MIDDLE EAST TECHNICAL UNIVERSITY

ELECTRICAL AND ELECTRONICS ENGINEERING DEPARTMENT

EE 462 Utilization of Electrical Energy

Midterm II Examination

11 May 2018

Duration: 110 minutes

Attempt all questions

Show all your calculations for full credit.

Write your name on all papers, and please mention it clearly if you continue your solutions on a different page.

Student Name: Dr Muammer ERMİŞ

Student ID: SOLUTIONS

Q1		35 pts
Q2		40 pts
Q3		35 pts
Total		

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Q1) (35 pts) A separately-excited DC motor with constant field excitation is supplied from a constant voltage DC bus via a chopper circuit and drives its load in quadrants I and II of the torque/speed plane. Operation in QI is forward driving and QII is regenerative braking. Assume continuous armature current.

a) Recommend a current bi-directional chopper circuit and draw its circuit diagram.

b) Define all operation modes for forward driving in QI. Mark the directions of all currents and polarities of all voltages on the associated circuit diagrams.

c) How do we transfer the operating point from QI to QII ?

d) Repeat (b) for regenerative braking in QII .

a)

This is the most economic soln. to the 2-Q operation.

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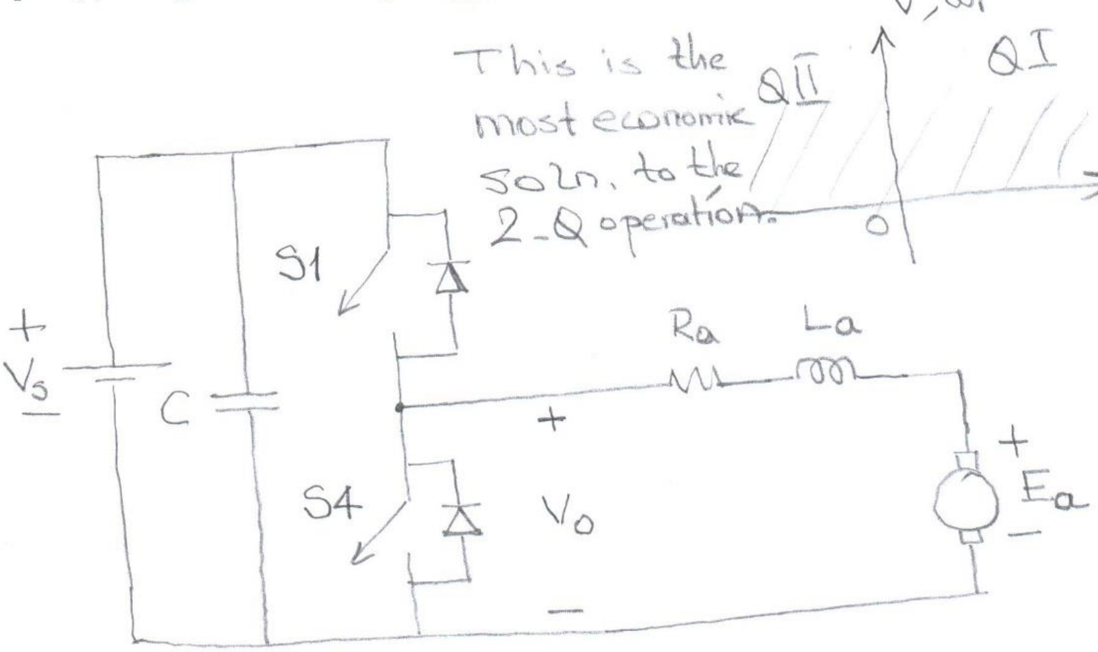

b)

Power Transfer Mode

S1 on.

