IDA III QP & Solution

CMR INSTITUTE OF TECHNOLOGY		USN							
Internal Assesment Test - III									
Sub:	Industrial Drives & Applications							Code:	17EE82
Date:	17/07/2021	Duration:	90 mins	Max Marks:	50	Sem:	8th(A & B)	Branch:	EEE
Answer Any FIVE FULL Questions									

		Marks	OBE	
			CO	RBT
1.a	Describe drive mechanism for textile mill.	[4]	CO6	L1
1.b	With a neat block diagram , explain the true synchronous mode variable frequency control of multiple synchronous motor	[6]	CO6	L2
2	Dicuss the operation of self controlled synchronous motor drive employing load commutated thyristor inverter	[10]	CO6	L2
3	Explain the 3 phase induction motor fed from a variable frequency CSI. What are its advantages and disadvantages and remedial measures?	[10]	CO5	L2
4.a	Explain brushless dc motor drive for servo application.	[5]	CO6	L2
4.b	With a neat diagram explain multi-stack stepper motor.	[5]	CO6	L1
5.a	Explain the closed loop control for VSI controlled induction motor.	[5]	CO5	L2
5.b	Explain with relevant diagrams the voltage source inverter (VSI) control of three phase induction motor.	[5]	CO5	L2
6	A star connected squirrel-cage induction motor has following ratings and parameters:400V,50Hz,4pole,1370rpm,Rs=2Ω,Rr’=3Ω,Xs=Xr’=3.5Ω,Xm=55 Ω. It is controlled by a current source inverter at a constant flux. Calculate (i) Motor torque, speed and stator current when operating at 30 Hz and rated slip speed (ii) Inverter frequency and stator current for rated motor torque and motor speed of 1200rpm.	[10]	CO5	L3
7	A 500 kW,3-phase,3.3V,50Hz.0.8(lagging) power factor, 4 pole, star-connected synchronous motor has following parameters: Xs=15Ω,Rs=0.Rated field current is 10A. Calculate (i)Armature current and power factor at half the rated torque and rated field current(ii) Field current to get unity power factor at the rated torque(iii) Torque for unity power factor operation at field current of 12.5A	[10]	CO6	L3

Q.1 a.

There are several processes involved by the time the finished cloth comes out of a mill from its basic raw material.The requirements of the motors are different for different processes. The several stages in the Textile Industry are discussed in the following:

1.Ginning: The process of separating seeds from the raw cotton picked from the field is called ginning. The ginning motors must have speed ranges of 250 to 1450 rpm. The load speeds are fairly constant. No speed control is required.

Commercially available squirrel cage induction motors may be employed.

2.Blowing: The ginned cotton in the form of bales is opened up and is cleaned up very well. Normally three phase Induction Motor may be
used for the purpose. No speed control is required. The motors having synchronous speed of 1000 or 1500 rpm may be employed.

3.Cording: The process of converting cleaned cotton into laps is done by lap machines which are normal three-phase standard squirrel cage motors. The motor selected must have a very high starting torque and low starting current so that starting losses are kept to a minimum. The motor must have sufficient thermal capacity to withstand the heat produced by the losses occurring during prolonged acceleration. These cord motors are standardised in IS: 2972 (part II) 1964 which gives the specifications for cord motors. Normally, three-phase totally enclosed or totally enclosed fan cooled squirrel cage induction motors with high starting torque may be employed. The rating of the motor depends upon the type of fabric. Smaller rating motors in the range 1.1 to 1.5 kW may be used for light fabric. For heavy fabric the rating increases to 2.2 to 5.5 kW. The operating speeds of these motors are in the range 750-1000 rpm.

4. Spinning: The next process is spinning. Before the thread is ready for final spinning it is thinned down in two or three stages by processing it on a fly or speed frame. A motor with smooth acceleration is necessary to drive in this frame. The drive motor should be capable of working in high ambient temperatures. The motor must be totally enclosed, with a clean floor construction. Its starting torque must be 150-200% and the peak torque 200-250%. A two speed pole change motor may be used. One can employ two different motors, one for starting and low speeds and the other for high speeds.

5.Looms: The weaving of yarn into cloth is done in looms.

Requirements of a loom motor are:

1. Starting torque must be high to complete the pickup job in a very short
2. The duty cycle consists of frequent starting and stopping. The load on the loom motor is variable and intermittent.
3. The operation requires a reciprocating mechanism. Actually rotary motion must be converted to linear reciprocating motion. The current and torque pulsations are present. A flywheel is required for smoothing.
4. These are also located in places where dust accumulates on the motor. The cotton fluff should not get collected on the motor surface to avoid burning of the same due to motor heating.
5. Loom motors must withstand the effects of humidity.

- high starting torque
- Control of ac Motors to Have Torque Control:
- From the foregoing discussion it is clear that the motors used for textile applications must have

Torque control providing uniform acceleration so that the breakage of the yarn is minimum and the quality of the product is improved.

