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Internal Assesment Test – 2

Sub: Special Electrical Machines (Professional Elective)				Code: 17EE554
Date: 14/10/2019	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	RBT
Q1a.	With a neat circuit diagram and current & torque waveforms, explain the following types of BLDC motors (i) one-phase and one pulse; and (ii) one-phase and two pulse.	[6]	CO1	L2
Q1b.	Compare BLDC motor and conventional DC motor.	[4]	CO1	L1
Q2.	A permanent magnet DC (PMDC) motor has an armature resistance of 1.03 Ω. It draws a current of 1.25 A at no load with 50 V supply and running at 2100 rpm. Find (i) speed-voltage constant; (ii) rotational losses; and (iii) output power when it runs at 1700 rpm at 48 V supply.	[10]	CO1	L3
Q3.	Derive the EMF equation of permanent magnet synchronous motor (PMSM).	[10]	CO2	L3
Q4.	A 3-phase, 4 pole, 50 Hz, 400 V, star connected synchronous reluctance motor (SyRM) has direct axis and quadrature axis synchronous reactances of 8 Ω and 2 Ω respectively. For a load torque of 80 N-m, find (i) load angle; (ii) line current; and (iii) power factor. neglect armature resistance and mechanical losses.	[10]	CO1	L3
Q5.	Explain with a neat circuit diagram the DSP-based control of PMSM.	[10]	CO3	L2
Q6a.	List any eight applications of SyRM.	[4]	CO1	L1
Q6b.	A 3-phase, 4 pole, star connected PMSM has 72 slots with 20 conductors/slot. The flux/pole is 0.05 Wb and the speed is 1500 rpm. Assuming full pitched coil, find the phase and line voltage. Assume $K_s = 1$ and $K_d = 0.986$.	[6]	CO1	L3

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ASSIGNMENT- 2

ELECTRICAL AND ELECTRONICS ENGG [MR. KASHIF AHMED]

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CLASS & SECTION:- '5'-'A' EEE

USN :- 1CR17EE006

DUE DATE FOR SUBMISSION:- 17th OCTOBER 2019

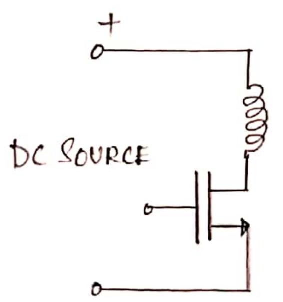
DATE OF SUBMISSION:- 17th OCTOBER 2019

1) a) With a neat circuit diagram and current & torque waveforms, explain the following types of BLDC motors (i) one-phase and one pulse; and (ii) one phase and two pulse.

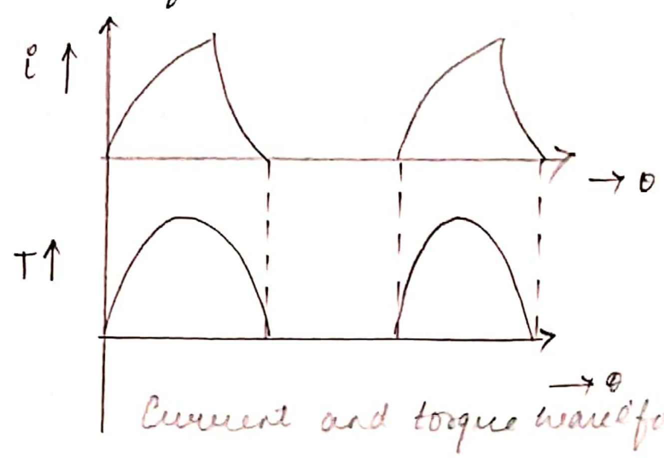
Soln

One phase and one pulse BLDC motor:-

- It has only one armature winding
- It uses only one semiconductor switch.
- When the rotor position sensor is influenced by N pole, the switch is turned ON and turned OFF when the sensor is influenced by S pole.
- Thus, torque is developed only for half cycle.
- Here the utilization of transistor and winding is 50%.
- The current and torque waveforms are shown below.