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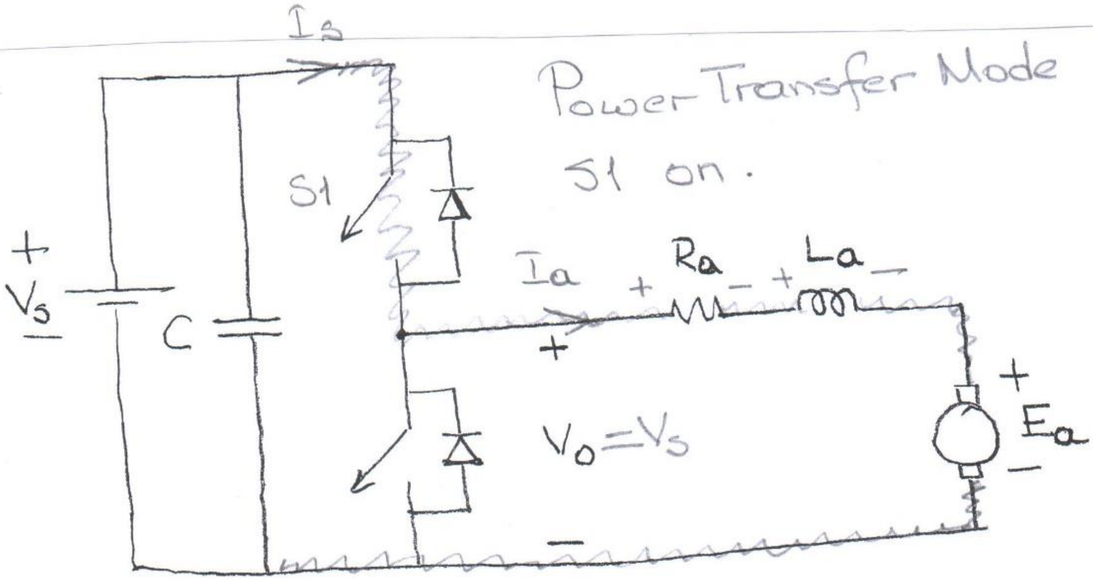

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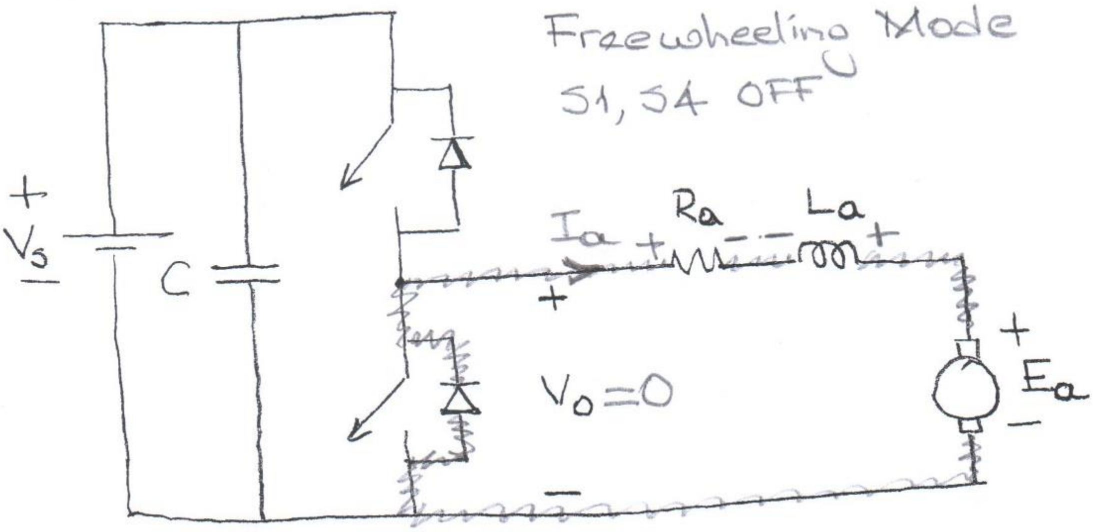
Freewheeling Mode
S1, S4 OFF



c)

