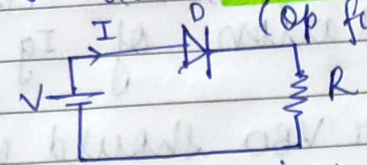
- Simulation
- Derivation
- Explanation of working

7/1/25

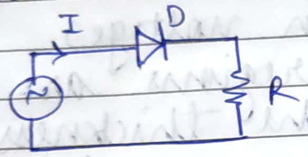
SCR

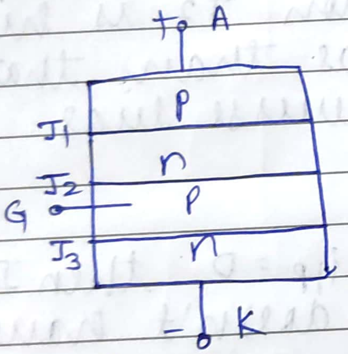
- SCR triggering has a range of about 10°-15° to ~170° (op fixed)

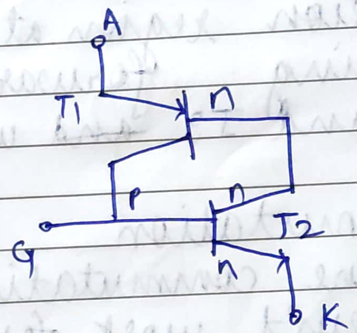


- As operating point of diode shifts, so does its resistance.

$\frac{\Delta V}{\Delta I}$ = dynamic







as $I_e \uparrow$, $\alpha \uparrow$ (<1)

$$I_b = \frac{I_{co}}{1-(\alpha_1+\alpha_2)}$$

Q. Why not give extremely high Ig at all points (100 mA) without giving 10 – 20 – 30 mA steps?

Ans 1. Device can get damaged, due to extreme increase of current, due to heating of device which can lead to breakdown of insulation.

2. Characteristics of the device can be regulated and maintained linearly if steps of incrementation is done.

3. More dependence on the device results can be maintained if the accuracy and control is taken care by steps incrementation of I_g.

Q. Logically V_{BR} or V_{BO} should be higher?

Ans: In SCR V_{BO} is greater than V_{BR}.

V_{BO} (Breakover voltage)

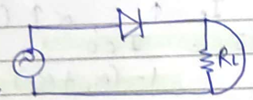
V_{BR} (Reverse) (Breakdown voltage)

→ The inner two p-n regions are lightly doped due to which the thickness of the depletion region at junction J_2 is higher during forward bias than that of J_1 and J_3 ~~and~~ under reverse bias.

Commutation

① Line commutation : $I_{i/p} = 0$ then $I_0 (< I_H) = 0$

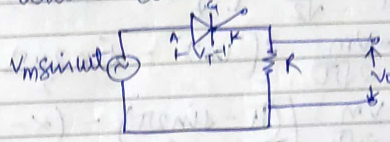
(doesn't work for DC → doesn't have natural $I_{DC} = 0$)

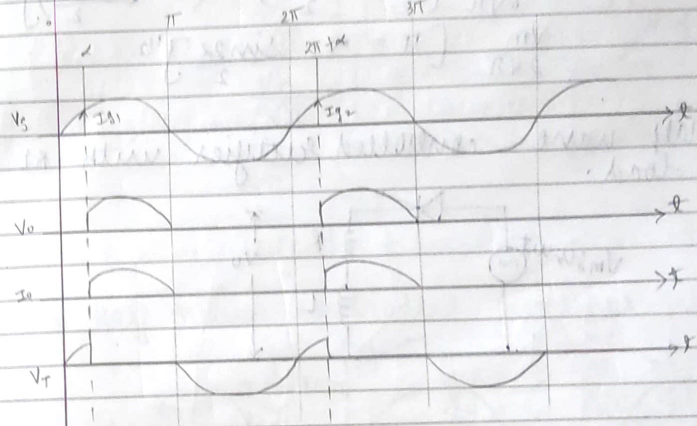


If load gets shorted SCR cant switch off.

Q: Draw neat ckt diagram & input output waveform for
i) Half wave controlled rectifier (R-RL-RE)
ii) Full wave controlled Rectifier
iii) Full wave bridge half & full controlled rectifier
iv) Define the output voltage for R, RL and RE load.

i) Half wave controlled rectifier with R load





* Avg output voltage

$$V_o = \frac{1}{2\pi}\int_\alpha^\pi V_m \sin\omega t \, d\omega t$$

$$= \frac{V_m}{2\pi}\int_\alpha^\pi \sin\omega t \, d\omega t$$

$$= \frac{V_m}{2\pi}\left\{-[\cos\pi - \cos\alpha]\right\}$$

$$= \frac{V_m}{2\pi}[1 + \cos\alpha]$$

* V_{rms}

$$= \left[\frac{1}{2\pi}\int_\alpha^\pi V_m^2 \sin^2\omega t \, d\omega t\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}}\left[\int_\alpha^\pi \sin^2\omega t \, d\omega t\right]^{1/2}$$

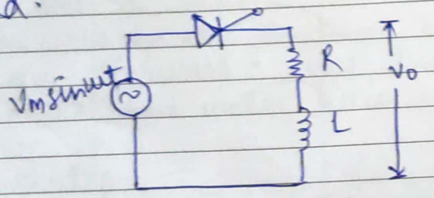
$$= \frac{V_m}{\sqrt{2\pi}} \times \frac{1}{\sqrt{2}} \left[\int_\alpha^\pi (1-\cos 2\omega t)\, d\omega t\right]^{1/2}$$

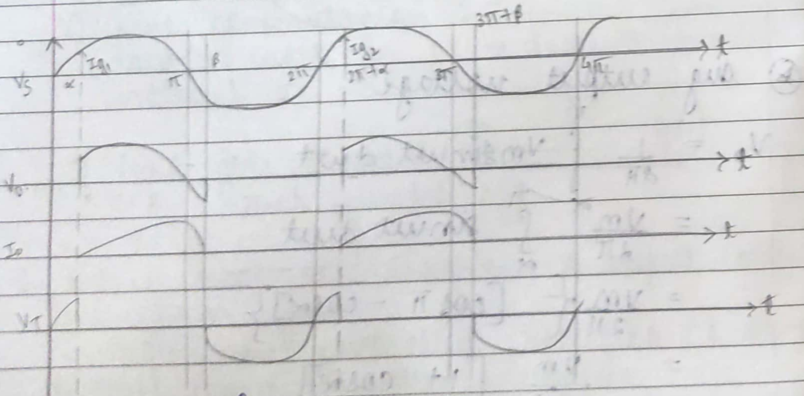
$$= \frac{V_m}{2\sqrt{\pi}} \left\{\left[\omega t - \frac{\sin 2\omega t}{2}\right]_\alpha^\pi\right\}^{1/2}$$

$$= \frac{V_m}{2\sqrt{\pi}} \left[\left(\pi - \frac{\sin 2\pi}{2}\right) - \left(\alpha - \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{V_m}{2\sqrt{\pi}} \left[\pi - \alpha - \frac{\sin 2\alpha}{2}\right]^{1/2}$$

2) Half wave controlled rectifier with RL load.





② $$V_o = \frac{V_m}{2\pi} \int_\alpha^\beta \sin\omega t\, d\omega t$$

$$= \frac{-V_m}{2\pi} (\cos\omega t)_\alpha^\beta$$

$$= \frac{V_m}{2\pi} (\cos\alpha - \cos\beta)$$

④ $$V_{rms} = \left[\frac{1}{2\pi} \int_\alpha^\beta V_m^2 \sin^2 \omega t\, d\omega t\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}} \times \frac{1}{\sqrt{2}} \left[\int_\alpha^\beta (1-\cos 2\omega t)\, d\omega t\right]^{1/2}$$

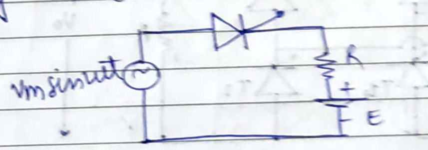
$$= \frac{V_m}{2\sqrt{\pi}} \left\{\left[\omega t - \frac{\sin 2\omega t}{2}\right]_\alpha^\beta\right\}^{1/2}$$

$$= \frac{V_m}{2\sqrt{\pi}} \left[\left(\beta - \frac{\sin 2\beta}{2}\right) - \left(\alpha - \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{V_m}{2\sqrt{\pi}} \left[(\beta-\alpha) - \frac{\sin 2\beta}{2} + \left(\frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

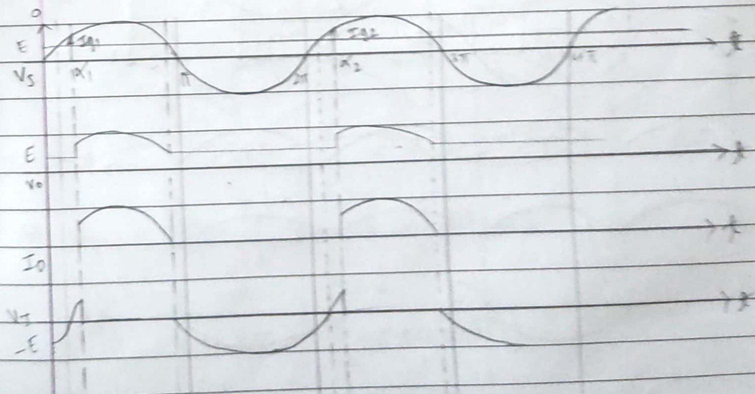
$$= \frac{V_m}{2\sqrt{\pi}} \left[(\beta-\alpha) - \frac{\sin 2\beta}{2} + \frac{\sin 2\alpha}{2}\right]^{1/2}$$

3) Half wave controlled rectifier with RE load



$V_s > E \rightarrow T$ (FB)

$V_s < E \rightarrow T$ (RB)



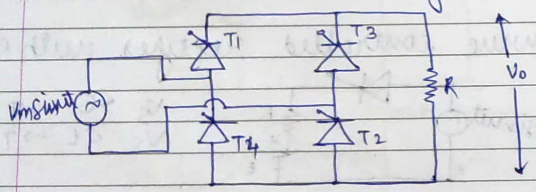
$$v_0 = \frac{1}{2\pi}\left[\int_0^{\alpha} E\,d\omega t + \int_{\alpha}^{\pi-\theta} V_m \sin\omega t\,d\omega t + \int_{\pi-\theta}^{2\pi} E\,d\omega t\right]$$

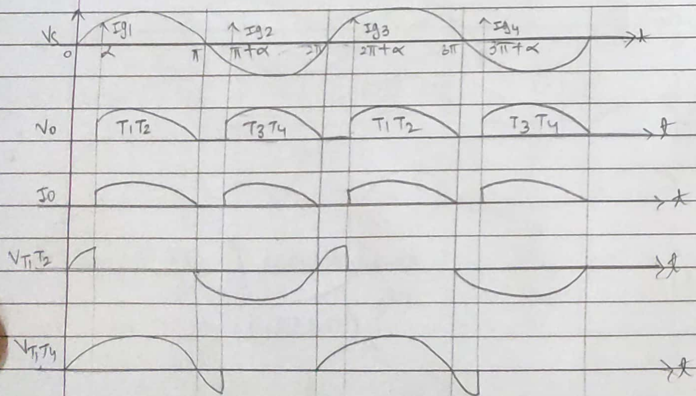
$$= \frac{1}{2\pi}\left[E\alpha + V_m(-\cos(\pi-\theta) + \cos\alpha] + E(\pi+\theta)\right]$$

$$= \frac{1}{2\pi}\left\{[E(\alpha+\pi+\theta)] + V_m(\cos\theta + \cos\alpha)\right\}$$

$$V_{rms} = \frac{1}{2\pi}\left[\int_0^{\alpha} E^2\,d\omega t + \int_{\alpha}^{\pi-\theta} V_m^2 \sin^2\omega t + \int_{\pi+\theta}^{2\pi} E^2\,d\omega t\right]^{1/2}$$

4) Full wave controlled rectifier with R load.





