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CMRIT

Internal Assesment Test – 1

Sub: Special Electrical Machines (Professional Elective)				Code: 17EE554
Date: 07/09/2019	Duration: 90 mins	Max Marks: 50	Sem: 5	Sections: A&B

Answer **ANY FIVE** full questions. Explain your notations explicitly and clearly.
Sketch figures wherever necessary. Good luck!

		Marks	OBE CO	OBE RBT
Q1a.	What are stepper motors? Classify them based on working principle.	[6]	CO1	L1
Q1b.	A stepper motor is wound for two phases and has four poles. It has 10 rotor poles. Find its revolution.	[4]	CO1	L2
Q2.	With a neat sketch, explain the construction and working of hybrid stepper motor in all the three modes of operation.	[10]	CO1	L2
Q3a.	Derive the torque equation of stepper motor.	[6]	CO1	L3
Q3b.	A permanent magnet stepper motor is driven by a series of pulses of duration 20 ms. It has 4 stator poles and 6 rotor poles. How long will it take for the motor to make a complete revolution?	[4]	CO1	L3
Q4a.	Explain with a neat circuit diagram the closed-loop control of stepper motor.	[6]	CO1	L2
Q4b.	Define the following (i) Step angle; (ii) Resolution; (iii) Stepping rate; and (iv) Stepping error.	[4]	CO1	L1
Q5.	Explain the constraints on Pole Arc and Tooth Arc of Switched reluctance motor (SRM). Draw L-θ diagram for 8/6 SRM assuming pole arc of 21° and 24° for the stator and rotor respectively.	[10]	CO2	L3
Q6a.	With a neat sketch, explain the current regulators used for SRM.	[6]	CO2	L2
Q6b.	A 4-phase SRM has 6 rotor teeth. Find the step angle and commutation frequency for a speed of 6000 rpm.	[4]	CO2	L2

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1. What are stepper motors? Classify them based on working principle.

- Stepper Motor is an electromechanical device which actuates a train of step movements of shaft in response to train of input pulses.
- Principle of magnetic interaction between stator and rotor.
- Stator has windings.
- Rotor has salient poles but no windings.
- No feedback as input-output relation is direct.

STEPPER MOTOR.

- Variable reluctance stepper Motor (VRSM)
  - Multi-stack VRSM
  - Single-stack VRSM
- Permanent Magnet Stepper Motor
- Hybrid stepper Motor
- Others.
  - 1-ϕ Stepper Motor
  - Disc Magnet Stepper Motor
  - Can-Stack or claw-tooth permanent magnet stepper Motor.

Single-stack VRSM, Permanent Magnet Stepper Motor and Hybrid stepper Motor:
- single phase ON
- two phase ON.
- Half step (2-1-2-1) or (1-2-1-2)

A stepper motor is wound for two phases and has four poles. It has 10 rotor poles. Find its revolution.