First reduce I_a to zero
S1, S4 OFF

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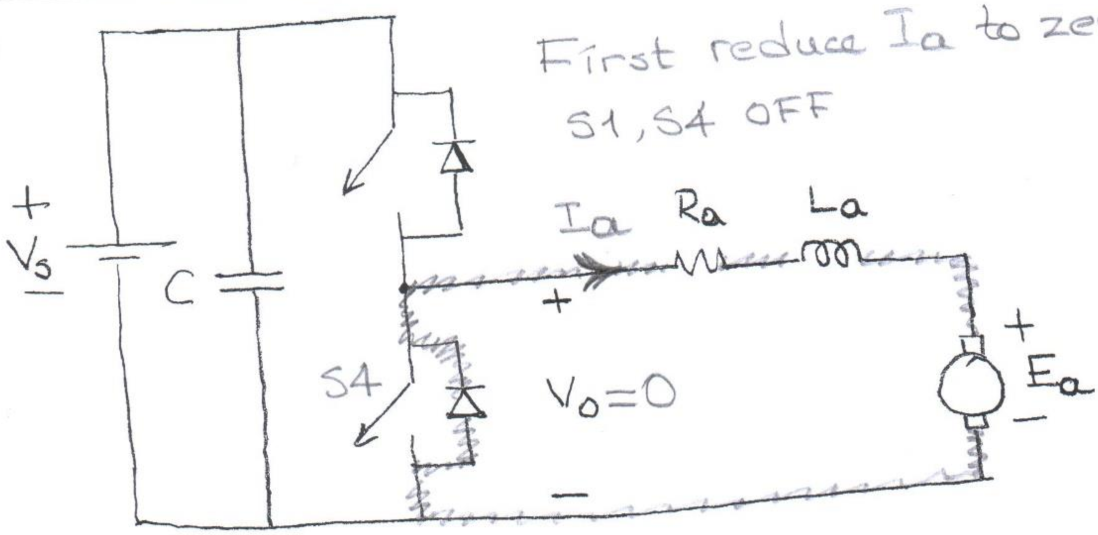
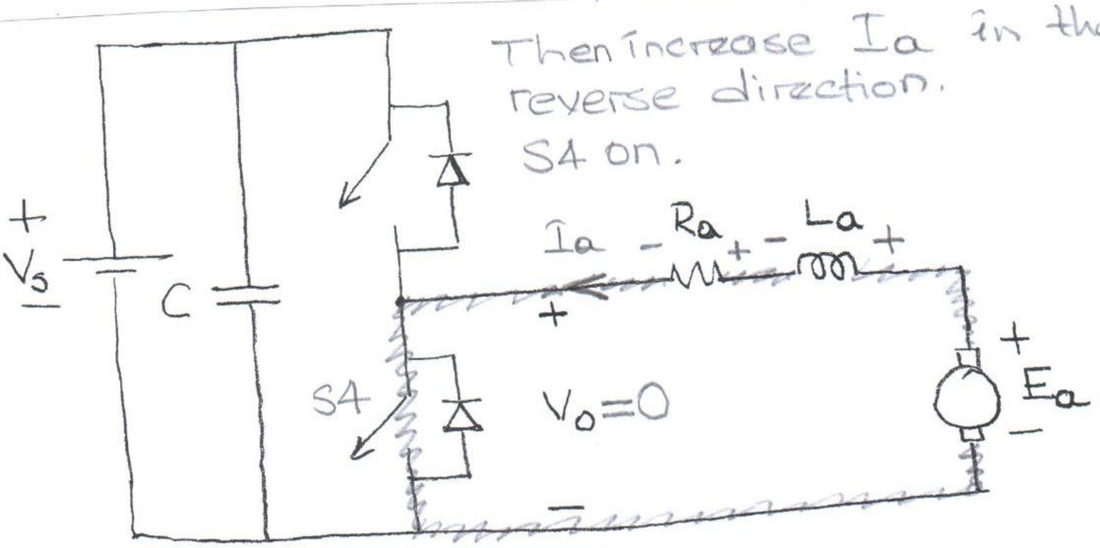


Then increase I_a in the reverse direction.
S4 on.