Q.1 b

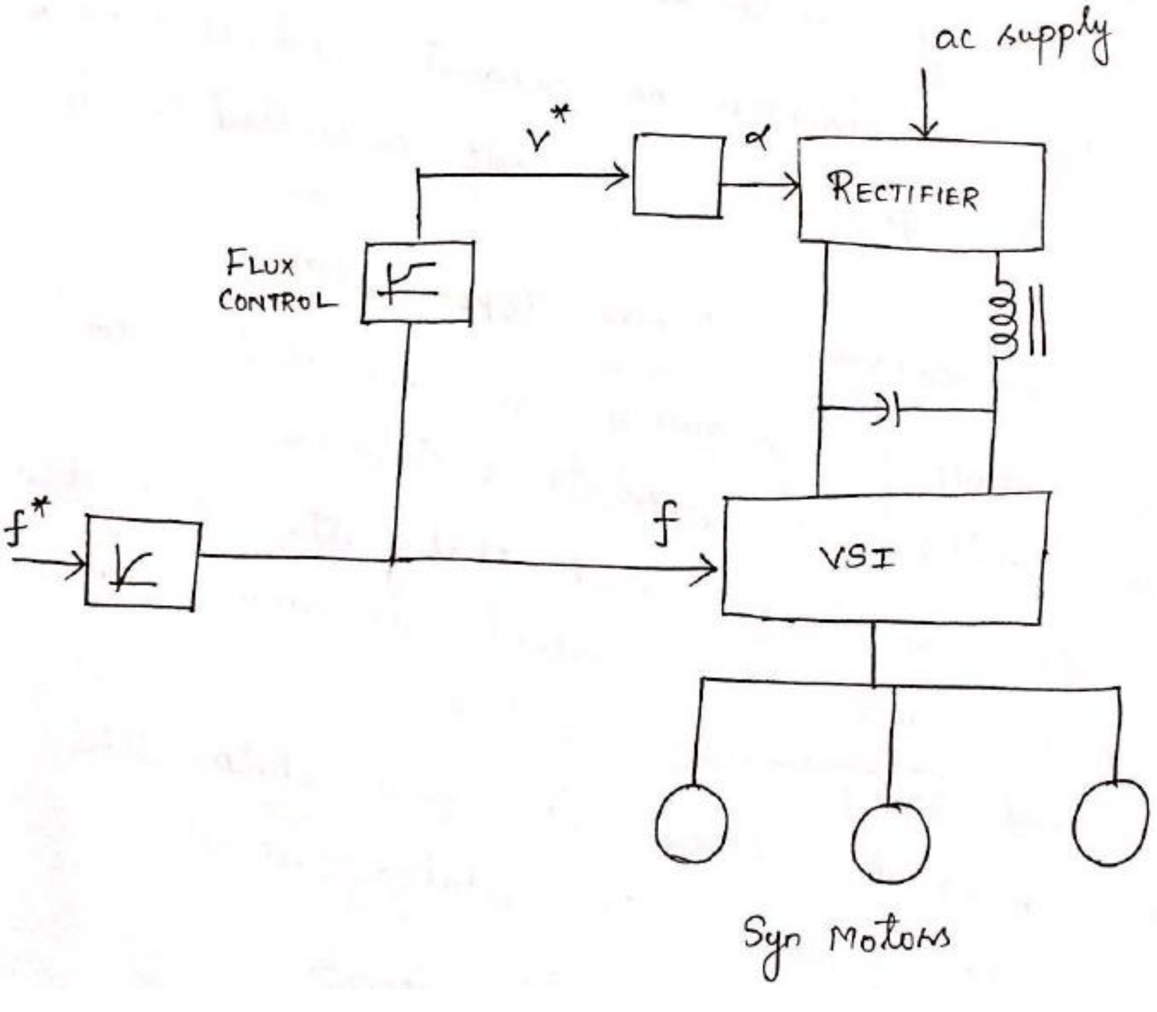
True Synchronous Mode. (OPEN-LOOP)

① stator supply frequency is controlled from outside using a separate oscillator

② The fre is changed such that the diff b/w syn speed and rotor speed is small during any speed change.

③ This gradual change in speed helps the rotor to follow the stator speed properly at all operating points.

Variable Frequency Control of Multiple Synchronous Motors (True Synchronous Mode).



The block diagram of fre control of multiple synchronous motor is shown in the figure.

=> A VSI is used to feed the synchronous motor. It may either a stepped wave inverter or PWM inverter

=> A rectifier is used to supply dc voltage to the inverter. The rectifier will be a full converter if a six step inverter is used.

=> If a PWM inverter is used, then a diode rect is sufficient at the i/p side.

