USN :

CMR Institute of Technology, Bangalore
DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING
II - INTERNAL ASSESSMENT

Semester: 8-CBCS 2017
Subject: INDUSTRIAL DRIVES & APPLICATIONS (17EE82)
Faculty: Ms Geethanjali P

Date: 20 Jun 2021
Time: 02:00 PM - 03:30 PM
Max Marks: 50

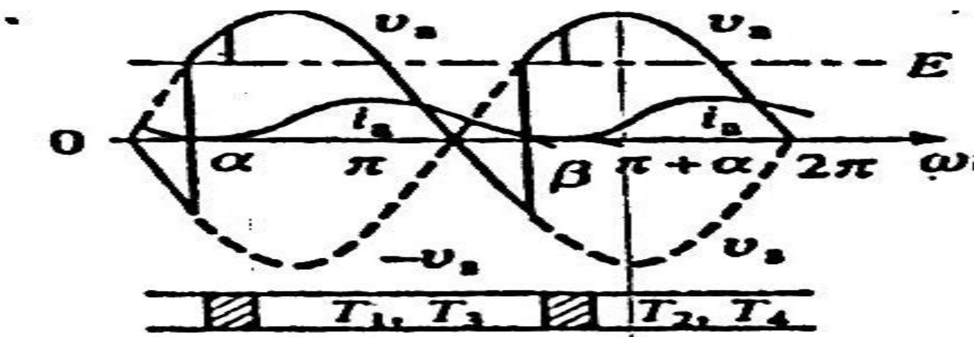
Answer any 5 question(s)

Q.No			Marks	CO	PO	BT/CL
1		Explain the single phase fully controlled rectifier control of separately excited DC motor. Also obtain equations for average output voltage Va and speed wm. Assume discontinuous conduction mode.	10	CO3	PO1	L1
2		A 220 V, 1500 rpm, 50 A separately excited motor with armature resistance of 0.5Ω, is fed from a 3-phase fully controlled rectifier. Available ac source has a line voltage of 440 V,50 Hz. A star-delta connected transformer is used to feed the armature so that motor terminal voltage equals rated voltage when converter firing angle is zero(i) Determine the value of firing angle when motor is running at 1000 rpm and rated torque.(ii) When the motor is running at -700 rpm and twice the rated torque.	10	CO3	PO2	L3
3		Explain the behaviour of 3 phase induction motor when fed from a non-sinusoidal voltage supply.	10	CO4	PO3	L1
4	a	Explain the braking of an induction motor by plugging.	4	CO4	PO1	L1
	b	Draw necessary circuit diagram and explain the operation of any two starting methods used for induction motors.	6	CO4	PO2	L2
5		A 2200 V, 50 Hz, 3- phase, 6 pole, Y – connected, Squirrel cage induction motor has following parameters: Rs =0.075Ω, Rr' = 0.12 Ω, Xs = Xr' = 0.5 Ω.The combined inertia of motor and load is 200 kg-m2.(i) Calculate time taken and energy dissipated in the motor during starting.(ii) Calculate time taken and energy dissipated in the motor when it is stopped by plugging. (iii) What resistance should be inserted in the rotor to stop motor by plugging in the minimum time? Also calculate stopping time and energy dissipated in the motor during braking.	10	CO4	PO3	L3
6	a	Explain the multiquadrant operation of separately excited DC motor using dual converters	5	CO3	PO1	L1
	b	Explain the chopper control of separately excited dc motor for regenerative braking.	5	CO3	PO2	L1

IAT II Qp & Soln

Q.1

SINGLE-PHASE FULLY-CONTROLLED RECTIFIER CONTROL OF dc SEPARATELY EXCITED MOTOR



(b) Discontinuous conduction waveforms.

$$V_a = \frac{1}{\pi}\left[\int_{\alpha}^{\beta} v_a + \int_{\beta}^{\pi+\alpha} E\right] d\omega t$$

$$= \frac{1}{\pi}\left[\int_{\alpha}^{\beta} V_m \sin\omega t \, d\omega t + \int_{\beta}^{\pi+\alpha} E \, d\omega t\right]$$

$$= \frac{1}{\pi}\left[V_m \left(-\cos\omega t\right)_{\alpha}^{\beta} + E \left(\omega t\right)_{\beta}^{\pi+\alpha}\right]$$

$$= \frac{1}{\pi}\left[V_m\left(-\cos\beta + \cos\alpha\right) + E\left(\pi+\alpha-\beta\right)\right]$$