Given, $m = 2$

$N_r = 10$

$Z = m N_r$

$Z = 20$ steps/revolution

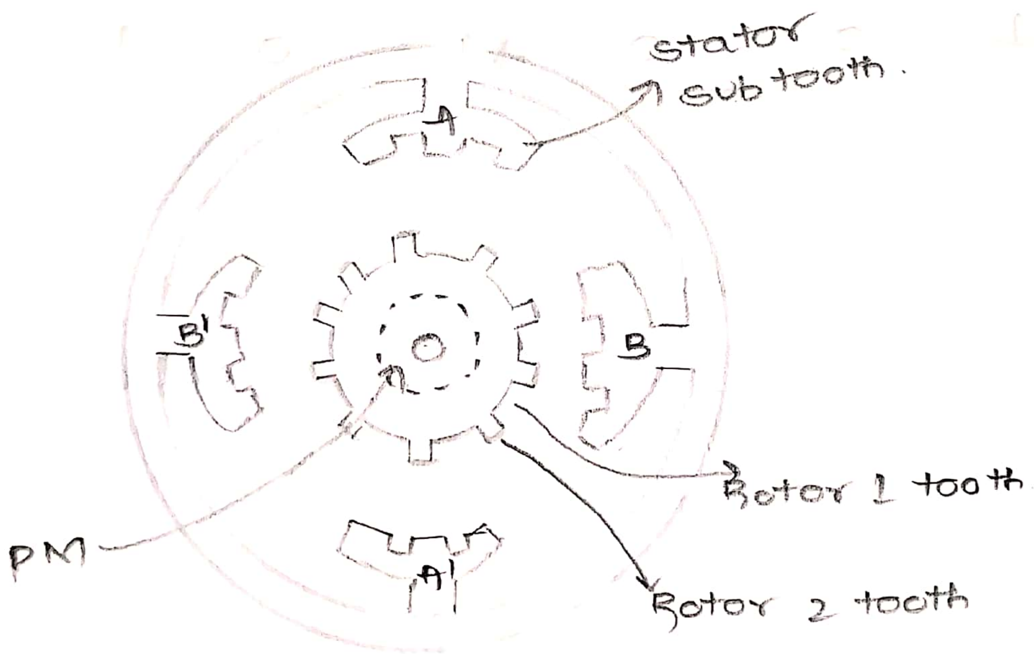
OR

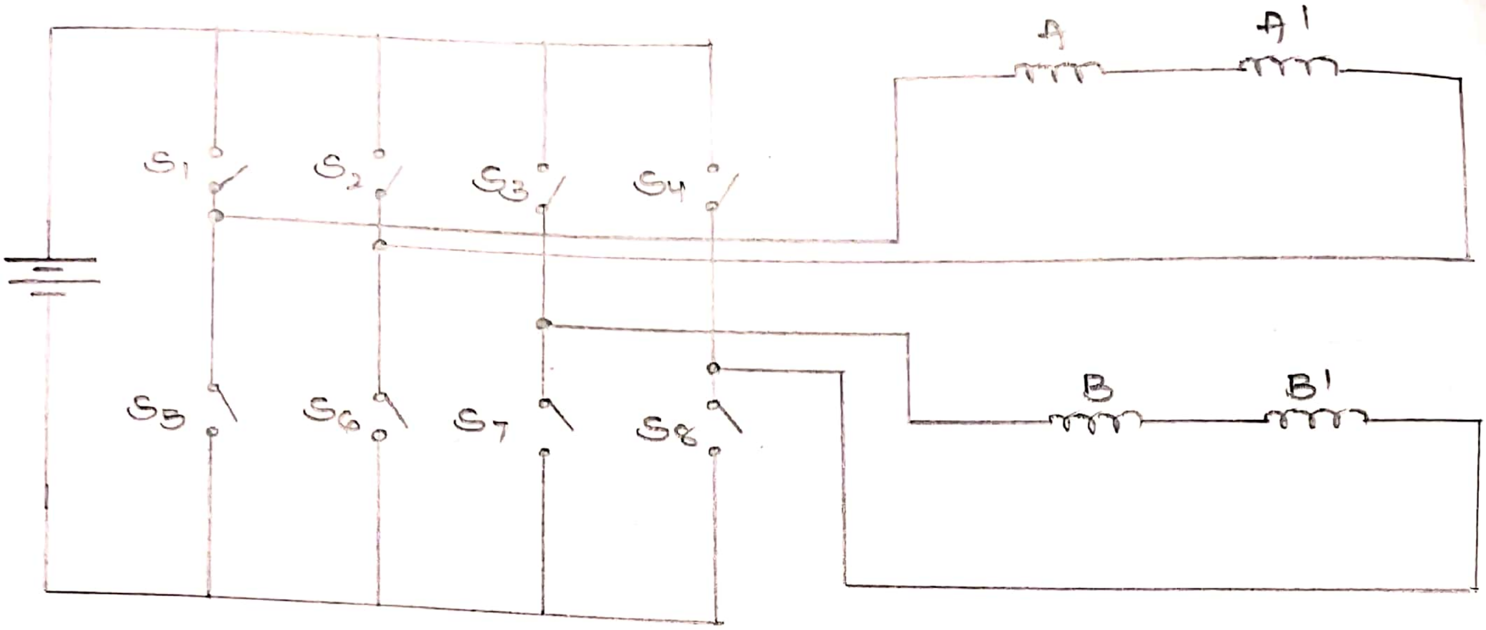
$$\theta_s = \frac{360}{m N_r}$$

$$\theta_s = \frac{360^\circ}{2 \times 10} = 18^\circ$$

$$Z = \frac{360^\circ}{\theta_s} \Rightarrow Z = \frac{360}{18} = 20 \text{ steps/rev}$$

With a neat sketch, explain the construction and working of hybrid stepper motor.