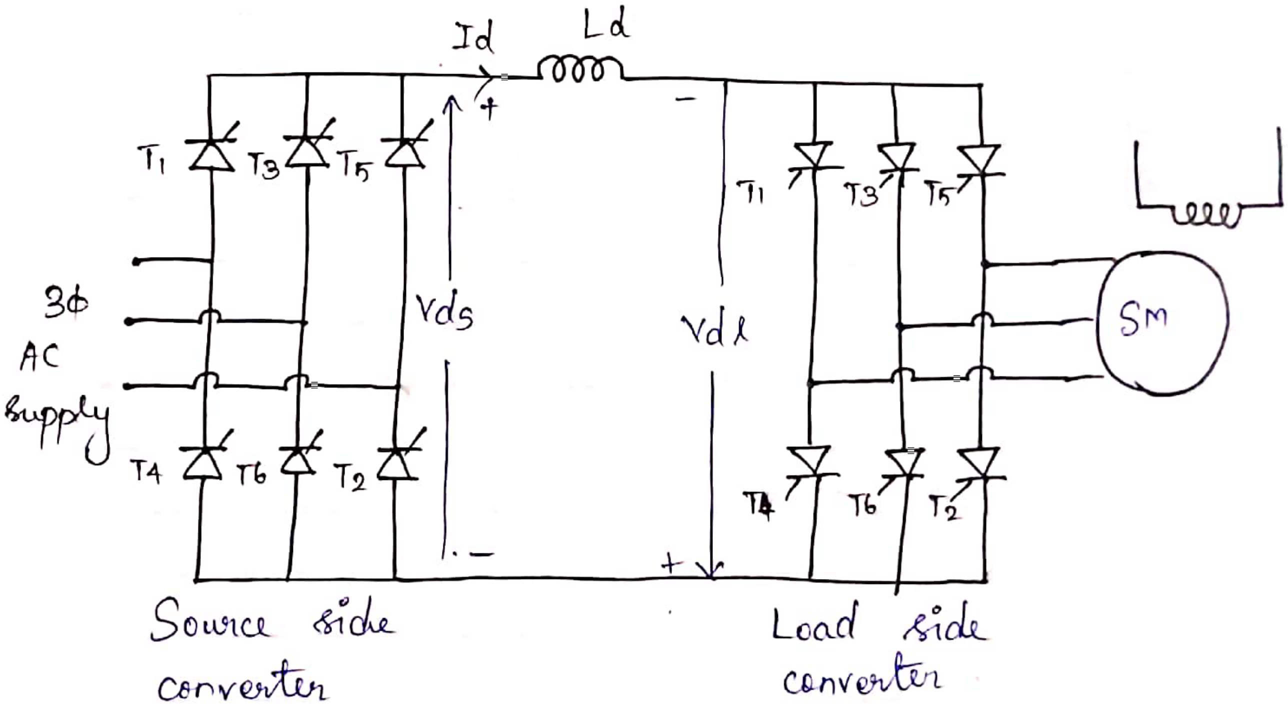
=> A smoothing inductor is used to filter out the ripples present in the dc link voltage.

=> The frequency command f^* is applied to the VSI through a delay ckt which ensures that the rotor follows the stator speed.

Q.2

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 $0 \leq \alpha_l < 90°$ 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 α_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 βl - 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 αl. As the motor current is opposite to converter i/p current, the motor current will lead the terminal voltage by βl. Thus the motor operates at leading PF

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

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

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

where tq- turn-off time

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

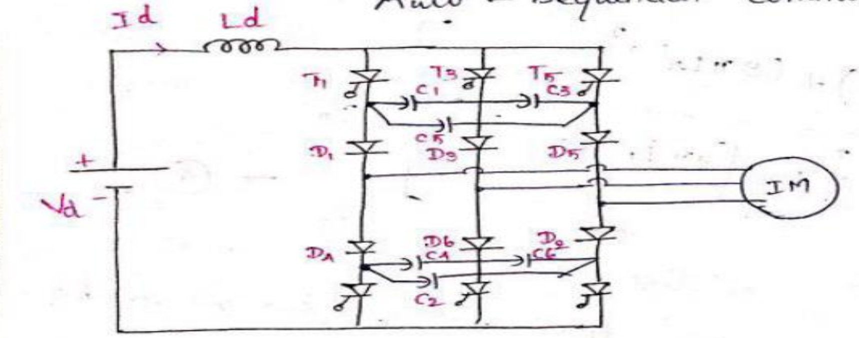
This control is called constant angle margin control

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

Q.3

CURRENT SOURCE INVERTER CONTROL

Auto - sequencial commutatid inverter.



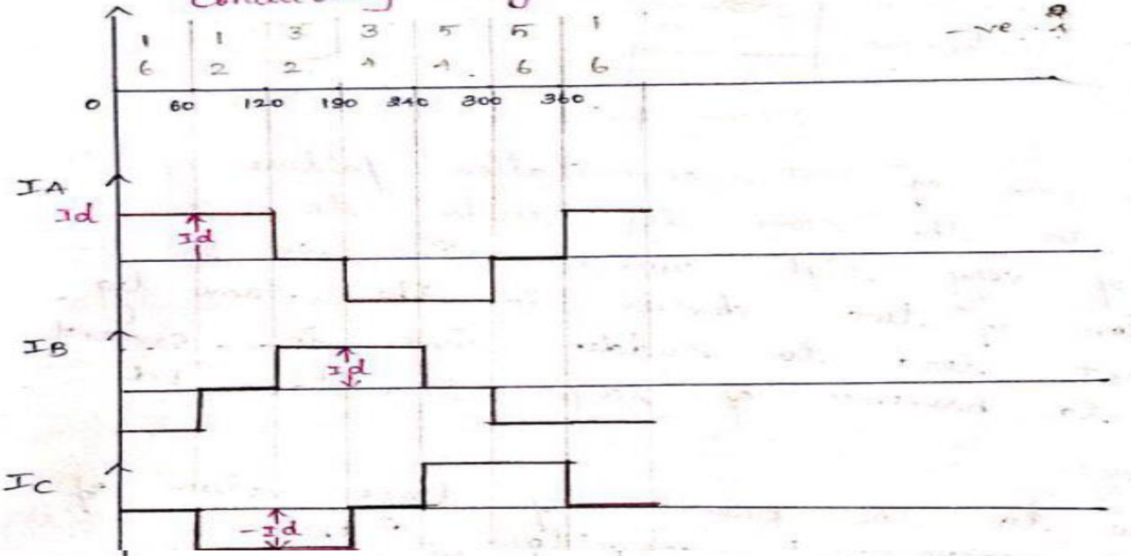
$C_1 - C_6$ and $D_1 - D_6$ provides commutation of thyristors.

