$ //

iii.

point OP 3

$I_a = 46.\bar{6}A$ + $E_a = 150V$ −



\+ $V_m = 103.\bar{3}V$ −

$T_e = -70$ Nm

$I_a = -\frac{70}{1.5}$

$I_a = -46.\bar{6}A$

$V_m = E_a + R_a I_a$

$V_m = 150 - 1.0 \times 46.\bar{6} = 103.\bar{3}V$ //

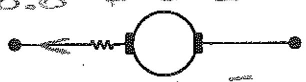
$D = \frac{103.\bar{3}}{250}$

$D = 0.41\bar{3}$ //

iv.

point OP 4

$I_a = 46.\bar{6}$ + $E_a = 0$



− $V_m = 46.\bar{6}V$ +

$T_e = -70$ Nm

$I_a = -46.\bar{6}A$

$V_m = E_a + R I_a$

$V_m = -1.0 \times 46.\bar{6} = -46.\bar{6}V$ //

$D = \frac{46.6}{250}$

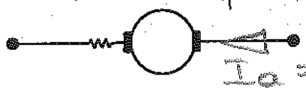
$D = 0.18\bar{6}$ //

v.

As in (i)

point OP 5

− $E_a = 150V$ +



$I_a = 33.\bar{3}A$ //

− $V_m = 183.\bar{3}V$ +

$D = 0.7\bar{3}$ //

In parts B to F, mark your answer (polarities of V_m, and E_a, directions of I_a and supply current I_s) on the attached circuit diagrams of the chopper. Use a separate diagram for each operation mode of the chopper circuit. Current path for each operation mode should be indicated by bold lines on the associated circuit diagrams.

B. How does the chopper circuit operate at OP 1 ?

C How do we bring operating point from OP 1 to OP 2 ?

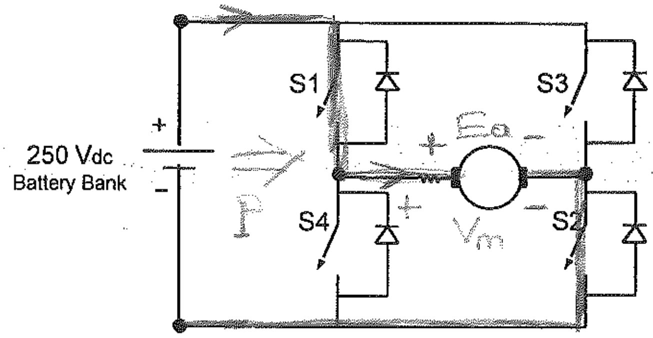
D. How do we bring operating point from OP 2 to OP 3 ?

E. How do we bring operating point from OP 3 to OP 4 ?

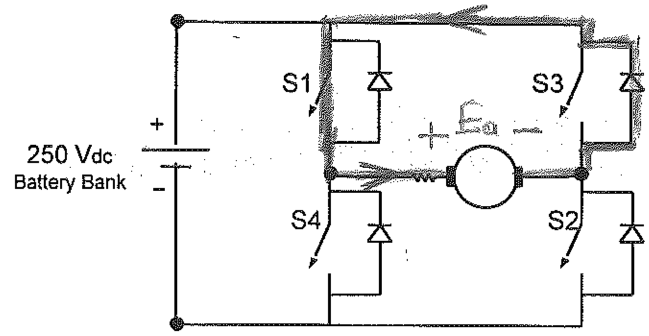
F. How does the chopper circuit operate at OP 5 ?

4 pts each

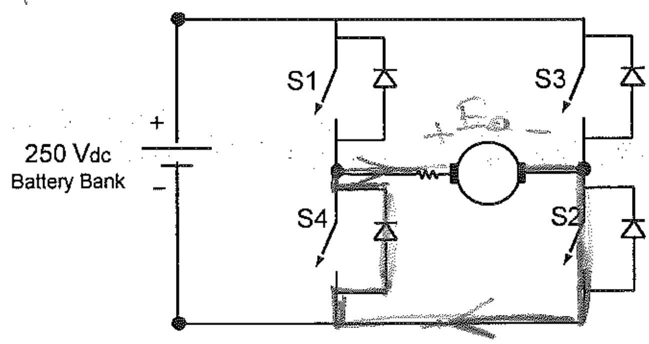
B. Power Transfer Mode:
S1 & S2 are conducting



