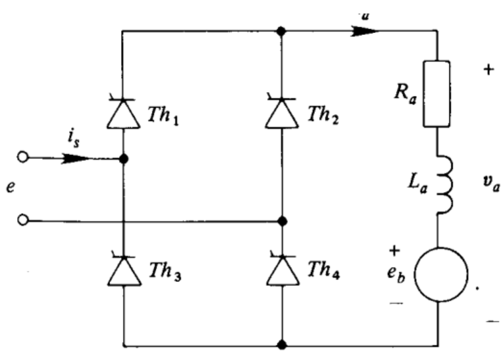
Application to motor control

1. A single-phase full converter is used to control the speed of small separately excited d.c. motor rated at 5 hp, 110V, 1200 rpm as shown in Fig.1. The converter is connected to a single – phase 120 V, 50 Hz supply. The armature resistance is Ra = 0.40 ohm and the armature circuit inductance is La = 5 mH. The motor voltage constant is Ke Φ = 0.09 V/rpm.

With the converter operates as a rectifier , the d.c. motor runs at 1000 rpm and carries an armature current of 30 A . Assume that the motor current is continuous, determine:

(a) The firing angle α.
(b) The power delivered to the motor.
(c) The supply power factor.

Fig.1

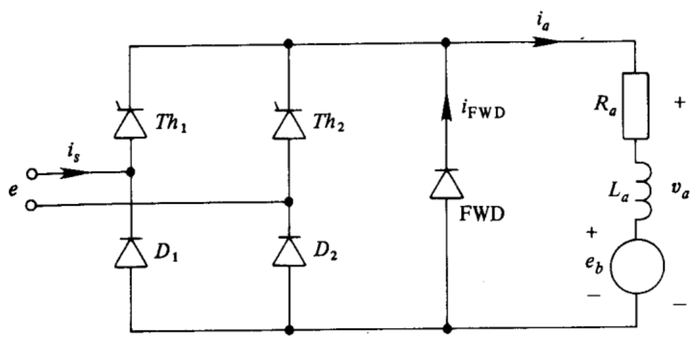


2. A single-phase semiconverter , shown in Fig.2 , is used to control the speed of small separately excited d.c. motor rated at 4.5 kW, 220V, 1500 rpm. The converter is connected to a single – phase 230 V, 50 Hz supply. The armature resistance is Ra = 0.50 ohm and the armature circuit inductance is La = 10 mH. The motor voltage constant is Ke Φ = 0.1 V/rpm.

With the converter operates as a rectifier , the d.c. motor runs at 1200 rpm and carries an armature current of 16 A . Assume that the motor current is continuous and ripple-free, determine:

(d) The firing angle α.
(e) The power delivered to the motor.
(f) The supply power factor.

Fig.2



3. A d.c. permanent magnet motor has the following parameters:

Ra = 3 Ω , Ke = 0.52 V/rpm.wb , Φ (flux per pole) = 150 mWb.

The motor speed is controlled by a full wave bridge rectifier. The firing angle α is set at 45°, and the average speed is 1450 rpm. The applied a.c. voltage to the bridge is vs=330sinωt volts. Assuming the motor current is continuous; calculate the armature current drawn by the motor and the steady-state torque for the cases of:

(a) Fully controlled brdge

(b) Half-controlled (semiconverter) bridge.

Note : Ea = Ke Φ n , T= K_T Φ Ia , K_T = 9.55 Ke , n = speed in rpm.

[Ans : (a) Ia= 11.8 A, T = 8.79 N.m , (b) Ia=22A,T=16.38 m]

4. A 100 hp , 1750 rpm , d.c. shunt motor has an armature inductance of 1.1 mH, a resistance of 0.0144 Ω and an armature voltage constant of 1.27 volt –sec /rad. The motor is operated from a 3 – phase half-wave controlled – rectifier at rated armature current of 340 A. Find the firing angle α, assuming that the supply voltage is 480 V and the motor speed is 1750 rpm. Consider the thyristors to have a forward voltage drop of 1 Volt and assume continuous conduction.

