CMR INSTITUTE OF TECHNOLOGY

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Internal Assessment Test - III

| Sub: | Industrial Drives and Applications | | | | | | Code: | 17EE82 |
|---|---|---|---|---|---|---|---|---|
| Date: | 18/06/2022 | Duration: | 90mins | Max Marks: | 50 | Sem: $8^{th}$ | Branch: | EEE |

Answer any **FIVE FULL** Questions.

| | | Marks | OBE CO | OBE RBT |
|---|---|---|---|---|
| 1. | A 400 V, star connected, 3- phase ,6-pole, 50 Hz induction motor has following parameters referred to the stator; Rs=Rr'=1 Ω, Xs =Xr' = 2 Ω<br>For regenerative braking operation of this motor determine:<br>(i)maximum overhauling torque it can hold and range of speed for safe operation<br>(ii)speed at which it will hold an overhauling load with a torque of 100 N-m | 10 | CO4 | L3 |
| 2. | Discuss the operation of self-controlled synchronous motor drive employing load commutated thyristor inverter. | 10 | CO5 | L1 |
| 3. | Explain the behavior of 3 phase induction motor when fed from a non-sinusoidal voltagesupply. | 10 | CO4 | L1 |
| 4. | Describe with relevant diagrams the voltage source inverter (VSI) control of three phase induction motor. | 10 | CO4 | L2 |
| 5. | Explain brushless dc motor drive for servo application. | 10 | CO5 | L1 |
| 6. | 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<br>The combined inertia of motor and load is 200 kg-$m^2$.(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 | CO5 | L3 |

**CCI** **CI** **HOD**

IDA IAT III solution

Q.1

(1) A 400V, $\lambda$ - connected $3\phi$, 6-pole, 50Hz IM has following parameters referred to stator

$R_s = R_r' = 1\Omega$, $X_s = X_r' = 2\Omega$.

For regenerative braking, determine.

(i) max torque (overhauling) it can hold and range of speed for safe operation.

(ii) speed at which it can hold an overhauling load with a torque of 100N-m.

$$N_s = \frac{120 \times 50}{6} = 1000.$$

$$\omega_{ms} = \frac{2\pi \times 1000}{60}$$

$$= 104.71 \text{ rad/sec}.$$

$$N_s = \frac{120f}{P}$$

$$\frac{2\pi N_s}{60} = \omega_{ms}$$

$$\frac{120 f \times 2\pi \times N_s}{60.}$$

$$N_s = \frac{60 \times \omega_{ms}}{2\pi}$$

$$= \frac{30 \omega_{ms}}{\pi}$$

$$S_m = -\frac{R_r'}{\sqrt{R_s^2 + (X_s + X_r')^2}} = -\frac{1}{\sqrt{1 + (2+2)^2}}$$

$$= \frac{-1}{4.123} = -0.2425$$

$$\boxed{S_m = -0.2425}$$

$$I_r'^2 = \frac{V^2}{\left(R_s + \frac{R_r'}{s}\right)^2 + (X_s + X_r')^2} = \frac{(400/\sqrt{3})^2}{\left[1 + \frac{1}{(-0.2425)}\right]^2 + (2+2)^2}$$

$$= \frac{53333.33}{9.7575 + 16} = 2070.594 \text{ A}.$$

$$\boxed{I_r' = 45.5 \text{ A}}$$

$$T_{max} = \frac{\frac{3 I_r'^2 R_r'}{s}}{\omega_{ms}} = \frac{\frac{3 \times (45.5)^2 \times 1}{(-0.2425)}}{104.71} = -244.59.$$

$$\boxed{T_{max} = -244.59 \text{ Nm}}$$

$$N_m = (1-s) N_s = [1 - (-0.2425)] 1000.$$

$$= 1.2425 (1000)$$

$$\boxed{N = 1242.5 \text{ rpm}}$$

i) $T_{max} = 100 \text{ N.m}$.