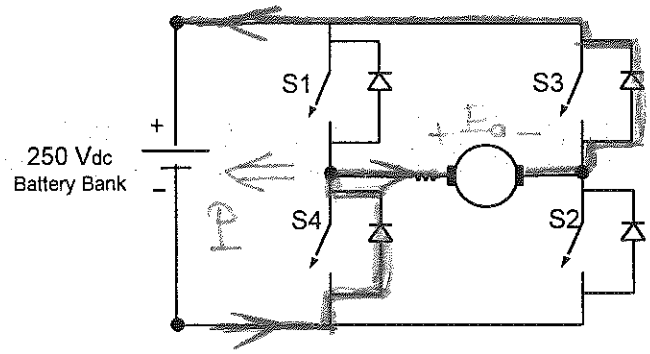
B. Free-wheeling period
S2 turned off



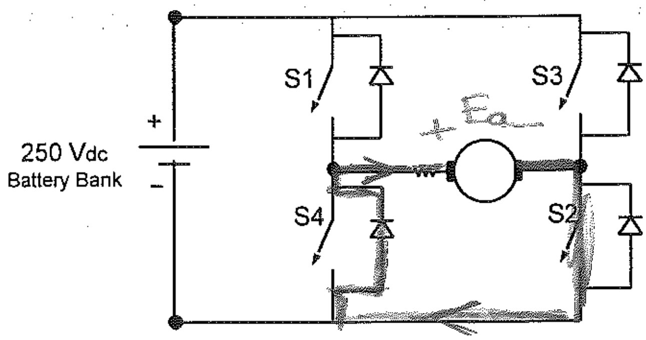
B. Free-wheeling period
S1 turned off
(S1 & S2 may be turned off repeatedly for equal heating).



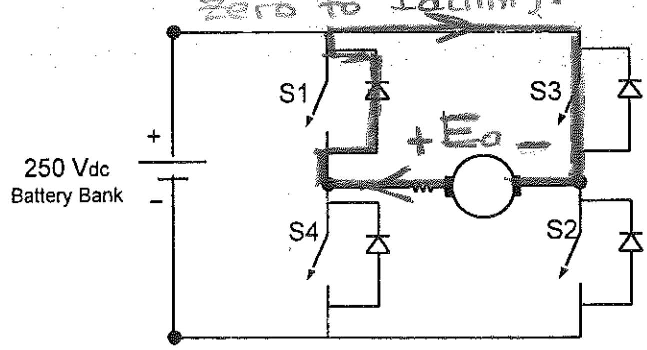
C. For rapid decay of i_a both S1 & S2 are turned off.



C. Apply one of the freewheeling modes in (B). which yields a slower response.

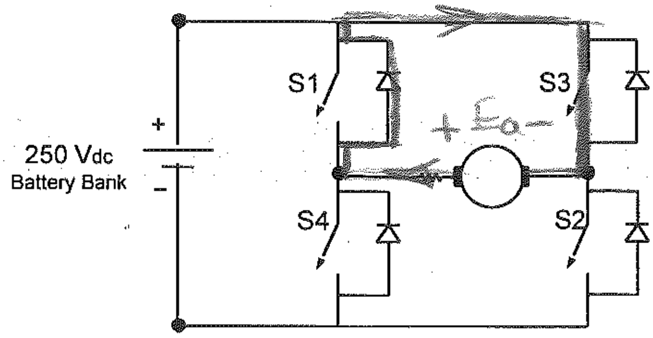


D. S3 or S4 are turned on.
i_a exponentially rises from zero to I_a(lim).

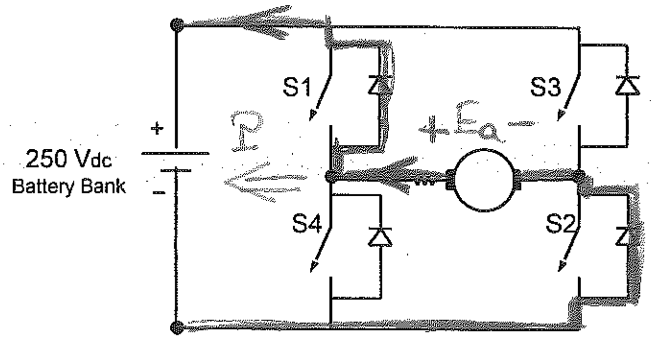


For more rapid rise of i_a both S3 and S4 can be turned on.