$i_a R_a$

$$V_a = \frac{V_m\left(\cos\alpha - \cos\beta\right) + \left(\pi+\alpha-\beta\right)E}{\pi}$$

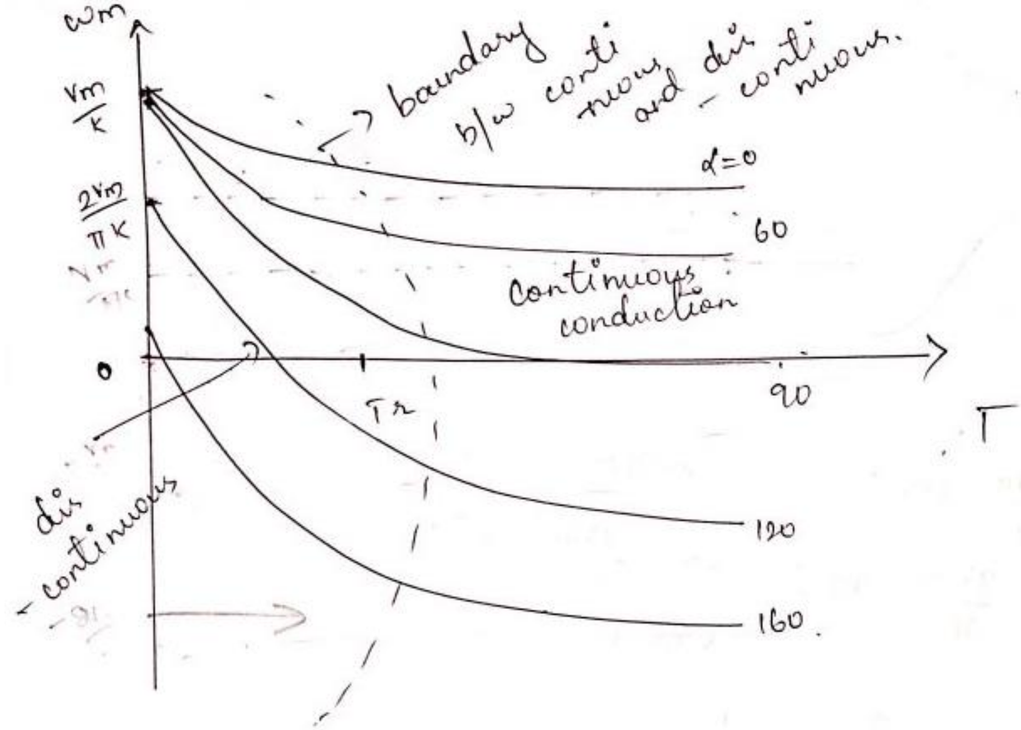
$T = K i_a$

$$\omega_m = \frac{V - i_a R_a}{K}$$

$$= \frac{V_m\left(\cos\alpha - \cos\beta\right) + \left(\pi+\alpha-\beta\right)E}{\pi K} - \frac{i_a R_a}{K}$$

$$\omega_m = \frac{V_m\left(\cos\alpha - \cos\beta\right) + \left(\pi+\alpha-\beta\right)K\omega_m}{\pi K} - \frac{R_a T}{K^2}$$

$$\omega_m - \frac{\cancel{K}\omega_m\left(\pi+\alpha-\beta\right)}{\pi \cancel{K}} = \frac{V_m\left(\cos\alpha - \cos\beta\right)}{\pi K} - \frac{R_a T}{K^2}$$



$$\omega_m \left[1 - \frac{(\pi + \alpha - \beta)}{\pi}\right] = \frac{V_m(\cos\alpha - \cos\beta)}{\pi K} - \frac{R_a T}{K^2}.$$

