POWER ELECTRONIC DRIVES

We use Sine because

* $V = L\frac{di}{dt}$; $i = C\frac{dv}{dt}$

Sinusoidal when integrating or differentiating doesnt change wave shape

△, □ wave change their shape

* Any wave can be represented as sinusoids.

Pushing dominant harmonics by increasing the gap between dominant harmonics not eliminating.

Assignment - 0 Submit on Friday

Midsem	35
Assignment	15
Endsem	50

Lecture 1 (4-1-24)

Drives that employ motors as prime mover are known as electrical drives

→ design depends on load requirement.

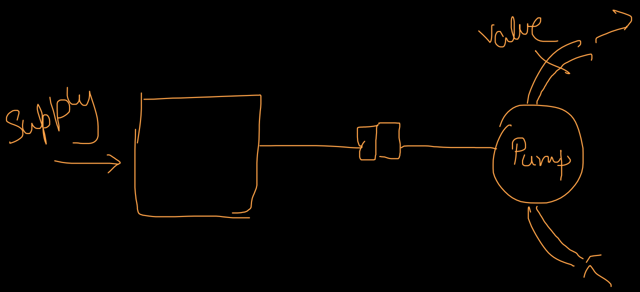
→ Majority of energy is used for drives

drives → fixed speed drive. → torque requirement change
Speed const

→ Variable speed drive.

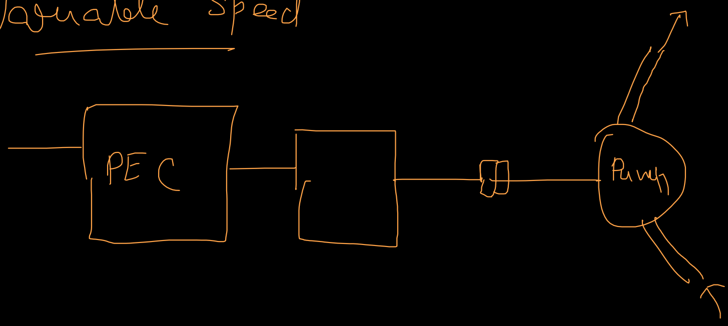
→ We are concentrating on this.

Const Speed



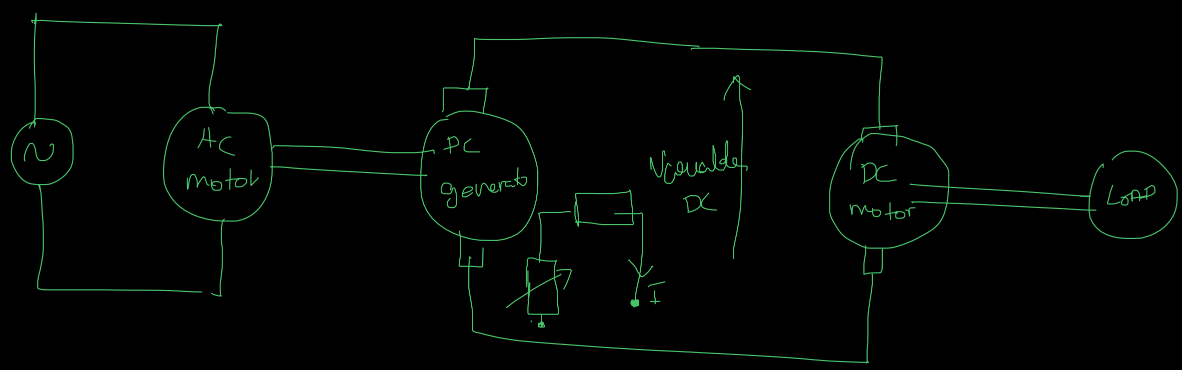
loss in valve is more

Variable Speed



loss in valve is none.

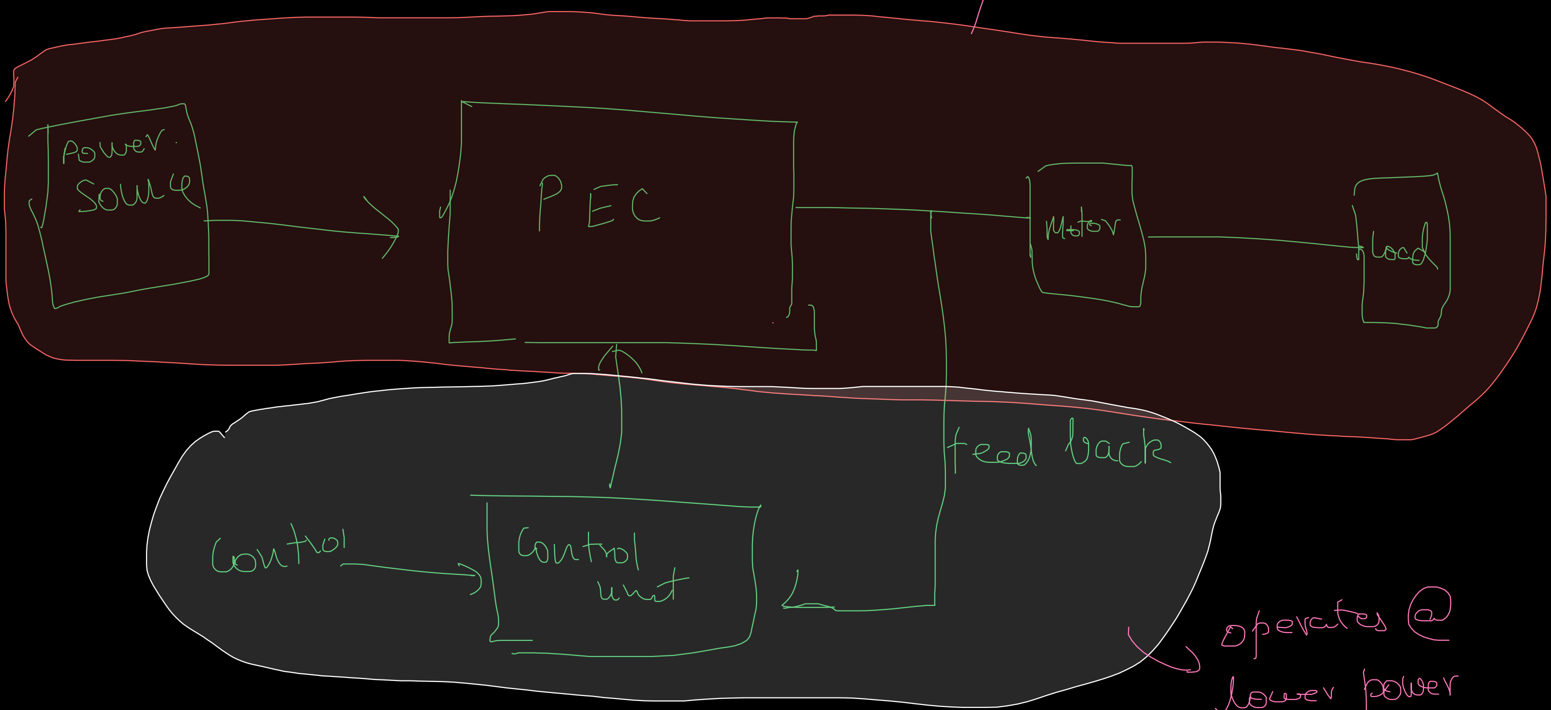
Conventional Electrical drive System



→ bulky
→ inefficient
→ inflexible

Modern electrical Drive

operates @ higher power



operates @ lower power

→ Small
→ efficient
→ flexible

Should be isolation between them (Optocoupler)

Power Processor

↳ Modulates the power flow to motor to source such that the motor is impacted with speed torque char required by load

→ During transient operations, it restricts source & motor currents to permissible limit

ie protection is incorporated into the PEC.

↳ Overcurrent, Over voltage

↳ Thermal limit

↳ heatsink design

→ Select mode of operation of motor.

↳ 4 quad

→ Converts power into suitable form for motor (AC, DC).

Adv of electrical drives

↳ Flexible control char

↳ Steady state & dynamic char can be shaped to meet load requirement.