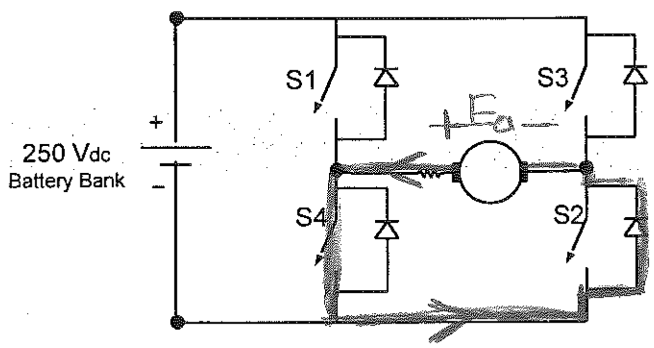
E. Charging period: S3 is turned on while the others are off



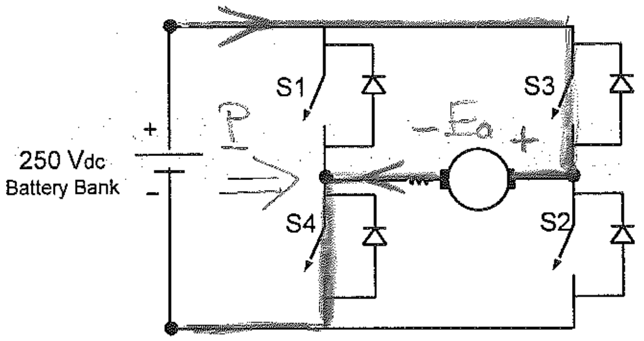
E. Regeneration Period: The conducting semiconductor (S3 or S4) is also turned off.



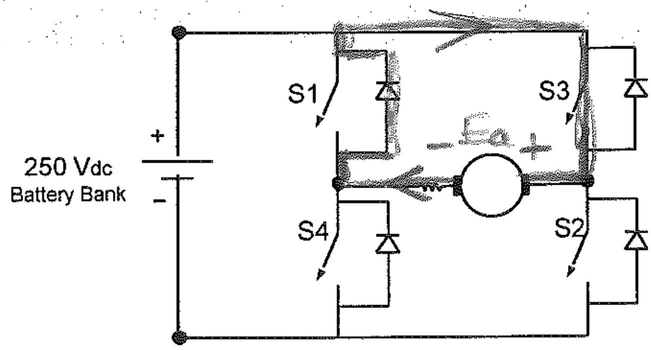
E. Alternative Charging period: S4 is turned on while the others are off.



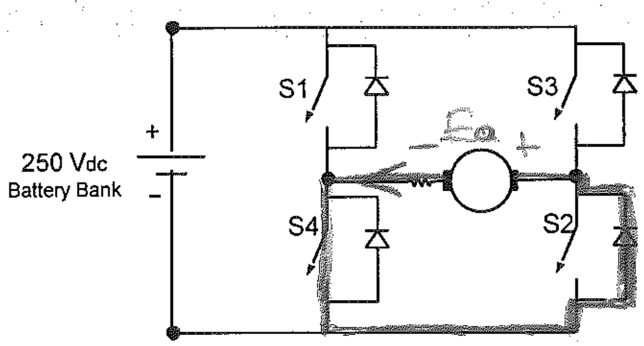
F. Power Transfer Mode: S3 and S4 are conducting



F. Freewheeling period: S4 is turned off while S3 is conducting



F. Freewheeling period: S3 is turned off while S4 is conducting.



S3 and S4 may be turned off one at a time repeatedly for equal heating.

Q2. (40 pts) A 4-pole, 400 V, 50 Hz, 1462,5 rpm , Δ-connected induction motor is employed in a four-quadrant adjustable speed motor drive as shown in Fig.1. Speed control is achieved by varying the frequency at the output of the inverter in Fig.2, and proper magnetic conditions in the machine core are maintained by applying 'Constant Volts per Hertz Operation' control strategy.