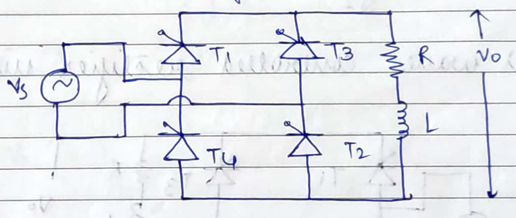
$$v_{0\,avg} = \frac{V_m}{\pi}\int_{\alpha}^{\pi} \sin\omega t\,d\omega t$$

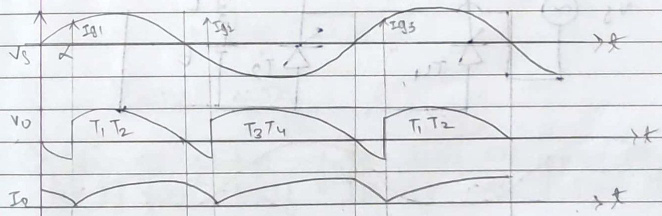
$$= \frac{V_m}{\pi}(1+\cos\alpha).$$

$$V_{rms} = \left[\frac{1}{\pi}\int_0^{\pi} V_m^2 \sin^2\omega t\,dt\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{\pi}}\left[\pi - \alpha - \frac{\sin 2\alpha}{2}\right]^{1/2}$$

5) Full wave rectifier with RL load.





$$V_0 = \frac{V_m}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin\omega t\,d\omega t$$

$$= \frac{V_m}{\pi}\left[-(\cos\omega t)\right]_{\alpha}^{\pi+\alpha}$$

$$= \frac{V_m}{\pi}(2\cos\alpha)$$

$$V_{rms} = \left[\frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m^2 \sin^2 \omega t \, d\omega t\right]^{1/2}$$

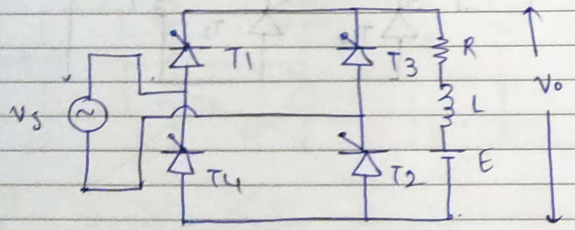
$$= \frac{V_m}{\sqrt{2\pi}} \left\{\left[\int_{\alpha}^{\pi+\alpha} (1-\cos 2\omega t)\, d\omega t\right]\right\}^{1/2}$$

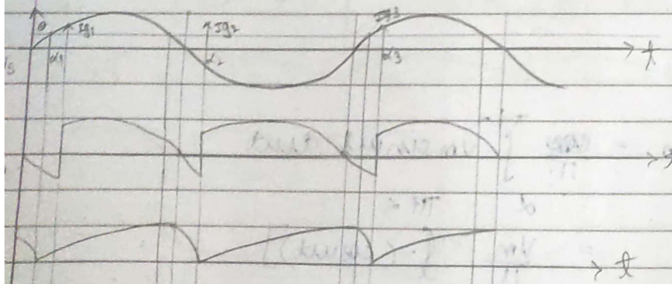
$$= \frac{V_m}{\sqrt{2\pi}} \left\{\left[\omega - \frac{\sin 2\omega}{2}\right]_{\alpha}^{\pi+\alpha}\right\}^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}} \left[\pi+\alpha - \frac{\sin 2(\pi+\alpha)}{2} - \left(\alpha - \frac{\sin 2\alpha}{2}\right)\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2}}$$

6) Full wave controlled rectifier with RLE



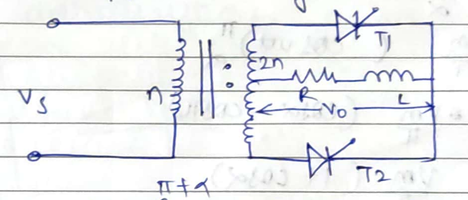


$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d\omega t$$

$$= \frac{V_m}{\pi}(2\cos\alpha)$$

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

7) 1 phase full wave controlled rectifier with joint tapped transformer configuration

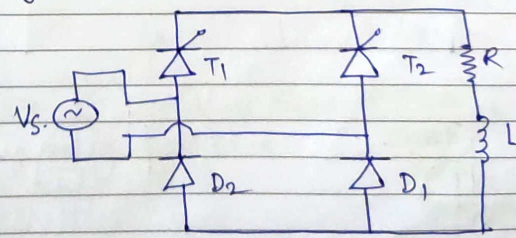


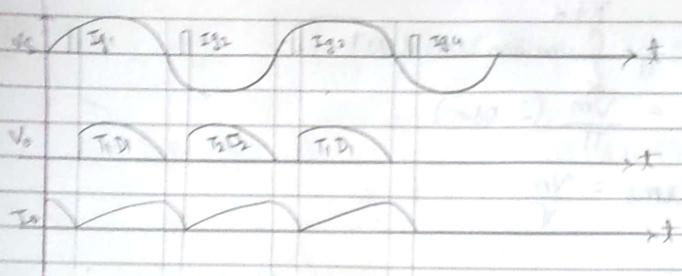
$$V_0 = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_m \sin \omega t \, d\omega t$$

$$= \frac{V_m}{\pi}\, 2\cos\alpha$$

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

8) Single phase full wave controlled rectifier Half bridge controlled config:-





$$V_0 = \frac{1}{\pi}\int_\alpha^\pi V_m \sin\omega t \, d\omega t$$

$$= \frac{-V_m}{\pi}(\cos\omega t)_\alpha^\pi$$

$$= \frac{V_m}{\pi}(\cos\alpha - \cos\pi)$$

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

$$V_{rms} = \frac{V_m}{\sqrt{\pi}}\left[\int_\alpha^\pi \sin^2\omega t \, d\omega t\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}}\left[\left(\omega - \frac{\sin 2\omega}{2}\right)_\alpha^\pi\right]^{1/2}$$

$$= \frac{V_m}{\sqrt{2\pi}}\left[\pi - \alpha - \frac{\sin 2\alpha}{2}\right]^{1/2}$$

10/1/25

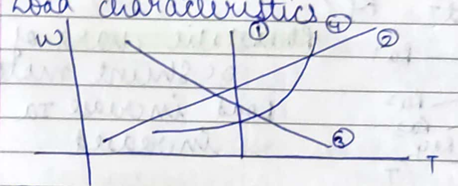
Drives

parts of drives

- controller, power source, load, feedback
- DC motor principle → current carrying conductor placed in magnetic field experiences force.

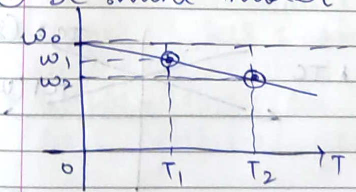
(*) Sources & loads have different characters. but if source & load charac dont match, no operating point [Require 1 intersecting pt]

* Load characteristics

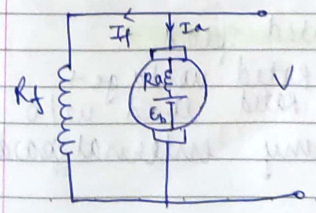


① 'ω' varies but 'T' const
② 'T' increases linearly with 'ω'
③ linear falling
④ x^2 chara (fan load)

(*) DC shunt motor



Source load chara known, then operating point gives speed of drive for particular torque.



$$\boxed{E_b = \frac{P\phi ZN}{60A}} = K\phi N = V - I_aR_a$$

$$K\phi N = V - I_aR_a$$

$$N = \frac{V}{K\phi} - \frac{I_aR_a}{K\phi}$$

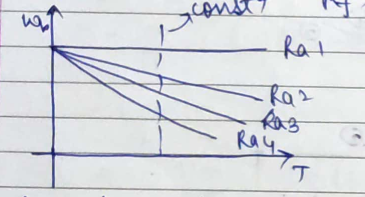
$$\left\{ \omega = \frac{V}{K\phi} - \frac{I_a r_a}{K\phi} \right\}$$ In terms I_a

* $T = K'\phi I_a$

$$I_a = \frac{T}{K\phi}$$

$$\omega = \frac{V}{K\phi} - \frac{T r_a}{K'\phi^2}$$ In terms T

- DC shunt is called constant flux machine
  (I_f is const $= \frac{V}{R_f}$)

- 

Rheostatic chara of DC shunt motor

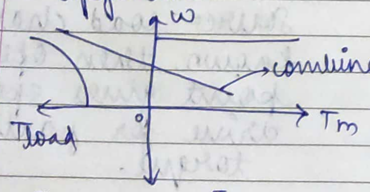
Load increase I_a increased

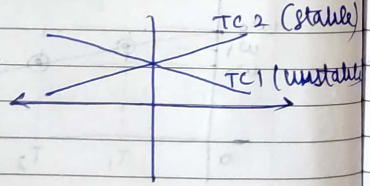
by changing Ra values

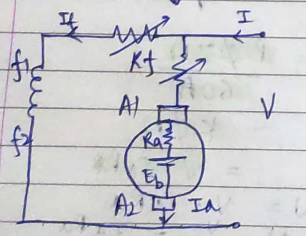
→ for const torque, we can get diff speed

→ for const speed, we get diff torque

- Load torque & source torque are equal & opposite







Rated speed

→ Rated voltage + Rated load w/o any external parameters

No load speed

→ Vrated + no ext para + no load

Speed control

→ To change speed

i) Decrease E_b by increasing R
($E_b = V - I_aR_a$) $E_b \propto N$

ii) Increase load to decrease E_b & speed
Load ↑ ω↓ E_b↓ $I_a = \left(\frac{V - E_b}{R_a}\right)$↑

iii) Voltage ↑ ω↑ but winding insulation can get damaged

iv) $N = \frac{V - I_aR_a}{K\phi}$, ϕ↓ N↑

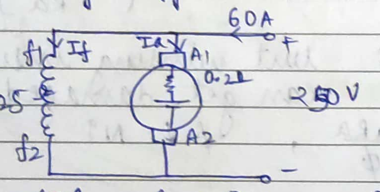
Can't increase speed this way too much, as mechanical structure won't be able to cope.

Losses.

* Hysterisis loss depends on:
  material, f^2, size of core, voltage, flux
* Eddy current loss
  core gets induced, circulating current
* copper loss: ~~air~~ in windings (F & A)
  but I_f is low, so we neglect it (I^2R)
* windage loss: air around shaft needs to be displaced for rotation.

** If loss ↑ heat ↑ temp of machine ↑
ϕ↓ T↓ ∴ $T \propto I_a\phi$

Q1) 250V DC shunt motor takes line current of 60A, while running at 800 rpm. $R_a = 0.2\,\Omega$, $R_f = 125\,\Omega$, brush drop 1V / ~~each~~ brush
① find No load speed if it makes 6 Amp current ~~at~~ at no load from supply.
② Also find percentage reduction in flux if speed is 1000 rpm & $I_a = 40A$



$I_1 = 60A$, $R_a = 0.2\,\Omega$, $R_f = 125\,\Omega$

① No load, $I_1 = 6A$

$$I_f = \frac{250}{125} = 2A$$

$I_{a0} = 6 - 2 = 4A$

$E_{b0} = V - I_{a0}R_a - 2 = 250 - 4\times0.2 - 2$ (Brush drop)

$= 249.2 - 2$

$= \boxed{247.2}$

For given data

$I_1 = 60A$

$I_f = 2A$

$I_a = 60 - 2 = \boxed{58A}$

$E_{b1} = V - I_{a1}R_a - 2$

$= 250 - 58\times0.2 - 2$

$= 236.2\ V$

since ϕ is const

$$\frac{E_{b1}}{E_{b0}} = \frac{N_1}{N_0}$$

$$\frac{236.2}{247.2} = \frac{800}{N_0}$$

$\therefore (N_0 = 838\ rpm)$

② $N_2 = 1000$ rpm

$I_{a_2} = 40A$

$E_{b2} = V - I_{a_2}R_a - 2$

$= 250 - 40\times0.2 - 2$

$= 240\ V$

Let the flux be ϕ_2

$$\frac{\phi_1}{\phi_2} \times \frac{E_{b2}}{E_{b1}} = \frac{N_2}{N_1}$$

$$\therefore \frac{\phi_1}{\phi_2} = \frac{1000}{800} \times \frac{236.2}{240}$$

$E = \phi N$

$$\frac{\phi_2}{\phi_1} = 0.812$$

$\therefore$ % flux deviation

$(1 - 0.812) \times 100 = 18.8\%$

Q2) A 230 ~~280~~ V dc shunt motor drives a load whose torque is proportional to speed. Neglecting armature resistance it takes 30A & running at 750 rpm. Find the speed at which it will run when a 10Ω resistance is inserted in series with armature.

