Sunday 22/9/2019

Electric Drive.

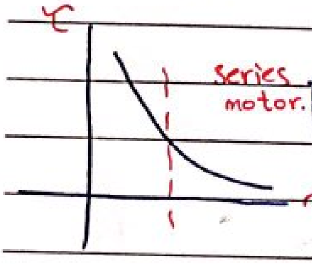
(electrical machines drive)

involved: ① Electrical machines

- DC motors (precise control), have more features than AC → Series, compound, shunt
- AC motors (inspecific: induction motor) ↳ very hard to control.

up to 90% of the market of DRIVE.

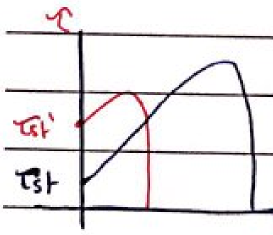
HINT: adding a resistor (—⌇—) to rotor would: ① reduce the starting current (I_{st})
② increase the starting Torque (τ_{st})



series motor. → very dangerous motor due to high starting Torque.
↳ it has to start (loaded).

- spark in commutation circuit: ↓ brush + commutator Produce sparks because of current break down. (armature reaction)

Question to wonder !!
why is low frequency (500 HZ) is enough in power applications ??
for the speed of the mechanical machine to be able to tolerate, it will add up to 10 times.



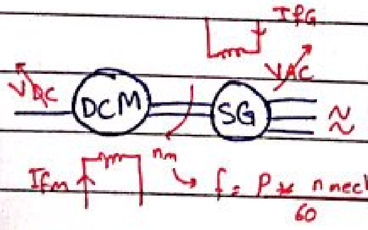
$n = \frac{60 f}{P} = \frac{120 f}{P}$

P ↳ pole pairs. P → # of poles

- vvvf: variable voltage, variable frequency.

② Power electronics (Power conditioning)

* DC machines are controlled through M-G set
↳ DC motor + synchronous generator.



↳ to the motor target.

↳ $f = \frac{P * n_{mech}}{60}$

*Speed is controlled from the Prime mover.

$Emf = 4.44\ K.W \propto \phi . f . N$
V ≃ ---
↳ related to I_{fG}

* Problems of Power electronics:

① Harmonics. ③ Torque pulsation.

② PF reduction ④ over heating.

$$I_{rms} = \sqrt{I_{av}^2 + I_{harmonics}^2}$$

↳ high value means more losses ($I^2 \times R$)

i.e → 20 % higher I_{rms} → 44 % over heating.

* over-heating is fatal to electrical machines.

* Insulation classes (A, B, C, ... F) → 155°C
↳ doesn't get deteriorated.

• Most important features in a motor
- Power
- frequency
- voltage
- speed
- Insulation class → heat v. imp

Tuesday 24/9/2019

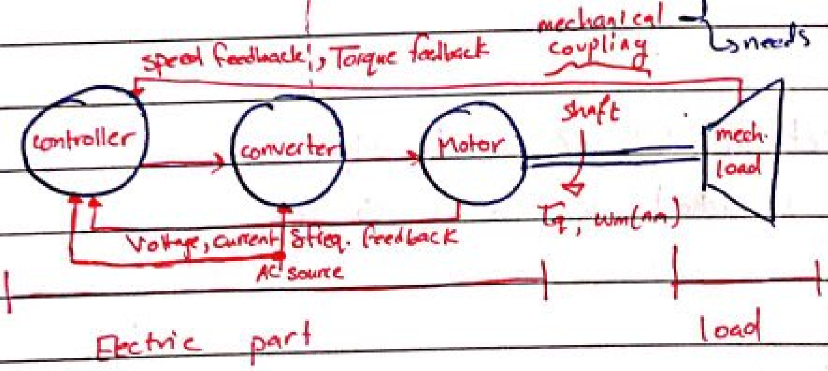
* Basic Drive system features:

① controller
② converter
③ Motor
④ Mechanical load

→ feedback to control

→ at least one PE converter either → rectifier or → AC regulator.

mechanical coupling → low efficiency
→ needs maintenence



what goes from the controller to the converter is pure Power electronics.