- Wide range of speed control.
- electric braking
- Wide range of speed, power, torque
- high η, low no load loss
- Short time overloading capacity
- flexible operating condition
- No pollution
- 4 quadrant operation
- no re fueling, warmup

Parts of electrical drive

DC Motor

- Regular maintenance, heavy, expensive, speed limit.
- Easy control, decoupled control of flux, torque.

AC Motor

- less maintenance, less expensive, high speed
- Coupling between torque & flux — variable spatial angle between rotor & stator flux.

Solved by
vector control.

Choice of drive

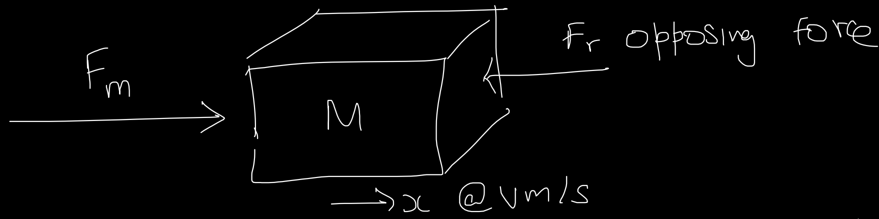
- SS operating requirement
  - S Vs T char
  - Speed regulation
  - Speed range
  - Dutycycle
  - Quadrants of operation
  - Speed fluctuation
- Transient operating requirement
- Requirement related to Source
- Capital cost, running cost, maintenance needs, life } Reliability engineering.
- Space & weigh restriction
- environment & location.
- Reliability.

Lecture - 2 5/1/24

Dynamics of electrical drive-

Fundamental torque eqn

(i) Linear motion



when F_m is greater than F_r (opposing)
the It'll move by x.

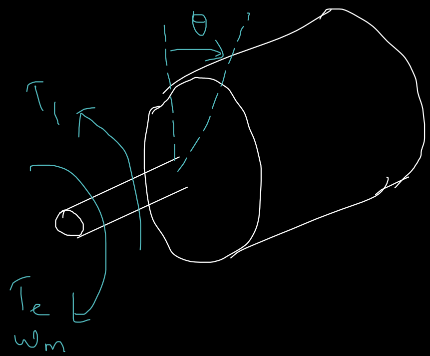
$$F_m - F_r = \frac{d(Mv)}{dt} \quad \text{or}$$

$$= M\frac{dv}{dt} \quad \text{or} \quad M\frac{d^2x}{dt^2}$$

First or second order diff eqn.

$$F_m - F_r = Ma$$

(ii) Rotational



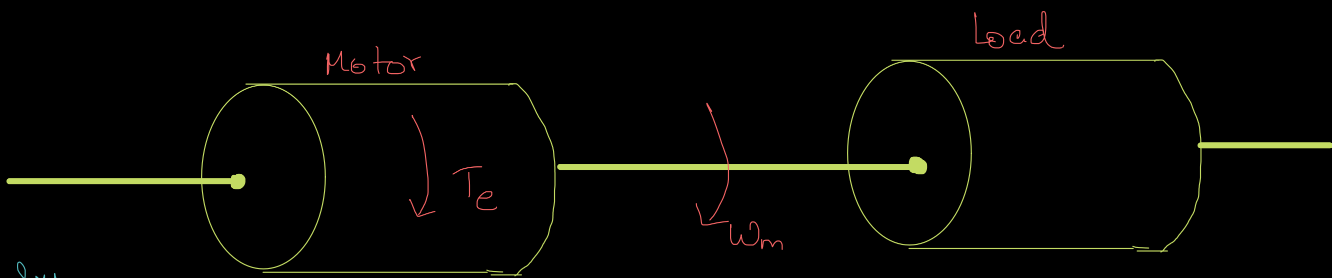
$$T_e - T_l = \frac{d(J\omega_m)}{dt}$$

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

$$= J\frac{d^2\theta}{dt^2}$$

1st or 2nd order diff eqn

Equivalent motor load system



$$T_e = T_L + J\frac{d\omega_m}{dt}$$

T_e → electromagnetic torque

T_L → Load torque

$J\frac{d\omega_m}{dt}$ → dynamic torque → It will be present only

* developed by motor
* we control this

all components that oppose the motion

during transient (in SS ω_m = const)

→ Starting
→ Braking
→ acceleration
→ deceleration

$$\omega_m T_e = \omega_m T_L + \omega_m J \frac{d\omega_m}{dt}$$

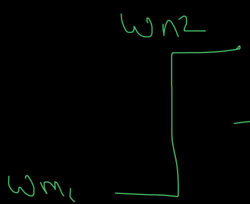
$$P_D = P_L + J\omega_m \frac{d\omega_m}{dt}$$

* driving power
* we supply

load power

Change in KE

$$KE = \left(\frac{1}{2} J\omega^2\right)$$



→ Step change in speed. ⇒ P_D should be infinite

not practically possible

There is a current limit that decides the maximum rate of change of speed.

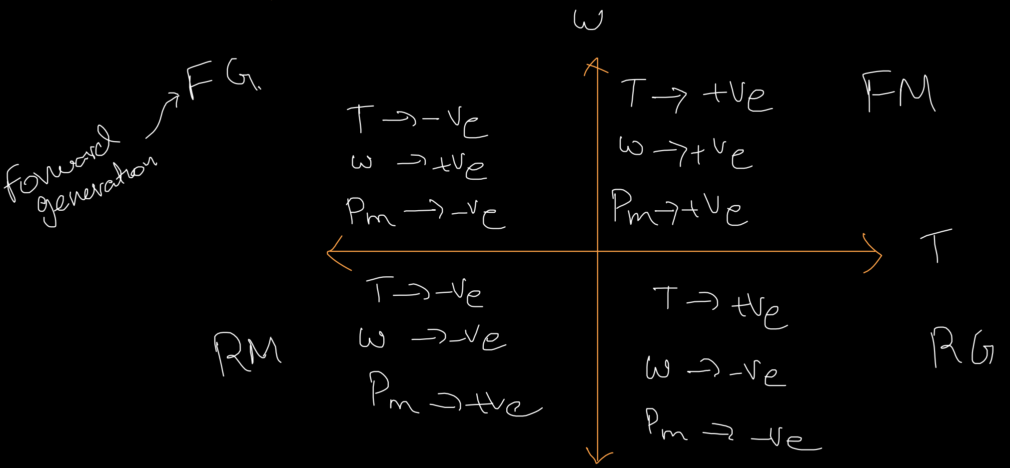
* So drive system that require fast acceleration require

→ Large motor torque capability
→ low moment of inertia

During acceleration → excess energy is supplied from stored KE.

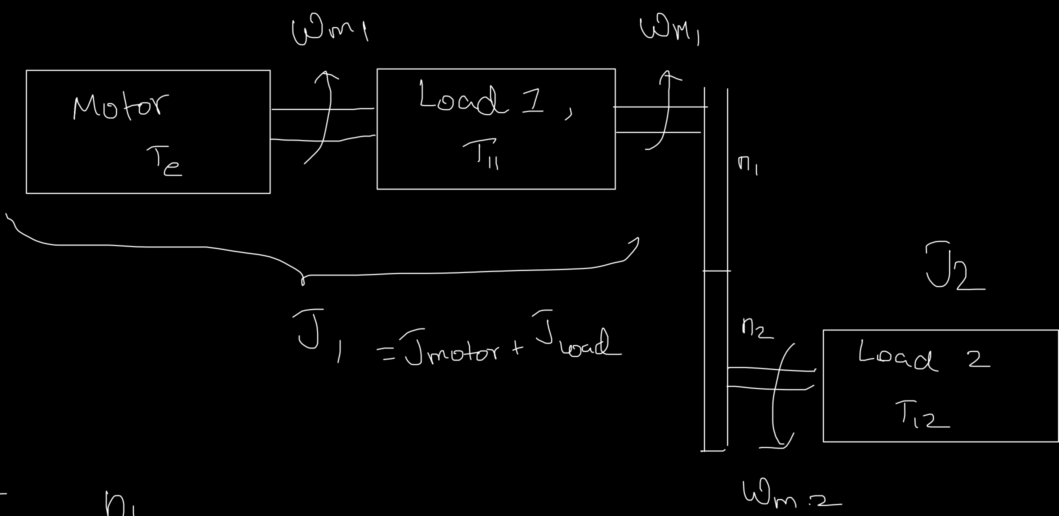
So sometimes purposefully J is increased to increase KE stored.