→ Two-phase Mode.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	0	1	0	0	1	0	1
0	1	1	0	1	0	0	1
0	1	0	1	1	0	1	0
1	0	0	1	0	1	1	0
1	0	1	0	0	1	0	1
0	1	1	0	1	0	0	1
0	1	0	1	1	0	1	0
1	0	0	1	0	1	1	0
1	0	1	0	0	1	0	1.

One-phase mode.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	0	0	0	0	1	0	0
0	0	1	0	0	0	0	1
0	1	0	0	1	0	0	0
0	0	0	1	0	0	1	0

Half-step mode.

S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8
1	0	1	0	0	1	0	1
0	0	1	0	0	0	0	1
0	1	1	0	1	0	0	1
0	1	0	0	1	0	0	0
0	1	0	1	1	0	1	0
0	0	0	1	0	0	1	0
1	0	0	1	0	1	1	0
1	0	0	0	0	1	0	0

13. Derive the torque equation of stepper motor

Let $i(t)$ = current / phase

$e(t)$ = emf induced / phase

$L(\theta)$ = Inductance / phase.

θ = Angular displacement.

emf induced / phase, $e(t) = \frac{d}{dt}[L(\theta) \cdot i(t)]$

$$e(t) = L(\theta)\frac{di(t)}{dt} + i(t)\frac{dL(\theta)}{dt}$$

$$= L(\theta)\frac{di(t)}{dt} + i(t)\frac{dL(\theta)}{d\theta}\cdot\frac{d\theta}{dt}.$$

$$e(t) = L(\theta)\frac{di(t)}{dt} + \omega\, i(t)\frac{dL(\theta)}{d\theta} \quad (\because \omega = \frac{d\theta}{dt})$$

Power Developed.

$$P_m = e(t) \cdot i(t)$$

$$P_m = L(\theta)\, i(t)\frac{di(t)}{dt} + \omega\,[i(t)]^2\frac{dL(\theta)}{d\theta} \rightarrow (1)$$

Energy stored in magnetic field.

$$W_e = \frac{1}{2}L(\theta)[i(t)]^2$$

Power due to energy stored

$$P_e = \frac{d}{dt}\cdot W_e$$

$$= \frac{d}{dt}\left[\frac{1}{2}L(\theta)[i(t)]^2\right]$$

$$= \frac{1}{2}\left[L(\theta)\frac{d}{dt}[i(t)]^2 + [i(t)]^2\frac{dL(\theta)}{dt}\right]$$

$$= \frac{1}{2}\left[2\, i(t)\, L(\theta)\frac{di(t)}{dt} + [i(t)]^2\omega\frac{dL(\theta)}{d\theta}\right]$$

$$P_e = L(\theta)\, i(t)\frac{di(t)}{dt} + \frac{1}{2}\omega\,(i(t))^2\frac{dL(\theta)}{d\theta} \rightarrow (2)$$

Total power available (P)

$P = P_m - P_e$.

Eq ① − ②

$$P = \frac{1}{2}\omega\,[i(t)]^2 \frac{dL(\theta)}{d\theta}$$

$$T = \frac{P}{\omega} = \frac{1}{2}[i(t)]^2 \frac{dL(\theta)}{d\theta}.$$

• A permanent magnet stepper motor is driven by a series of pulses of duration 20ms. It has 4 stator poles and 6 rotor poles. How long will it take for the motor to make a complete revolution?