∴ Solution

$E_{b2} = V - I_a r_a$

$= 230 - I_2 \times 10$

Since flux is const not changed

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

- Output power developed proportional to NT
- Electrical power developed $= E_b I_a$

Equating

$E_b I_a = NT$ $\left[T = \frac{E_b I_a}{N}\right]$

$$\frac{T_2}{T_1} = \frac{E_{b2} I_2/N_2}{E_{b1} I_1/N_1} = \frac{E_{b2} I_2}{E_{b1} I_1} \times \frac{N_1}{N_2}$$

→ We also know that the load is having characteristics whose torque is proportional to speed.

$$\frac{T_2}{T_1} = \frac{N_2}{N_1}$$

So, $$\frac{E_{b2} I_a}{E_{b1} I_a} = \left(\frac{N_2}{N_1}\right)^2$$

However $$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{I_{a2}}{I_{a1}} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{I_{a2}}{30} = \frac{230 - I_{a2} 10}{230}$$

$$230 I_{a2} = 690 - 300 I_{a2}$$

$$\boxed{I_{a2} = 13.02 A}$$

$$\frac{N_2}{750} = \frac{230 - 13.02 \times 10}{230}$$

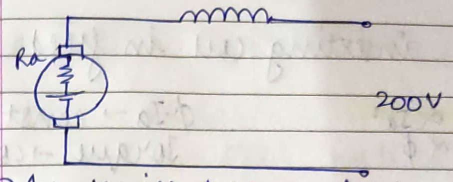
$$N_2 = 750 \frac{(230 - 1302 \times 10)}{230}$$

$$\boxed{N_2 = 825.45 \text{ rpm}}$$

Q3) 200V DC ~~shunt~~ series motor when operating at its full load current is 20 A & runs at 700 rpm. The total motor resistance that is $R_a + R_{se} = 0.5\,\Omega$

① What is speed if the load torque is increased by 44%.

② when the total current is 10A.



① In series DC motors

$R_a + R_{se} = 0.5\,\Omega$

$T \propto \phi I_a$

$\phi \propto I_a$

$T \propto I_a^2$

$T_1 \propto I_{a1}^2$

$T_2 \propto I_{a2}^2$

$T_2 = 1.44\, T_1$

$$1.44 = \left(\frac{I_{a2}}{I_{a1}}\right)^2$$

$1.44 \times 20^2 = I_{a2}^2$

$I_{a2} = \sqrt{1.44 \times 20^2}$

$I_{a2} = 24A$

$E_{b1} = V - I_a r_a = 200 - 20 \times 0.5 = 180\,V$

$E_{b2} = V - I_a r_a = 200 - 24 \times 0.5 = 188\,V$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$\frac{N_2}{700} = \frac{188}{180} \times \frac{20}{24}$$

$$\boxed{N_2 = 577 \text{ rpm}}$$

② $E_{b2} = V - I_a R_a$
$= 200 - 10 \times 0.5 = 195\,V$

$$\therefore \frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$N_2 = \frac{195}{190} \times \frac{20}{10} \times 700$$

$= 1436.8 = 1437$ rpm

17/01/25

Rating (under normal cond^n)

① ϕ changed by inserting coil in field winding

Torque $\propto I_a^2$ $\propto \phi$

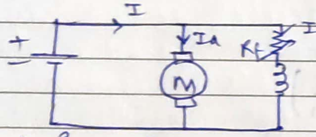
$\phi \cdot I_a \rightarrow$ const

Torque $\rightarrow$ const

Q1) Discuss various methods of speed control of DC shunt motor, DC series motor

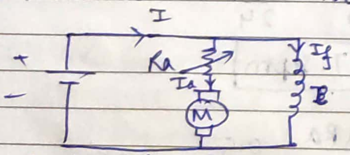
(a) Shunt Motor

① Flux Control Method



- Speed is inversely proportional to flux
- Rheostat added ~~to~~ in series with field winding. More resistance → More speed, flux decrease
- Efficient method since field current is small, I_{sh}^2R loss small

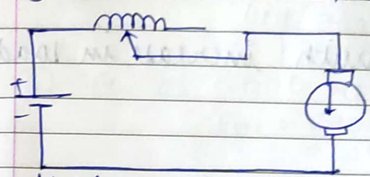
② Armature Control Method



- Speed is directly proportional to back emf E_b and $E_b = V - I_aR_a$
- supply voltage V and armature resistance R_a are kept constant.
- Speed $\propto I_a$
- Adding resistance in series with armature, I_a decreases, speed decreases

(b) Series Motor

① Flux control method



- Field coil is tapped dividing number of turns
- Thus, by selecting different values of ϕ by selecting different number of turns.

② Variable resistance in series with armature

→ Voltage ~~to~~ across armature can be reduced by this

→ speed reduced in proportion with it

Q2) Draw torque speed chara for DC shunt motor & DC series motor. Explain factors on which torque & speed depend on.

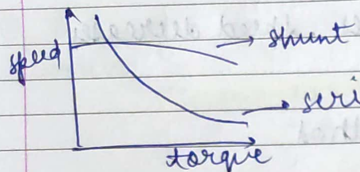
① DC Shunt motor

- Torque increases with load current while speed decreases slightly
- Inverse relation in torque & speed.
- At const supply voltage, field current remains const → speed remains const
- Armature reaction effect distorts distribution of air gap flux, which causes slight decrease in speed.

17/11/25

For shunt $I_a \propto N$

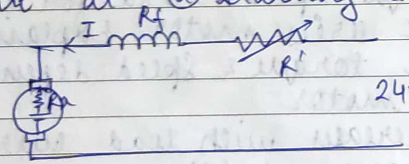
series $I_a \propto 1/N$



- Torque increases with increase in load current.

② DC series motor
- speed decrease as torque increases.
- Due to armature current increases as load increases, reduced speed.
- ~~before ma~~ Parabolic nature (torque produced increases proportional to square of armature current upto limit)

Q. 240 V series motor takes 40 Amps at full load running at 1500 rpm. Resistance 0.3 Ω ($r_a + r_{se}$). Determine the value of resistance to be inserted to obtain rated torque at ⓐ starting ⓑ 1000 rpm



$$I_a = \frac{V - E_b}{R_a + R_f}$$

→ ~~At start~~

→ At start, if we need rated torque then, Ia must be same as that required for rated output.

17/11/25

ⓐ $I_a(\text{start}) = 40\,A$

$$I_a = \frac{V - E_b}{R_a + R_f} \quad E_b \rightarrow 0 \text{ (start)}$$

$$I_a = 40 = \frac{240}{0.3 + R'}$$

$$40R' = 228$$

$$\boxed{R' = 5.7\,\Omega}$$

ⓑ E_{b1} at 1500 rpm at 40 amp

$$E_{b1} = 240 - 40 \times 0.3$$
$$= 240 - 12$$
$$= 228\,V$$

$n_1 = 1500$ rpm

$E_{b1} = 228\,V$

$n_2 = 1000$ rpm

$$\frac{E_{b2}}{E_{b1}} = \frac{n_2}{n_1}$$

$$E_{b2} = \frac{1000}{1500} \times 228 = \boxed{152V}$$

For rated torque $I_a = 40\,A$

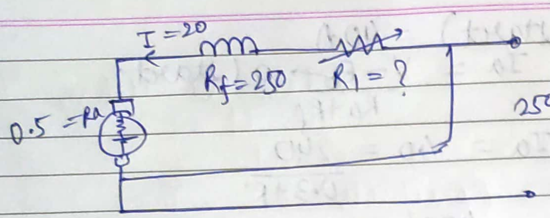
$$40 = \frac{240 - 152}{0.3 + R'}$$

$$40R' = 76$$

$$\boxed{R' = 1.9\,\Omega}$$

Q. A 250 V DC shunt motor has $R_a = 0.5\,\Omega$, $R_f = 250$ drives load of const torque at 600 rpm. Determine value of resistance to be added in the field ~~curse~~ circuit so that the speed changes from 600 to 800 rpm, $I_a = 20A$, when 600 rpm.

17/1/25



$$I = \frac{V - E_{b_2}}{R_a + R_f + R'} = \text{series}$$

→ Torque is constant

$$\phi_1 I_{a_1} = \phi_2 I_{a_2}$$

$$\frac{I_{a_2}}{I_{a_1}} = \frac{\phi_1}{\phi_2} = \frac{I_{f_1}}{I_{f_2}}$$

$$I_{f_1} = 1\,A$$

$$I_{f_2} = \frac{250}{R'}$$

$$R' = 250 + R_{ext}$$

$$I_{a_2} = I_{a_1} \times \frac{1}{250/R'}$$

$$= \frac{R' \times 20}{250} = (0.08R')$$

$$\frac{800}{600} = \frac{250 - 0.04R'}{240} \times \frac{R'}{250}$$

$$\frac{4}{3} = \frac{250R' - 0.04R'^2}{240 \times 250}$$

$$320 \times 250 = 250R' - 0.04R'^2$$

$$\boxed{R' = 88\,\Omega}$$

(*) Machine stops when kinetic energy = 0

Q. Explain difference in braking, dynamic braking, plugging

17/1/25

- Breaking → general act of slowing down a motor
  → any method to slow down a motor.

- Dynamic breaking → a controlled breaking method where motor acts as generator, converting kinetic energy into electrical energy which is then dissipated as heat through a resistor, providing a smoother deceleration.

- Plugging → A rapid braking method achieved by reversing the ~~motor's power supply~~, causing it to try & rotate in the opposite direction, resulting in a sudden stop but potentially high current spikes & mechanical stress on the motor.

DC → Reverse armature voltage or field winding

3φ IM → Phase sequence changed

2/1/25

3φ Induction motor

$S = \frac{N_s - N_r}{N_s}$

$f = f_s$ (starting)

$\frac{E_2}{E_1} = \frac{N_2}{N_1}$ (start)

$E_2' = SE_2$ (at slip)

$I_2 = \frac{E_2}{Z_2}$

$Z_2 = \sqrt{R_2^2 + X_2^2}$

$X_2 = 2\pi f L$

$= S \cdot X_2$

* flux proportional to EMF / voltage applied

$T \propto \phi I \cos\phi$

$\phi \propto E_2$

$T = KE_2 I \cos\phi$

$= \frac{KSE_2 \, R_2}{Z_2^2}$

3 phase

$= \frac{3K \, SE_2 R_2}{(R_2^2 + (SX_2)^2)}$

$K = \frac{1}{2\pi N_s}$

* For max torque $(R_2 = X_2)$

$(R_2 = SX_2)$ Not for squirrel cage

Slip at Tmax $= \frac{R_2}{X_2}$ → changed for slip ring → can't be changed

Generally $X_2 > R_2$

If we need max torque at start then we must adjust rotor resistance at X_2 at standstill

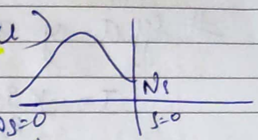
21/1/25

X_2 → Reactance of rotor at standstill (fixed)

The value of Tmax can be found out by substituting $R_2 = SX_2$ and $\boxed{S = \frac{R_2}{X_2}}$

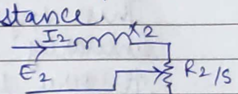
So $T_{max} = \frac{KE_2^2}{2X_2}$ → emf in rotor at standstill

If $R_2 \uparrow$ (power loss more)



1) Max^n torque is independent of slip

2) Speed at which Tmax occurs (or slip) will be dependent on rotor resistance



22/1/25

• P_g can be written as $I_2^2 R_2 + I_2^2 R_2 \left(\frac{1-S}{S}\right)$

Rotor cu power loss + Mech power developed in rotor

$P_g = \frac{I_2^2 R_2}{S}$ (as X_2 does not consume power)

Rotor copper loss can also be calculated as

$= I_2^2 R_2 = \left(\frac{S}{1-S}\right) P_{mech} = S \cdot P_g$

The mechanical power developed in the rotor friction & windage loss will be the power available at the shaft.