Torque - Speed quadrant of operation



ref Slide -9 for diagram

Loads with rotational Motion



$$\frac{\omega_{m2}}{\omega_{m1}} = \frac{n_1}{n_2} = a_2$$

neglect loss,

Then KE due to eq MoI = KE due to all moving parts.

$$\frac{1}{2} J_{eq} \omega_m^2 = \frac{1}{2} J_1 \omega_{m1}^2 + \frac{1}{2} J_2 \omega_{m2}^2 \left(+ a_3^2 J_3 \omega_{m3}^2 \ldots \right)$$

if there is more loads)

$$J_{eq} = J_1 + a_2^2 J_2$$

$$\left(\because \frac{\omega_{m1}}{\omega_m} = 1 \quad \& \quad \frac{\omega_{m2}}{\omega_{m1}} = a_2 \right)$$

|||ly Power total = Power of individual

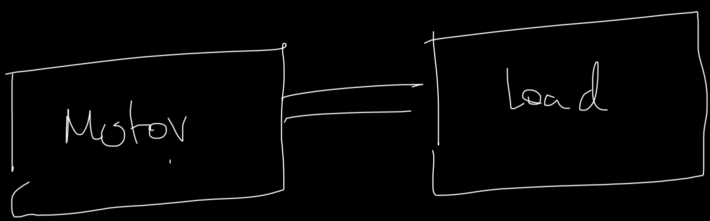
Say, Transmission eff η_2

$$T_{1eq}\omega_m = T_{11}\omega_{m1} + \frac{T_{12}\omega_{m2}}{\eta_2}$$

$$T_{1eq} = T_{11} + \frac{T_{12}a_2}{\eta_2}$$

So any System can be represented as motor load system.

∴



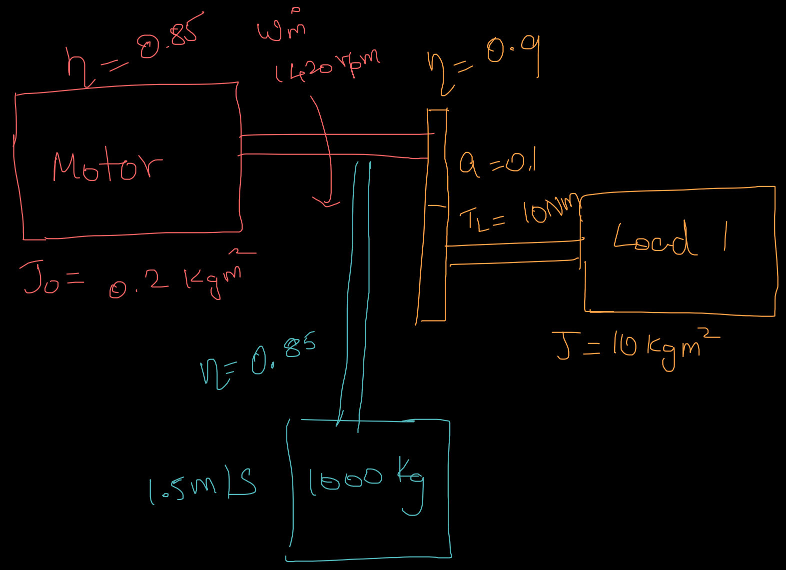
Say there are m other loads

$$J_{eq} = J_0 + a_1^2 J_1 + a_2^2 J_2 + \cdots + a_m^2 J_m$$

$$T_{eq} = T_{10} + \frac{a_1 T_1}{\eta_1} + \frac{a_2 T_2}{\eta_2} + \cdots + \frac{a_m T_m}{\eta_m}$$

given

$a = 0.1$	$M = 1000$ kg	$N = 1420$ rpm
$\eta = 90\%$	$V = 1.5$ m/s	
$J = 10$ kgm^2	$\eta = 85\%$	
$T_L = 10$	$J = 0.2$ kgm^2	



$$\frac{1}{2} J_{eq} \omega_{mo}^2 = \frac{1}{2} J_{L1} \omega_m^2 + \frac{1}{2} M v^2 + \frac{1}{2} J_{motor} \omega_{mo}^2$$

$$\frac{1}{2} J_{eq} \omega_{mo}^2 = \frac{1}{2} J_m a^2 \omega_{mo}^2 + \frac{1}{2} M v^2 + \frac{1}{2} J_{motor} \omega_{mo}^2$$

$$J_{eq} = J_m a^2 + M \left(\frac{v}{\omega_{mo}}\right)^2 + J_0$$

$$= (0.1)^2 10 + 1000 \left(\frac{1.5}{148}\right)^2 + 0.2$$

$$= 0.4027$$

$$T_{eq} \omega_{mo} = T_{L1} \omega_{m1} + F V$$

$$= \frac{T_{L1} a \omega_{mo}}{\eta_1} + \frac{F V}{\eta_2}$$

$$T_{leq} = T_{L1} \frac{a}{\eta_1} + \frac{F}{\eta_2} \frac{V}{\omega_{mo}}$$

$$= T_{L1} \frac{a}{\eta_1} + \frac{mg}{\eta_2} \frac{V}{\omega_{mo}}$$

$$= 10 \frac{0.1}{0.9} + \frac{1000 \times 9.81 \times 1.5}{0.85(148.7)}$$

$$= 117.53 \text{ Nm}$$

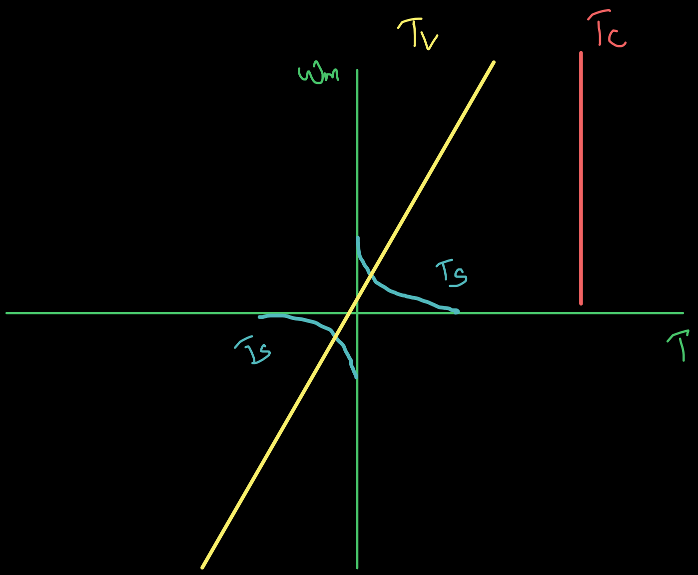
$$P = 117.53 \times 148.7 \qquad T\omega_{mo}$$

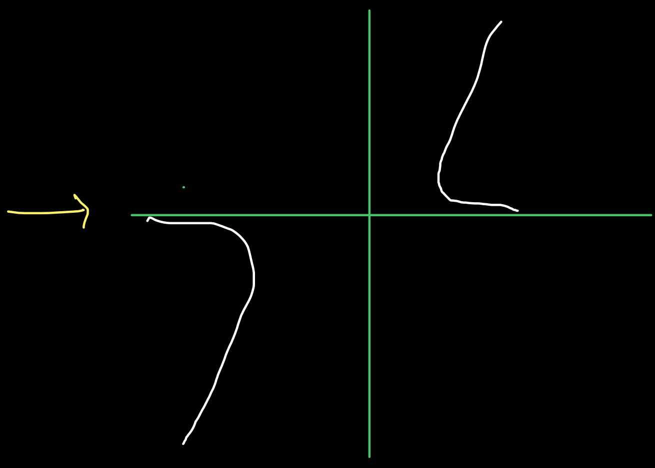
$$\boxed{P = 17476.711 \text{ W}}$$

Lecture-3 8/1/24

Components of Load Torque

① Frictional Torque (Passive Load) T_F





Static Friction

- Stationary
- exists when there is no relative motion b/w objects.