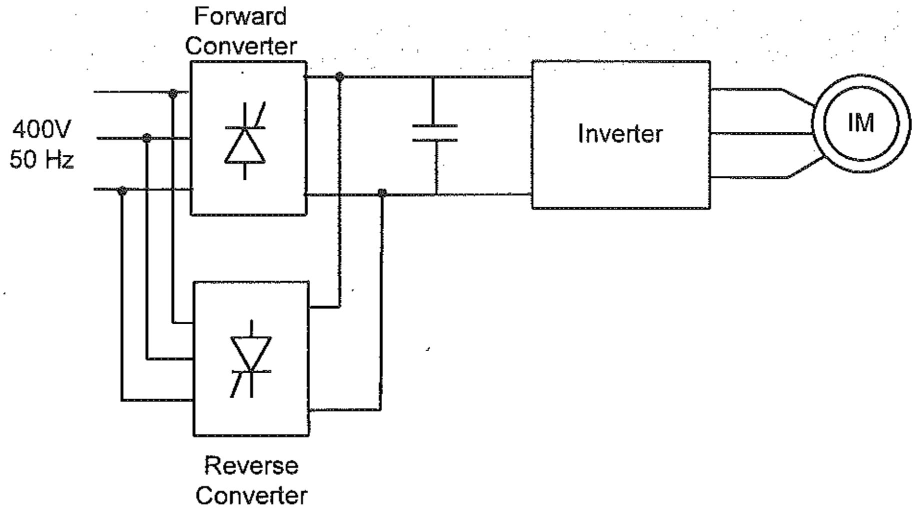


Fig.1. Four-quadrant induction motor drive

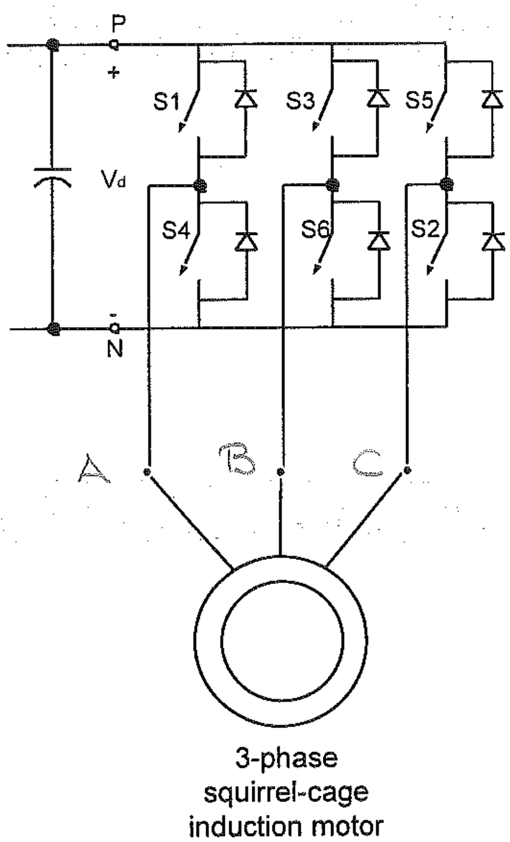


Fig.2. Circuit diagram of the voltage-fed inverter circuit

Part A. (4 pts each)

Phase sequence

Mark the gating signals of power semiconductors S1 to S6 on Fig.3 by assuming that each semiconductor receives a control signal for a period of 180° for the operating conditions defined below:

ABC i- f = 50 Hz to run the motor in forward direction, $T = 1/f = 20$ ms $120° = 20/3 = 6.\bar{6}$ ms

ABC ii- f = 25 Hz to run the motor in forward direction, $T = 40$ ms $120° = 13.\bar{3}$ ms

ABC iii- f = 100 Hz to run the motor in forward direction, $T = 10$ ms $120° = 3.\bar{3}$ ms

ACB iv- f = 50 Hz to run the motor in reverse direction,

Part B. (24 pts)

Operating characteristics of the adjustable speed drive described above are as given in Fig.4 for two different speed settings. Useful range of the torque/slip characteristic for the induction machine is shown in Fig.5. To simplify the calculations, you may assume that it remains the same for all operating frequencies. It may also be assumed that torque/slip characteristic in Fig.5 is symmetric in both motoring and generating regions.

5 pts a. Calculate the frequency and rms value of line-to-line voltage at the motor terminals for operation at point 1.

4 pts b. Calculate the frequency of applied stator voltage at point 2. Identify the operation mode of the induction machine.

4 pts c. Repeat (b) for point 3.

5 pts d. Repeat (a) for point 4.

6 pts e. Calculate the time spent in bringing operation point 1 to 4. Assume total inertia J = 0.2 kg-m2, and damping and stiffness are negligible.

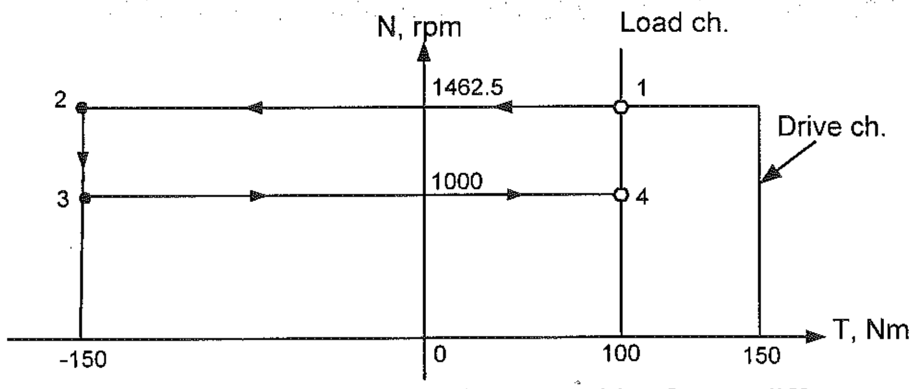


Fig 4. Operating characteristics of the induction motor drive for two different speed settings