one phase one pulse motor



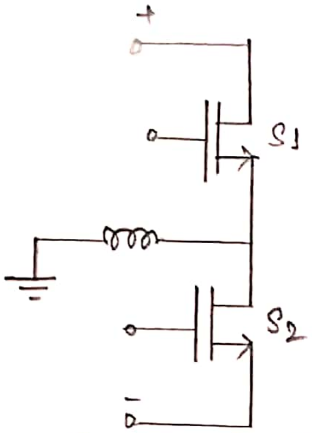
Current and torque waveforms

One phase and two pulse BLDC motor:-

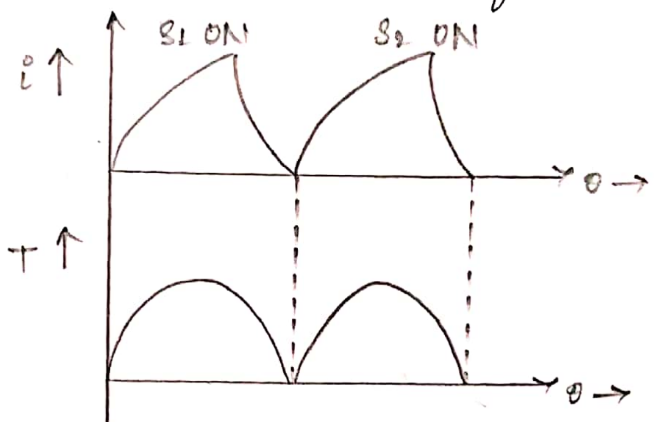
- This motor has one armature winding and two static switches which are used to supply the armature.
- This requires a three phase wire DC supply and better

winding utilisation.

- This scheme requires a position sensor and two switching devices S_1 and S_2.
- S_1 is switched ON when the sensor is under the influence of N pole and is switched OFF when it is under the influence of S pole.
- S_2 is turned ON only when the sensor is influenced by S pole and switched OFF when it is influenced by N pole.



One phase - two pulse motor



Current and torque waveforms

1b) Compare BLDC motor and conventional DC motor.

Soln

BLDC motor	Conventional DC motor
1- Permanent magnet field system is on the rotor	1- Electromagnet field system on stator.
2 - Armature is on stator	2- Armature is on rotor.
3- Commutation is done by power semiconductor devices.	3- Commutation is done by brushes and commutator mechanically.
4- Star or delta connected armature winding.	4- Ring type armature winding
5- Rotor position should be sensed and feedback for switching of static switches.	5- Position is automatically sensed and no external sensor for feedback is needed.
6- Direction of rotation is changed by changing the switching sequence.	6- Direction is changing by interchanging the terminals of armature or field.

2) A permanent magnet DC (PMDC) motor has an armature resistance of 1.03 Ω. It draws a current of 1.25A at no load with 50V supply and running at 2100 rpm. Find (i) Speed-voltage constant; (ii) rotational losses; and (iii) output power when it runs at 1700 rpm at 48V supply

Soln Given : $R_a = 1.03\,\Omega$; $I = 1.25A$; $V = 50V$; $N = 2100\,rpm$.

$E_b = V - I_a R_a$

$E_b = 50 - (1.03 \times 1.25)$

$E_b = 48.71\,V$

$\omega = \frac{2\pi N}{60} = \frac{2\pi \times 2100}{60} = 219.91\,rad/s$

$E_b = K_T \omega$

(i) $K_T = \frac{E_b}{\omega} = \frac{48.71}{219.91} = 0.2215\,V/rad/s.$

(ii) Rotational losses $= E_b I_a = 48.71 \times 1.25$

$= 60.89\,W.$

(iii) Output power when $N = 1700\,rpm$, $V = 48V$.

$K_T = 0.2215\,V/rad/s$, $\omega = \frac{2\pi N}{60} = \frac{2\pi \times 1700}{60} = 178.02\,rad/s.$

$E_b = K_T \omega = 0.2215 \times 178.02$

$E_b = 39.43\,V.$

$I_a = \frac{V - E_b}{R_a} = \frac{48 - 39.43}{1.03} = 8.32A$

Power developed $= E_b I_a = 39.43 \times 8.32 = 328.057\,W$

$\therefore P_{o/p} = 328.057 - 60.89$

$= 267.16\,W$

3) Derive the EMF equation of permanent magnet synchronous motor (PMSM).