$$\rightarrow \frac{\cancel{\pi} - \cancel{\pi} - \alpha + \beta}{\pi}$$

$$\omega_m \frac{-(\alpha - \beta)}{\pi} = \frac{V_m(\cos\alpha - \cos\beta)}{\pi K} - \frac{R_a T}{K^2}$$

$$\times\frac{\pi}{(\alpha-\beta)}$$

$$\omega_m = \frac{V_m(\cos\alpha - \cos\beta)}{K-(\alpha - \beta)} - \frac{R_a T}{K^2}$$

$$\omega_m \frac{(\beta - \alpha)}{\pi} = \frac{V_m(\cos\alpha \cdot \cos\beta)}{\pi K} - \frac{R_a T}{K^2}$$

$$\boxed{\omega_m = \frac{V_m(\cos\alpha - \cos\beta)}{K(\beta - \alpha)} - \frac{R_a T \pi}{K^2(\beta - \alpha)}}$$

Q.2

V_{ml} - max value of line voltage

$= \sqrt{2} \times V_L$

V_L = Line voltage

$V_{ph} = \frac{V_L}{\sqrt{3}}$

$V_0 = \frac{3 V_{ml}}{\pi} \cos\alpha$; $V_L = 440V$

$\alpha = 0$; → motor terminal voltage = rated voltage

$V_{ml} = \frac{\pi V_a}{3\cos\alpha} = \frac{\pi \times 220}{3} = 230.38\ V$

$V_{rms}(Ph = line) = \frac{230.38}{\sqrt{2}} = 162.9\ V$

$K = \frac{V_1(\lambda)}{V_2 \Delta} = \frac{440/\sqrt{3}}{162.9} = 1.559$

i) $N_2 = 1000$ rpm   T ⇒ T_r I_a rated

$E_1 = N_1$; $E_2 = N_2$

$E_1 = V_a - i_a R_a = 220 - (50 \times 0.5) = 195$

$\frac{E_1}{E_2} = \frac{N_1}{N_2}$ $E_2 = E_1 \frac{N_2}{N_1} = 195 \times \frac{1000}{1500} = 130$

$V_a = E + i_a R_a = 130 + (50 \times 0.5) = 155\ V$

$V_a = \frac{3 V_{ml}}{\pi} \cos\alpha$

$\cos\alpha = \frac{V_a \pi}{3 V_{ml}} = \frac{155 \times \pi}{3 \times 230.38} = 0.7041$

$\boxed{\alpha = 45.24}$

(ii) $N_2 = -700$ rpm

$$E_2 = \frac{N_2}{N_1} \times E_1 = \frac{-700}{1500} \times 195 = -10$$

$$= -91V$$

$$V_a = E + i_a R_a = -91 + ((2 \times 50 \times 0.5)) = -41$$

$$\cos\alpha = \frac{V_a \pi}{3V_{ml}} = \frac{-41 \times \pi}{3 \times 230.38} = -0.1862$$

$$\boxed{\alpha = 100.73}$$

Q.3

Analysis of IM fed from non-sinusoidal voltage supply

* The motor terminal voltage becomes non-sinusoidal when fed from inverter or cyclo-converter.
* voltage has half-wave symmetry:

Non-sinusoidal waveform can be resolved into fundamental and harmonic components (Fourier analysis). For half-wave symmetry only odd harmonics will be present.

+ve sequence harmonics - same phase sequence as that of fundamental.

-ve sequence harmonics - opposite phase sequence to fundamental.

zero sequence harmonics - all 3 phase voltages are in phase.

Let fundamental phase voltage be,

$$V_{AN} = V_1 \sin \omega t$$
$$V_{BN} = V_1 \sin(\omega t - 2\pi/3)$$
$$V_{CN} = V_1 \sin(\omega t - 4\pi/3)$$

with phase sequence ABC.

5th Harmonic Phase Voltage :-

$$V_{AN} = V_5 \sin 5\omega t$$
$$V_{BN} = V_5 \sin 5(\omega t - 2\pi/3)$$
$$= V_5 \sin 5\omega t - 10\pi/3 = V_5 \sin 5\omega t - 4\pi/3$$
$$V_{CN} = V_5 \sin 5\omega t - \cancel{4\pi/3}\ \frac{20\pi}{3} = V_5 \sin 5\omega t - 2\pi/3$$

7th harmonic has phase sequence ABC

5th harmonic has phase sequence ACB.