Gross torque developed will be equal to mechanical developed $\div \omega_r$

→ $\frac{(1-S) P_g}{(1-S) \omega_s} = \frac{P_g}{\omega_s}$ → $\omega_s = \frac{2\pi N_s}{60}$

$= \frac{P_g \times 60}{2\pi N_s}$

22/1/25 Change freq → N_s change → slip change

Non linear load → which ~~directly~~ disturbs sinusoidal waves (sin & cos same waves)

Ex → Rectifier switch boards, digital ckt

switching → High freq

Effect of change in supply voltage

$$T = \frac{KSE_2^2R_2}{R_2^2+(SX_2)^2}$$ At start $s = 1$

$$T_{start} = \frac{KE_2^2R_2}{R_2^2+X_2^2}$$ $E_2 \propto V$

This represents that $T_{start} \propto V^2$

Similarly, running torque $\propto SV^2$

At very low slip, torque will be low infact when $s=0$, torque $= 0$

So motor cannot run at N_s.

In the running condn, any reduction in supply voltage will decrease torque.

In order to maintain same torque (for const torque load) slip will increase, speed decreases.

Let slip at full load $= S_f$

slip corresponding to $T_{max} = S_{mT} = R_2/X_2$

$$T_{full\ load} = \frac{KS_fE_2^2R_2}{R_2^2+(S_fX_2)^2} \quad \text{—(1)}$$

$$T_m = \frac{KE_2^2}{2X_2}$$

using (1) & (2)

$$\boxed{\frac{T_f}{T_m} = \frac{2}{\frac{S_f}{S_{mT}} + \frac{S_{mT}}{S_f}}}$$

Low slip → $T \propto S$

Increased slip → $T \propto 1/S$

22/1/25

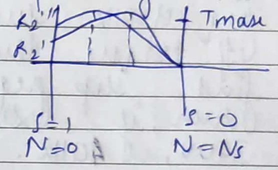
We have $T = \frac{KSE_2^2R_2}{R_2^2+(SX_2)^2}$

At low value of slip i.e. $N_r \approx N_s$

$(R_2^2 \gg SX_2^2)$ $T \propto S$

As slip increases $R_2^2 < (SX_2)^2$ $T \propto 1/S$

so, slip torque chara / speed torque chara will be a linear curve for low value of slip ($T \propto S$) & becomes rectangular hyperbola for high value of s ($T \propto 1/S$)



Tmax remains same, however the slip at which it occurs will be decided by rotor resistance.

28/1/25

- Full load torque < max^m torque [else unstable]

→ typical value of slip 0.3 or 0.4.

Power flow

$\sqrt{3}V_LI_L\cos\phi$

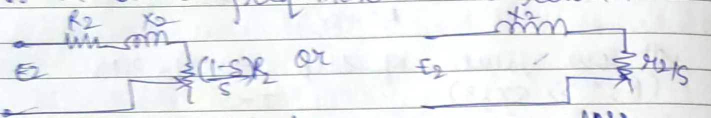
Input → stator cu loss → Air gap power → Rotor cu loss → Mechanical power → Friction windage → Shaft loss

- starting torque should be adjusted to full load torque → Load available already → motor should run.

max^m reactance at standstill $\rightarrow 2\pi f L$.
freq of rotor current decreases

28/1/25

$\therefore$ at start freq max hence reactance max



representation of load   rotor cu loss.

rotor power input $- I_2^2 R_2 \rightarrow$ power developed

Q. Induction motor is running at slip freq of 2Hz, supply voltage is 400V, 50Hz. If torque developed remains same, find slip freq at which machine will run, if supply voltage is changed to 340V, 40Hz. The slip corresponding to max torque at 50Hz is 0.1.

$\rightarrow S_{Tm} = 0.1$

$$0.1 = \frac{R_2}{X_2} = \frac{R_2}{2\pi f L} = \frac{R_2}{2\pi \times 50}$$

$$L \times 0.1 \times 2\pi \times 50 = R_2$$

$$(31.4\,\Omega = R_2)$$

For 400V, 50Hz   Torque remains same $E_2 \propto V$

$f = sf$

$2 = s \times 50$

$\boxed{S = 0.04}$

$$T = \frac{KSE_2^2 R_2}{R_2^2 + (SX_2)^2}$$

For 340V, 40Hz   case

$X_2' = 2\pi f L = 2\pi \times 40 \times L$

$(X_2 = 80\pi L)$

$$\frac{K \times 0.04 \times E_2^2 \times (0.1X_2)}{(0.1X_2)^2 + S^2X_2^2}$$

$$T_1 = T_2 \Rightarrow \frac{S_1 E_2^2 (0.1X_2)}{0.1X_2^2 + S_1^2 X_2^2} = \frac{S_2 E_2'^2 (0.1X_2)}{0.1X_2^2 + S_2^2 X_2^2}$$

28/1/25

$X_1 = 2\pi 50 \cdot L$
$X_2' = 2\pi 40 \cdot L$ $X_2 = \frac{40}{50} = 0.8L$ → value of L does not change

$$\frac{0.04 \times 400^2 \times 0.1}{0.01 + (0.04)^2} = \frac{S_2 \times 340^2 \times 0.1 \times 0.8}{(0.008 + S_2^2)\,0.8}$$

$$\frac{640}{0.0116} = \frac{S_2 \times 9248}{0.008 + S_2^2\, 0.8}$$

$$640(0.008 + S_2^2) = S_2 \times 107.27$$

$$5.12 + 640 S_2^2 - 107.27 S_2 = 0$$

$$(S_2 = 0.07)$$

freq of rotor current will be $S_2 \times f = 0.07 \times 40 = \boxed{2.80}$

$f \rightarrow \boxed{2.8\text{ Hz}}$

Q. 3φ star connected 6.6kV, 20 pole, 50Hz induction motor with full load speed of 292.5 rpm, $R_2 = 0.12\,\Omega$, $X_2 = 1.12\,\Omega$. Calculate slip at max^m torque & ratio of max torque to full load torque.

$\rightarrow S_{Tm} = \frac{R_2}{X_2} = \frac{0.12}{1.12} = \boxed{0.107}$

$V = 660V$, 50Hz, 20 pole

N_r (full load) $= 292.5$ rpm $N_s = \frac{120f}{P} = \frac{120 \times 50}{20} = 300$ rpm

$$S_f = \frac{N_s - N_r}{N_s} = \frac{300 - 292.5}{300} = \boxed{0.025}$$

$$\frac{T_f}{T_m} = \frac{2}{\frac{S_f}{S_{mT}} + \frac{S_{mT}}{S_f}} = \frac{2}{\frac{0.025}{0.107} + \frac{0.107}{0.025}} = \frac{2}{0.234 + 0.132} = \frac{2}{0.366} = \boxed{0.443}$$

Ans $\frac{T_m}{T_f} = \boxed{0.183}$ $\boxed{2.25}$

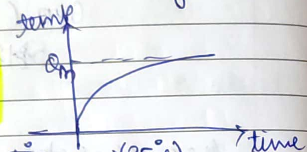
29/1/25

temp: Once load is fixed → losses fixed.
Temp difference huge → rate of heat dissipation huge.

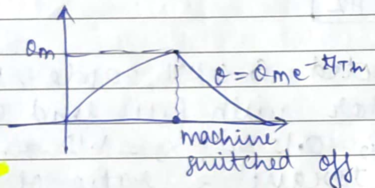
- Rate of heat generation ≠ Rate of heat dissipation.

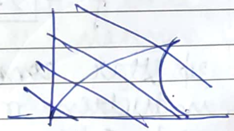
$$\theta = \theta_m \left(1 - e^{-t/T_h}\right)$$

(t = time, T_h = heating const, θ_m ↳ max temp)



- Ambient temp for calculation → (25°C)
- θ_m decides how much can be overloaded.





31/1/25 Let Q = heat developed i.e. in Joules/sec
m = Mass of the machine part in kg
S = Specific heat for material of the machine J/kg°C
change at envison change: λ = specific heat dissipation (emissivity)
θ = Temp at any time (t)
θ_i = Initial temp
θ_m = Max steady state temp.

* Heat produced in small time $(dt) = Q\,dt$
* Heat stored in body = mass of body × specific heat × temp diff
* Heat dissipated = surface area × specific heat of dissipation × time

31/1/25

* θ_i is temp of m/c at the time of start also referred as cold temp ↓ alsue ambient temp

Heat produced = $Q\,dt$
Heat stored = $ms \cdot d\theta$
Heat dissipated = $A\lambda\theta\,dt$
Heat produced = Heat stored + Heat dissipated

$$Q\,dt = ms\cdot d\theta + A\lambda\theta\,dt$$
$$Q = ms\frac{d\theta}{dt} + A\lambda\theta$$
$$d\theta/dt = Q/ms - A\lambda\theta/ms$$
$$d\theta/dt + A\lambda\theta/ms = Q/ms \quad \text{—①}$$

Above eq^n is 1st order differential eq^n for $di/dt + pi = q$
where $q = Q/ms$
$p = A\lambda/ms$

$$\theta = \frac{q}{p} + Ke^{-pt}$$

- steady state ↑ time varying

$$\theta = Q/\lambda A + Ke^{-pt}$$

at $t = 0$, $\theta = \theta_i$

$$\theta_i = \frac{Q}{A\lambda} + K \quad \therefore K = \theta_i - Q/\lambda A$$

$Q/\lambda A$ represents steady state value of θ means max temp rise at steady state.

Let it be θ_m $\quad [\theta_m = Q/A\lambda]$ emissivity

so $K = \theta_i - \theta_m$ $\qquad t = 5\tau$

$$\theta = \theta_m + (\theta_i - \theta_m)e^{-pt}$$

where $p = \dfrac{\lambda A}{ms}$

31/1/25 Insulation cut off → short circuit → Burns [Materials Class A Class B]

Let $T_h \to \frac{ms}{A\lambda}$ → heating time constant

$\theta = \theta_m + (\theta_i - \theta_m) e^{-pt}$

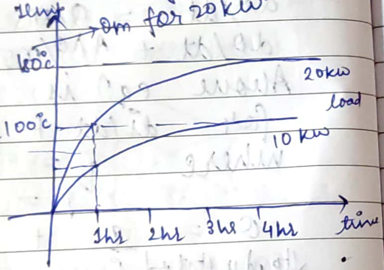
$= \theta_m + (\theta_i - \theta_m) e^{-t/T_h}$

$$\boxed{\theta = \theta_m (1 - e^{-t/T_h}) + \theta_i e^{-t/T_h}}$$

imp. $\left\{T_h = \frac{ms}{A\lambda}\right\}$ (if rest parameters fixed, Time const fixed)

Ex (load) 10kW → $\theta_m = 100°C$

if loading increased & max temp attained by the machine is below θ_m, then loading possible, else ~~that~~ leads to burning.



Similar way, we have equation for cooling of machine where

$$\boxed{\theta = \theta_i e^{-t/T_h}}$$

⊛ time constant → property of given item (same for cooling & heating)

Note that heating time constant & cooling time constant is same $= \frac{ms}{A\lambda}$

⊛ same machine can be loaded more for cooler environment.

Q1. Give different classification of insulating materials. Also state the temp for which these materials are used. Name some of materials for each class.

31/1/25

Q2. Explain different duty cycles of electrical machine and how the short time ratings will be decided for machines.

Q3. In case of intermittent duty cycle of the machine, show how the temp of the machine increases and reaches to steady state value. Explain with calculation, variation of temp for a machine having time constant of 1 hr & $\theta_m = 100°c$ subjected to intermittent duty of 1 hr on & 1 hr off. Calculate time required to reach to steady state.