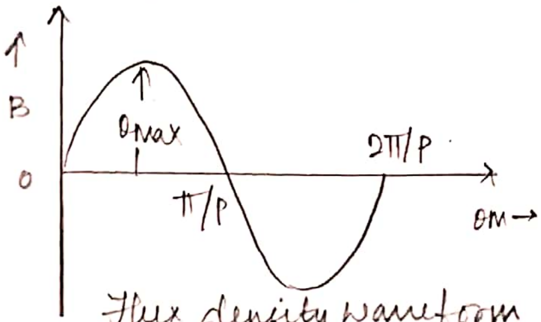
Soln <u>EMF Equation of PMSM :-</u>

Let B = flux density, Tesla

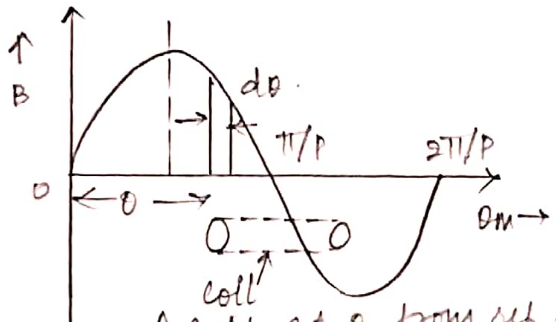
B_{max} = maximum flux density, Tesla.

P = number of pole pairs

ω_m = mechanical rotor velocity, rad/s.
θ_m = mechanical rotor position
ω_e = electrical rotor velocity
θ_e = electrical rotor position
e_{ph} = instantaneous emf per phase
E_{phmax} = Maximum emf per phase
E_{ph} = RMS value of induced emf per phase.
ϕ = flux, Wb (instantaneous)
Φ = flux / pole, Wb.
l = length of armature, m
r = radius of armature, m.
K_{s1} = skew factor for fundamental component
K_{p1} = Chording factor for fundamental component
K_{d1} = distribution factor for fundamental component.
K_{w1} = winding factor.
A = Ampere Conductor density.
A_{max} = Maximum ampere Conductor density.
T_{ph} = turns per phase.
f = frequency, Hz.
α = angle between the axis of ampere Conductor density and flux density distribution.



Flux density waveform



A coil at θ from ref axis

Flux density in the air gap of PMSM is represented as sine wave $B = B_{max} \sin P\theta$.

Incremental of flux in strip, $d\phi = B_{max} l r \sin P\theta \, d\theta$

Flux enclosed by the coil in the position shown is:

$$\phi = \int_{\omega_m t}^{\omega_m t + \pi/P} d\phi = \int_{\omega_m t}^{\omega_m t + \pi/P} B_{max} l r \sin P\theta \, d\theta .$$

$$\phi = B_{max}\, l r \left[-\frac{\cos P\theta}{P} \right]_{\omega_m t}^{\omega_m t + \pi/p}$$

(ie) $\phi = \frac{2 B_{max}}{p}\, l r \cos P\omega_m t$

The emf induced in single turn coil is given by

$$e_{turn} = -\frac{d\phi}{dt} = -\frac{d}{dt}\left[\frac{2 B_{max}\, l r}{P} \cdot \cos P\omega_m t\right]$$

$$= 2 B_{max}\, l r\, \omega_m \sin P\omega_m t$$

The emf induced per phase (instantaneous) is

$$e_{ph} = T_{ph} \times e_{turn}$$

$$= 2 B_{max}\, l r\, \omega_m T_{ph} \sin P\omega_m t$$

$$e_{ph} = 2 B_{max}\, l r\, \omega_m T_{ph} \sin P\omega_m t$$

$$e_{ph} = E_{phmax} \sin P\omega_m t$$

$$e_{ph} = E_m \sin \omega_e t$$

$$\omega_e = \omega_m \cdot P$$

$$\omega_m = \frac{\omega_e}{P}$$

$$E_{phmax} = 2 B_{max}\, r l\, T_{ph}\, \omega_m$$

Flux per pole, $\phi = B_{av} \times \frac{2\pi r}{2p} \cdot l$

$$B_{av} = \frac{2}{\pi} B_{max}$$

$$\phi = \frac{2}{\pi} B_{max} \frac{\pi r l}{P}$$

$$B_{max} \cdot r l = \frac{P\phi}{2}$$

$$E_{phmax} = 2 B_{max}\, r l\, T_{ph}\, \omega_m$$

$$E_{phmax} = 2 \cdot \frac{P\phi}{2} \cdot T_{ph} \cdot \frac{\omega_e}{P} = \phi T_{ph} \omega_e = 2\pi f \phi T_{ph}$$

$$E_{ph} = \frac{E_{phmax}}{\sqrt{2}}$$

$$E_{ph} = \sqrt{2}\pi f \phi T_{ph}$$

$$E_{ph} = 4.44 f \phi T_{ph} \rightarrow (1)$$

EMF eqn of PMSM if i) slots are not skewed ($K_{si} = 1$)

ii) winding are full pitched ($K_{pi} = 1$)

iii) winding are not distributed ($K_{di} = 1$)

$E_{ph} = 4.44 f \phi T_{ph} K_{pi} K_{di} K_{si}$

$E_{ph} = 4.44 f \phi T_{ph} K_{wi}$

$K_{wi} = K_{si} K_{pi} K_{di}$

$K_{si} = \frac{\sin \sigma/2}{\sigma/2}$.