Viscous Friction

↳ Varies linearly with speed

Coloumb Friction

② Windage Torque (T_w)

↳ wind generates a torque that opposes the motion

$$T_w = C\omega_m^2$$

③ Torque required to do useful mechanical work (T_L)

↳ depends on application

↳ Const or independent of speed

∴ for a finite speed,

$$T = T_L + B\omega_m + \underbrace{T_c + C\omega_m^2}_{\text{neglected}}$$

static torque is neglected because its not Stationary

Sometimes, $T_c + C\omega_m^2$ is compensated by updating $B \to B'$

Coupling Torque

↳ when even there is a tortional elasticity in shaft coupling load to motor

$$T_{cp} = K_e \theta_e$$

$\theta_e \rightarrow$ tortional angle of coupling

$K_e \rightarrow$ rotational stiffness.

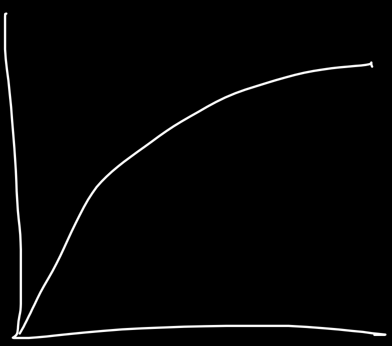
We can assume the shaft is perfectly stiff and ignore in most cases.

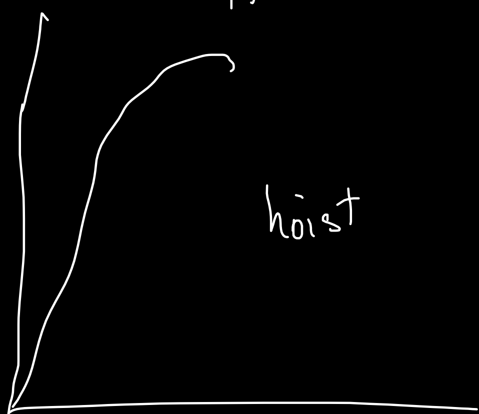
$\therefore$ with all approximations,

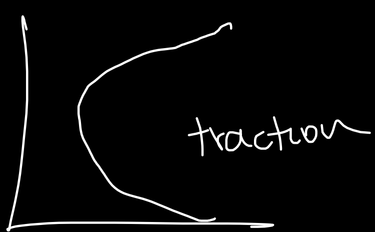
$$T_e = J \frac{d\omega_m}{dt} + T_L + B\omega_m$$

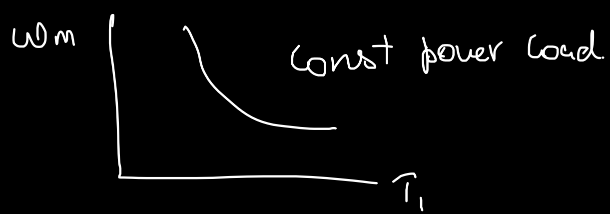
Nature & Classification of load Torque

↳ depends on application

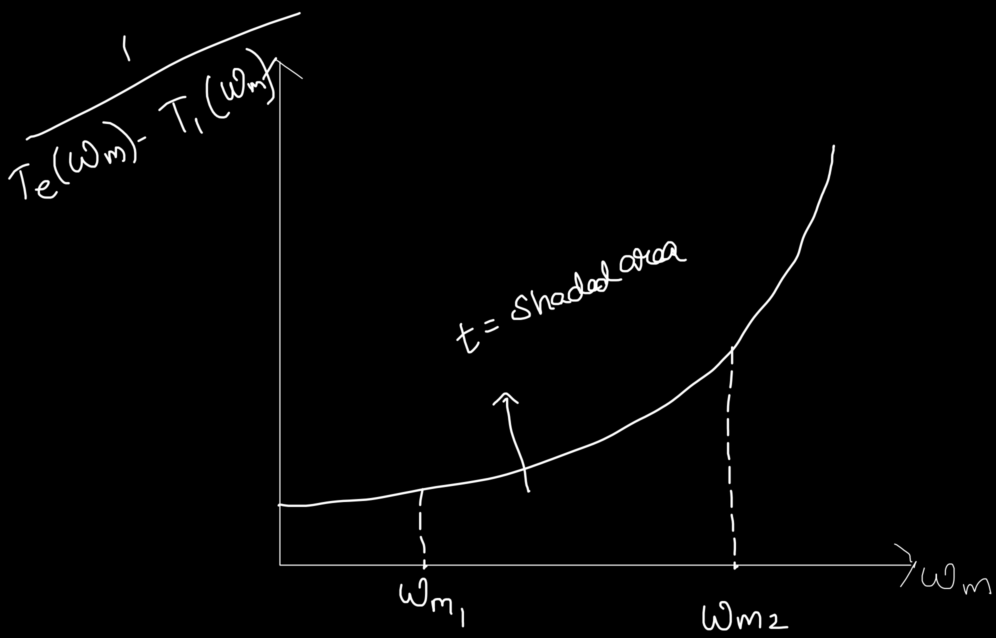








Calculation of time & energy loss in transient operation



$$T_e = T_L + J\frac{d\omega_m}{dt}$$

$$dt = \frac{J}{T_e - T_L}$$

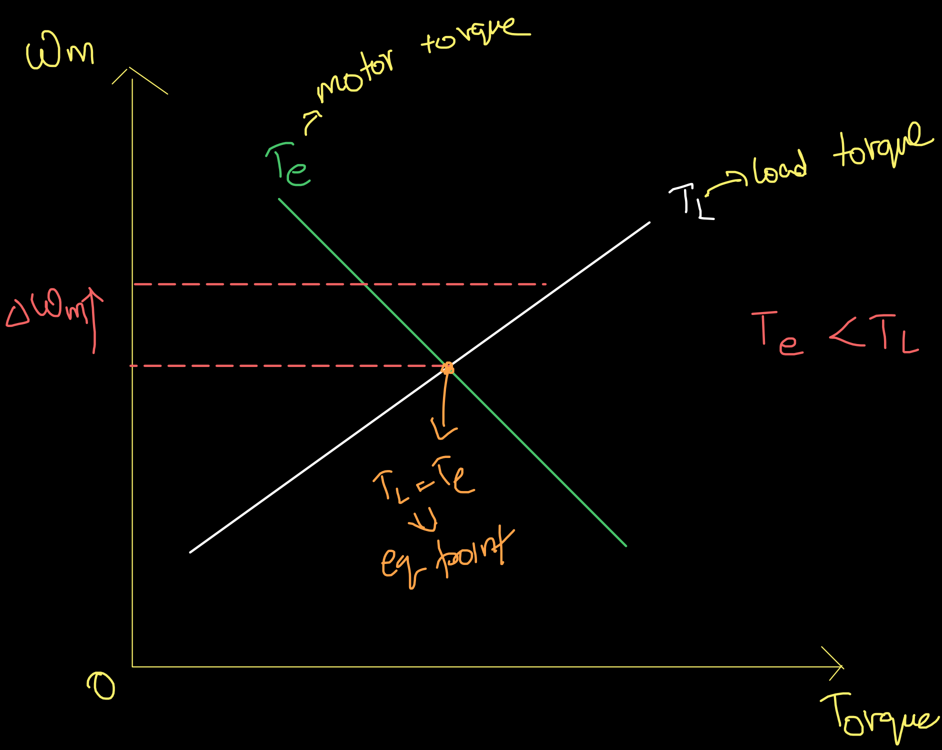
$$t = \int_{\omega_{m_1}}^{\omega_{m2}} \frac{J}{T_e - T_L}\, d\omega_m$$