Given, Pulse duration = 20 ms

$N_s = 4$, $N_r = 6$

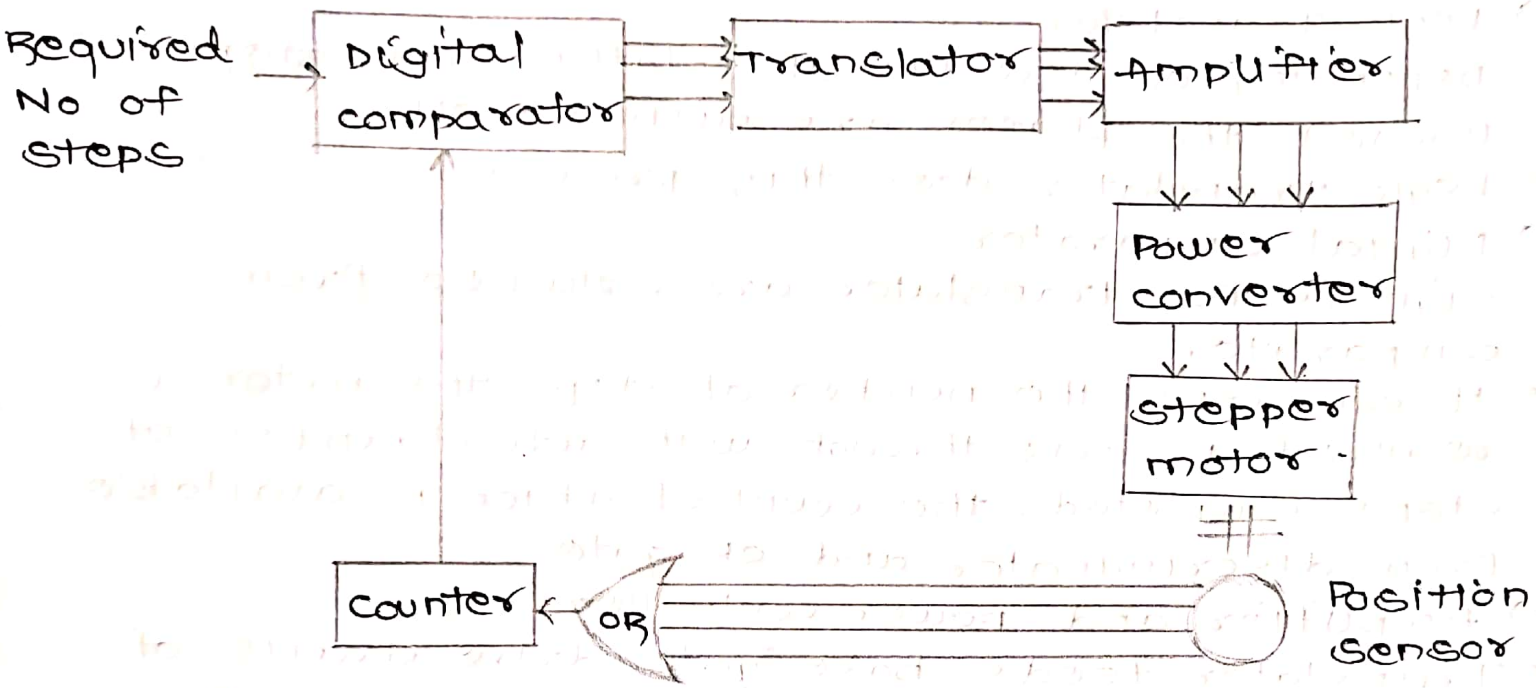
$$\theta_s = \frac{N_s \sim N_r}{N_s N_r} \times 360^\circ = 30^\circ$$

$\therefore Z = \frac{360}{\theta_s} = 12$ steps/revolution.

Time for one revolution $= 12 \times 20$

$= 240$ ms.