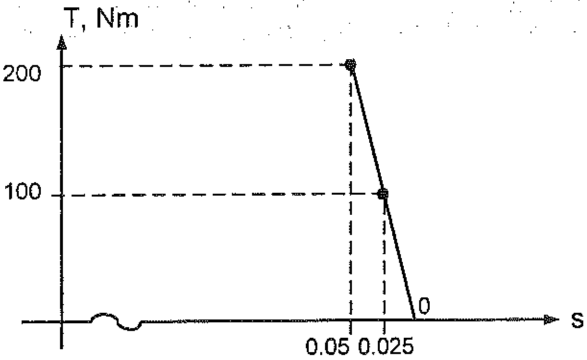


Fig.5. Straight-line approximation of the useful range of torque-slip characteristic

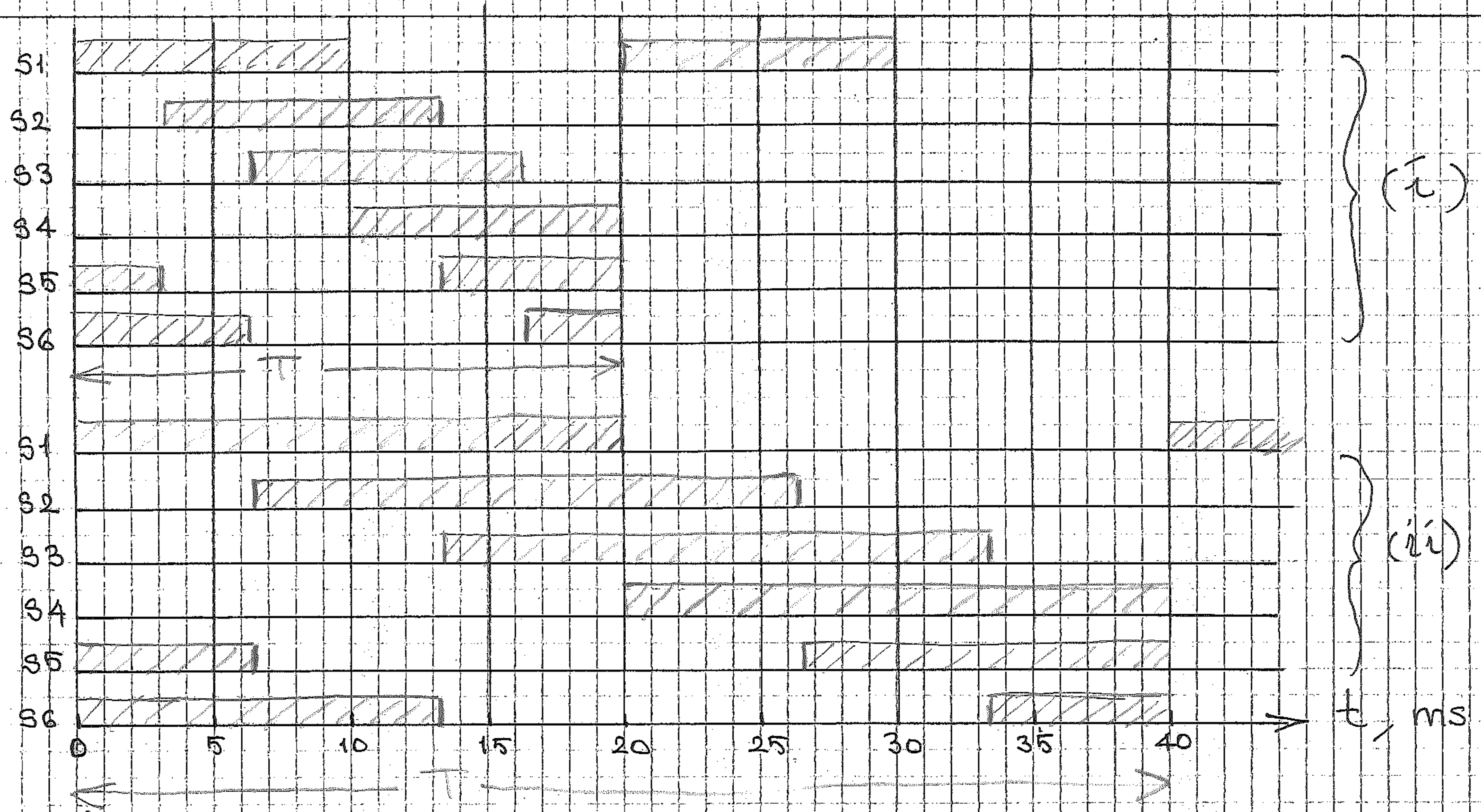