area gives time

Steady State Stability

→ Stable equilibrium point → Satisfy BIBO

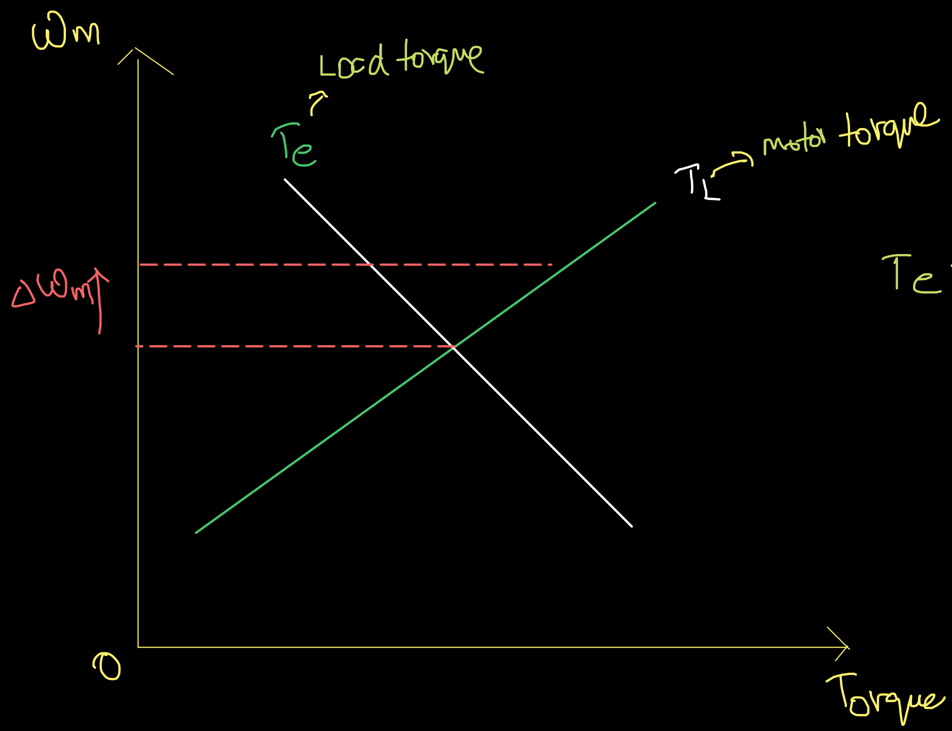
→ will come back to equilibrium.



$T_e < T_L \Rightarrow$ system decelerates

so comes down to eq point

So System is Stable.



wm $\omega_m \uparrow$

$T_e > T_L \Rightarrow$ acceleration

so moves away from the eq point

So this System is unstable

Say, small perturbation in speed $\Delta\omega_m \Rightarrow \Delta T_e$ & ΔT_L

$$(T_e + \Delta T_e) = (T_L + \Delta T_L) + J\frac{d(\omega_m + \Delta\omega_m)}{dt}$$

$$\Delta T_e - \Delta T_L = J\frac{d}{dt}\Delta\omega_m$$

$$J\frac{d}{dt}\Delta\omega_m + \left(\frac{dT_e}{d\omega_m} + \frac{dT_L}{d\omega_m}\right)\Delta\omega_m = 0$$

Solving DE

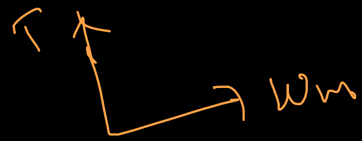
$$\Delta\omega_m = (\Delta\omega_m)_0\, e^{-\frac{1}{J}\left[\frac{dT_L}{d\omega_m} - \frac{dT_e}{d\omega_m}\right]t}$$

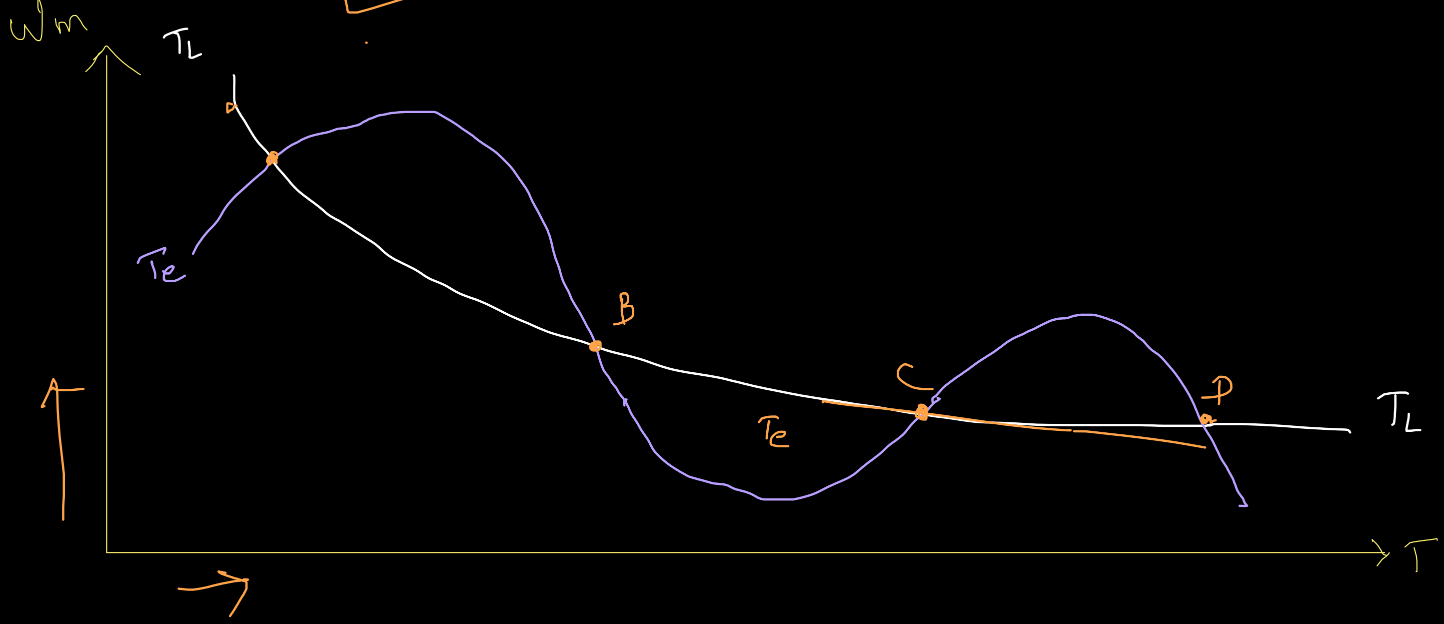
Should be -ve so that it exponentially decreases & reaching Stable state.

ie $\frac{dT_L}{d\omega_m} - \frac{dT_e}{d\omega_m} > 0$

$$\frac{dT_L}{d\omega_m} > \frac{dT_e}{d\omega_m}$$

So, Slope of Load torque > Slope of motor torque





A → $\frac{dT_e}{d\omega_m} > \frac{dT_L}{d\omega_m}$ → Stable

B → $\frac{T_e}{d\omega_m} < \frac{dT_L}{d\omega_n}$ → U Stable

C → → Stable

D → → U Stable

<u>H.W</u> → photo

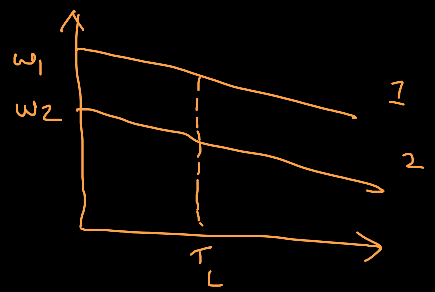
Missed class

Lecture # 5 12/1/24

Control of electrical drives

↳ controlling wrt requirement of load

↳ Steady State ⟶ Load torque = Motor torque



$T_L \rightarrow$ required torque

↳ Acceleration (including starting)

↳ Deceleration (including braking)

* Const Speed drives (can be variable torque)
* Variable Speed drives { Const torque mode, Const power mode } operation
  - ↳ Multi Speed drives → (100, 200, 300) ↳ only at particular speeds
  - ↳ Steppers Speed drives
* Multi Motor drive