$\therefore$ 7th, 13th, 19th — +ve seq

5th, 19th, 17th — -ve seq

3rd and its odd multiples zero seq harmonics.

m = 6K+1 — +ve seq

m = 6K-1 — -ve "

m = 3K — zero "

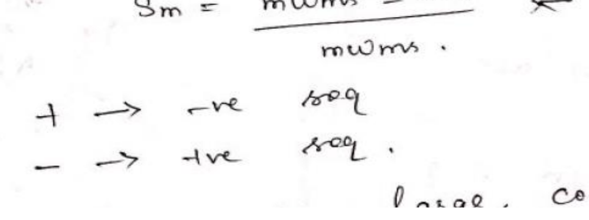
which

> +ve seq produces RMF ~~whose~~ which moves in dir as fun at a speed m times that of the fun field.

> -ve seq opposite dir

> zero seq donot produce rotating field.

Harmonic equivalent ckt



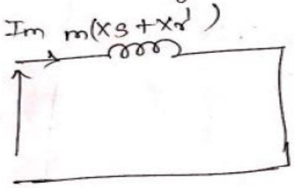
$$S_m = \frac{m\omega_{ms} \pm \omega_m}{m\omega_{ms}}$$ ← slip for m^{th} harmonic

+ → -ve seq

- → +ve seq.

large compared to resistance

Reactance are large, compared to resistance



$$I_m = \frac{V_m}{m X}$$

where $X = X_s + X_r'$

Supply will re odd harmonics.

When stator is λ connected, 3^{rd} and its multiple harmonics will not flow.

$$I_{rms}^2 = I_s^2 + \sum_{m=5,7,11} I_m^2$$

Δ - connected

$$I_{rms}^2 = I_s^2 + \sum_{m=3,5} I_m^2 .$$

∴ For a given motor torque and power, the rms current flow thro motor has higher value.

∴ ↑ in cu loss and ↓ in η.

∴ motor derating.

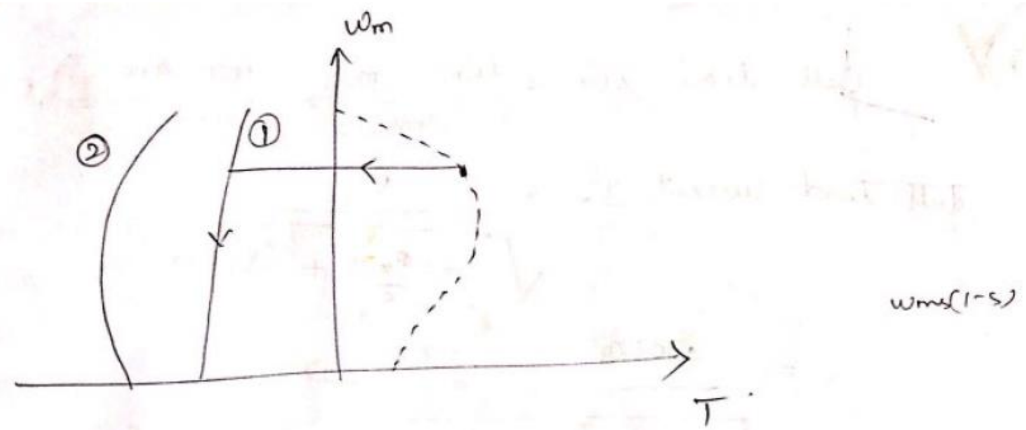
another effect is production of pulsating torque bcoz of interaction b/w the RMF produced by one harmonic and rotor current of other harmonic.

∴ the life of the motor gets reduced.

Q.4 a

Plugging or Reverse Voltage Braking.

* When phase sequence of supply of the motor running at a speed is reversed, by interchanging connections of any 2 phases of stator w.r.t supply terminals, operation shifts from motoring to plugging.