$K_{ci} = \frac{\cos \delta}{2}$

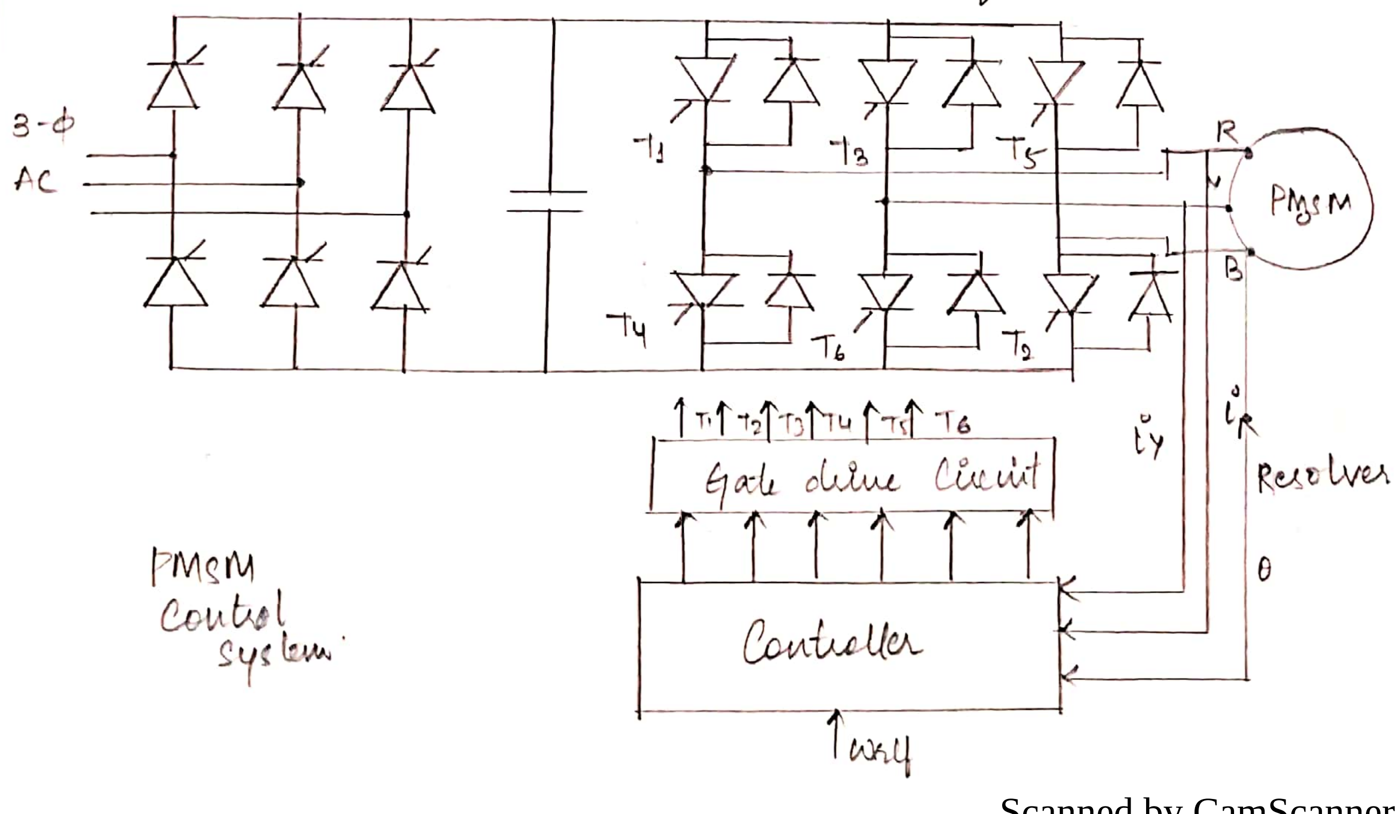
$K_{di} = \frac{\sin m\beta/2}{m \sin\beta/2}$

5) Explain with a neat circuit diagram the DSP based control of PMSM.