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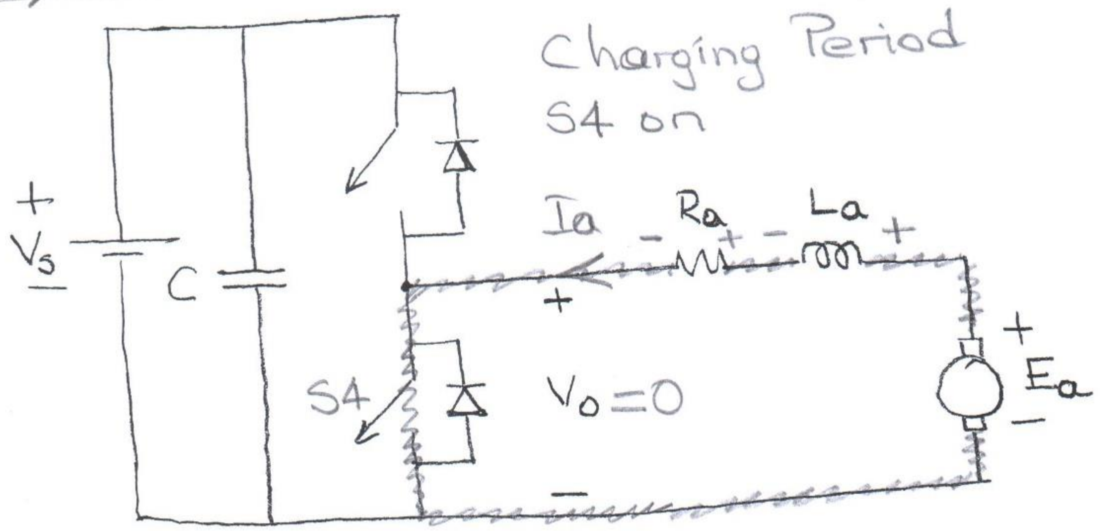
d)



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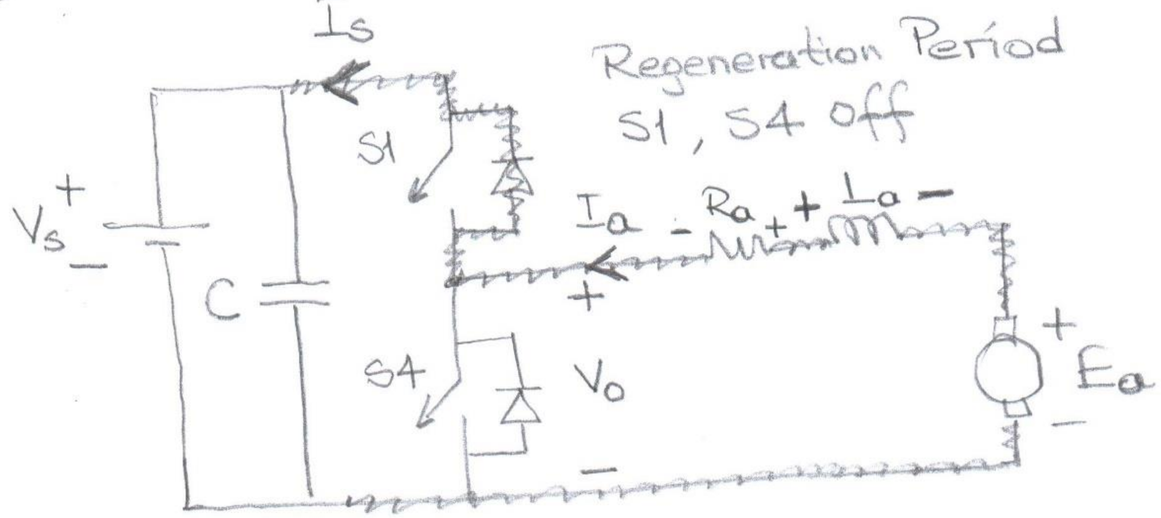

$$E_a + L_a \frac{di_a}{dt} > V_s$$

E_a and $L_a \frac{di_a}{dt}$ additive

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Q2) (40 pts) A 3-phase, 400 $V_{l\text{-}l}$, 50 Hz, 4 pole, wye connected wound rotor induction motor drives a load in quadrant – I, in the steady state. The rotor is short circuited.