S_n = slip (plugging)

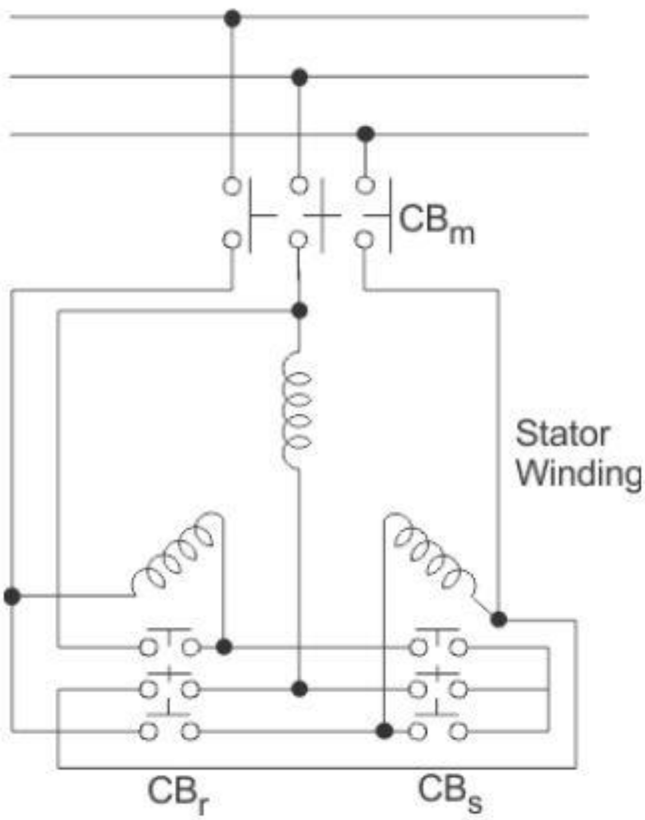
$$= \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}} = \frac{-\omega_{ms} - \omega_{ms} + s\omega_{ms}}{-\omega_{ms}}$$

$$\boxed{S_n = 2 - s}$$

② → with external resistance in rotor (to limit current)

Q. 4 b

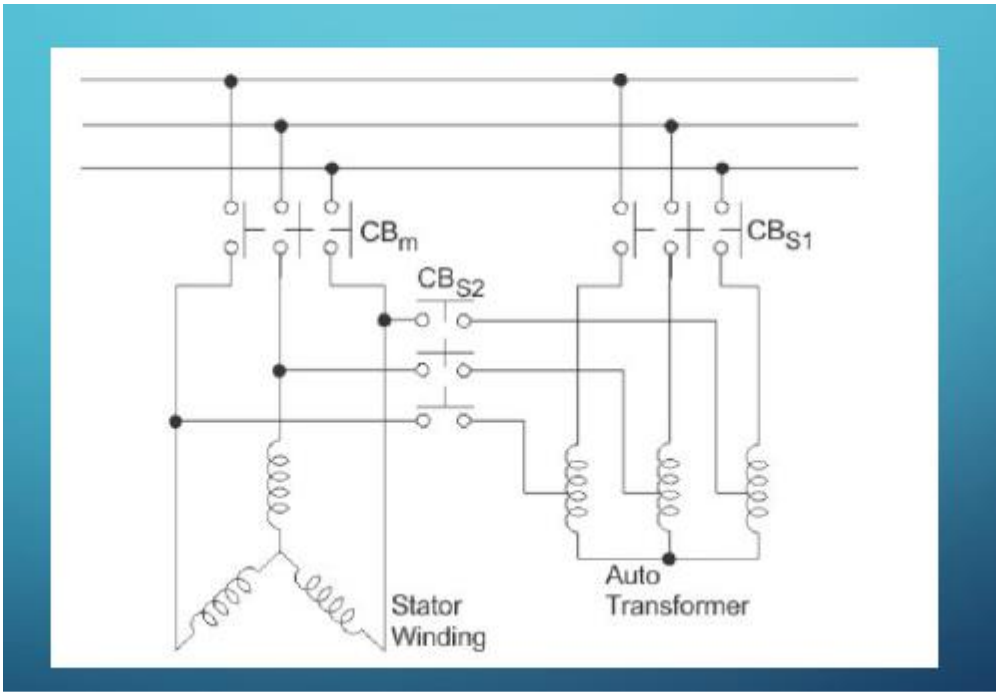
Star –delta starter



- Induction motor designed to run on delta connection
- but during starting the supply is given from star connection because then the starter voltage and current reduces by 1/√3 times than the delta connection. When the motor reaches a steady state speed the connection changes from star to delta connection.