$$T = \frac{3R_r'}{\omega_{ms}\, s} \cdot \frac{V^2}{\left(R_s + \frac{R_r'}{s}\right)^2 + (X_s + X_r')^2}$$

$$100 = \frac{3\,(1)}{104.71\,(s)} \left[\frac{(400/\sqrt{3})^2}{\left(1 + \frac{1}{s}\right)^2 + 16}\right]$$

$$00 = \frac{0.02}{s} \left[\frac{230.9^2}{1 + \frac{1}{s^2} + \frac{2}{s} + 16}\right]$$

$$\frac{1066.29}{S + \frac{1}{S} + 2 + 16/S} = 100.$$

$$1066.29 = 100 \left[ \frac{S^2 + 1 + 2S + 16}{S} \right]$$

$$\frac{100\,(S^2 + 17 + 2S)}{S} = 1066.29.$$

$$100S^2 + 1700 + 200S = S\,1066.29$$

$$100S^2 + 1700 - S\,866.290 = 0$$

$$17S^2 + 17.3S + 1 = 0.$$

$S = -0.957$ or $S = -0.063$.

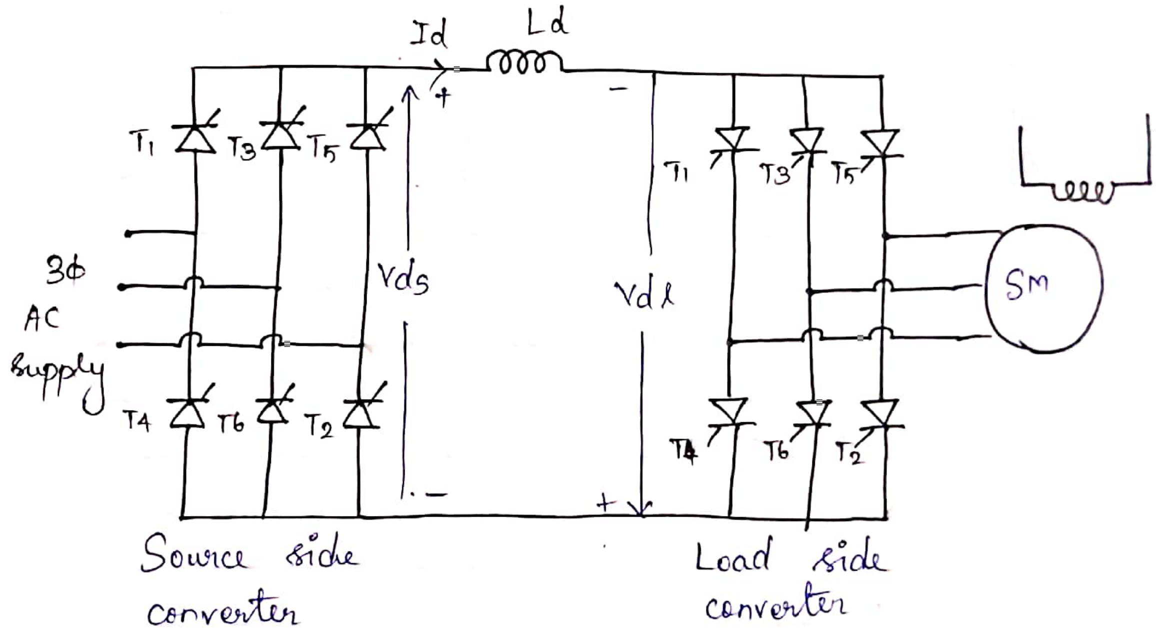
choose $\boxed{S = -0.063}$

$$N_m = (1 - S)\,N_s = 1 - (-0.063)(1000)$$

$$\boxed{N_m = 1063.}$$

Self controlled Synchronous motor fed from a load commutated thyristor inverter.

This drive employs two converters
① Source side converter
② Load side converter




Source side converter :-

=> acts as a line commutated controlled rectifier for $0 \le \alpha_s \le 90°$

o/p voltage Vds and o/p current Id are +ve.

=> acts as a line commutated inverter for $90° \le \alpha_s \le 180°$.

o/p voltage Vds is -ve and Id is +ve.

Load side converter :-

=> When SM operates at leading PF, the thyristors of the load side converter can be commutated by the motor induced voltages. This is called load commutation.

=> This converter operates as an inverter for $90 < \alpha_l < 180$ and delivers $-ve$ $V_{dl}$ and $+ve$ $I_d$.
It operates as a rectifier for $0 \le \alpha_l < 90^\circ$ and delivers $+ve$ $V_{dl}$ and $I_d$.