Figure 3. For Part A of Question 2

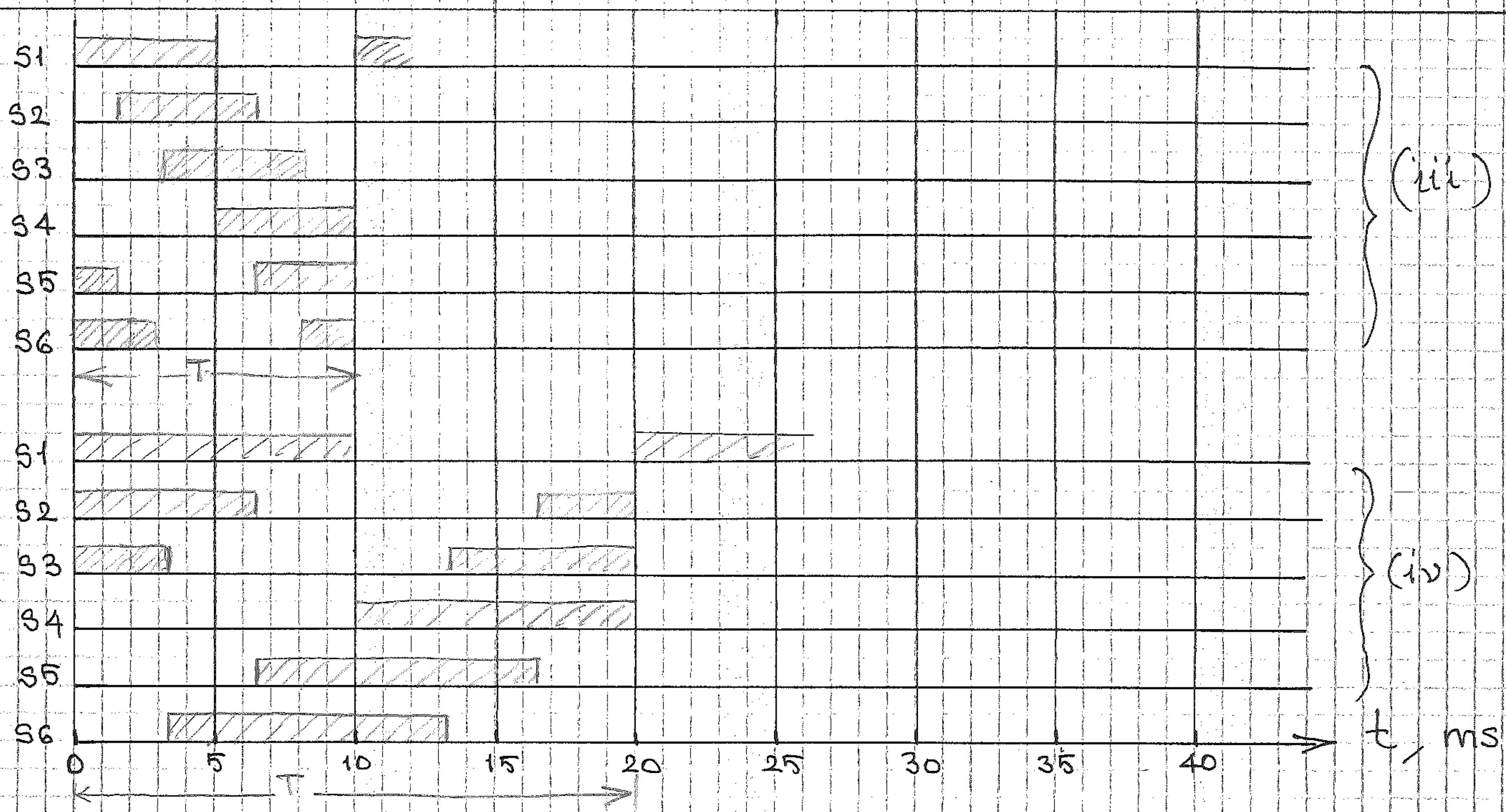


Figure 3. For Part A of Question 2

a. Point 1 (Motoring Mode)