Auto transformer starter

- Another type of starting method of induction motors is the auto transformer starting. Since we know that the torque is proportional to square of the voltage. By auto transformers the starting voltage and current are reduced to overcome the problem of overheating due to very high current flow. During starting the ratio of the transformer is set in a way that the starting current does not exceed the safe limit. Once the induction motor starts running and reaches a steady state value, the auto transformer is disconnected from the supply.



Q.5

$$t_s = \tau_m \left[\frac{1}{4 s_m} + 1.5 s_m \right]$$

$$\tau_m = \frac{J \omega_{ms}}{T_{max}}$$

$$s_m = \frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}} = \frac{0.12}{\sqrt{0.075^2 + (0.5+0.5)^2}}$$

$$\boxed{s_m = 0.1196}$$

$$I_r'^2 = \frac{V^2}{\left(R_s + \frac{R_r'}{s}\right) + (X_s + X_r')^2} = \frac{(2200/\sqrt{3})^2}{\left(0.075 + \frac{0.12}{0.1196}\right)^2 + (0.5+0.5)^2}$$

$= 745937.362$ A

$I_r' = 745.9$ kA.

$$T_{max} = \frac{3 I_r'^2 R_r'}{\omega_{ms} \cdot s}$$

$$\omega_{ms} = \frac{2\pi N_s}{60} = 104.7 \text{ rad/s}$$

$$N_s = \frac{120 f}{P} = \frac{120 \times 50}{6}$$

$N_s = 1000$ rpm

$$T_{max} = \frac{3 I_2'^2 R_2'}{\omega_{ms} \cdot S} = \frac{3 (745.9 \times 10^3) \times 0.12}{104.7 \times 0.1196}$$

$$= 21443.97 \text{ Nm}$$

$$t_s = \tau_m \left[\frac{1}{4(0.1196)} + (1.5 \times 0.1196) \right]$$

$$\tau_m = \frac{J \omega_{ms}}{T_{max}} = \frac{200 \times 104.72}{21443.97} = 0.9766 \text{ sec.}$$

$$t_s = 0.9766 \times \left[\frac{1}{4 \times 0.1196} \right) + (1.5 \times 0.1196) \Big]$$

$$t_s = 2.21659$$

$$E_s = \frac{1}{2} J \omega^2 \left[1 + \frac{R_s}{R_2'} \right]$$

$$= \frac{1}{2} \times 200 \times (104.72)^2 \left[1 + \frac{0.075}{0.12} \right]$$

$$= 1782.02 \text{ kJ}$$

ii) $t_b = \tau_m \left[\frac{0.75}{s_m} + 0.3465 s_m \right]$

$= 0.9766 \left[\frac{0.75}{0.1196} + 0.3465 (0.1196) \right]$

$= 6.16 \text{ sec}$

$E_b = \frac{3}{2} J \omega_{ms}^2 \left[1 + \frac{R_s}{R_r} \right]$

$= \frac{3}{2} \times 200 \times (104.72)^2 \left[1 + \frac{0.075}{0.12} \right]$