- in voltage source inverters (VSI), the o/p voltage is constant with o/p (load) current changing with the load.
- in CSI, the current is nearly constant with change in the voltage as load changes.

Diodes are connected in series with each thyristor to prevent the commutating capacitors from discharging

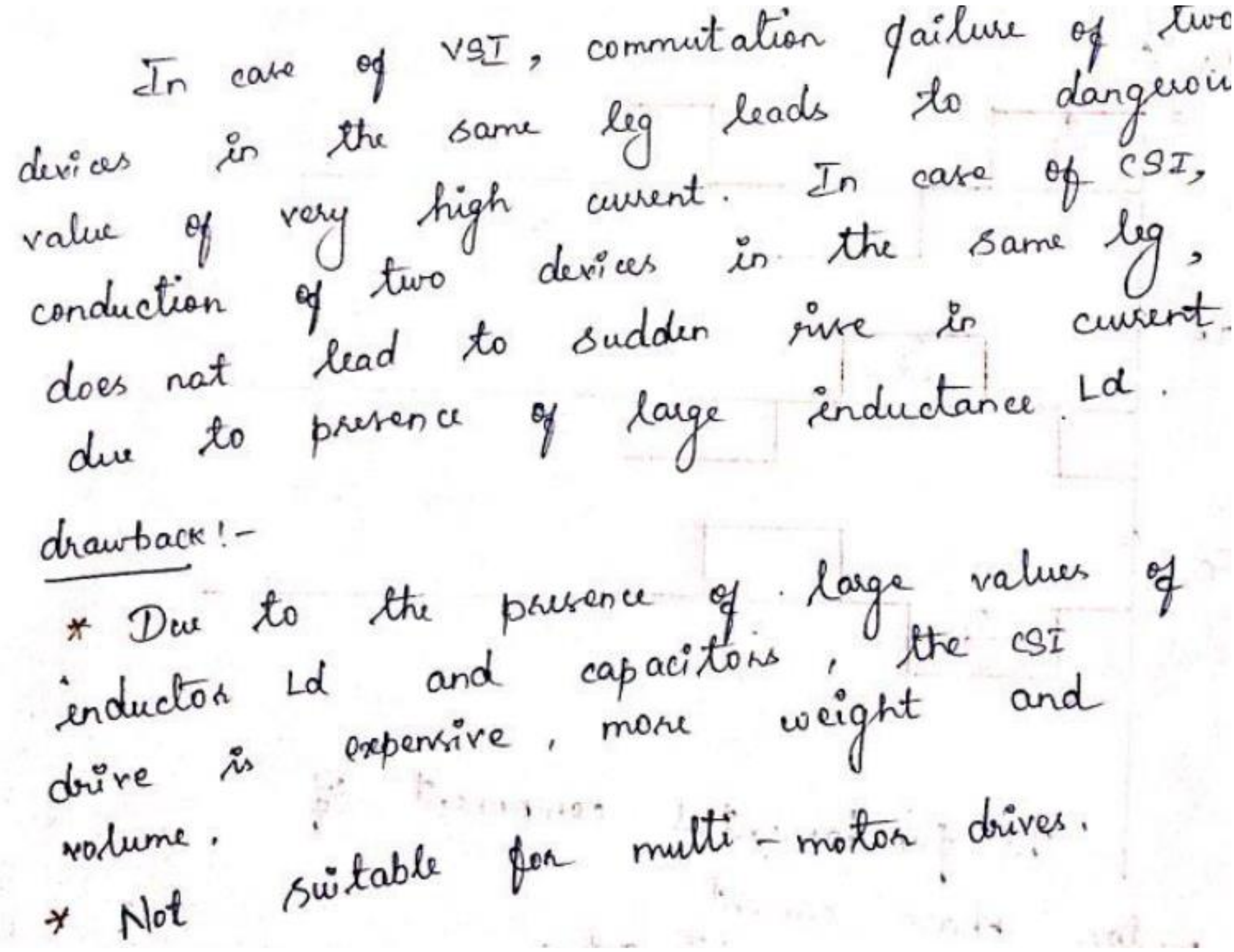
	A	B	C
+ve	1	3	5
-ve	4	6	2

Conducting thyristors



The fundamental component of motor phase current

$$I_s = \frac{\sqrt{6}}{\pi} I_d .$$



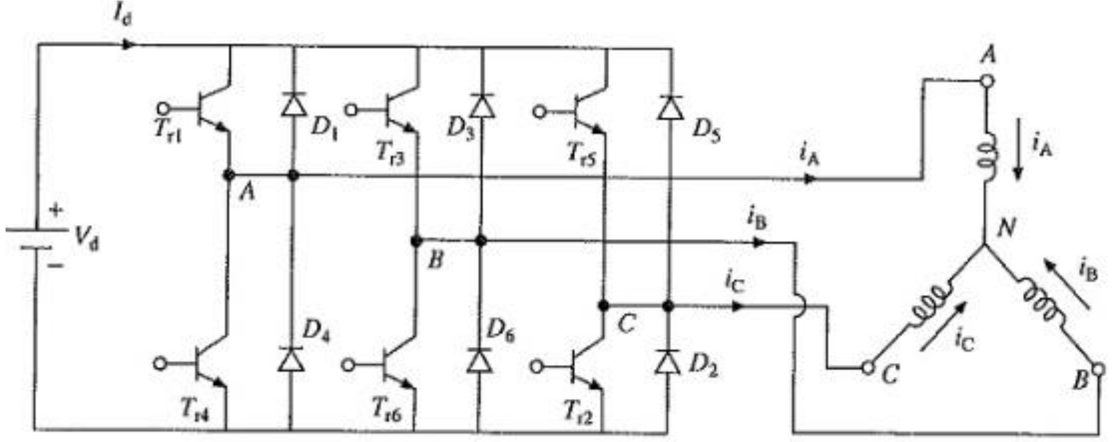
In case of VSI, commutation failure of two devices in the same leg leads to dangerou value of very high current. In case of CSI, conduction of two devices in the same leg, does not lead to sudden rise in current due to presence of large inductance Ld.

drawback :-

* Due to the presence of large values of inductor Ld and capacitors, the CSI drive is expensive, more weight and volume.
* Not suitable for multi-motor drives.