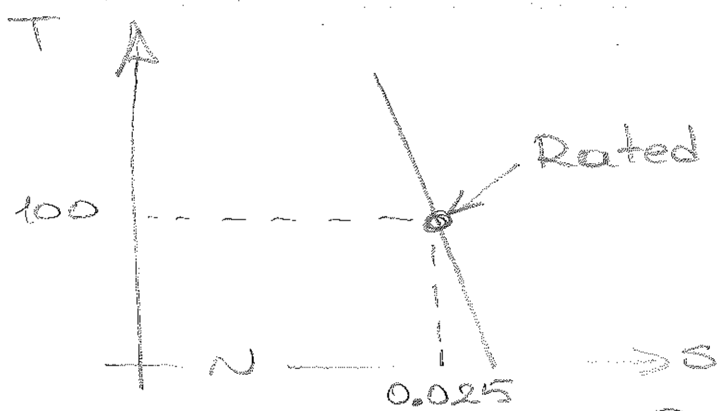
From basic motor data:

$N_s = \frac{120f}{p} = \frac{120 \times 50}{4} = 1500$ rpm

at full-load: $s = \frac{1500 - 1462.5}{1500} = 0.025$

Therefore,

(5 pts)



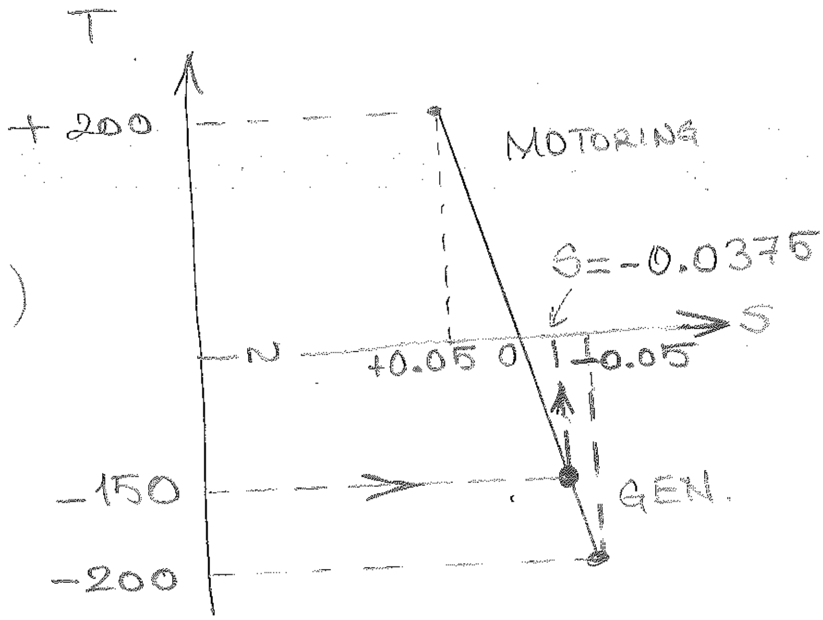
It means that $f = 50$ Hz //

According to constant volts-per-hertz operation strategy $V = 400$ V $_{L-to-L}$ //

b. Point 2 (Generating Mode)

$T_e = -150$ Nm $\quad N_r = 1462.5$ rpm

(4 pts)



$S = -0.0375 = \frac{N_s - 1462.5}{N_s}$

$-0.0375 = 1 - \frac{1462.5}{N_s}$

$\frac{1462.5}{N_s} = 1.0375$

$N_s = 1409.64$ rpm //

Since $N_s = \frac{120f}{p}$

$f = 46.99$ Hz //

$V = 400 \times \frac{46.99}{50} = 375.9$ V line-to-line // not asked!

c. Point 3 (Generating Mode)

$T_e = -150$ Nm $N_r = 1000$ rpm

From IM characteristic $S = -0.0375$

$$-0.0375 = 1 - \frac{1000}{N_s} \Rightarrow N_s = \frac{1000}{1.0375}$$

(4 pts)

$N_s = 963.8$ rpm //

$$f = \frac{PN_s}{120} = 32.13 \text{ Hz} \ //$$

d. Point 4 (Motoring Mode)

$T_e = 100$ Nm $N_r = 1000$ rpm

From IM characteristic $S = 0.025$

$$0.025 = 1 - \frac{1000}{N_s} \Rightarrow N_s = \frac{1000}{0.975}$$

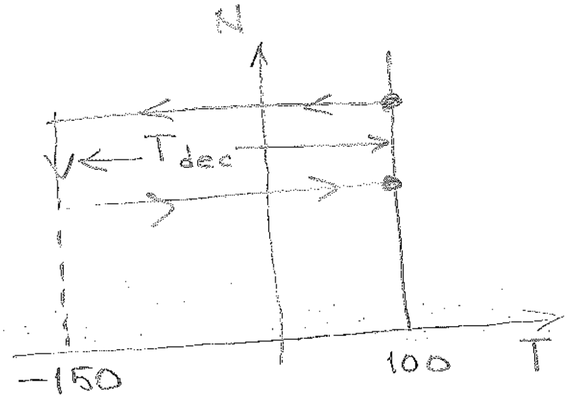
(5 pts)