[α = 42.6°]

5. The speed of 10 hp, 230V 1200 rpm separately excited d.c. motor is controlled by single-phase fully controlled full-wave rectifier bridge. The rated armature current is 38A, Ra = 0.3 ohm ,the ac supply voltage = 260V.The motor voltage constant is Ke Φ = 0.182 V/rpm .Assume sufficient inductance is present in the armature circuit to make Ia continuous and ripple-free:

(a) For α = 30° and rated motor current calculate,

(i) motor torque (ii) motor speed (iii) supply power factor

(b) the polarity of the armature emf is reversed say by reversing the field excitation ,calculate :

(i) the firing angle to keep the motor current at its rated value .

(ii) the power fed back to the supply.

[Ans: (a) (i) 66.12 N.m ,(ii) 1051.8 rpm,(iii) p.f=0.78, (b) (i) α = 140°,(ii) 6840 W]

6. The speed of a 125 hp, 600 V, 1800 rpm, separately excited d.c. motor is controlled by a three-phase fully controlled full- converter (6-pulse converter). The converter is operating from a 3 – phase 480, 60 Hz supply. The rated armature current of the motor is 165 A. The motor parameters are:

Ra = 0.0874Ω La = 6.5 mH , Ke Φ = 0.33 V/rpm

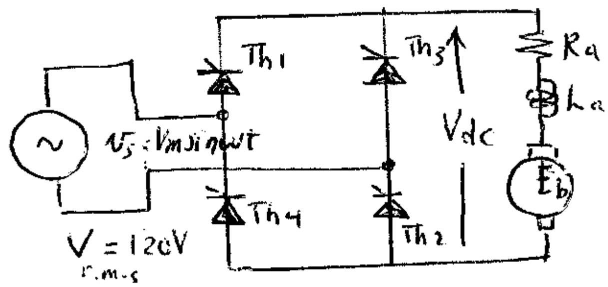
(a) Find no – load speeds at firing angles α = 0° and α = 30° .Assume that ,at no load, the armature current is 10% of the rated current and is continuous .

(b) Find the firing angle to obtain the rated speed of 1800 rpm at rated motor current.

[Ans: (a) 1959 rpm, 1696 rpm, (b) α = 20.1°]

Typical problem Solutions

Question 1



(a) $E_a = K_e \phi n$

$= 0.09 \times 1000 = 90V$

$V_a = V_{dc} = E_a + I_a R_a$

$= 90 + 30 \times 0.4 = 102V.$

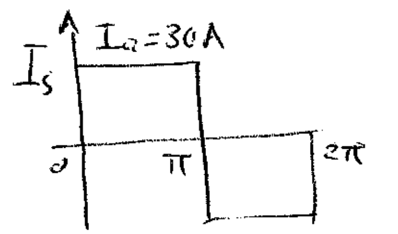
We have for the full-wave full-converter:

$$V_{dc} = V_a = \frac{2V_m}{\pi}\cos\alpha = \frac{2\times\sqrt{2}\times 120}{\pi}\cos\alpha = 102$$

$$\therefore \cos\alpha = \frac{102\,\pi}{2\sqrt{2}\times 120} \quad \text{or} \quad \alpha = 19.2^\circ.$$

(b) $P = V_a I_a = 102 \times 30 = 3060W.$

(c) The supply current has a square wave with amplitude $I_a = 30$ A.

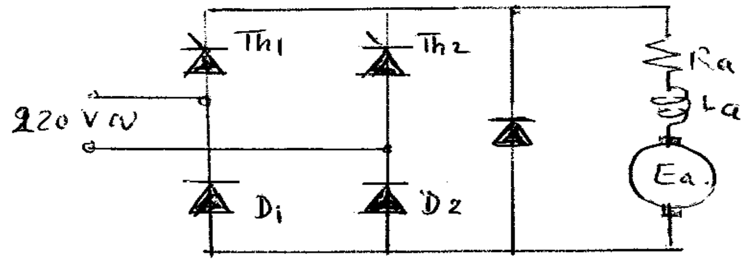


$$I_s = \sqrt{\frac{1}{\pi}\int_0^{\pi}(I_a)^2\,d\omega t} = I_a = 30A.$$

The supply VA $= S = 120 \times 30 = 3600$

$$\therefore \text{power factor} = \frac{\text{Active Power (W)}}{\text{Apparent Power (VA)}} = \frac{3060}{3600} = 0.85$$