Q.4 a

- A brushless DC motor drives employing a **current regulated voltage source inverter** (VSI) and a trapezoidal PMAC motor is shown in fig



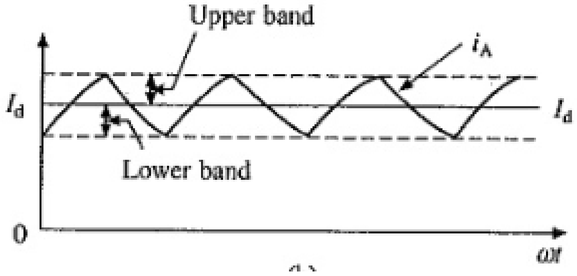
The stator winding are star connected and rotors are having rotor sensors which is not shown in the figure

- 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.



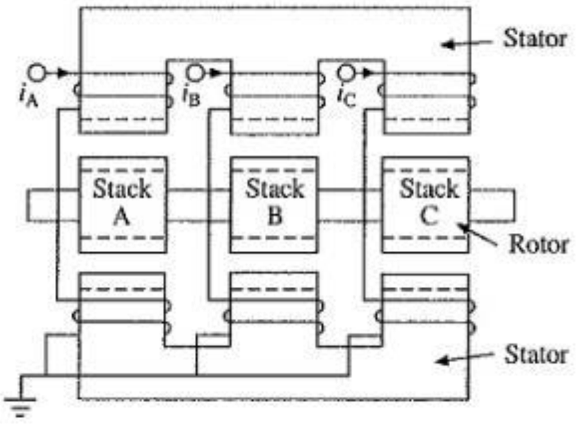
Q.4b

Multi-Stack (or m-Stack) Variable Reluctance Motor:

These are used to obtain smaller step sizes, typically in the range of 2 to 15°. Although three stacks are common, a multi-stack motor may employ as many as seven stacks.

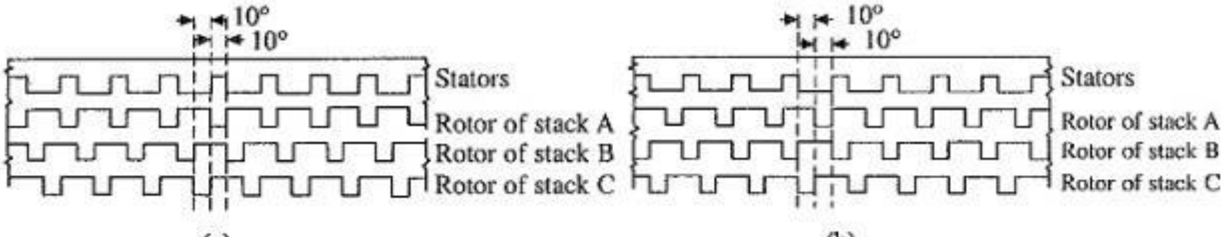
A m-stack motor can be viewed as consisting of m identical single stack variable reluctance motors with their rotors mounted on a common shaft. The stators and rotors have the same number of poles (or teeth), and therefore, same pole (tooth) pitch. While the stator poles (teeth) in all m stacks are aligned, the rotor poles (teeth) are shifted by 1/m of the pole pitch from one another. All the stator pole windings in a given stack are energised simultaneously, unlike the single-stack motor, where only the winding on single pair of poles are energised. Since all the stator pole windings in a given stack are excited simultaneously, the stator winding of each stack forms one phase. Thus the motor has the same number of phases as the number of stacks.

Figure



Cross section of a three stack variable reluctance motor parallel to the shaft.

Figure shows the cross-section of a three stack (three-phase) motor parallel to the shaft. In each stack, stators and rotors have 12 poles. While the stator poles in the three stacks are aligned, the rotor poles are offset form each other by one-third of the pole pitch or 10°. Relative positions of stator and rotor poles for the three stacks when phase A (i.e. stator of stack A) is excited is shown in Fig. (A). Rotor poles of stack A are aligned with the stator poles. Now if phase A is de-excited and B excited, rotor poles of stack B will get aligned with the stator poles. Thus, rotor will move by one-third of the pole pitch in anticlockwise direction (Fig.(b)). Now if phase B is de-excited and C excited, rotor will move by another one-third of pole pitch in the anticlockwise direction. When phase C is de-excited and A excited, rotor will have moved by one pole pitch compared to its position in Fig. (a).



(a) (b)

Position of stator and rotor poles in a 3-stack variable reluctance motor: (a) Phase A is excited. Stator and rotor poles in stack A are aligned, (b) Phase B is excited. Stator and rotor poles in stack B are aligned.

The operation of a motor where stator stacks are aligned but rotor stacks are offset from each other is considered above. In alternative design the rotor stacks are aligned and stator stacks are offset.