11. Explain with a neat circuit diagram the closed loop control of stepper motor.



- Releases new command only when previous command is fulfilled.
- Due to inertia of load and motor first step takes more time.
- second takes less time than first step.
- Third step takes less time than second step and so on.
- Hence step duration varies as step advances.
- Block diagram consists of many blocks such as

→ Discriminator (Photo sensor)

- To decide exact time of i/p command for successive step rotor position should be known.
- It is done using position sensor.
- It consists of a thin opaque disc having holes equal to number of teeths on its pheriphery.
- Photo emitters and photo detectors are placed along the periphery on either side of the disc.

- Light emitted from emitter is received by detector placed on opposite side when a hole on the disc comes in between them.
- Number of sensors is equal to number of switching devices for exciting phase windings independently.
- They should be placed at a distance of [(360/N_r) + step angle].

→ Logic Translator
- Depending on direction of rotation and steps involved the phases are switched ON.
- Logic translator does this process.

→ Digital comparator
- Signals for translator are obtained from comparator
- It compares the number of steps the motor is required to move through with actual number of steps completed, the count of which is available from discriminator and OR gate.

→ Amplifier and power controller.
- Translator feeds base/gate drive circuits of semiconductor power switching devices after sufficient amplification.

12. With a block diagram and flow chart, explain the microprocessor-based control of stepper motor.

8. Define the following.

i) Step angle (θ_s)

- Angle of displacement of rotor for a single pulse of excitation of stator.

$$\theta_s = 360° / m N_r.$$

For Hybrid, $\theta_s = 360° / 2 m N_r$.

ii) Resolution (z)

- Number of steps per revolution

$$z = 360° / \theta_s.$$

iii) Stepping Rate or stepping Frequency.

- Number of steps completed per second.

iv) Hold position.

- Resting position of rotor of an excited motor.

v) Detent position.

- Position of rotor of a unexcited motor

vi) stepping error.

- Due to tolerance actual step angle differs from theoretical step angle.

$$\% \text{ Stepping error} = \frac{\text{Actual step angle} - \text{Theoretical step angle}}{\text{Theoretical step angle}} \times 100$$

1. Explain the constraints on pole Arc and Tooth arc of SRM. Draw L-θ diagram for 8/6 assuming pole arc 21° & 24° for stator & Rotor respectively.

→ To obtain optimum feasible values of L_{max} and L_{min}.

- To build current quickly from supply, the stator phase must be turned ON when inductance is min. and constant. Hence dwell period is required.

  i.e. $\beta_s < \alpha_r$

  $$\beta_s < \frac{2\pi}{N_r} - \beta_r$$

  $$\beta_s + \beta_r < \frac{2\pi}{N_r}.$$

- Stator slot angle must be less than stator pole pitch.

  $$\beta_s < \frac{2\pi}{N_s}.$$

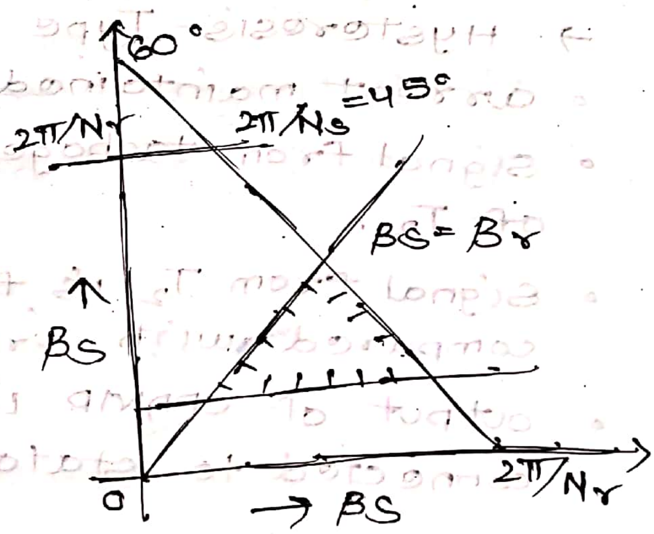
- To avoid negative torque, to have dwell period when L stays at max.

  $$\beta_r > \beta_s.$$

- Positive slope L-θ curve period should be more than step angle (θ_s) so as to develop a positive torque.