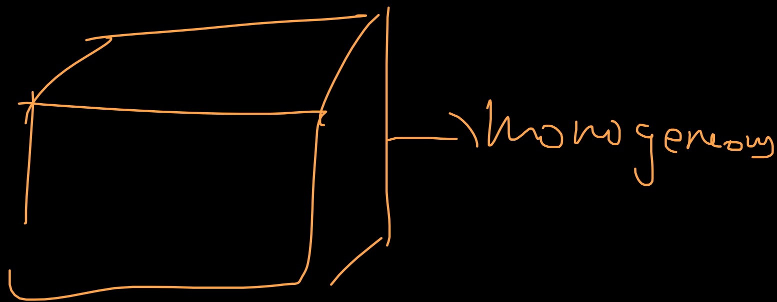
Thermal consideration

↳ power loss

↳ insulation of wdg } temp

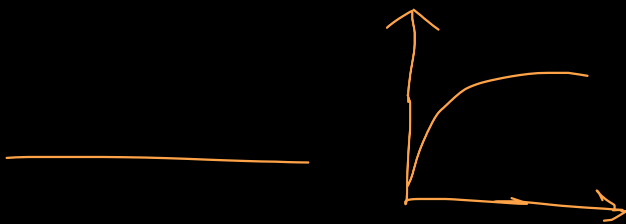
Conductor, Core, friction } Causes.

assume motor to be homogeneous,



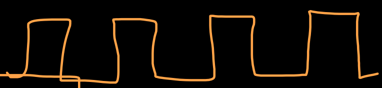
$$\frac{C\,dt}{dt} = P_1 - P_2 \rightarrow \text{Power balance.}$$

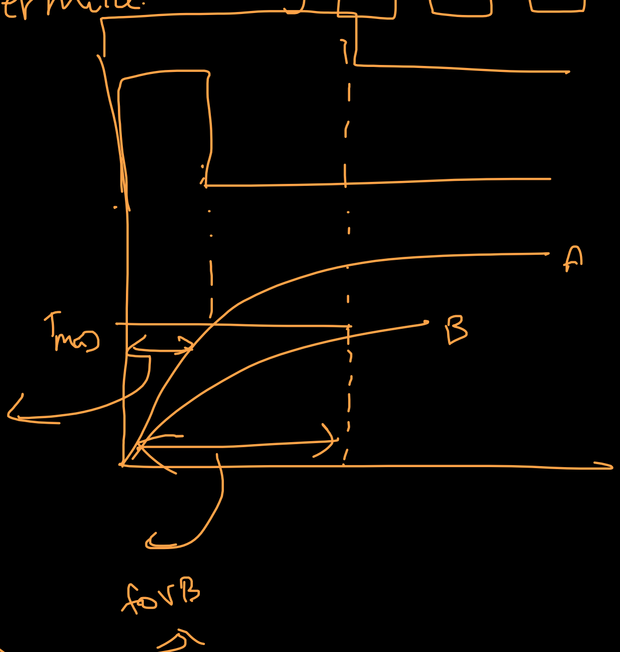
Continuous duty → temp reaches steady state



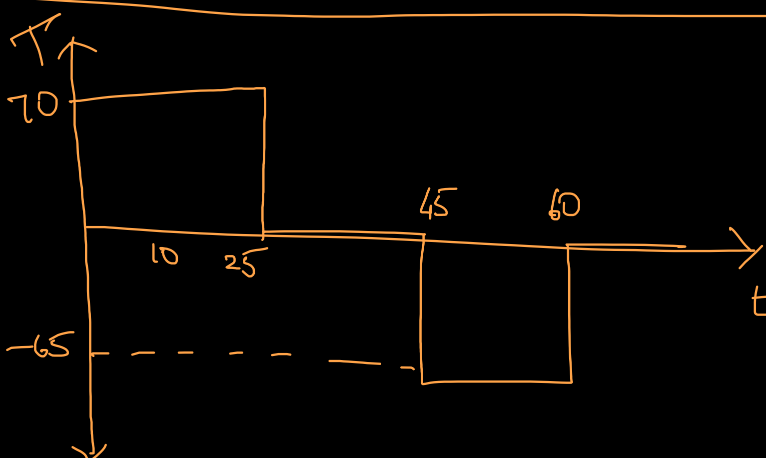
Short time intermittent

Periodic intermittent





this is the time motor is allowed to overload the machine



$J = 0.01\ kgm^2$

$B = 0.1\ Nm/rad$

$T_{load} = 5\ Nm$

What would be the speed profile

Sol

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt}$$

0 – 25 (ms)

$$70 = 5 + 0.1\,\omega_m + 0.001\frac{d\omega_m}{dt}$$

$$65 = 0.1\,\omega_m + 0.001\frac{d\omega_m}{dt}$$

$\omega_m(0) = 0$

$$\frac{65}{S} = 0.1\,\omega_m(S) + 0.001\left(S\,\omega_m(S) + 0\right)$$

$$\frac{65}{S} = (0.1 + 0.001S)\,\omega_m(S)$$

$$\omega_m(S) = \frac{65}{S(0.001S + 0.1)}$$

$$=$$

finish

Design of Inductor

L, I_p, I_{rms}, Core table, Wire table, J, B_m, K_w

① Compute

$$A_c A_w = \frac{L I_p I_{rms}}{K_w J B_m}$$

② Select a core from core table with the required $A_c A_w$ (it should be more than $A_c A_w$)

③ Find A_c, A_w for the selected core from core table

④ Compute $N = \frac{L I_p}{A_c B_m}$, Select nearest whole number of N^*.

⑤ Compute $a_w = \frac{I_{rms}}{J}$, select nearest whole number of wire gauge, a_w^* from wire table

⑥ Compute the required air gap in the core

$$l_g = \frac{\mu_0 N^2 I_p}{B_m}$$

⑦ Check assumptions

→ Core reluctance <<< airgap reluctance:

$R_c << R_g$;

$$\frac{l_m}{\mu_0 \mu_r A_c} << \frac{l_g}{\mu_0 A_c}$$

$$\boxed{\frac{l_m}{\mu_r} << l_g}$$

→ No fringing

$$l_g << \sqrt{A_c}$$

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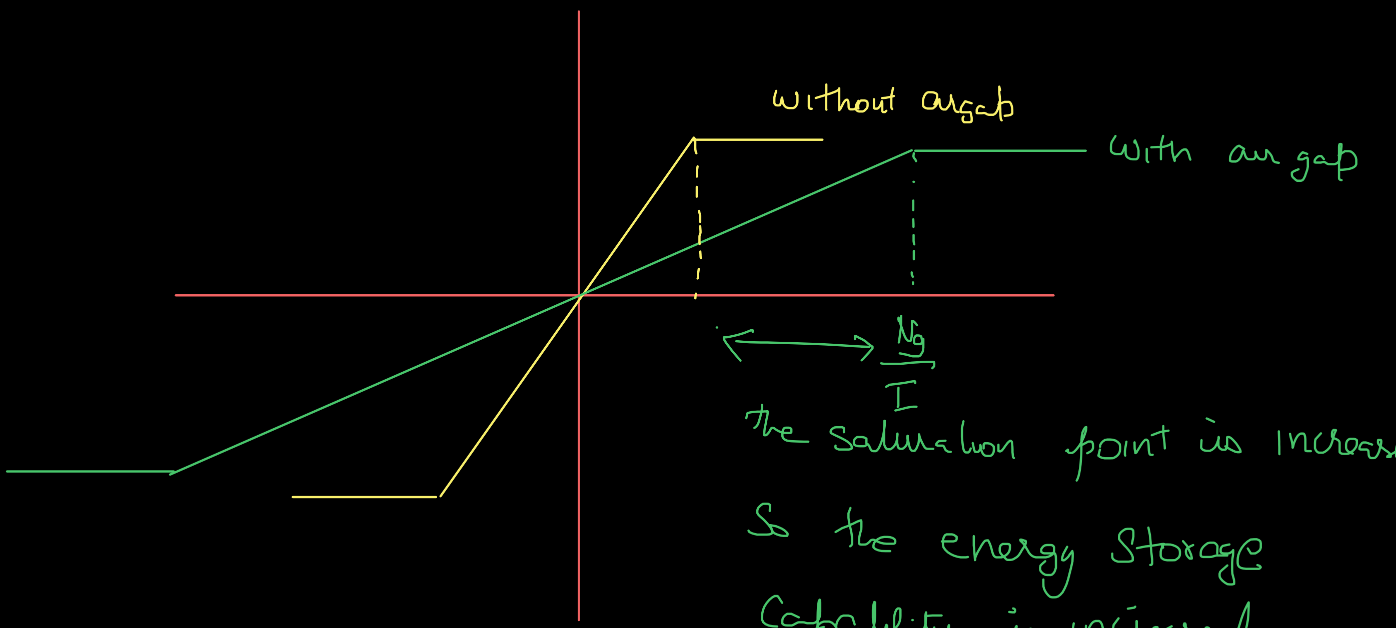
diff between Inductor & Air gap is presence of airgap in inductor



the saturation point is increased

So the energy storage capability is increased

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(8) recalculate $J^* = \frac{I_{rms}}{a_w^*}$