=> The SM can be operated at leading PF by adjusting the field excitation. when source side converter is operated as inverter and load side converter as rectifier then the power flows from the motor to ac source which gives regenerative braking operation

=> For motoring operation, source side con acts as rect and load side converter as inverter. The torque produced by the motor depends on the difference in voltages i.e $V_{ds} - V_{dl}$.

=> The speed of the motor is changed by changing the voltage $V_{ds}$ i.e by controlling $\alpha_l$.

=> When both the converters are working as inverters, the firing angle should be less than 180 to avoid the short of supply. So care should be taken for commutation overlap and turn-off of thyristors.

Let $\beta l$ - commutation lead angle for load side converter.

Then $\beta l = 180° - \alpha l$.

=> If commutation overlap is neglected, then the i/p ac current will lag the i/p dc voltage by an angle $\alpha l$. As the motor current is opposite to converter i/p current, the motor current will lead the terminal voltage by $\beta l$. Thus the motor operates at leading PF

=> If $\mu$ is the commutation overlap, then the duration for which reverse bias applied is given by

$$\gamma = \beta l - \mu.$$

for successful commutation, $\gamma > \omega t_q$

where $t_q$ - turn-off time

Commutation overlap is proportional to the dc link current $I_d$. Keeping $\gamma = \gamma_{min}$, $\beta l$ will be reduced and PF will improve.

This control is called constant angle margin control

=> At lower speeds, forced commutation is used, since the motor voltage is less and not enough for thyristor commutation

# 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 :-

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

$\frac{10\pi}{3}$

$x - 10\pi/3$

$= 4\pi/3$

$x = 4\pi/3 +$

$14\pi/$

## $7^{th}$ Harmonic phase voltage

$V_{AN} = V_7 \sin 7\omega t$

$V_{BN} = V_7 \sin(7\omega t - 2\pi/3)$

$V_{CN} = V_7 \sin(7\omega t - 4\pi/3)$.

$\frac{10\pi}{3} = 3\pi + \pi/3$

$\frac{10\pi}{3} = \frac{4\pi}{3}$

$\frac{20\pi}{3} = 2\pi/3$.

$7^{th}$ harmonic has phase sequence ABC

$5^{th}$ harmonic has phase sequence ACB.

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

$5^{th}$, $11^{th}$, $17^{th}$ — −ve seq

$3^{rd}$ and its odd multiples zero seq harmonics.

$m = 6K+1$ — +ve seq

$m = 6K-1$ — −ve "

$m = 3K$ — zero "

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

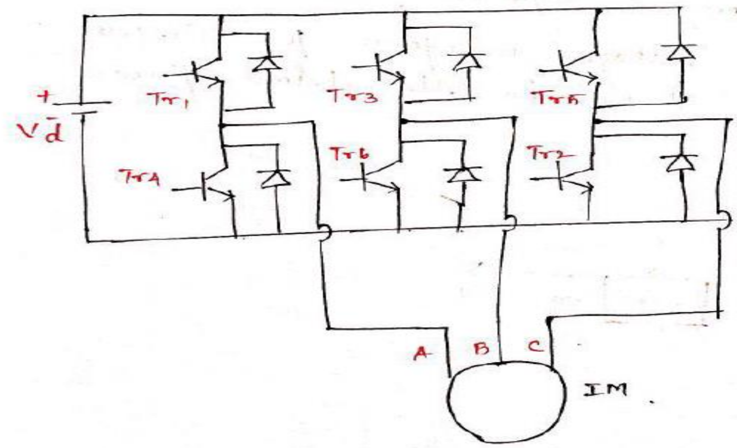
→ −ve seq opposite dir

→ zero seq donot produce rotating field.

Q.4

## VSI IM Drives:-

⇒ VSI allows a variable fre from dc supply. Transistor inverter fed IM drive is shown in the below figure.



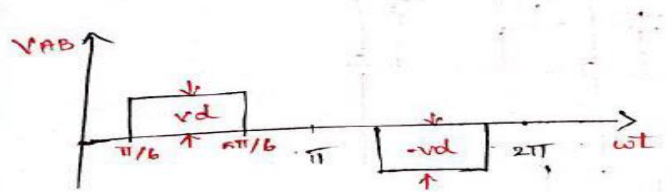

⇒ instead of transistors, any other self commutated devices [MOSFET (low voltage and low power), IGBT, GTO, IGCT - high power levels can be used].