1/2/25 Answers

Q1. Insulating materials can be classified by temperature resistance, composition and use.

Temp

① Class Y insulating materials – 90°c
→ Cotton, silk, paper and similar organic material

② Class A insulating materials – 105°c
→ Impregnated paper, silk, cotton, polyimide resins

③ Class E insulating materials – 120°c
→ Enameled wire insulation on the base of molded polyvinyl ~~exp~~ epoxy resins, powder plastics

④ Class B insulating materials – 130°c
→ Inorganic materials (mica, fibre glass, asbestos) impregnated with varnish.

1/2/25 * Temp above ~~the~~ ambient condⁿ as reference

(5) Class F insulating materials - 155°c
→ Mica, polyester, epoxide varnished and other varnish & in high heat resistance

(6) Class H insulating materials - 180°c
→ composite materials on mica, fiberglass, & other asbestos bases impregnated in the silicon rubbers except for other rubber compounds.

(7) Class C insulating materials > 180°c
→ mica, ceramics, glass, Teflon & Quartz.

Y A E B F H C
(90) (105) (120) (130) (155) (180) (>180)

Composition

(1) ~~[illegible]~~ organic Insulators
→ Rubbers, plastics, synthetic polymers
→ offer good electrical insulation
→ used in cables, wiring, electrical equipment.

(2) Inorganic Insulators
→ Ceramic, glass, mineral compounds.
→ Excellent thermal resistance
→ Used for high temperature

Use

(1) Electrical applications
→ Based upon dielectric strength & ability to withstand high voltages
→ Used where electrical resistance & insulation thickness are critical factors

(2) Thermal applications
→ Ability to resist heat ~~the~~ transfer.
→ Used like fiberglass and mineral wool where heat ~~loog~~ loss or gain is imp.

1/2/25

⊗ Draw with diagram

Q2) There are eight different duty cycle designations to describe electrical motor operating conditions:

(a) S1 : Continuous duty → motor works at constant load for enough time to reach temperature equilibrium

(b) S_2 : short-time duty → Motor works at constant load, but not long enough to reach temp equilibrium. The rest periods are long enough for the motor to reach ambient temperature.

(c) S_3 : Intermittent periodic duty → sequential, identical run and rest cycles with constant load. Temperature eqⁿ is never reached. Starting current has little effect on temperature rise.

(d) S_4 : Intermittent periodic duty with starting → sequential, identical start, run & rest cycle with const load. Temp eqⁿ is not reached, but starting current affects temp rise.

(e) S_5 : Intermittent periodic with electric ~~duty~~ braking → sequential, identical cycles of running with constant load & running with no load. No rest periods.

(f) S_6 : Continuous operation with intermittent load → sequential, identical cycles of running with constant load & running with no load. No rest periods.

(g) S_7 : Continuous operation with electric braking & → sequential identical cycles of starting, running at constant load

|2|25

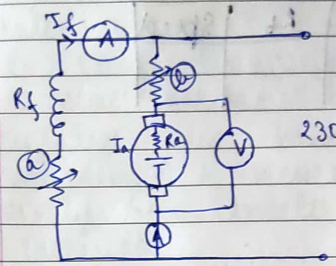
② & electric braking. No rest periods.
⑧ Continuous operation with periodic changes in load & speed → sequential, identical duty cycles run at constant load & speeds. No rest periods.

* Determination of short time rating machine
→ Considering its design limitations, the expected peak load condition it might encounter during operation, and the max^{m} current it can safely handle for a brief period without damage.
→ This brief period is specified by the manufacturer based on factors like
- Motor starting currents
- Inrush currents
- Intermittent duty cycle
→ These account for temporary high current situations.
→ Primary concern when determining a short time rating is preventing excessive heat generation within machine.

Q3)

4|2|25 ED Lab

① Speed control of DC shunt machine



Readings
1. Ammeter
2. Tacometer

Instrument	Rating	Quantity
Resistance	0-30Ω	2
Ammeter	0-5A	2
Voltmeter	230V	1

ⓐ Method 1: Changing field resistance
1) Variable resistance will be connected in series with the field resistance of a DC shunt machine.
2) Ammeter of suitable rating (0-5A) will be connected in series with the R_f
3) Once machine switched on, the field resistance will be set on maximum to prevent inrush current damage.
4) As Ra is increased, the R_f must be cut down to operate the machine on a rated speed.
5) Now, varing the variable resistance, the ammeter measure the I_f which depicts the increasing resistance and hence the corresponding speed change.

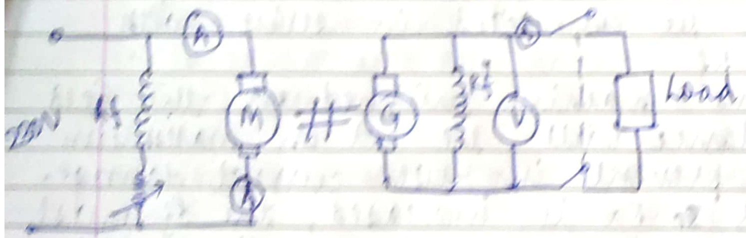
ⓑ ~~Method 2: Voltage variation~~

4/2/25

Observation Table

V	I_f	I_a	R_a	R_b	Speed

② Speed torque characteristics of DC shunt



Instrument	Rating	Quantity
Resistance	0-30 Ω	1
Voltmeter	230 V	1
Ammeter	0-5A	3
Load (bulbs)	230 V	1

To measure → Speed (Tacometer)
Power (using Ammeter & voltmeter)

$P = T\omega$ $\omega = \frac{2\pi N}{60}$

4/2/25

1) Making the required arrangements the speed of the motor is brought to the rated value
2) Through the coupled shaft, the generator receives mechanical power and some residue flux which initiates the field winding of generator.
3) The voltmeter measures the voltage received.
4) The load is supplied with ~~that~~ power and can be varied by the variable resistance
5) Torque will be attained by calculations and speed torque characteristics will be obtained.

Observation Table

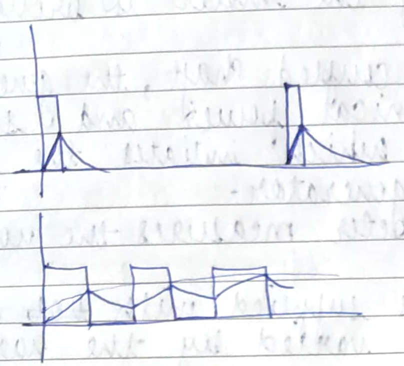
V	I_f	I_a	~~R_a~~	Speed	W	~~Torque~~ $P = \omega T$	Power

5/2/25

- In a given rating, machine can work lifelong without heating.
  For little more load → overload.
- If hay an hour rating is 25KW, 20 KW rating will be lesser.

5/2/25

* Different duty cycle with heating



Q. For a given machine $\theta_i = 45^\circ c$ (initial). Heating time const $= 2.4$ hr, Ambient temp $= 25^\circ c$. Calculate the temp of machine after 1.2 hrs. if $\theta_m = 85^\circ c$.

Ans Initial temp of machine $= 45^\circ c$

Ambient temp $= 25^\circ c$

θ_i (actual) $= 45 - 25 = 20^\circ c$

$$\theta = \theta_m(1 - e^{-t/T_h}) + \theta_i e^{-t/T_h}$$
$$= 85(1 - e^{-1.2/2.4}) + 20e^{-1.2/2.4}$$
$$= 85(1 - e^{-1/2}) + 20e^{-1/2}$$
$$= \boxed{45.5755}\,^\circ c$$ (above the ambient)

Q. A typical machine delivers 10 kW with efficiency of 90%. It has surface area of $2.64\ m^2$ and specific heat of $700\ J/kg^\circ C$ & $\lambda = 12.5\ W/m^2\,^\circ c$. The motor weighs 450 kg. Find the max^m temp at this load & approx time to reach this load.

→ $\theta_m = \frac{Q}{A\lambda}$ $T_h = \frac{ms}{A\lambda} = \frac{450 \times 700}{2.64 \times 12.5} = \boxed{9545.4545}$ sec

5/2/25

Heat produced = losses.

$$\frac{9545.45}{3600} = \cancel{2.26}\ \boxed{2.65\text{ hrs}}$$

Time required to reach $\theta_m = 5 \times T_h = \boxed{13.25\text{ hrs}}$

$$\theta_m = \frac{Q}{A\lambda}$$

Output power 10 kW and input power $\frac{10000}{0.9}$

$= 11.11$ kW

Losses $Q =$ Input − Output $= 1.11$ kW

$$\theta_m = \frac{Q}{A\lambda} = \frac{\cancel{1.11\text{ kW}}\ 1111}{2.64 \times 12.5} = \boxed{33.67\,^\circ c}$$

Q. For a DC machine running at full load, temp after 1 hr is $15^\circ c$ and after 2 hrs is $25^\circ c$. Find the final steady state temp & heating time constant.

$\theta_1 = \theta_m(1 - e^{-1/T_h})$ $15 = \theta_m(1 - e^{-1/T_h})$

$\theta_2 = \theta_m(1 - e^{-2/T_h})$ $25 = \theta_m(1 - e^{-2/T_h})$

$$75 = 5\theta_m(1 - e^{-1/T_h})$$
$$75 = 3\theta_m(1 - e^{-2/T_h})$$
$$5\theta_m(1 - e^{-1/T_h}) = 3\theta_m(1 - e^{-2/T_h})$$
$$5 - 5e^{-1/T_h} = 3 - 3e^{-2/T_h}$$
$$+2 = -3e^{-2/T_h} + 5e^{-1/T_h}$$
$$+2 = e^{1/T_h}(-3e^{-2} + 5e^{-1})$$
$$\frac{2}{1.433} = e^{1/T_h}$$
$$1.39 = e^{1/T_h}$$
$$\ln 1.39 = \frac{1}{T_h}$$

$(T_h = 2.46\text{ hrs})$

5/2/25 For any machine, when load changes by x, copper loss changed by x^2, iron loss remains same.

Q. An induction motor has $\theta_m = 40°C$ while delivering full load. If the cu losses at full load is 1.25 times its iron loss, find half an hour rating.

$T_h = 90$ mins $= 90/60 = 3/2 = 1.5$ hr

$\theta = \theta_m(1 - e^{-t/T_h})$

half an hour rating will be greater than continuous rating & can be found by restricting temp rise to θ_m.

At full load, total losses $=$ Cu + Iron loss
$= 1.25x + x$
$= \boxed{2.25x}$

Let half an hour rating be y times full load.

So loss for 1/2 hr rating $= (1.25x)y^2 + x$

Let the max^m temp rise that may occur when the machine runs at ~~full~~ 1/2 hr rating, we

$$\frac{\theta_m'}{\theta_m} = \frac{y^2 \times 1.25x + x}{2.25x}$$

$$= \frac{y^2 \times 1.25 + 1}{2.25}$$

$40 = \theta_m'(1 - e^{-0.5/1.5})$

$40 = \theta_m'(1 - e^{-1/3})$

$\frac{40}{0.283} = \theta_m'$

$\boxed{141.1 = \theta_m'}$

$$\frac{141.1}{40} = \frac{y^2 \times 1.25 + 1}{2.25}$$

$y^2 = 5.5495$

$\boxed{y = 2.35}$

- common point in load chara & source chara is operating point.
- using converter & inverter → creates harmonics (not sine)

12/2/25

- Harmonics removed by capacitor & Inductor & filters.