Let N be the number of rotor poles (or teeth) and in the number of stacks or phases. Then

$$\text{Pole (or tooth) pitch} = \frac{360^\circ}{N}$$

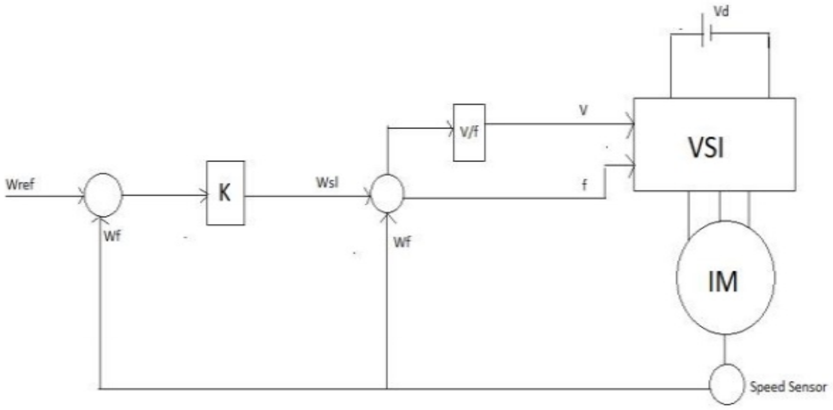
$$\text{Step angle} = \frac{360^\circ}{m \times N}$$

The variable reluctance motors, both single and m-stack types, have high torque to inertia ratio, giving high rates of acceleration and fast response. They do not have detent or residual torque-torque acting on the rotor to oppose its movement when no current is flowing in the stator coils. Detent torque is important in some applications, e.g. when the power is switched off it helps the rotor to retain its position.

Q.5 a

Closed Loop V/F Control

The basis of constant V/F speed control of induction motor is to apply a variable magnitude and variable frequency voltage to the motor. Both the voltage source inverter and current source inverters are used in adjustable speed ac drives. The following block diagram shows the closed loop V/F control using a VSI



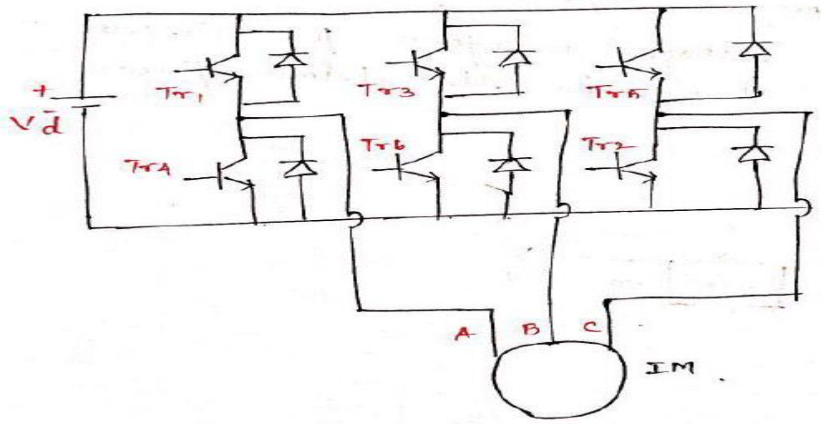
Block diagram for closed loop V/F control for an IM

A speed sensor or a shaft position encoder is used to obtain the actual speed of the motor. It is then compared to a reference speed. The difference between the two generates an error and the error so obtained is processed in a Proportional controller and its output sets the inverter frequency. The synchronous speed, obtained by adding actual speed ωf and the slip speed ω_{SI}, determines the inverter frequency The reference signal for the closed-loop control of the machine terminal voltage ωf is generated from frequency

Q.5 b

VSI IM Drives:-

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



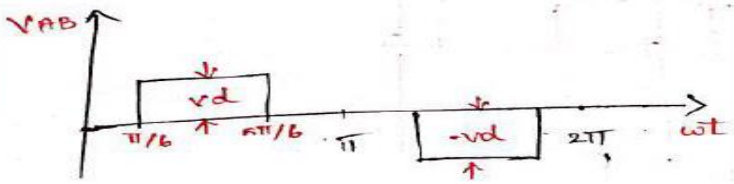
⇒ instead of transistors, any other self commutated devices [MOSFET (low voltage and low power), IGBT, GTO, IGCT - high power levels can be used].

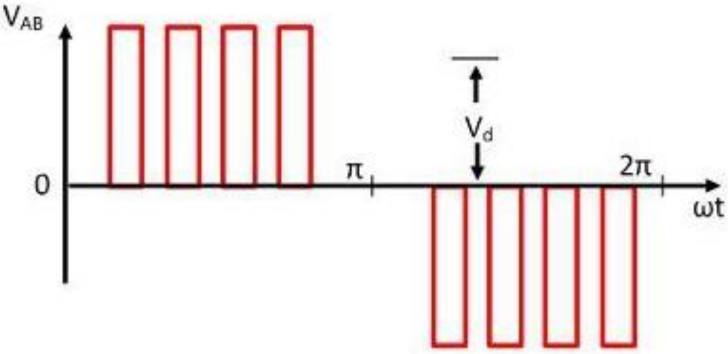
⇒ VSI can be operated as stepped wave inverter or a PWM inverter.

* 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.