Question 2



(a) $E_a = K_e \phi n$

$= 0.1 \times 1200$

$= 120 \, V.$

$V_a = V_{dc} = E_a + I_a R_a$

$= 120 + 16 \times 0.5 = 120 + 8 = 128 \, V.$

For Half-Controlled (Semiconverter) rectifier:

$$V_a = V_{dc} = \frac{V_m}{\pi}(1 + \cos\alpha)$$

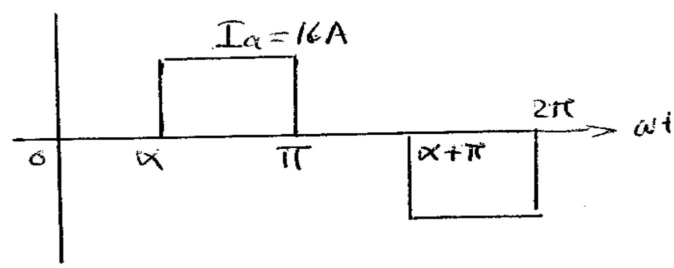
$$= \frac{\sqrt{2} \times 220}{\pi}(1 + \cos\alpha) = 128$$

$\cos\alpha = 1.292 - 1.0 = 0.292$

$\therefore \alpha = 73.0^\circ$

(b) $P = V_a I_a = 128 \times 16 = 2048 \, W.$

(c) The supply current is shown in Figure below



$$I_{s_{r.m.s}} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}(I_a)^2 d\omega t}$$

$$= \sqrt{\frac{I_a^2}{\pi}\left[\omega t\right]_{\alpha}^{\pi}}$$

$$= I_a \sqrt{\frac{\pi - \alpha}{\pi}} = 16\sqrt{\frac{\pi - \left[73 \times \frac{\pi}{180}\right]}{\pi}} = \sqrt{\frac{3.14 - 1.27}{3.14}}$$

$= 12.33 \, A.$

The supply VA $= 220 \times 12.33 = 2712.91$

$$\therefore P.f = \frac{W}{VA} = \frac{2048}{2712.91} = \underline{0.7549}.$$

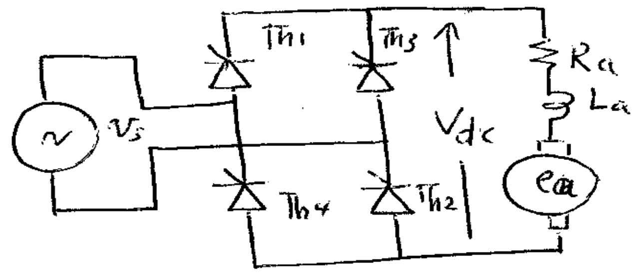
Q3.

(a) For Fully - controlled bridge

$V_{dc} = \frac{2V_m}{\pi} \cos\alpha$

$= \frac{2 \times 330}{\pi} \cos 45^\circ$

$= 148.53V.$



$V_{dc} = V_t = E_a + I_a R_a$

$148.53 = K_e \phi n + I_a \times 3$

$= 0.52 \times 0.15 \times 1450 + 3 I_a.$

$\therefore I_a = 11.81\ A.$

$K_T = 9.55\ K_e = 4.966$

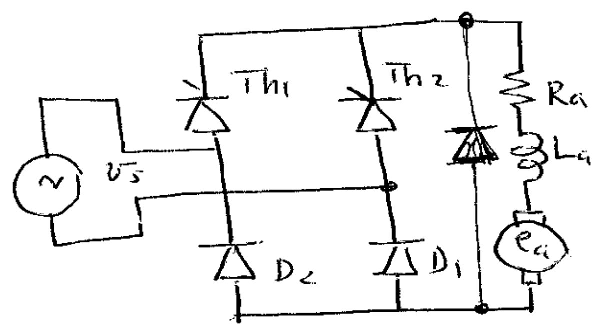
$T = K_T I_a \phi = 4.966 \times 0.15 \times 11.81 = 8.79\ N.m.$