R. Krishnan (New Topic) CHP 1

- Modelling → Transfer of machine in equivalent ckt
- Analysis → Excitation and then parameters measured.
- Drives used for variable operations (speed) [in inverter, ac → done by inverters]
→ variable voltage variable freq
- when saturation, relation b/w ϕ and I, not change in flux, but current increases drastically → heats → burns.
- Saturation about knee point. [problem in DC since in AC, +ve −ve makes shift]

Power converter
- Rectifier → AC to DC
- Inverter → DC to AC
- Chopper → DC to DC
- Cycloconverter → AC to AC (with variable freq)

14/2/25

- ~~Active~~ effective current → I_{rms}
- Questions from Rajput (Based on Ratings)

Effective value → $\sqrt{\frac{\Sigma \text{Individual}^2}{\text{time}}}$

- Performance Analysis Drives
  - Steady state [Easier]
  - Dynamic [disturbance: change in load, voltage]
- $T = \phi I_a$ $P = T\omega$

Input commands → position of shaft
- freq changes → speed changes [N_s]
- Slip problems

14/2/25

- Speed & torque control → voltage & freq should be controlled

DC motor: Decoupled parameters → current & flux

- Gear wheel → if radius less → speed more
Pulley → slips
Radius more → more torque

Mechanical parameters of drive
→ Moment of interia (weight ∝)
→ Frictional coefficient (friction ∝)

CHP 2 Modelling of DC machine

1) Separately, Self } Excitation

2) $e = \frac{Z \phi_f P n_r}{60 a}$ → speed in rpm
Z → total no. of conductor
a → no. of $\parallel$ path in armature winding
→ Lap (no. of poles = no. of $\parallel$ paths)
→ wave $(a=2)$

3) High voltage, low current → wave
Low voltage, high current → lap [Thickness of ~~wire~~ more conductor → outer]

4) Shunt machine → ϕ constant

5) ϕ_f → field flux [neglecting ϕ_a (armature)]

6) $\phi = \frac{mmf \rightarrow nI}{Reluctance}$] [Ohm's law for magnetic ckt]
Ampere ~~tur~~ turns

7) $\frac{nI}{l}$ → H

19/2/25

$T \propto \frac{1}{\omega}$ Transient → differential

8) K_b → constant representing back emf
9) $I_f \uparrow \rightarrow \phi \uparrow \rightarrow$ Emf induced $\uparrow$ → speed $\downarrow$
10) e → emf induced in armature
Q. Equation derivations [before 2.3 section] [before section 2.4]
11) For DC → no freq → no X_L or X_C (∵ transient)
Sinusoidal ckt → transients presents
12) T_e → electromagnetic torque
13) DC motor / Induction motor → Power transferred through air gap (most efficiency lost here)
14) Machine acceleration → Accelerating Torque → Dynamic
$T_e > T_{load}$
$T_e - T_L \rightarrow T_{acc}$ < +ve : acc, −ve : de acc

15) Acceleration depends on MOI & friction

16) Assuming flux is constant → shunt machine or separately excited then block diagram is valid
- For series → some parameters are changed.

Q. Ex 2.3, 2.1, 2.2
Q. Explain dynamic modelling of DC machine
Q. Draw block diagram of DC machine & explain each block.
Q. Explain the effect of different connections of field winding on modelling of DC machine.

Scanned with OKEN Scanner

14/2/25

Derivations

I] For induced emf

Poles → P

Armature conductors → Z

Flux per pole → ϕ_f

Rotation speed → n_r rpm.

Time to cut ϕ_f flux lines by conductor → t

∴ Induced emf (By Faraday's Law)

$$e = \frac{Z}{a}\frac{d\phi_f}{dt} = \frac{Z}{a}\frac{\phi_f}{t} \quad -①$$

$$t = \frac{1}{2 \times freq} = \frac{1}{2\left(\frac{P}{2}\right)\left(\frac{n_r}{60}\right)} \quad -②$$

where a → no. of ‖el ~~parts conductors~~ path in armature windings

Put ② in ①

$$e = \frac{Z\phi P n_r}{60 a} \quad -③$$

• Arrangements of conductors in armature,

cond^n

> Wave winding → High voltage, low current

> Lap Winding → Low voltage, high current

↳ (Thickness of outer conductor is more)

$$a = \begin{cases} 2 & ; \text{ wave} \\ P & ; \text{ lap} \end{cases} \quad -④$$

compact form

$$e = K\phi_f \omega_m \quad -⑤$$

where $\omega_m = \frac{2\pi n_r}{60}$ rad/sec

14/2/25

$$K = \left(\frac{P}{a}\right) Z \left(1/2\pi\right)$$

• For shunt machine → ϕ is constant (field flux) neglecting ϕ_a (armature)

then,

Induced emf ∝ rotor speed

constant of proportionality → Back emf const. (K_b)

$$e = K_b \omega_m \quad -⑥$$

$$K_b = K\phi_f \text{ volt/(rad/sec)} \quad -⑦$$

• From Ohm's Law for magnetic ckt,

$$\phi_f = \frac{mmf}{Reluctance} = \frac{N_f i_f}{R_m} \quad -⑧$$

where

N_f → no. of turns in field winding

i_f → field current

Mutual flux : Resultant of ϕ_f and ϕ_a

Put ⑧ in ⑥

$$K_b = \frac{K N_f i_f}{R_m} = M i_f \quad -⑨$$

M → fictitious mutual inductance bet^n armature & field windings

$$M = \frac{KN_f}{R_m} = \frac{P}{\pi} \cdot \frac{Z}{2a} \cdot \frac{N_f}{R_m} \quad -⑩$$

Put ⑨ in ⑥

$$\boxed{e = M i_f \omega_m} \quad -⑪$$

• M is func of i_f

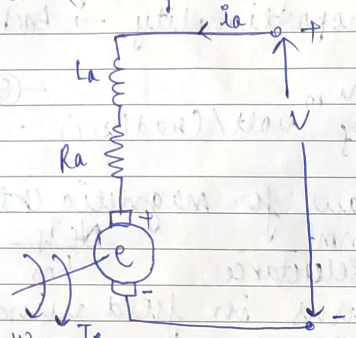
Leads to saturation of magnetic materials

→ Assumed to be constant.

14/2/25

II] Electromagnetic torque

Considering DC motor equivalent circuit, focusing on armature consisting of resistance Ra, self inductance La, & induced emf.



Rotational speed ω_m T_e ↳ Air gap torque

∴ Using KVL (Transients: Differential)

$$V = e + R_a i_a + L_a \frac{di_a}{dt} \quad -① $$

For steady state $(di_a/dt = 0)$

$$V = e + R_a i_a \quad -②$$

Power Eqn: effective power

$$\underbrace{V i_a}_{\text{total input power}} = e i_a + \underbrace{R_a i_a^2}_{\text{armature copper loss}} \quad -③$$

$e i_a$ → Air gap power → P_a (In terms of T_e and ω_m)

$$P_a = \omega_m T_e = e i_a \quad -④$$

14/2/25

$$\therefore T_e = \frac{e i_a}{\omega_m} \quad -⑤$$

using $e = K_b \omega_m$

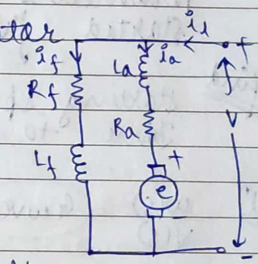
$T_e = K_b i_a \quad -⑥$

:- Torque const = EMF const (if expressed in volt-sec/rad for constant flux machine.

$\boxed{\text{EXAMPLES}}$

2.3

Given: A separately excited dc motor



$R_a = 0.5\ \Omega$

$L_a = 0.003$ H

$K_b = 0.8$ V/rad/sec

$J = 0.0167$ kg-m^2 (Load)

$B_l = 0.01$ N·m/rad/sec

$T_L = 100$ Nm

DC supply voltage = 220 V

provided with rated field current.

To find: Speed of motor?

Solution: Electromagnetic torque: $T_e = T_l + B_l\omega_m + J\frac{d\omega_m}{dt}$

steady state $\frac{d\omega_m}{dt} = 0$

$$T_e = T_l + B_l \omega_m = 100 + 0.01 \times \omega_m$$

$$K_b I_a = 100 + 0.01 \times \omega_m$$

$$0.8 \times I_a = 100 + 0.01\,\omega_m$$

$$I_a = 125 + 0.0125\,\omega_m$$

14/2/25

Also

$e = V - R_a i_a = 220 - 0.5(125 + 0.0125\omega_m)$

$= 157.5 - 0.00625\omega_m = K_b \omega_m$

$\therefore \omega_m(0.8 + 0.00625) = 157.5$

Ans $\boxed{\omega_m = 195.35 \text{ rad/sec}}$

? $\boxed{2.1}$

Given DC Motor
Parameters same
Started from 220V dc supply → No Load

To find Starting speed response
Time to reach 100 rad/sec.

Sol^n $\frac{\omega(s)}{V(s)} = G_{\omega v}(s) = \frac{K_b}{s^2(JL_a) + s(B_1L_a + JR_a) + (B_1R_a + K_b^2)}$

$V(s) = \frac{220}{s}$

$\omega(s) = \frac{3.512 \times 10^6}{s(s^2 + 167s + 12874)}$

$\omega(t) = 272.8(1 - 1.47e^{-83.5t}\sin(76.02t + 0.744))$

Ans Time to reach 100 rad/sec → 10 rad/ms

14/2/25

$\boxed{2.2}$

Given Separately excited dc motor
Rated torque at rated speed
1500 kW, 600V, rated current = 2650A,
600 rpm
Brush voltage drop = 2V
Field power input = 50kW
$R_a = 0.003645\ \Omega$ $L_a = 0.1$ mH
Machine frictional torque coeff = 15 Nm/rad/sec

To find Efficiency

Sol^n $\eta = \frac{\text{Output}}{\text{Input}} = \frac{P_m}{P_i}$

- P_i Rated $I_a = 2650$A

Steady state; $V_a = R_a I_{ar} + K_b \omega_{mr} + V_{br}$ (Rated I_a, Rated ω_m, Brush)

Torque constant = EMF const

$K_t = \frac{T_{er}}{I_{ar}} = \frac{T_s + T_f}{I_{ar}}$ (Rated T_e; Rated Shaft T; friction T)

$\therefore$ Rated output torque

Rated speed $\omega_{mr} = \frac{2\pi \times 600}{60} = 62.83$ rad/sec

Rated shaft torque, $T_s = \frac{P_m}{\omega_{mr}} = \frac{1500 \times 10^3}{62.83} = 23,873$ Nm

Friction torque, $T_f = B_1\omega_{mr} = 15 \times 62.83 = 942.45$ Nm

$T_{er} = T_s + T_f = 24,815.45$ Nm

14/2/25

Torque const

$$K_t = \frac{T_{er}}{I_{ar}} = 9.364 \text{ Nm/A}$$

$$K_b = 9.364 \text{ V/rad/sec}$$

$\therefore$

$$V_a = 0.003645 \times 2650 + 9.364 \times 62.83 + 2 = 600\text{V}$$

Total input (armature & field)

$\Rightarrow V_a I_{ar}$ + Field power input $= 600 \times 2650 + 50{,}000$

$= 1640$ kW

- $P_{out} = 1500$ kW

$$\eta = \frac{1500}{1640} \times 100 = \boxed{91.46\%}$$ Ans

Q. Explain dynamic modelling of DC Machine

→ Modelling of any machine refers to making the equivalent circuit of the machine and subsequently in a block diagram.

→ Electromechanical Modeling

- Load ⇔ Moment of interia (J)
- Viscous friction coefficient (B_1)
- (T_a) Acceleration torque drives load

$$J\frac{d\omega_m}{dt} + B_1\omega_m = T_e - T_l = T_a \quad \text{—①}$$

Also we know, applying KVL (for armature ckt)

$$V = e + R_a i_a + L_a\frac{di_a}{dt} \quad \text{—②}$$

⇒ Eqn ① and ② constitute the dynamic

14/2/25

model of dc motor with load; expressions of Acceleration Torque and supply voltage.