$= 5346 \text{ kJ}$

iii) $t_{b(min)} = 1.027 (0.9766)$

$= 1 \text{ sec}$

$(R_r' + R_e) = 1.47 (X_s + X_r')$

$0.12 + R_e = 1.47 (0.5 + 0.5)$

$R_e' = 1.35 \Omega = R_e$

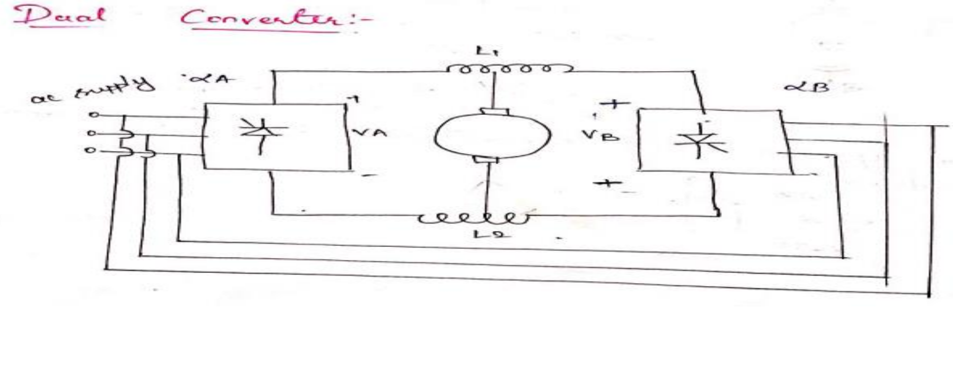
$E_b = \frac{3}{2} J \omega_{ms}^2 \left[1 + \frac{R_s}{R_r' + R_e} \right]$

$= \frac{3}{2} \times 200 \times (104.72)^2 \left[1 + \frac{0.075}{0.12 + 1.35} \right]$

$= 3{,}456 \text{ kJ}$

Q.6a

Dual Converter:-



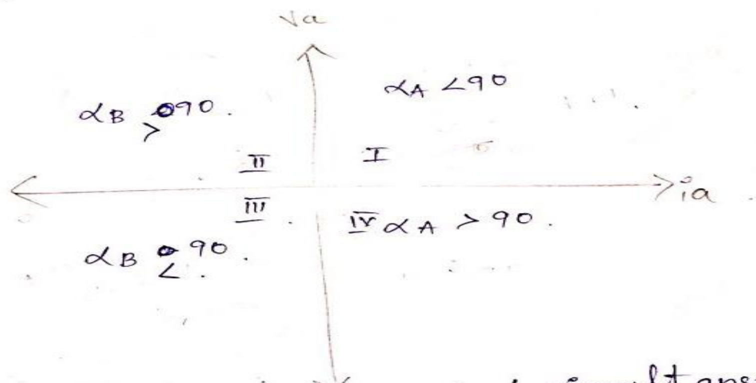
→ 2 fully controlled converters connected in anti-parallel across the armature.

→ Rectifier A – +ve current and +VA and –VA
∴ I and IV quadrant

→ Rectifier B – –ve current and +VB and –VB.
∴ III and II quadrant.

E =

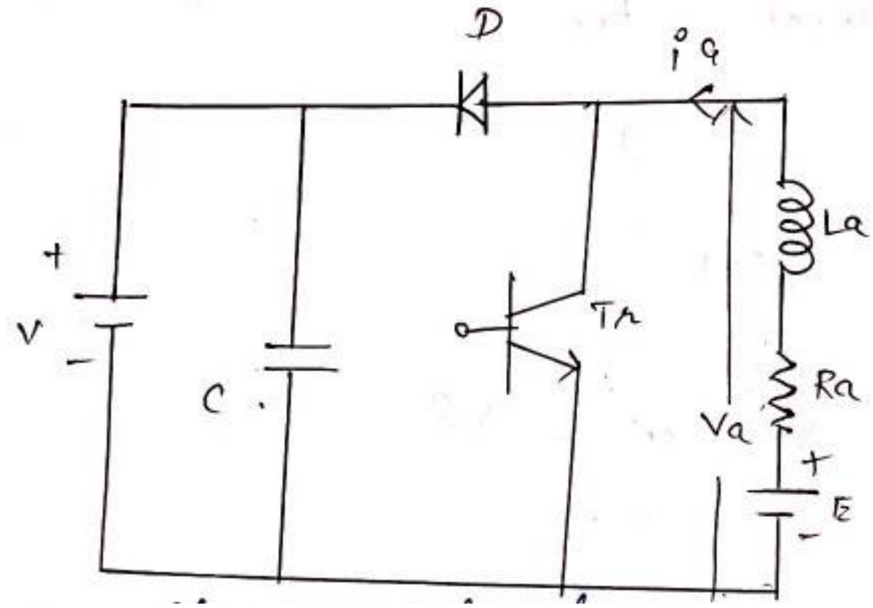
Refer Bimbra.



i) circulating current mode / simultaneous mode.
$\alpha_A + \alpha_B = 180$.