In the case where the induction motor is to be started under load, static external rotor resistance control method should be applied in order to maintain maximum torque during starting.

This motor has the following parameters per-phase-wye:

$$r_1 = 0.01\ \Omega\ ,\ r_2' = 0.01\ \Omega\ ,\ x_1 + x_2' = 0.1\ \Omega$$

Stator/rotor turns ratio per phase is 1.5.

Use the approximate equivalent circuit.

a) Show that:

$$s_{\max T} = \frac{r_2' + r_{ext}'}{\sqrt{r_1^2 + (x_1 + x_2')^2}}$$

b) Draw the circuit diagram of the static rotor resistance control system. Assume that R is controlled by a shunt connected IGBT chopper and in the DC side there is a sufficiently large smoothing inductor.

c) Show that:

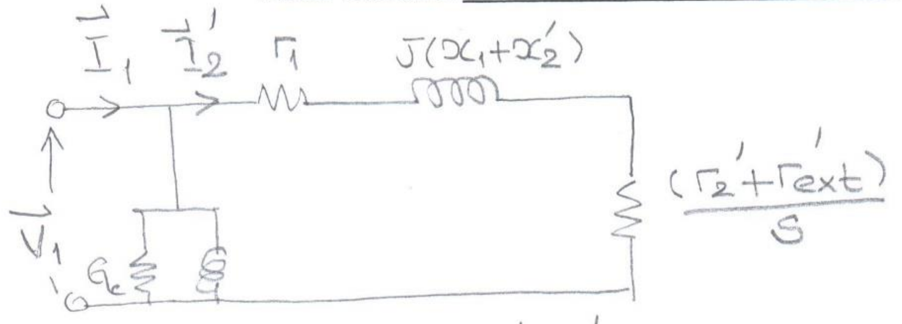
$$r_{ext} \cong \frac{(1 - D).R}{2}$$

Sketch all necessary voltage and current waveforms.

d) Calculate R to give maximum torque just at the starting instant by assuming that D can be varied ideally in between zero and unity. Voltage drop on power semiconductors in conduction state can be neglected.

e) What is the value of r_{ext}' at the steady state operating point?

a)



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$$P_g = T_e \cdot \underset{\substack{\uparrow \\ \text{cnst}}}{\omega_s} = 3(I_2'^2)\left(\frac{r_2'+r_{ext}'}{s}\right)$$

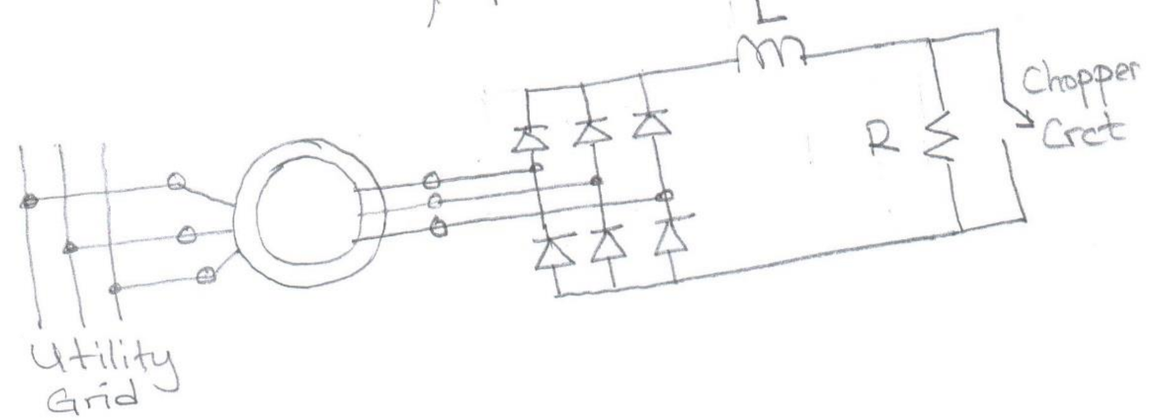
Therefore, P_g and T_e become maximum at the same slip, S_{maxT}.