  $$\beta_s > \frac{2\pi}{N_r} - \frac{2\pi}{N_s}$$

  $$\beta_s > \theta_s$$



→ $\frac{2\pi}{N_s} = 21°$

$\frac{2\pi}{N_r} = 24°$

constraints:

$\beta_s + \beta_r < \frac{2\pi}{N_r}$

$\rightarrow \beta_s + \beta_r < 60^\circ$

$\beta_s < \frac{2\pi}{N_s}$

$\rightarrow \beta_s < 45^\circ$

$\beta_r > \beta_s$

$\beta_s > \frac{2\pi}{N_r} - \frac{2\pi}{N_s}$

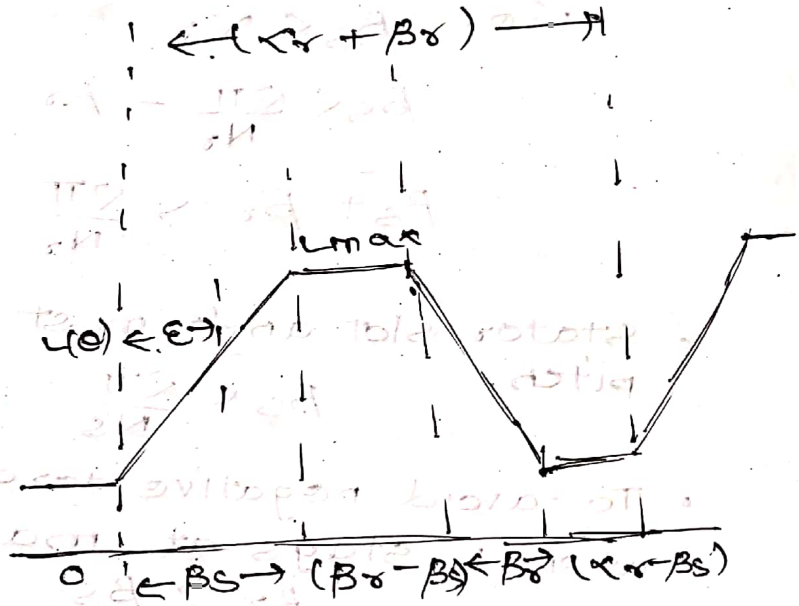
$\rightarrow \beta_s > \theta_s \rightarrow \beta_s > 15^\circ$