(9) Recalculate $K_w^* = \frac{N^* a_w^*}{A_W}$

(10) Compute from geometry of core, mean length per turn — ______

Problem

given: $L = 2mH$

$I_p = 0.5A = I_{rms}$

Core 26×19, $A_w = 40mm^2$; $A_c = 90mm^2$; $N = 37$ turns

$a_w = 0.29mm^2$ (23 SWG)

To find

peak flux density, peak current density - - -

$$J_{max} = \frac{I_p}{a_w} = \frac{0.5}{0.29 \times 10^{-6}} = 1.724 \times 10^6 \, A/m^2$$

$$K_w = \frac{N a_w}{A_w}$$

$$= \frac{37 \times 0.29}{40} = 0.268$$

$$B_{max} = \frac{I L^2}{K_w J A_c A_w}$$

$$= 0.3$$

$$L = \frac{N^2}{R} \; ; \; R = \frac{l_g}{\mu_0 A_C}$$

(i) $l_g = 0.08mm$

$$R = \frac{0.08 \times 10^{-3}}{4\pi \times 10^{-7} \times 90 \times 10^{-6}}$$

$$= 707.355$$

(ii) $l_g = 1mm$

$$R = \frac{1 \times 10^{-3}}{4\pi \times 10^{-7} \times 90 \times 10^{-6}}$$

$$L = \frac{37^2}{707.355}$$ $L = 0.$

$= 1.93\ mH$

Design of Transformer

1.25 KVA	$B_m = 1.2\,T$
230V / 115 V	$K_w = 0.3$
$J = 2.5 \times 10^6\ A/m^2$	$f = 250\,Hz$

$$A_c A_w = \frac{VA}{2 f K_w J B_m}$$

$$= \frac{1.25 \times 10^3}{2 \times 250 \times 0.3 \times 2.5 \times 10^6 \times 1.2\,T} = 2.7 \times 10^{-6}\ mm^4$$

from core table } $A_c = 1451.6\ mm^2$

$A_w = 1935.5\ mm^2$

$$N_1 = \frac{230}{4(250) \times 1.2 \times 1451.6 \times 10^{-6}} = 132.129$$

$$N_2 = \frac{115}{4(250) \times 1.2 \times 1451.6 \times 10^{-6}} = 66.0646$$

we can take $N_1 = 134$ & $N_2 = 67$

$$a_{\omega_1}^{*} = \frac{T}{J} = \frac{6.521}{2.5\times10^{6}}$$

$$=$$

Lecture #6 16/1/24 & 23/1/24

DC Motor drives

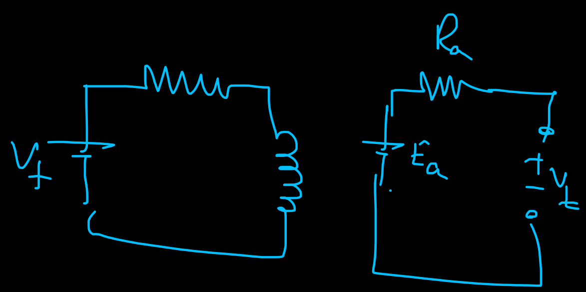
$$T \propto \phi I_a$$

$$E \propto \phi \omega_m$$

Variable speed → seperately excited is better.

$$E_a = V_t - I_a R_a \quad ; \quad V_f = R_f I_f$$

$$E_a = K_a \phi \omega_m$$



$$\omega_m = \frac{E_a}{K_a \phi}$$

$$= \frac{V_t - I_a R_a}{K_a \phi}$$

$$\omega_m = \frac{V_t}{K_a \phi} - \frac{I_a R_a}{K_a \phi}$$

$$T_e = K_a \phi I_a$$

$$\boxed{\omega_m = \frac{V_t}{K_a\phi} - \frac{T_e R_a}{(K_a\phi)^2}}$$ → Speed Control is based on this expression

example - 1

given, $R_a = 2\Omega$

$I_a = 5A$

$E_a = 220V$

$N_m = 1200\ rpm$

w.k.t = $E_a = V_t - I_a R_a$

$220 = V_t - 2(5)$

$$\boxed{V_t = 230\ V}$$

$E_b = K_a\phi\omega_m$

$\omega_m = 1200 \times \frac{2\pi}{60}$

$= 40\pi$

$K_a\phi = \frac{E_b}{\omega_m} = \frac{220}{40\pi}$

$T_{er} = K_a\phi I_a$

$= \frac{220}{40\pi} \times 5 = 8.7535$

Lecture 9

Modelling of DC Machines

all^{el} pathy

↳ lap windg

$W_n = \frac{2\pi N}{60}$

$$V = e + i_a R_a + L \frac{di_a}{dt} \Rightarrow \frac{di_a}{dt} = \dot{i}_a = \frac{V - e}{L_a} - \frac{i_a R_a}{L_a}$$

$$T_e = T_L + J \frac{d\omega_m}{dt} + B_\ell \omega_m \Rightarrow \frac{d\omega_m}{dt} = \dot{\omega}_m = \frac{T_e - T_L}{J} - \frac{B_L W_m}{J}$$

$$\begin{bmatrix} \dot{i}_a \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & 0 \\ 0 & -\frac{B_L}{J} \end{bmatrix} \begin{bmatrix} i_a \\ \omega_m \end{bmatrix} + \begin{bmatrix} \frac{V-e}{L_a} \\ \frac{T_e - T_L}{J} \end{bmatrix}$$

$$\boxed{e = K_b \dot{i}_a}$$

Sub

$$\begin{bmatrix} \dot{i}_a \\ \dot{\omega}_m \end{bmatrix} = \begin{bmatrix} -\frac{R_a}{L_a} & -\frac{K_b}{L_a} \\ +\frac{K_b}{J} & -\frac{B_L}{J} \end{bmatrix} \begin{bmatrix} i_a \\ \omega_m \end{bmatrix} + \begin{bmatrix} \frac{1}{L_a} & 0 \\ 0 & \frac{1}{J} \end{bmatrix} \begin{bmatrix} V \\ T_e \end{bmatrix}$$

$$\lambda I - A = 0$$

↳ Char eqn

$$\begin{vmatrix} \lambda + \frac{R_a}{L_a} & \frac{K_b}{L_a} \\ -\frac{K_b}{J} & \lambda + \frac{B_L}{J} \end{vmatrix} = 0$$

$$\left(\lambda + \frac{R_a}{L_a}\right)\left(\lambda + \frac{B_L}{J}\right) + \frac{K_b^2}{J L_a} = 0$$

$$\lambda^2 + \lambda\left(\frac{B_L}{J} + \frac{R_a}{L_a}\right) + \frac{R_a B_L}{L_a J} + \frac{K_b^2}{J L_a} = 0$$

$$= \frac{-\left(\frac{B_L}{J} + \frac{R_a}{L_a}\right) \pm \sqrt{\left(\frac{B_L}{J} + \frac{R_a}{L_a}\right)^2 - 4\left(\frac{R_a B_L}{L_a J} + \frac{K_b^2}{J L_a}\right)}}{2}$$