From Maximum Power Transfer Theorem,

$$\frac{(r_2'+r_{ext}')}{S_{maxT}} = \sqrt{r_1^2 + (x_1+x_2')^2} \quad //$$

$$\Rightarrow S_{maxT} = \frac{(r_2'+r_{ext}')}{\sqrt{r_1^2+(x_1+x_2')^2}}$$

b)



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c) $r_{ext} \simeq \dfrac{(1-D)R}{2}$

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see the notes!

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d) $$S_{maxT} = 1.0 = \frac{0.01 + r'_{ext}}{\sqrt{(0.01)^2 + (0.1)^2}}$$

$$0.01 + r'_{ext} = 0.1005$$

$$r'_{ext} = 0.0905$$

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$$r_{ext} = r'_{ext} / (1.5)^2$$

$$r_{ext} = 0.04$$

$$r_{ext} \simeq \frac{(1-D)R}{2}$$

$$R \cong \frac{2 \cdot r_{ext}}{(1-0)}$$

$$R \simeq 0.0804\ \Omega \equiv 80.4\ m\Omega \quad //$$

5 e) $D = 1.0 \Rightarrow r'_{ext} = 0 \quad //$

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Q3) (35 pts) The block diagram representation of a 4-quadrant, variable frequency induction motor is as shown in Fig. 3.a.

IGBTs are used in the construction of the DC-link converter. The phase sequence of applied stator voltages is ABC to give a rotating magnetic field in clockwise direction. Speed reduction is achieved by regenerative braking in both directions of rotation.