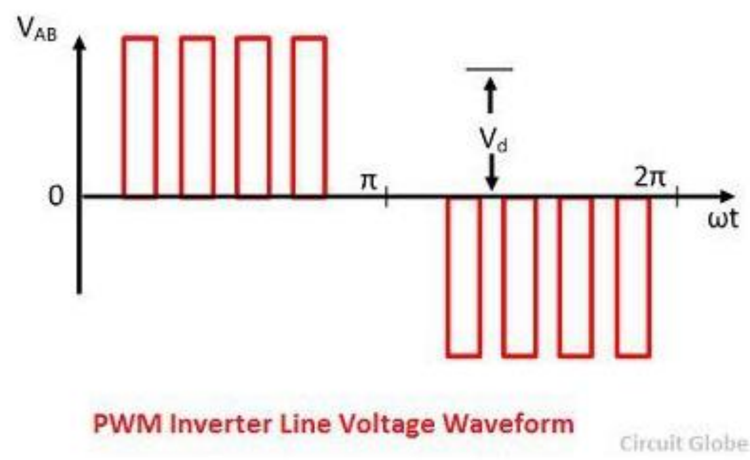
⇒ VSI can be operated as stepped wave inverter or a PWM inverter.

* For a given time period T (one cycle), each device is ON for T/2 duration, in which all the devices are switched in the sequence of their numbers with a time difference of T/6.

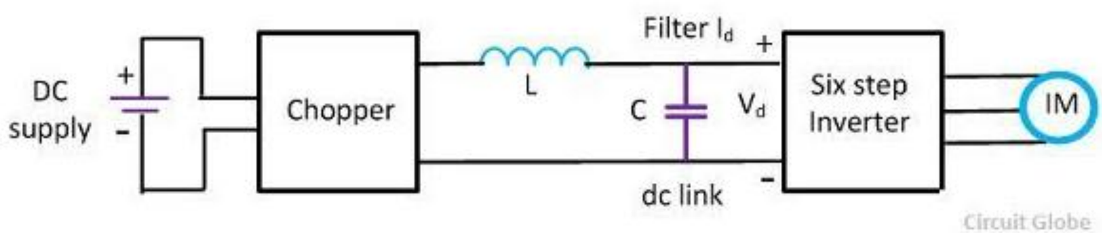
* frequency is varied by varying T and o/p voltage is varied by varying dc i/p voltage (chopper is required).

The line voltage waveform for stepped wave inverter is shown in the below figure.



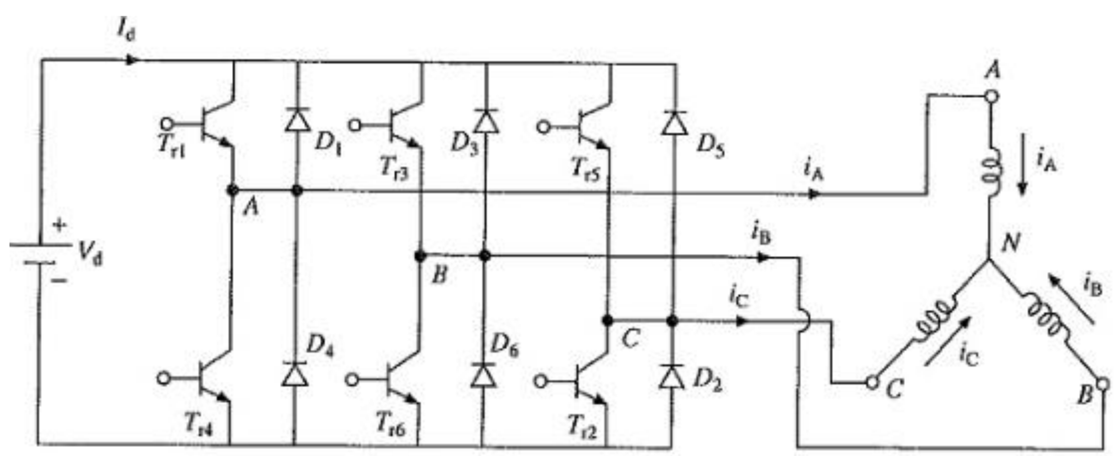



When the supply is DC, then the variable DC input is obtained by connecting a chopper between DC supply and inverter.