(b) For Semiconverter (half-controlled)

$V_{dc} = \frac{V_m}{\pi}(1 + \cos\alpha)$

$= \frac{330}{\pi}(1 + 0.707)$

$= 179.307$ Volts.



$V_{dc} = E_a + I_a R_a$

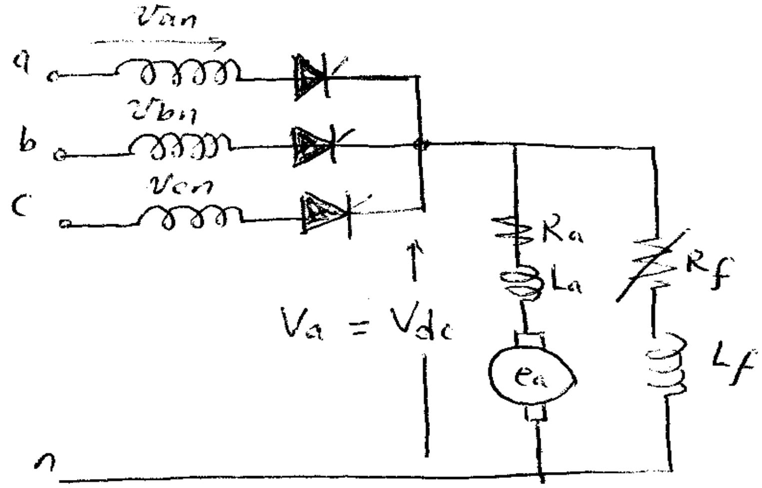
$179.307 = K_e \phi n + 3 I_a$

$= 0.52 \times 0.15 \times 1450 + 3 I_a$

$\therefore I_a = 22\ A.$

$T = 4.966 \times 0.15 \times 22 = 16.38\ Nm.$

Q4.



Speed of the motor in r.p.m:

$n = 1750$ rpm.

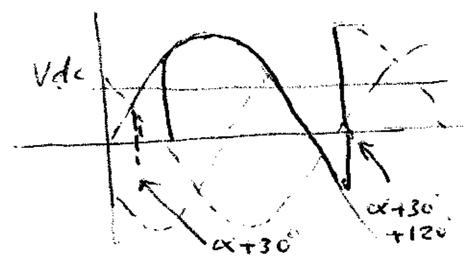
Change the speed from rpm to rad/sec:

$$\omega = \frac{2\pi n}{60} = \frac{2\pi}{60} \times 1750 = 183.25 \text{ rad/sec.}$$

Armature voltage constant $K'_e = \frac{E_a}{\omega} = 1.27$ V.

$\therefore \quad E_a = 183.25 \times 1.27 = 232.72$ V.

$$V_{dc} = \frac{1}{\frac{2\pi}{3}} \int_{\alpha+30^\circ}^{\alpha+30^\circ+120^\circ} V_m \sin\omega t \, d\omega t$$



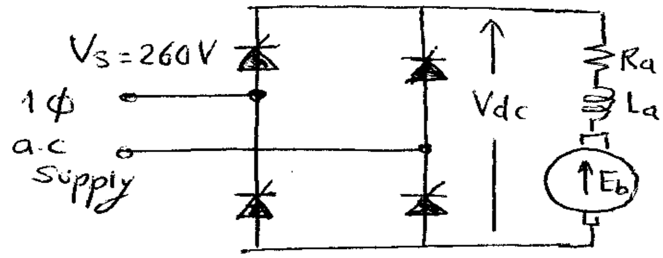
$$= 324.1 \cos\alpha$$

$V_a = E_a + I_a R_a + \Delta V_b$ ← brush drop

$$324.1 \cos\alpha = 232.7 + 14.4 \times 10^{-3} \times 340 + 1$$

$$\therefore \alpha = 42.6^\circ$$

Question 5



(a) Torque Calculation:

(i) $T_e = K_T \phi I_a$

$K_e\phi = 0.182$ V/rpm.

but $K_T\phi = K_e\phi \times 9.55$

$= 0.182 \times 9.55 = 1.74$

$\therefore K_T\phi I_a = T = 1.74 \times 38 = \underline{66.1}$ N.m [2M]

(ii) Speed Calculation:

For Full-wave fully-controlled rectifier:

$$V_{dc} = \frac{2\sqrt{2}V}{\pi}\cos\alpha = \frac{2\sqrt{2}\times 260}{\pi}\cos 30^\circ = 202.82V.$$

$$E_b = V_{dc} - I_a R_a = 202.82 - 38\times 0.3 = 191.4V.$$

Since $E_b = K_e\phi n$ $\therefore$ $n = \frac{E_b}{K_e\phi} = \frac{191.4}{0.182} = \underline{1051}$ rpm.

[2M]

(iii) Power factor calculation:

$$PF = \frac{V_{dc} I_a}{V_s I_a} = \frac{V_{dc}}{V_s} = \frac{202.8}{260} = 0.78$$ [2M]

(b) (i) when the polarity reversed on the motor terminals

$$E_b' = -E_b = -191.42 V.$$

$$\therefore V_{dc}' = E_b' - I_a R_a = -191.42 - 38\times 0.3 = -180V.$$

$$V_{dc}' = \frac{2\sqrt{2}\times 280}{\pi}\cos\alpha = -180 \Rightarrow \alpha = 140^\circ$$ [2M]

(ii) power fedback to the supply:

$$P = V_{dc}' I_a = -180\times 38 = 6840.7 W.$$

$\cong \underline{6.84}$ KW [2M]

Tutorial sheet No. 6

Q. 6 :

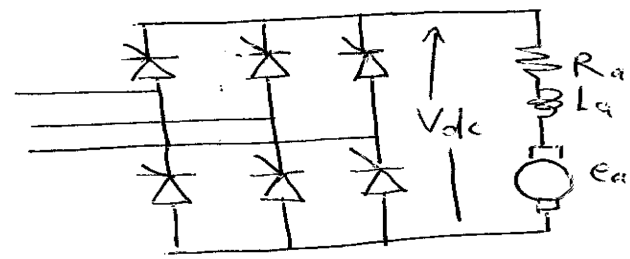
(a) No-load Condition : The supply phase current

$$V_{ph} = \frac{480}{\sqrt{3}} = 277\ V.$$

$$V_{ph(max)} = \sqrt{2} \times 277.$$

For full-wave fully-controlled Rectifier bridge

$$V_{dc} = \frac{3\sqrt{3}\, V_{ph(max)}}{\pi} \cos\alpha$$



$$= \frac{3\sqrt{3} \times \sqrt{2} \times 277}{\pi} \cos\alpha$$

$$= 648 \cos\alpha$$

For $\alpha = 0^\circ$

$V_{dc} = V_a$.

$E_a = V_a - I_a R_a = 648 - (16.5 \times 0.0874)$

$= 646.6\ V.$

No-load speed is

$$n_o = \frac{E_a}{K_e \phi} = \frac{646.6}{0.33} = 1959\ rpm$$

For $\alpha = 30^\circ$ $V_a = 648 \cos 30^\circ = 561.2\ V.$

$E_a = 561.2 - (16.5 \times 0.0874) = 559.8\ V$

The no load speed is:

$$n_o = \frac{559.8}{0.33} = 1696\ rpm.$$

(b) Full-load Condition: At 1800 rpm :

$E_a = 0.33 \times 1800 = 594\ V$

$V_a = 594 + (165 \times 0.0874) = 608.4\ V.$

$\therefore\ 648 \cos\alpha = 608.4$

or $\alpha = 20.1^\circ.$

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