Soln.

DSP based control of PMSM :-

- It has a simple rectifier for converting input AC into DC and an inverter to supply the PMSM.
- The controller has the inputs, reference speed, ω_{ref}, rotor position signal θ and stator current signals i_R and i_Y. The controller outputs the signals for turning ON the SCRs. The main function of the controller is to generate appropriate triggering signals for the thyristors.



- Functions of the Controller can be achieved by using a DSP with simple software.
- The implementation of Controller using DSP is shown.
- The scheme is developed on the basis of vector control.

6.a) List any eight applications of SyRM.

Soln. Applications:

1) SyRM are used in pumps or conveyers for proportioning devices.
2) Synthetic fibre manufacturing industries.
3) In wrapping and folding machines.
4) For positioning of Control rods in nuclear reactors.
5) In synchronized textile drives.
6) For processing of continuous sheet or film material.
7) In constant speed applications such as recording instruments, control apparatus.
8) regulators, time devices, phonograph turn table & so on.

6.b) A 3-phase, 4 pole, star connected PMSM has 72 slots with 20 conductors/slot. The flux/pole is 0.05Wb and the speed is 1500rpm. Assuming full pitched coil, find the phase and line voltage. Assume $k_s = 1$ and $k_d = 0.986$.

Soln. Given: $3-\phi$, $P=4$, $\phi = 0.05Wb$, $N = 1500rpm$

$Z = 72 \times 20 = 1440$ Conductors.

$$T_{ph} = \frac{Z_{ph}}{2} = \frac{\frac{1440}{3}}{2} = 240$$

$$E_{ph} = 4.44 \times \phi \times f \times T_{ph} \times K_d \times K_s \times K_c$$

$$N = \frac{120f}{P} \Rightarrow f = \frac{PN}{120} = \frac{4 \times 1500}{120} = 50Hz$$

$E_{ph} = 4.44 \times 0.05 \times 50 \times 240 \times 1 \times 1 \times 0.986$

$E_{ph} = 2626.704$ V.

$E_L = \sqrt{3} \times E_{ph} = \sqrt{3} \times 2626.704$

$E_L = 4549.58$ V.

4) A 3-phase, 4 pole, 50 Hz, 400 V star connected synchronous reluctance motor (SyRM) has direct axis and quadrature axis synchronous reactance of 8 Ω & 2 Ω respectively. For a load torque of 80 N-m. Find i) load angle ii) Line current and iii) power factor neglect armature resistance & mechanical losses.

Soln Given: 3φ, P=4, $V_L = 400$ V, $X_{ds} = 8\,\Omega$, $X_{qs} = 2\,\Omega$, $\tau = 80$ N-m

Star Connected, $V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{400V}{\sqrt{3}} = 230.94$ V.

(i) $\tau = \frac{3}{\omega_s} V_{ph}^2 \frac{X_{ds} - X_{qs}}{2 X_{ds} X_{qs}} \sin 2\delta$

$\omega_s = \frac{2\pi f}{P/2} = \frac{2\pi \times 50}{4/2} = 157.079$ rad.

$\sin 2\delta = \frac{80 \times 157.079 \times 2 \times 8 \times 2}{3 \times (230.94)^2 \times (8-2)} = 0.4188$

$2\delta = 24.76 \Rightarrow \boxed{\delta = 12.38°}$

ii) $I_{ph} = I_L = \sqrt{I_d^2 + I_q^2}$

$I_d = \frac{V \cos\delta}{X_{ds}} = \frac{230.94 \times \cos(12.38)}{8} = 28.19$ A.

$I_q = \frac{V \sin\delta}{X_{qs}} = \frac{230.94 \times ~~\cos~~ \sin(12.38)}{2} = 24.75$ A.

$I = \sqrt{(28.19)^2 + (24.75)^2} = 37.51$ A

(iii) $P = \sqrt{3} V_L I_L \cos\phi$

$\tau = \frac{P}{\omega_s} \Rightarrow P = \tau \omega_s = 80 \times 157.079 = 12566.32$ W.

$\cos\phi = \frac{12566.32}{\sqrt{3} \times 400 \times 37.51} = 0.4835$.