$N_s = 1025.6$ rpm //

$f = 34.19$ Hz //

$$V = \frac{34.19}{50} \times 400 = 273.5 \ V \ \text{L-to-L} \ //$$

e.



$$J \frac{d\omega}{dt} = T_e - T_l$$

$$0.2 \frac{d\omega}{dt} = -150 - 100$$

$$\frac{d\omega}{dt} = -\frac{250}{0.2}$$

$$\frac{d\omega}{dt} = -1250 \ //$$

(6 pts)

$$\Delta t = \frac{\Delta\omega}{1250} = \frac{(1462.5 - 1000)\frac{2\pi}{60}}{1250}$$

$$\Delta t = 0.039 \text{ s} \ //$$

Q3. (25 pts) A three-phase, 4-pole, 400 V, 50 Hz, Δ-connected squirrel-cage induction motor drives a load having fixed torque-speed characteristic. The direction of rotation should be reversed repeatedly by the use of back-to-back (antiparallel) connected thyristor switches (a few hundreds of time per day). Torque/speed characteristics of the motor and its load are symmetrical in both directions of rotation (clockwise and counter-clockwise).

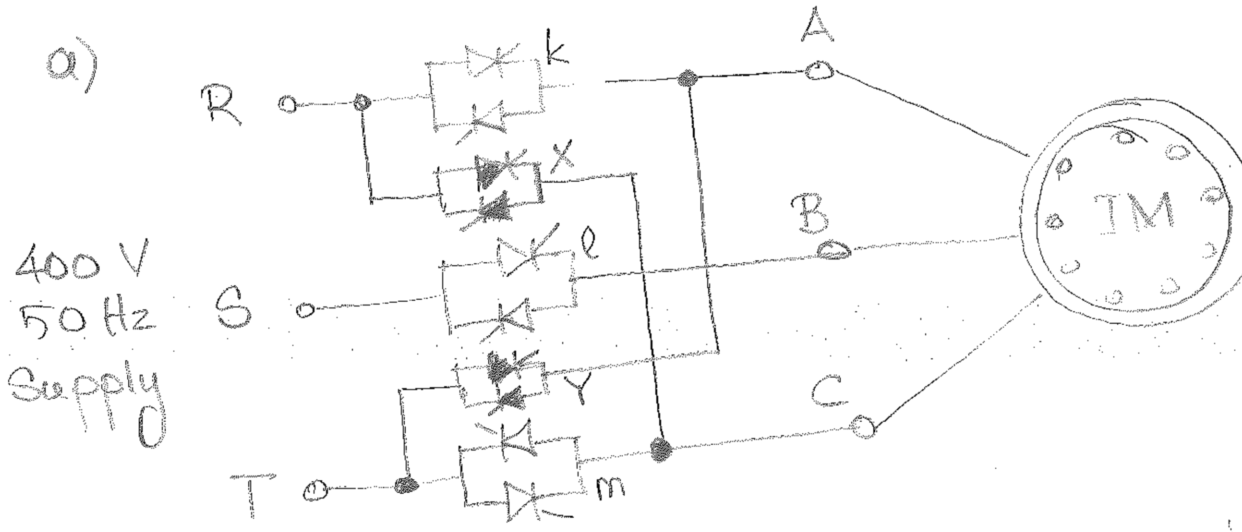
a. Recommend a circuit which permits forward driving, reverse driving and reversing. Draw the circuit diagram. Mark 400 V, 50 Hz supply terminals by R, S, and T, and motor terminals by A, B, and C.

b. Explain its operation.

c. What do we call the operation mode of the induction machine during reversing ?

d. Is it the most economic solution? If not, propose another circuit which saves money.

a)



b) Forward Driving: k, l, m activated ; x and y blocked.
Phase sequence of applied voltages RST at motor terminals A,B,C.

Reverse Driving : k and m blocked ; x and y activated.
Phase Sequence at motor terminals TSR

To reverse the direction of rotation block k and m and activate X and Y.

c) PLUGGING Mode of operation.

d) Since the stator of IM does not have the neutral point and hence neutral wire, back-to-back connected thyristor switch "l" can be deleted.

This will be the most economic soln.