→ The dynamic eqn are cast in state space form.

differential operator wrt time

$$\underbrace{\begin{bmatrix} p i_a \\ p\omega_m \end{bmatrix}}_{\dot{X}} = \underbrace{\begin{bmatrix} -R_a/L_a & -K_b/L_a \\ K_b/J & -B_1/J \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} i_a \\ \omega_m \end{bmatrix}}_{X} + \underbrace{\begin{bmatrix} 1/L_a & 0 \\ 0 & -1/J \end{bmatrix}}_{B} \underbrace{\begin{bmatrix} V \\ T_l \end{bmatrix}}_{U} \quad \text{—③}$$

③ is expressed compactly as

$$\dot{X} = AX + BU \quad \text{—④}$$

→ Input vector
↳ state variable vector

→ Roots of system ⇒ [Answer of A matrix]

$$\lambda_1, \lambda_2 = \frac{-\left(\frac{R_a}{L_a} + \frac{B_1}{J}\right) \pm \sqrt{\left(\frac{R_a}{L_a} + \frac{B_1}{J}\right)^2 - 4\left(\frac{R_a B_1}{JL_a} + \frac{K_b^2}{JL_a}\right)}}{2}$$

Interference

Eigen values (λ_1, λ_2): will have −ve real part ⇒ Motor is stable on open loop operation.

14/2/25

Q. Draw block diagram of DC machine & explain each block.

→ The dynamic modelling equations are

$$J\frac{d\omega_m}{dt} + B_1\omega_m = T_e - T_l = T_a$$

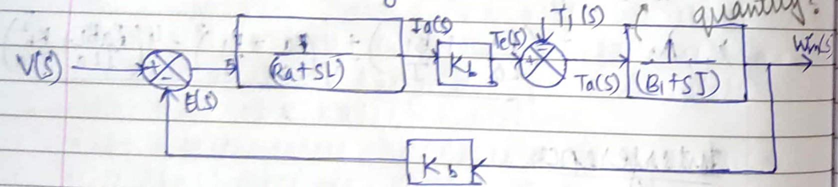
and $$v = e + R_a i_a + L_a\frac{di_a}{dt}$$

⇒ Taking Laplace transforms (no initial cond^n)

$$I_a(s) = \frac{V(s) - K_b\omega_m(s)}{R_a + sL_a}$$

$$\omega_m(s) = \frac{K_b I_a(s) - T_l(s)}{(B_1 + sJ)}$$

These 2 equations are jointly designed in a block diagram. what is the quantity?



1. Input supply voltage on left end enters : V(s)
2. On the summing junction, at the negative feedback, the back emf constant along with speed ($\omega_m(s)$) gives the emf.
3. Multiplying with the conductance (reciprocal of resistance), we obtain the armature current in DC machine.

14/2/25

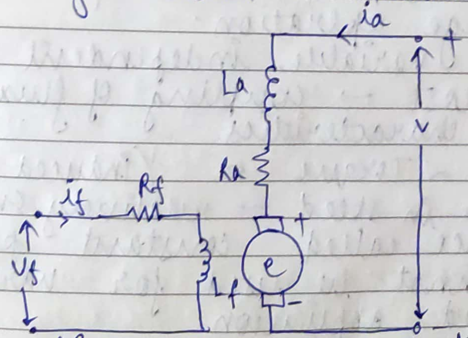
4. Considering the value of $I_a(s)$, the emf constant is multiplied with $I_a(s)$.
5. At the ~~negative~~ positive feedback the electromagnetic torque (T_e) is obtained of the summing junction along with $T_l(s)$ (load torque) at the negative positive.
6. Obtaining the overall acceleration torque, it is multiplied by mechanical equivalent of load to obtain the speed of the motor.

Q. Explain the effect of different connections of field winding on modelling of DC machine.

→ Connections of field winding are relative to armature winding.

(a) Separately excited DC machine (physically & electric)

→

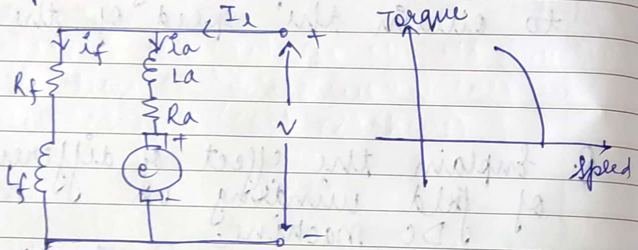


→ provides high performance control over the machine. {torque & flux controlled independently & precisely}

14/2/25

→ field flux controlled by field current [Now take field const]
→ β Torque $\propto$ I_a (dynamics control)
→ Speed Regulation can be zero.
→ These features come with feedback control.

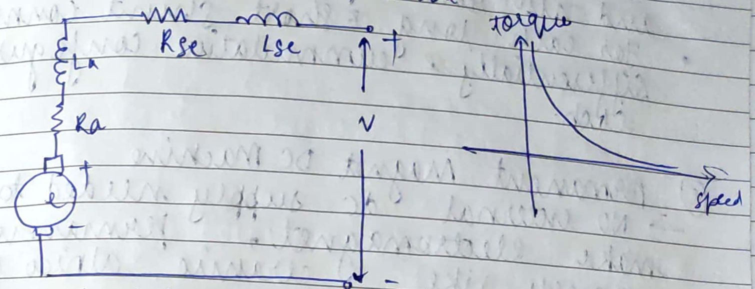
(b) Shunt excited dc machine
→ Field parallel to armature



→ constant supply → constant field current and fixed field flux are constant
→ Good for constant input voltage operation; trouble for variable voltage operation.
→ In variable, independent operations are lost → coupling of flux & β torque
→ Wrt characteristics
$I_a \propto$ Torque $\propto$ 1/induced emf
→ Drop in speed → relatively small
→ Hence called constant speed machine
→ Cannot be used for variable speed application.

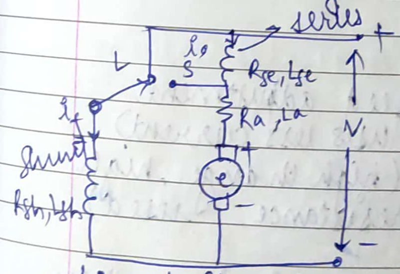
14/2/25

(c) Series Excited dc machine



→ No independence in field & armature current
→ $T_e \propto I_a^2$ ($\because I_f = I_a$)
→ High torque at starting since at low speeds, high I_a → small emf.
→ Zero speed & low speeds → large torque → curtailed from square current law due to saturation of flux path with high currents.

(d) DC compound Machine
→ Combining best of DC shunt & series



L → Long
S → Short

• Long Shunt → Shunt field encompasses series field & armature winding.
• Short shunt → shunt field in ||el to armature winding.
→ Shunt field excitation is slave to emf_{ind}

14/2/25

and also rotor speed.
- For each long & short shunt connections: Differentially & cummulative configurations each.

(e) Permanent Magnet DC Machine
→ No external dc supply needed to make electromagnet, permanent magnets like ceramic, alnico provide excitation.
→ Advantage: Compactness of field structure & elimination of resistive loss in field winding. (cool machine)

24/2/25

Q. Simulate DC machine block diagram with help of MATLAB and plot Vvsw (values from ex-2.3)

CHAPTER 3

Quicker Response of speed adjustment
→ Field current (uses less current)
→ Armature voltage (high change, high resistance used)

(Field current) Inductance more in field winding → More time constant (L/R) → More time to reach steady state → Slower Response

24/2/25

RLE → DC motor
- Same time const for half hour & full hour rating

Power Electronics Control
0 to 180° voltage change by changing α in Rectifier → speed control.

→ But sine wave is distorted, response added with harmonics.
→ Pulsating flux generated: affects torque.

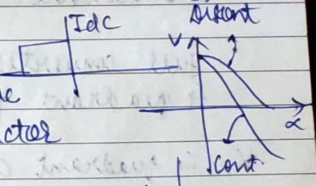
- Power increases when torque const (Below Rated)
- Speed increase, torque decrease → power const

After rated, ϕ should be reduced
$\phi I_a \propto T$

(electrical in) Forward Reverse Motoring → 1st & 3rd.
(Mech in) Forward Reverse Regeneration → 2nd & 4th

- Single phase Controlled converter → voltage at output can be reversed, not current.
- Single phase Semi controller → No voltage change.

→ Reversal when: $\alpha > 90°$
: current is continuous.
↳ when inductor



Effect of changing firing angle on avg voltage out

(CH3)
CH 3 → pg 54
3.34 Fig
3.3.6, 3.3.7
Fig 3.20 + Explain

3.4.3
3.26 Fig
3.27 Fig
3.39 Fig
Schematic + Explain

(CH1, CH2)

27/2/25

(a) separately excited field

- ~~to~~ Critical Angle depends upon L.
  β → conduction angle
  For R Load or RL load with discontinuous
  $\alpha + \beta = \pi$ (180°)
- Speed control 2 quadrant → 1 Bridge converter
  If 2 → 4 Quad
- Heating time const increased by cooling.

CH4 Chopper

→ Fixed DC to variable DC (increase/decrease voltage)
→ Used as switch → Only for DC machine

12/3/25

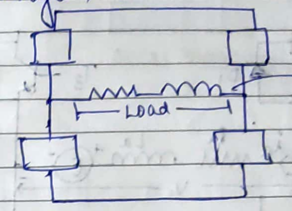
- Step up chopper
  Step down chopper.
- Disturbance takes place in transient state.
- Full converter → 6 SCR
  4 quadrant full converter → 12 (thyristor & inverter)
- * 4 quadrant chopper
- Transistor used as switch < cutoff (open) / saturation (closed)
  ↳ npn or pnp → used both?
- Active → Amplifier
  npn → on when +ve base w.r.t emitter
  pnp → on when −ve base

V_c → +ve ∴ switch open ($V_s \neq V_o$)

12/3/25

If no grounded terminal → floating

- Having fixed freq better → else changes in firing angle, etc.

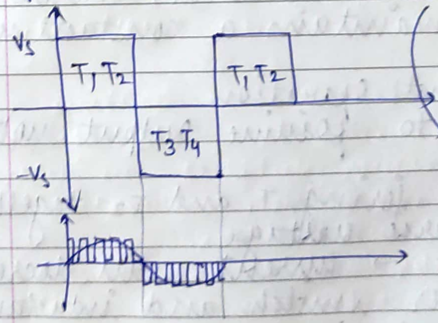


T_3 & T_4

Reverse voltage → D_3 & D_4 on.

1st → +ve voltage +ve current
3rd → −ve voltage −ve current
2nd → −ve voltage +ve current

Diodes used in ‖el to SCR → freewheeling & feeding power back to supply.



PWM sinusoidal
Inverter ckt (DC to AC)
→ Pulse width modulation
+ Adjustment of firing angle

Q. Draw a neat diagram of 4 quadrant chopper ckt, explain operation of the ckt in each quadrant, showing polarity of the voltage & direction of current, etc.

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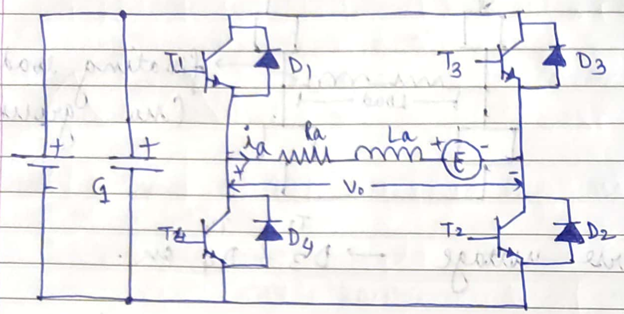
Ans A four quadrant chopper circuit



- Each transistor has a freewheeling across it.
- The resistor, inductance and induced emf ~~consists~~ make the load.
- DC source V_s is connected and a capacitor connected across it, controls the ability to maintain a constant voltage.

① First Quadrant Operation

→ corresponds to positive output voltage & current.