DRIVE

- Controller
  Electronic circuitries (from basic diode to micro-controller)
  ex: Triggering circuit of SCRs.
  Drive circuit of power transistors.

- Trigger → pulse & then the signal vanishes & the thyristor is still ON.
- Drive → signal must remain to keep the transistor ON.

- Converter: (piece of equipment which does electric power conditioning)
  Power conditioning: (shape (Nature), Amplitude (average for DC, RMS, Fundamental), frequency)
  → Rectifiers
  → choppers
  → Inverters.
  → AC regulators.

- Motor
  → DC Motors (Recently limited for precise control applications & certain loading conditions). 10%
  → AC Motors (90% of Drive systems & mainly induction motors & rarely synchronous motors).

Thursday 26/9/2019

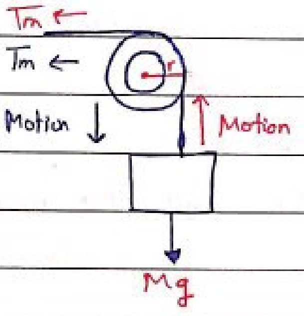
* Torque / Speed characteristics:

- Load Requirements & Motor capability.

Load Requirements:
- Torque value
- speed value
- direction of rotating.
- Braking.

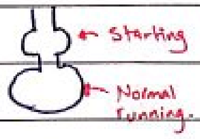
Motor capability:
- Torque (value & direction)
- Speed (value & direction)

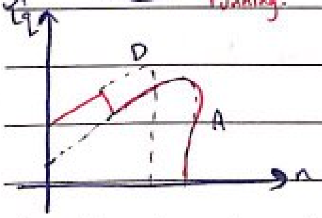
to match the load's requirements.



- direction of Torque doesn't change even if the direction of motion changes.

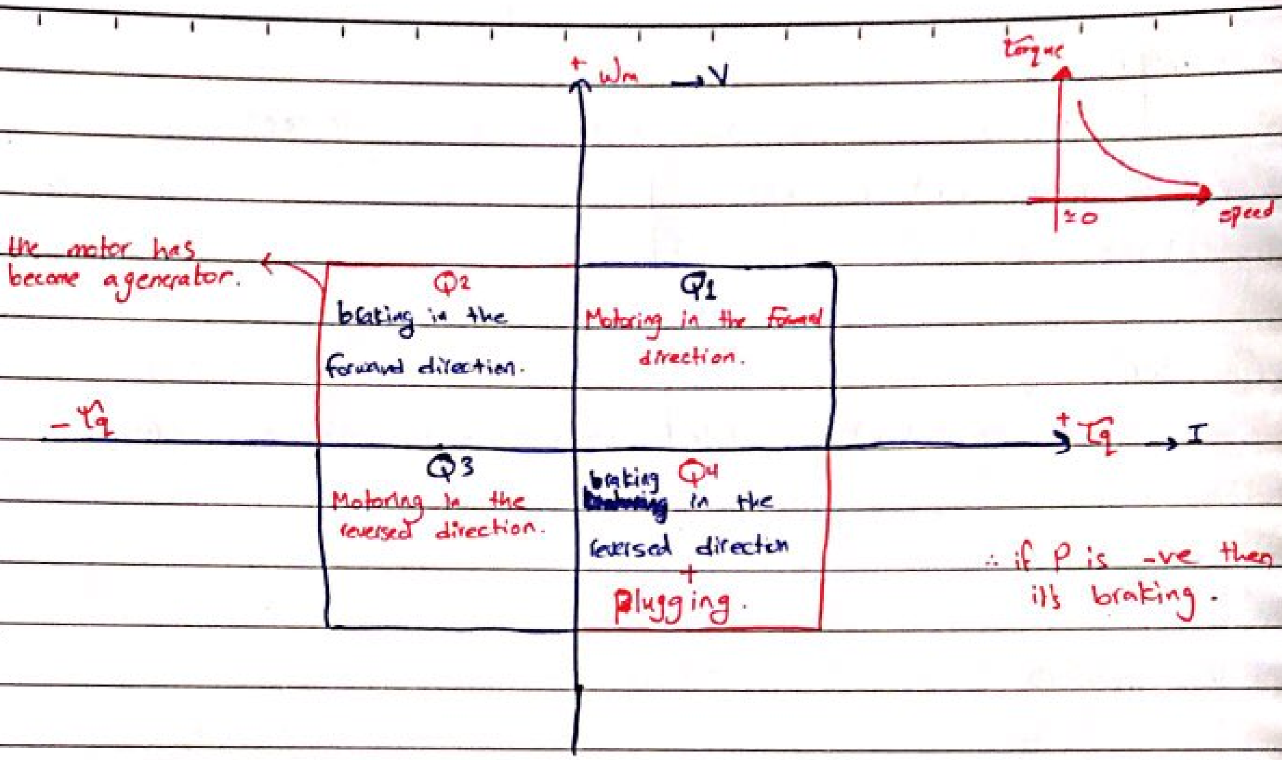
Hint:





*Power = Tq * wm

- Motor with -ve power means it's a generator.



∴ if P is −ve then it's braking.

- Quadrant 1 :

Motor running at certain direction to drive mechanical load.

Both Torque & speed are considered positive.

$P = T_q * w_m \quad (+)$

- Quadrant 3 :

Motor running in the opposite direction to drive mechanical load.

Both Torque & speed are considered negative.

$P = -w_m * (-T_q) \quad (+)$

- Quadrant 2 :

Negative Torque but positive speed.

$P = (-T_q) * w_m \quad (-)$; the motor is running in the opposite direction as a generator to brake the load.

- Quadrant 4 :

case ①: the machine is running as a generator to brake the load in the reversed direction.

$P = (-w_m) * T_q \quad (-)$

Case ②: a type of breaking referred to as Plugging.

$\tau_q \oplus \rightarrow \omega_m (-)$

$P \rightarrow -ve$

$P = -(\omega_m) * \tau_q \quad (-)$

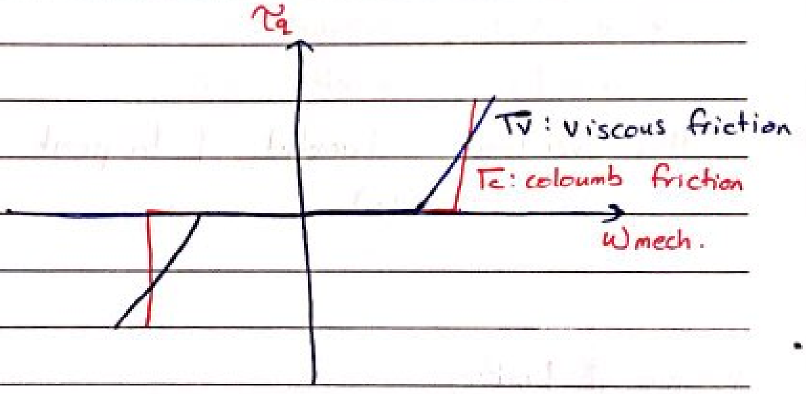
* why do we need braking?
  - energy saving / efficiency.
  - precise precision control. (that's why electrical cars are easy & simple to brake)

Sunday 29/9/2019

* Types of loads:

① Friction

$T_F = T_V + T_C$



② Acceleration / Desceleration.

$T_{acc} = J \cdot \frac{d\omega_{mech}}{dt}$

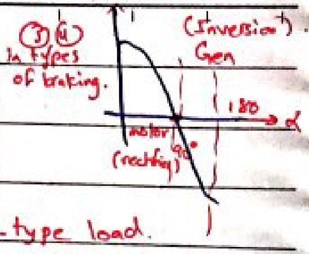
↳ moment of Inertia ($kg.m^2$)

a. for positioning systems (i.e: PV array movement, Antenna movement)
b. Starting of a certain load (Motor / load)
c. braking (Desceleration).

③ Windage.