Q.6b

Regenerative Braking.



Energy Storage interval

→ When T_r is on ($0 \le t \le t_{on}$), the o/p voltage is zero. $\boxed{v_0 = v_a = 0}$

→ Though $v_a = 0$, voltage E drives current thro L_a and T_r.

→ L_a stores energy during t_{on}.

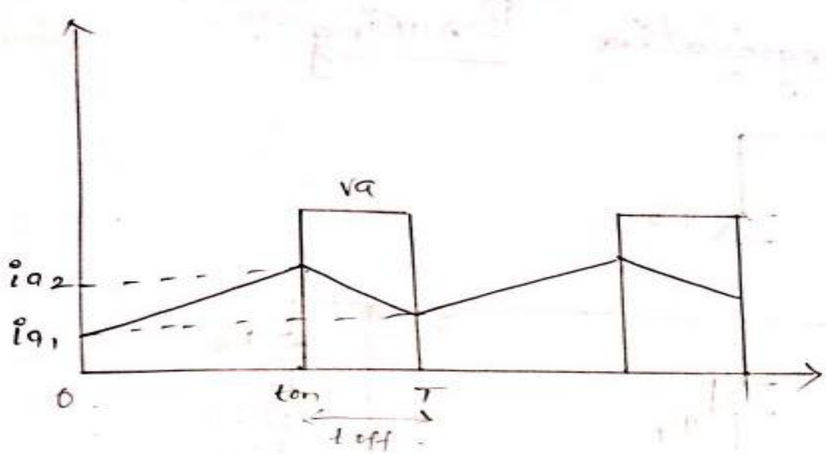
→ i_a ↑s from i_{a1} to i_{a2}.

Duty interval :- ($t_{on} \le t \le T$)

→ When T_r is off, $v_0 = E + L_a \frac{di_a}{dt} = V$

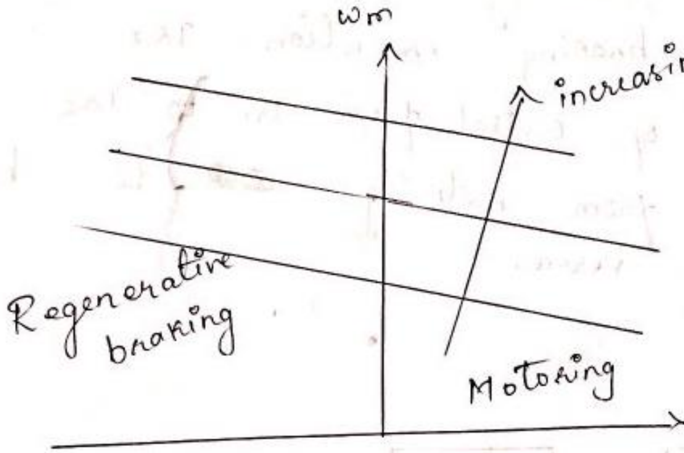
bcoz of this, D is forward biased and begins conduction, thus allowing power flow to the source.

→ i_a flows thro D, and source V and reduces from i_{a2} to i_{a1}.



$$\delta = \frac{\text{duty interval}}{T} = \frac{t_{off}}{T} = \frac{T - t_{on}}{T}$$

$$\cancel{V_a = \frac{1}{T}\int_{t_{on}}^{T}} \qquad V_a = \frac{1}{T}\int_{t_{on}}^{T} v \, dt = \frac{V}{T}(T - t_{on})$$



$$\cancel{V_a = V\left(1 - \frac{t_{on}}{T}\right) = V(1-\delta)} \qquad V_a = V\delta$$

where $\delta = 1 - \frac{t_{on}}{T}$.

$E_g = K\omega_m$

$T = -K I_a$ (∵ I_a is reversed)

$$\omega_m = \frac{V_a + i_a R_a}{K} = \frac{\overset{V}{\cancel{V(1-\delta)}}}{K} + \frac{R_a T}{K^2}$$

$$\omega_m = \frac{V\delta}{K} + \frac{R_a T}{K^2}.$$