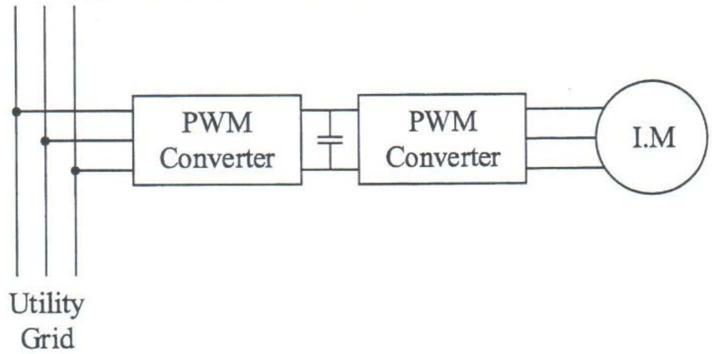


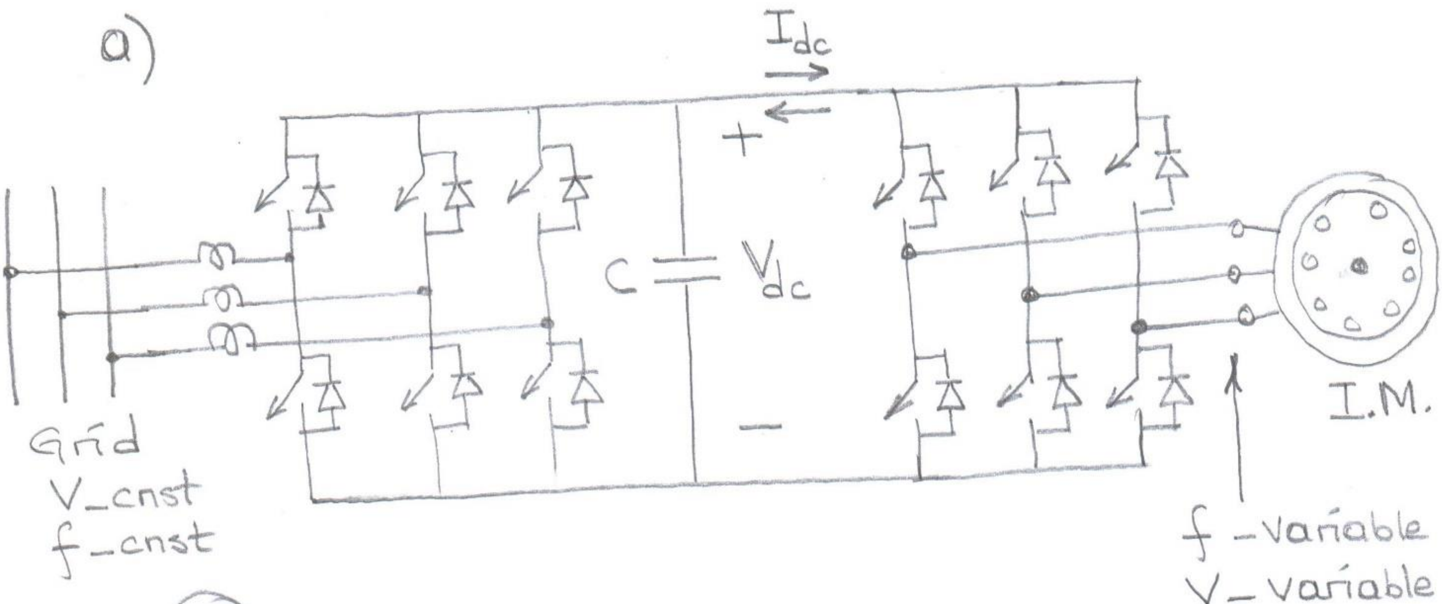
Figure 3.a.

a) Draw the circuit diagram of the above system. Each IGBT may be represented by an ideal switch with a mark showing the current direction and an anti-parallel diode.

b) In Fig. 3.b, mark on each quadrant the phase-sequence of applied voltages, operating modes of the drive, induction machine, supply side converter and motor side converter. Also compare the synchronous speed n_s with shaft speed n_r. Indicate the power flow direction.

c) Describe briefly two methods for voltage control in order to maintain proper magnetic conditions in the machine core, as the frequency is reduced below the rated value.

a)