① State Variable as nodes

$$\frac{\omega_m(s)}{V(s)} = \frac{\dfrac{K_b}{(R_a + sL_a)(B_l + sJ)}}{1 + \dfrac{K_b^2}{(R_a + sL_a)(B_L + sJ)}}$$

$$\frac{\omega_m(s)}{V(s)} = \frac{K_b}{(R_a+sL_a)(B_L+sJ)+K_b^2}$$

$$\frac{\omega_m(s)}{T_L(s)} = \frac{\frac{1}{B_l+sJ}}{1+\frac{K_b^2}{(R_a+sL_a)(B_L+sJ)}}$$

$$= \frac{R_a+sL_a}{K_b^2+(R_a+sL_a)(B_l+sJ)}$$

Problem

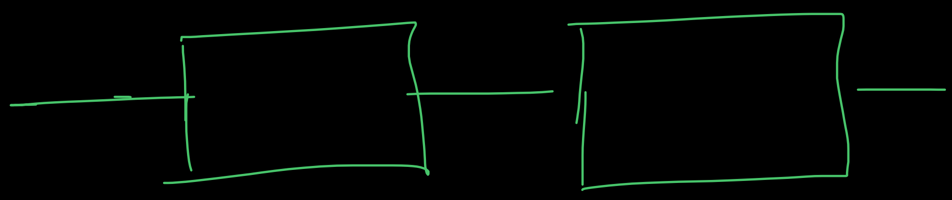
(1) $V = 220V$

ω_m

Lecture-10

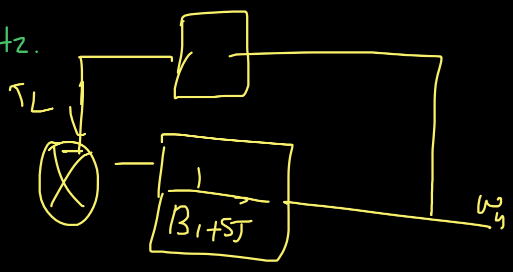
(b)

Lecture -11



We dont take delay into consideration because, in DC DC → switching freq is high So delay is small can be neglected

for rectifiers, freq is 50 Hz.



$$\frac{V(s)}{I_a(s)} = \frac{1/R_a+SL_a}{1 - \frac{1}{R_a+SL_a}\,\frac{K_b^2}{B_1+SJ}}$$

$$= \frac{B_1+SJ}{(R_a+SL_a)(B_1+SJ) - K_b^2}$$

$$\frac{I_a(s)}{W_m(s)} = \frac{K_b / B_1+SJ}{1 - \frac{1}{R_a+SL_a}\,\frac{K_b^2}{B_1+SJ}}$$

$$= \frac{K_b(R_a+SL_a)}{(R_a+SL_a)(B_1+SJ) - K_b^2}$$

$$= \frac{\frac{1}{B_1 + SJ}}{1 + \frac{1}{B_1 + SJ} B_L}$$

$$= \frac{1}{B_1 + SJ + B_L}$$

$$\frac{\frac{1}{R_a + SL_a}}{1 + \frac{1}{R_a + SL_a} \frac{K_b^2}{B_1 + B_L + SJ}} = \frac{\overbrace{B_1 + B_L}^{B_t} + SJ}{(R_a + SL_a)(\underbrace{B_1 + B_L}_{B_t} + SJ) + K_b^2}$$

given

$V = 220V$

$N = 1470$

$R_a = 4\,\Omega$

$J = 0.0607$

$L_a = 0.072H$

$B_t = 0.0869$

$K_b = 1.26$ V/rad/s

$$= \frac{B_t + SJ}{(R_a + SL_a)(B_T + SJ) + K_b^2}$$

$T_a =$

$$\frac{\omega(s)}{T(s)} = \frac{B_t}{(1 + ST)} = \frac{0.0869}{1 +}$$

$$T_m = \frac{J}{B_t} = \frac{0.0607}{0.0869} = 0.69850$$

$$K_1 = \frac{B_t}{R_a + B_t + K_b^2}$$

$$= \frac{0.0869}{4 + 0.0869 + 1.126}$$

$$= 0.045$$

$$\boxed{T_1 > T_2}$$

$$\boxed{\begin{aligned} T_2 &= 0.026 \\ T_1 &= 0.107 \end{aligned}}$$

$$\longrightarrow \boxed{0.0449\,\frac{1+0.6985S}{(1+0.107S)(1+0.026S)}} \longrightarrow \boxed{\frac{14.49}{1+0.6S}} \longrightarrow$$

---

given,

$V = 220V$

$I = 8.3\ A$

$N = 1470$ RPM

$R_a = 4\Omega$

$J = 0.0607\ kg\ m^2$

$L_a = 0.072H$

$B_t = 0.0869\ Nm/rad/s$

$K_b = 1.26 V/s$

Converter:

230V, 3ϕ, 60Hz

i/p Voltage is $\pm 10V = V_c$

Tacho generator TF : $\frac{0.065}{(1+0.002S)}$

$V_{ref\,max} = 10V \Rightarrow$

$I_{max} = 20A.$

Converter TF

60Hz, 3ϕ

$$\Rightarrow T_r = \frac{1}{6(60)\times 2}$$

$$= \frac{1}{720}$$

$$= 0.00138 \text{ S.}$$

$$= 1.38 \text{ ms}$$

$$V_c = \pm 10V$$

$$K_r = \frac{3}{\pi}\sqrt{2}\,V$$

$$= \frac{3\sqrt{2}\; 230}{\pi}$$

$$K_r = 310.609$$

Check

$$V_{c_{max}} = 7.09$$

(ii)

$$I_{max} = 20A$$

$$H_c = \frac{7.09}{I_{max}} = \frac{7.09}{20} = 0.355 \text{ V/A.}$$

(ii) Motor TF

T_m, T_1, T_2

$$V_a(s) \longrightarrow \boxed{\frac{K_1(1+sT_m)}{(1+sT_1)(1+sT_2)}} \longrightarrow \boxed{\frac{K_b/B_t}{1+sT_m}} \longrightarrow \omega(s)$$

$$\frac{K_b}{B_t} = \frac{1.26}{0.0869} = 14.49$$

$$T_m = \frac{J}{B_t} = \frac{0.0607}{0.0869}$$

$$= 0.699$$

$$T_1, T_2 = -\frac{1}{2}\left[\frac{B_t}{J} + \frac{R_a}{L_a}\right] \pm \sqrt{\frac{1}{4}\left(\frac{B_t}{J} + \frac{R_a}{L_a}\right)^2 - \frac{K_b^2 + R_a B_t}{J L_a}}$$

Check $\longleftarrow$ $$= -\frac{1}{2}\left[\frac{1}{0.699} + \frac{4}{0.072}\right] \pm \sqrt{\frac{1}{4}\left(\frac{1}{0.699} + \frac{4}{0.072}\right)^2 - \frac{1.26^2 + 4(0.0869)}{0.0607(0.072)}}$$

$$\frac{I_a(s)}{V_s(a)} = \frac{0.0449(1+0.7s)}{(1+0.0208s)(1+0.1077s)}$$

$$\frac{\omega_m(s)}{I_a(s)} = \frac{14.5}{(1+0.7s)}$$

(iv) Current Controller

$$T_c = T_2 = 0.0208 \ S$$

approximation !! $K = \frac{T_1}{2T_r} = \frac{0.1077}{2 \times 0.001388} = 38.8$

$\delta = 0.707$

damping ratio

actual $K = \frac{(T_1 + T_r)^2}{2T_1 T_r} = 40$

$$K_c = \frac{K T_c}{K_1 H_c K_f T_m} = 2.33$$

Small difference

$$K_c = 2.44$$

(v) Current loop approximation

$$\frac{I_a(S)}{I_a^*(S)} = \frac{K_i}{1 + ST_i}$$

$$K_i = \frac{K_{f1}}{H_c} \frac{1}{(1 + K_{f1})} = 2.75$$

$$K_{f1} = \frac{K_c K_r K_1 T_m H_c}{T_c} = 38.8$$

$$T_i = \frac{T_s}{1 + K_{f1}} = \frac{0.109}{1 + 38.8} =$$

Speed controller design

$$T_4 = T_i + T_w$$

$$= 0.0027 + 0.002$$

$$= 0.0047$$

R. Krishnan book

$$K_2 = \frac{K_1 K_b H_w}{B_1 T_m} = \frac{2.75 \times 1.20 \times 0.065}{0.0869 \times 0.7}$$

$$= 3.70$$

$$K_s = \frac{1}{2 K_2 T_4} = \frac{1}{2 \times 3.70 \times 0.0047} = 28.73$$

$$T_s = 4 T_4 = 4 \times 0.0047 = 0.0188 \text{ sec}$$