Q.5 A brushless DC motor drives employing a **current regulated voltage source inverter** (VSI) and

a trapezoidal PMAC motor is shown in fig




The stator winding are star connected and rotors are having rotor sensors which is not shown in the figure

• The stator is fed with current pulses whose polarity is same as that of induced voltage

• Since air gap flux is constant , the induced voltage is prop to speed of the rotor

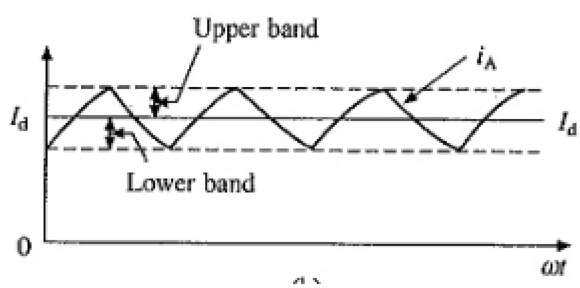
• i.e E = KeWm

• Also P = EId + (-E * -Id ) = 2EId = 2KeWmId

• T = P/Wm = 2KeId = KT Id

During the period 0◦ to 60◦ , Ia = Id and Ib = –Id. The current Ia enters through the phase A and leaves through the phase B. When transistors Tr1 and Tr6 are on, terminals A and B are respectively connected to positive and negative terminals of the dc source Vd. A current will flow through the path consisting of Vd, Tr1, phase A, phase B and Tr6 and rate of change of current Ia will be positive. When Tr1 and Tr6 are turned off this current will flow through a path consisting of phase A, phase B, diode D3, Vd and diode D4. Since the current has to flow against voltage Vd, the rate of change of Ia will be negative. Thus, by alternately turning on and off Tr1 and Tr6 phase A current can be made to follow the reference current Id within a hysteresis band as shown in fig..

**By reducing the band sufficiently nearly a dc current of desired value can be produced.**




Q.6

i) $t_s = \tau_m \left[ \frac{1}{4S_m} + 1.5\, S_m \right]$

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

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

$\boxed{S_m = 0.1196}$

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

$= 745937.362\,A$
$= 745.9\,KA$

$I_r' = 863.67\,A$

$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = 1000$

$T_{max} = \frac{3\, I_r'^2\, R_r'}{\omega_{ms}\, s}$ ; $\omega_{ms} = \frac{2\pi N_s}{60}$

$= 104.7$ rad/sec

$= \left[ \frac{3\,(745.9 \times 10^3) \times 0.12}{[illegible]} \right] = 21443.97\ Nm.$

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

$$\tau_m = \frac{J\omega_{ms}}{T_{max}} = \frac{100 \times 104.72}{21443.97} = 0.4884 \text{ sec}$$

$$t_s = 0.4884 \left[ \frac{1}{(4 \times 0.1196)} + (1.5 \times 0.1196) \right]$$

$$t_s = 1.1084 \text{ sec}$$

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

$$= \frac{1}{2} \times 100 \times (104.72)^2 \left[ 1 + \frac{0.075}{0.12} \right]$$

$$E_s = 891 \text{ kJ}$$

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

$$= 0.4884 \left[ \frac{0.75}{0.1196} + 0.3465 (0.1196) \right]$$

$$= 3.08 \text{ sec.}$$

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

$$= \frac{3}{2} \times 100 \times (104.72)^2 \left[ 1 + \frac{0.075}{0.12} \right]$$

$$= 2673 \text{ kJ.}$$

iii) $t_{b(min)} = 1.027\,(0.4881)$

$= 0.5015$

$(R'_r + R_e) = 1.47\,(x_s + x'_r)$

$0.12 + R_e = 1.47\,(0.5 + 0.5)$ assume

$R'_e = 1.35\,\Omega$ $\quad R'_e = R_e$ $\boxed{\because k = 1}$

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

$$= \frac{3}{2} \times 100 \times (104.72)^2 \left[1 + \frac{0.075}{0.12 +}\right.$$

$= 1728\ KJ$