$\boxed{V=V_s}$ → Obtained by firing T_1 and T_2 together: voltage = source voltage

$\boxed{V=0}$ → T_1 off now → current will decrease in power switch and inductance → current decrease in inductance → voltage induced ∝ Rate of fall of current (polarity opposite to load induced emf)

→ D_4 becomes forward biased (path for i_a)

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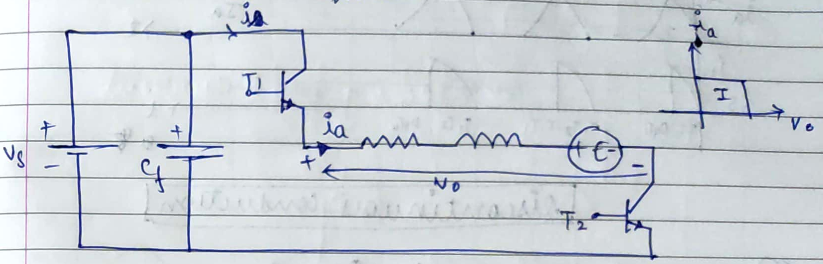
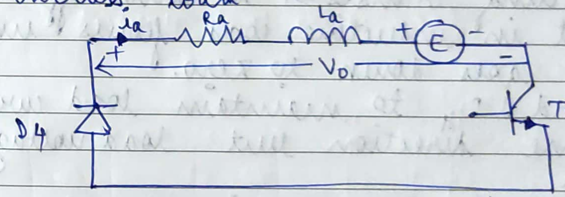
→ Load is short circuited → voltage reduces to zero.

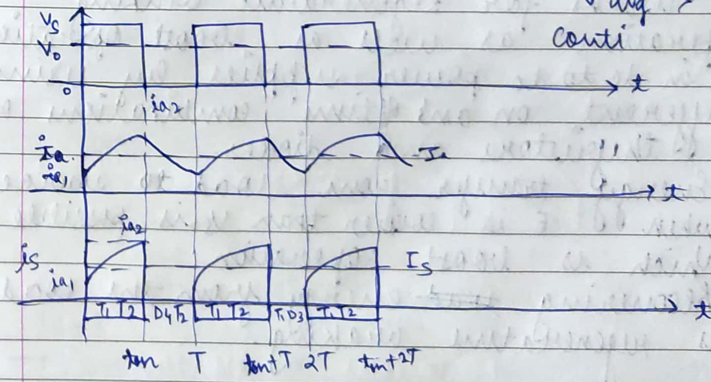
- 1st quadrant operation with +ve voltage & current in load.



- 1st quadrant operation with zero voltage across load.



V avg > V avg
conti discont



~~cont~~ $\boxed{\text{Continuous Cond}^n}$

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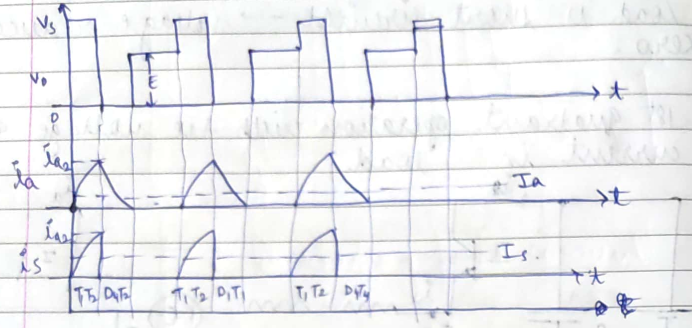

Discontinuous conduction

② Second quadrant Operation

→ Positive current with a negative voltage
→ conducting transistor is turned off.
→ current in inductive load flows until energy goes down to zero.
→ D_3 and D_4 to maintain load current in same direction but load voltage is negative
→ works for Regenerative braking operation as well as boost operation in dc to dc power supplies by using different on and off time combinations of thyristors and diodes.
→ Energy transfer from load to source when E is lower than V_S is possible which is boost operation
→ Recovering ~~load~~ energy from the load is regenerative braking.

• Power flow: load to source.

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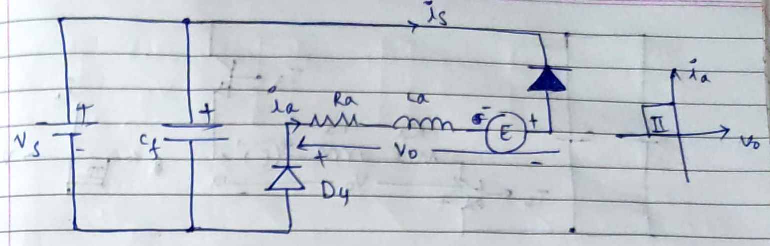

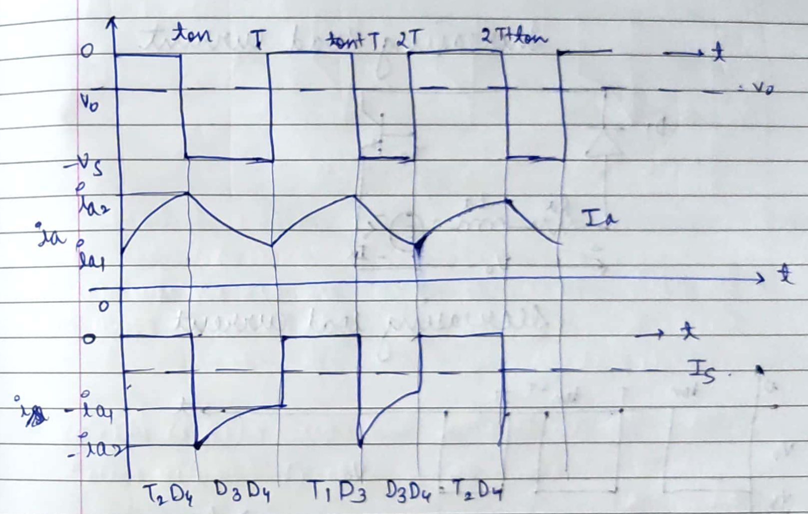

③ Third Quadrant Operation

→ Negative current and negative voltage
→ Negative emf source, −E is assumed the load.
→ Switching on T_3 and T_4 increases current in load, turning off one of the transistors short circuits the load, load current decreases.
→ Load current is controlled within externally set limits.

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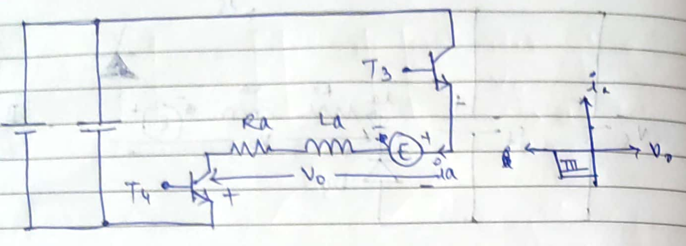
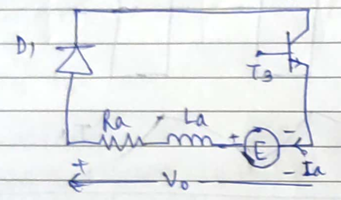
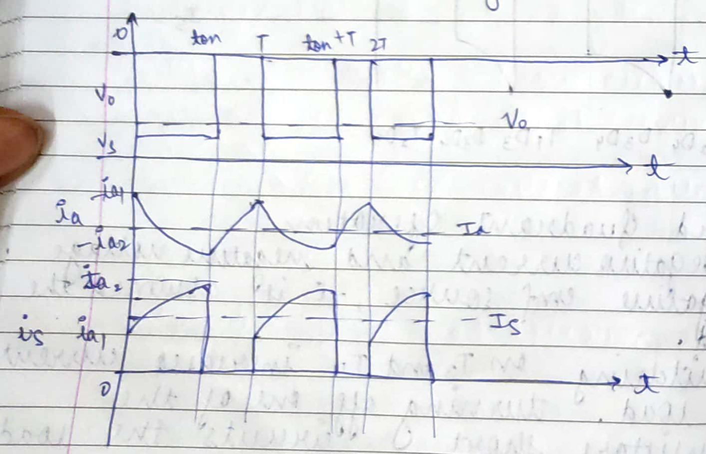


Increasing load current



decreasing load current



Continuous Conduction

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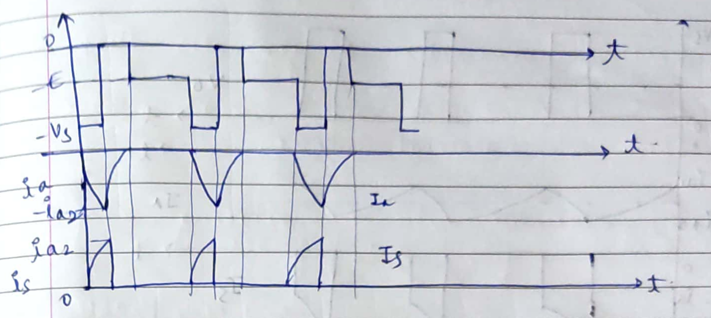


discontinuous Conduction

④ Fourth Quadrant Operation

→ positive voltage and negative current in load.

→ A positive load-emf E assumed.

→ direction of current is negative.

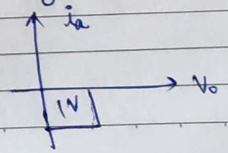
→ when machine is operating in Quad 1, brake command is received and thereafter torque and current command goes negative.

→ Opening T_1 & T_2 will enable D_3 and D_4 to allow current via source, reduce current to zero.

→ For negative current, T_4 is turned on.

→ The average voltage is positive and average current is negative across the load.

→ source power is ~~zero~~ negative.



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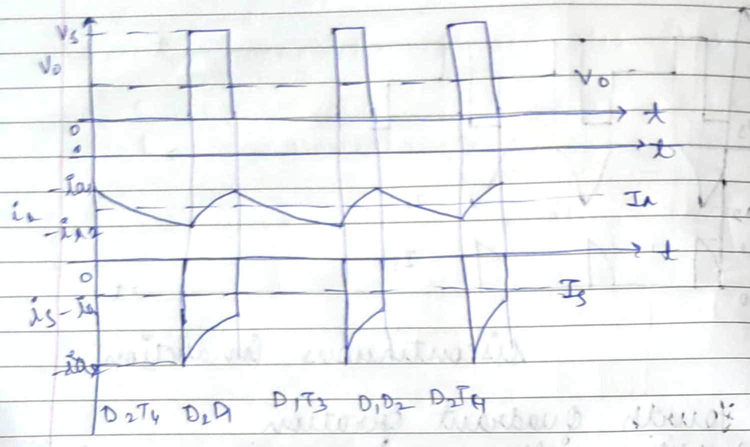

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- Current becomes zero in discontinuous
  Current ~~becom~~ does not become zero in continuous.
- Due to inductor → continuous / discontinuous
- $\frac{RL}{3\omega L}$ More than critical (continuous) / Less than critical (discontinuous)
- Ex 4.3, 4.1, 4.2

Topics: 4 Quadrant ops, 1 quad operation, 2 quad operation

Code in matlab

19/3/25

CHP 5 Polyphase Induction Motor < Steady state / Dynamic

Transformer

- 3 flux
- Rotating magnetic field makes this rotate.
- direct axis and Quadrature axis.
- Phasor diagram → draw when only sine waveform
- Ex 5.1, 5.2

Q. Write a code in MATLAB to implement flowchart 5.5 (krishnan book).

Q. To plot torque slip / torque speed chara for 3φ induction motor : MATLAB code.

* Dynamic modelling of induction Machine
→ Sudden load rise / load drop / freq variation
→ Machine can't be purely resistive : needs flux → flux from inductor. → for rotation

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Q MST paper resolve.

- varying induction due to changing flux.
- Dynamic Modelling process.
  3phase → 2 phase → stationary
- Need a stationary refrence frame.

⟹ stator frame, rotor frame, arbitary frame

(*) Fig 5.13 and Eqⁿ 5.46, 5.47, 5.48, 5.49 (Imp).

- Flux at 90° → no mutual on each other.

» Generalized Theory by PS Bimbhra $\boxed{\text{Chp 2}}$

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27/8/25

Magnetomotive Force = NI

- mmf in magnetic ckt generates flux.

$I\uparrow$ → conductor size ↑ heat increase

$N\uparrow$ → material more.

- 3ϕ machine into 2ϕ : equating mmf.

Current $\left[i_2 = \frac{3}{2} i_3\right]$ phase

of each phase $\frac{3}{2}$ ×2

Power Total
2ϕ system ⇒ 3VI
3ϕ system ⇒ 3VI

Q. (PS Bimbra) Write procedure for obtaining per phase voltage & current for 3ϕ to 2ϕ transformation. (Eq 2.6 upto). Also discuss how equivalent mmf can be obtained in 3ϕ and 2ϕ system.