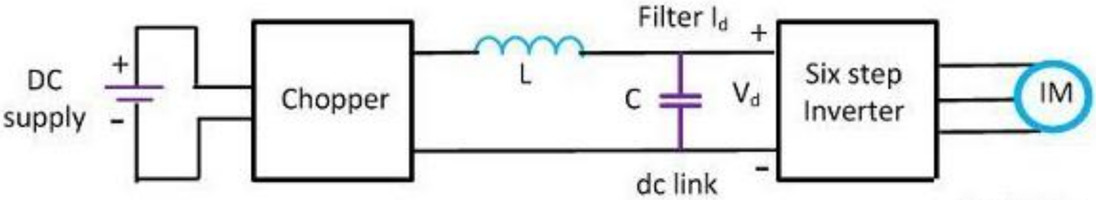




PWM Inverter Line Voltage Waveform

Circuit Globe

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



Circuit Globe

The o/p line voltage and phase voltage are given by following expressions :-

$$V_{AB} = \frac{2\sqrt{3}}{\pi} V_d \left[\sin\omega t - \frac{1}{5}\sin 5\omega t - \frac{1}{7}\sin 7\omega t + \frac{1}{11}\sin 11\omega t + \frac{1}{13}\sin 13\omega t \ldots\right] \ldots\ldots$$

$$V_{AN} = \frac{2V_d}{\pi}\left[\sin\omega t + \frac{1}{5}\sin 5\omega t + \frac{1}{7}\sin 7\omega t\right]$$

The rms value of fundamental phase voltage,

$$V = \frac{V_{AN}}{\sqrt{2}} = \frac{\sqrt{2}\, V_d}{\pi}.$$

drive:-

Q.6

Solution

$$\text{Synchronous speed} = 1500 \text{ rpm or } 50\pi \text{ rad/sec}$$

$$\text{Full load slip } s_f = \frac{1500 - 1370}{1500} = 0.0867$$

$$\text{Full load slip speed} = 1500 - 1370 = 130 \text{ rpm}$$

From Fig. E.6.15 motor impedance

$$Z = 2 + j3.5 + \frac{j55\left(\frac{3}{0.0867} + j3.5\right)}{\frac{3}{0.0867} + j(55 + 3.5)}$$

$$= 24.65 + j20.19 = 31.86 < 39.3^\circ \ \Omega$$

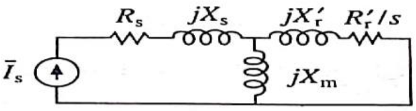


Fig. E.6.15

Full load stator current

$$I_{sf} = \frac{400/\sqrt{3}}{31.86} = 7.2486 \text{ A}$$

Full load rotor current

$$I'_{rf} = I_{sf}\left[\frac{jX_m}{(R'_r/s_f) + j(X'_r + X_m)}\right] = 7.2486\left[\frac{j55}{\frac{3}{0.0867} + j(58.5)}\right] = 5.865 \text{ A}$$

$$T_F = \frac{3}{\omega_{ms}}\left[I'^2_{rf} R'_r/s_f\right] = \frac{3}{50\pi} \times (5.865)^2 \times \frac{3}{0.0867} = 22.73 \text{ N-m}$$

(i) According to Example 6.14 at rated slip speed, torque and I_s will have same values as at 50 Hz operation. Thus

$$T = 22.73,\ I_s = 7.2486 \text{ A}$$

Now at 30 Hz synchronous speed $= \frac{30}{50} \times 1500 = 900$ rpm

Full load slip speed = 130 rpm

Motor speed = 900 – 130 = 770 rpm

(ii) At rated motor torque, slip speed and I_s will be same as at 50 Hz operation. Therefore