$\beta_r = 0.4 \frac{2\pi}{N_r} = 24^\circ$

$\alpha_r = 36^\circ$

$\beta_s = 21^\circ$

$\alpha_s = 39^\circ$

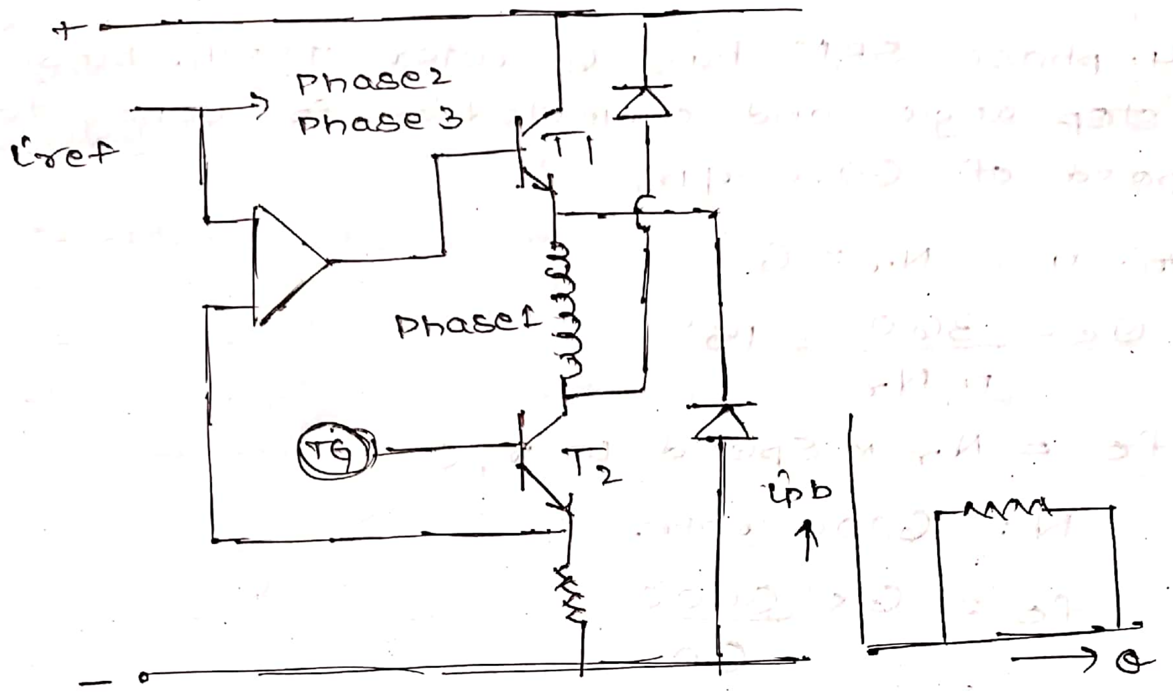


2.

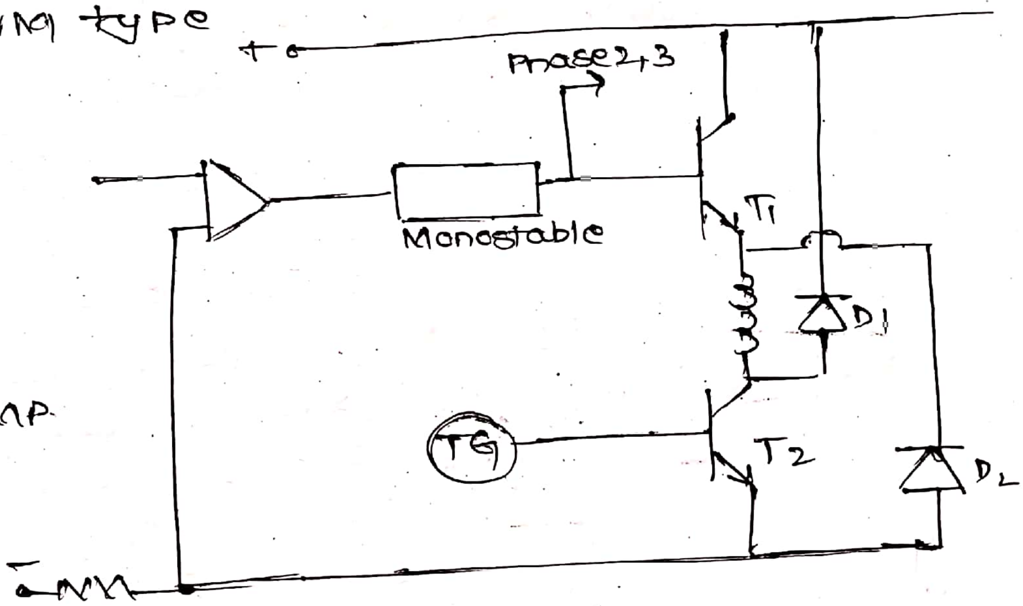
a) With a neat sketch, explain the current regulators used for SRM.

→ Hysteresis-Type current regulators

- current maintained almost constant.
- Signal from tachogenerator (TG) is given to base of T_2.
- Signal from T_2 is fed to OPAMP where it is compared with i_{ref}.
- output of OPAMP is fed to T1 which in turn is connected to stator phase.



→ Voltage PWM type



- Signal from TG is fed to T_2.
- Voltage is compared with Vref by OPAMP.

- output of monostable is base signal to T_1
- Current in phase 1 is modified based on requirement.

2.

b) A 4-phase SRM has 6 rotor teeth. Find the step angle and commutation frequency for a speed of 6000 rpm.

$m = 4$, $N_r = 6$

$$\theta_s = \frac{360}{m N_r} = 15^\circ$$

f_c = N_r x Speed in rps

N = 6000 rpm.

$$f_c = 6 \times \frac{6000}{60}$$

f_c = 600Hz.