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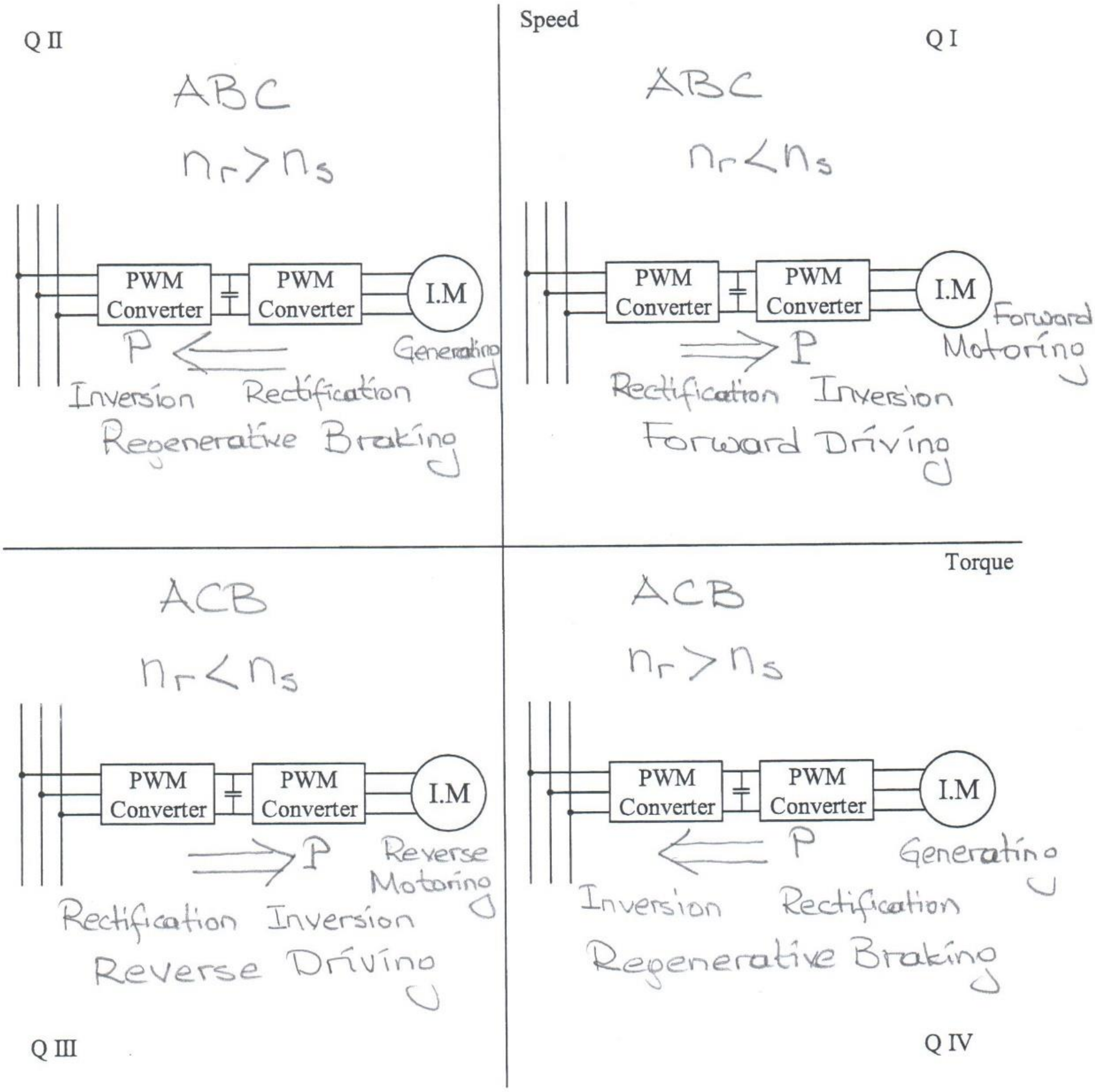

Figure 3.b.

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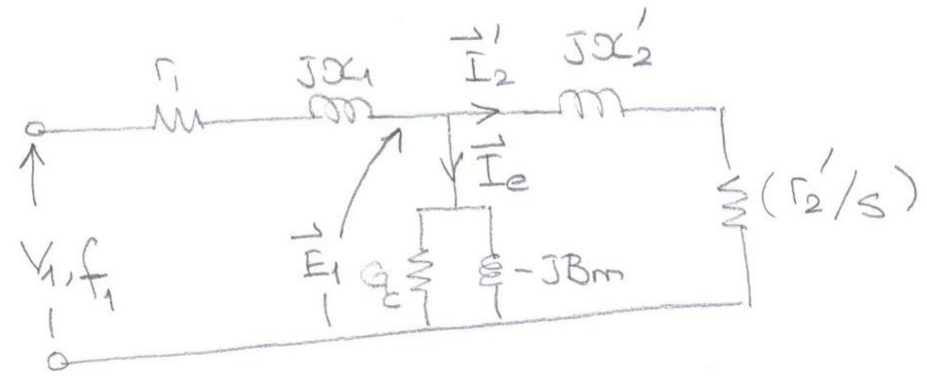
c)

(10)



Let $0 < f_1 \leq f_{1(rated)}$

1. (E_1/f_1) – cnst.
CONSTANT FLUX OPERATION

2. (V_1/f_1) – cnst.
CONSTANT VOLTS-PER-HERTZ OPERATION

Let $f_{1(rated)} < f_1$

V_1 is kept constant at $V_{1(rated)}$

CONSTANT POWER OPERATION