$$I_s = 7.2486, \text{ slip speed} = 130 \text{ rpm}$$

Synchronous speed = 1200 + 130 = 1330 rpm

$$\text{Frequency} = \frac{1330}{1500} \times 50 = 44.33 \text{ Hz}$$

(iii) When speed-torque curves are assumed to be straight lines,

Slip speed at half the rated torque $= \frac{130}{2} = 65$ rpm

At 30 Hz, synchronous speed = 900 rpm

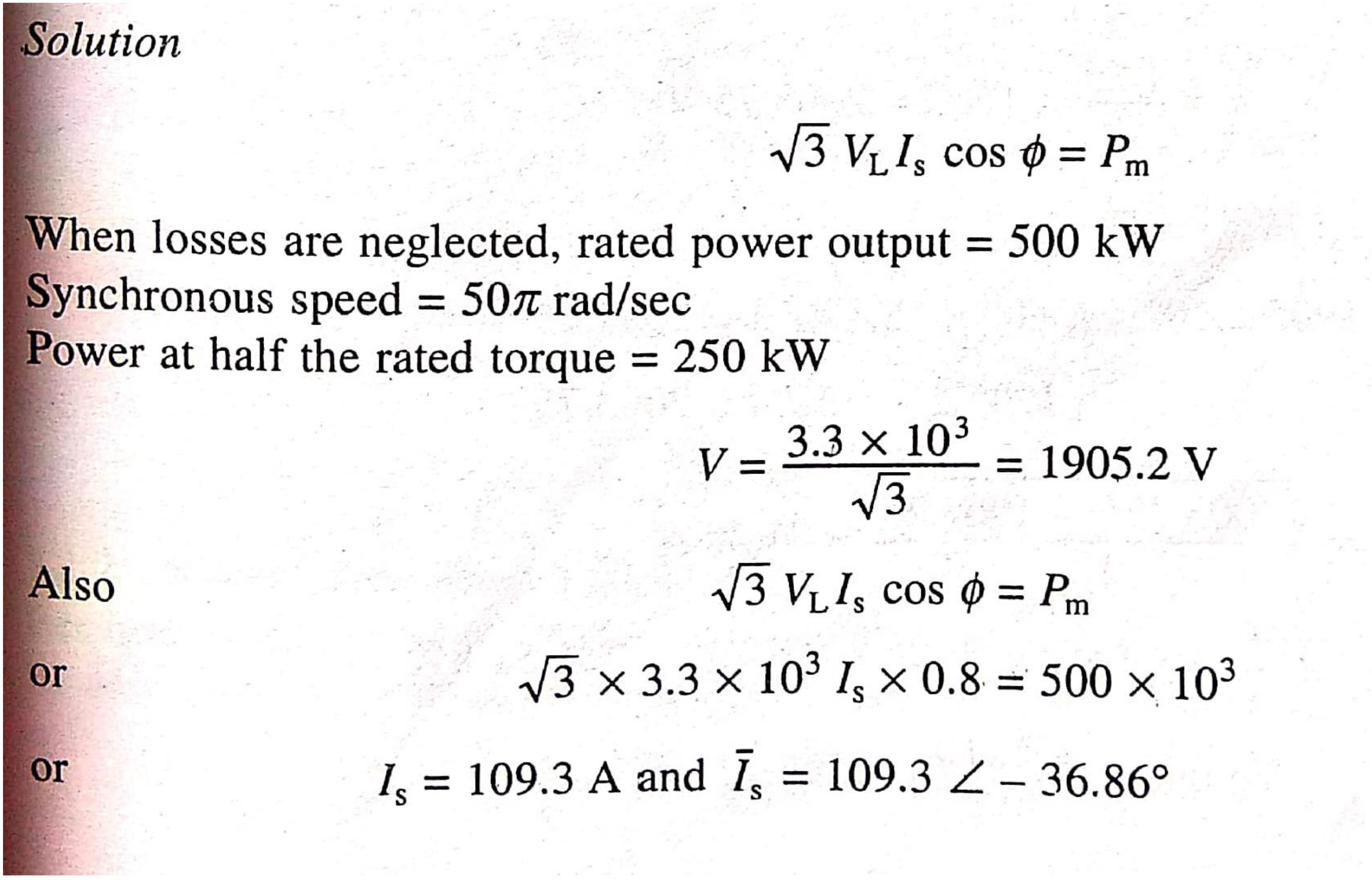
Motor speed = 900 – 65 = 835 rpm

(iv) At rated braking torque, slip speed = – 130 rpm

Synchronous speed at 45 Hz $= \frac{45}{50} \times 1500 = 1350$ rpm

Motor speed = 1350 + 130 = 1480 rpm

Q.7



Solution

$$\sqrt{3}\, V_L I_s \cos\phi = P_m$$

When losses are neglected, rated power output = 500 kW
Synchronous speed = 50π rad/sec
Power at half the rated torque = 250 kW

$$V = \frac{3.3 \times 10^3}{\sqrt{3}} = 1905.2 \text{ V}$$

Also $$\sqrt{3}\, V_L I_s \cos\phi = P_m$$

or $$\sqrt{3} \times 3.3 \times 10^3\, I_s \times 0.8 = 500 \times 10^3$$

or $$I_s = 109.3 \text{ A and } \bar{I}_s = 109.3 \angle -36.86°$$

$$\bar{E} = \bar{V} - \bar{I}_s j X_s = 1905.2 \angle 0° - 109.3 \angle -36.87 \times 15 \angle 90°$$

$$= 921.5 - j1311.6 = 1603 \angle -54.9$$

(i) As field current has not changed, $E = 1630$

$$P_m = \frac{3VE}{X_s} \sin \delta$$

$$250 \times 10^3 = \frac{3 \times 1905.2 \times 1603}{15} \sin \delta$$

$$\sin \delta = 0.409 \quad \text{or} \quad \delta = 24.16°$$

or

$$\bar{I}_s = \frac{V - E\angle -\delta}{jX_s} = \frac{1905.2 - 1603\angle -24.16°}{15\angle 90°}$$

$$= 127 \angle -90° - 106.9 \angle -114.16 = 52.75 \angle -34°$$

Power factor = cos (–34°) = 0.83 (lagging)

(ii) At unity power factor and rated torque

$$3VI_s = P_m$$

or

$$3 \times 1905.2 I_s = 500 \times 10^3$$

or

$$I_s = 87.48 \text{ A}$$

$$\bar{E} = 1905.2\angle 0° - 87.48\angle 0° \times 15 \angle 90° = 1905.2 - j1312.2$$

$$E = 2313.4 \text{ V}$$

$$\text{Field current} = \frac{2313.4}{1603} \times 10 = 14.43 \text{ A}$$

(iii) At the field current of 12.5 A

$$E = \frac{12.5}{10} \times 1603 = 2003.75 \text{ V}$$

$$|\bar{V} - \bar{I}_s(jX_s)| = E$$

or

$$|1905.2\angle 0° - I_s\angle 0° \times 15\angle 90°| = 2003.75$$

or

$$|1905.2 - j15\, I_s| = 2003.75$$

or

$$I_s = \frac{\sqrt{2003.75^2 - 1905.2^2}}{15} = 41.38 \text{ A}$$

$$P_m = 3VI_s \cos \phi = 3 \times 1905.2 \times 41.38 = 236.51 \text{ kW}$$

$$\text{Torque} = \frac{236510}{50\pi} = 1505.7 \text{ N-m}$$