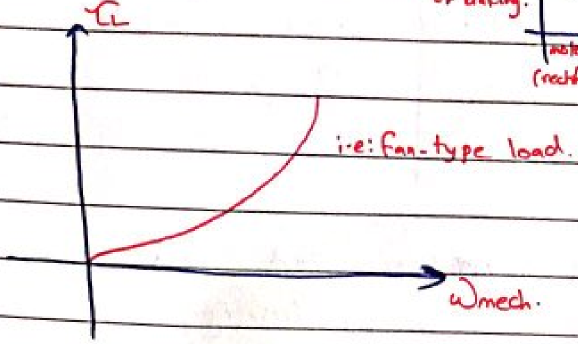
Torque required to move the air surrounding the rotational elements.

• motor → generator (reverse the direction of the field)



④ Mechanical load Torque.

$T_L = f(\omega_{mech})$



$T_L = T_F + T_W + T_{acc.} + T_{mech}.$

$T_{motor}(shaft) = T_L$

$T_{motor}(shaft) = T_d - P_{losses}(motor)$
↳ developed Torque.

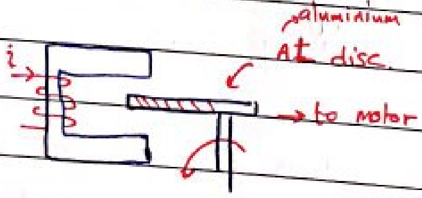
$T_{\underset{rated}{motor}}(shaft) = T_{Load}$ → the motor is fully-loaded $(T_q = \frac{P}{\omega_{mech.}})$

* the motor can be over-loaded for short periods of time.
ex: at starting (acceleration).
at braking (desceleration).
this over load is harmful if frequent starting / braking is applied. (i.e: lifts).

* Types of braking: Tuesday 1/10/2019

① conventional mechanical braking.
kinetic energy dissipated as heat (loss).

② Eddy-current braking.



- usually used in machine labs for testing purposes.
- kinetic energy is dissipated as heat.

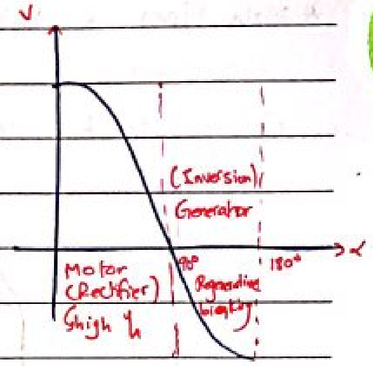
• $P_e \rightarrow f(B_m^2)$
• $P_h \rightarrow f(B_m^2)$ → 1.5 - 2.5

③ Dynamic braking.
The motor is controlled to run as a generator.
The generated power is locally used for other purposes (water heating, air conditioning).

④ Re-generative braking:

The motor is controlled to run as a generator.

The generated power is pumped back to supply.

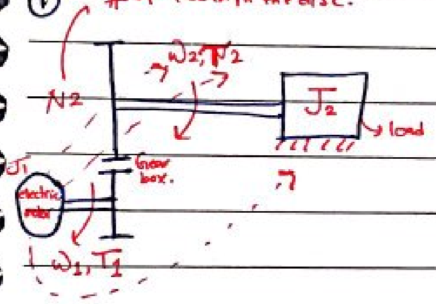


• HINT: efficiency is a very big advantage in Power electronics.

* Mechanical coupling (between Motor's Shaft and mechanical load's shaft):

① Gearing - Coupling.
② Belt-coupling.
} speed & Torque transformation. (+J) ↳ Inertia.

① # of teeth in the disc.



$T_q \longrightarrow V$ (transformer)

$\omega \longrightarrow I$ (transformer)

$J \longrightarrow Z$ (transformer).

• each load has a specific inertia → acceleration / braking.

$\tau = J \frac{d\omega_{mech}}{dt}$

$\tau = \frac{J}{r} \cdot \frac{dv}{dt}$ (linear motion)

v: linear speed.

• $v = \omega \cdot r$ (rotational & linear relation).

• $\boxed{\frac{T_1}{T_2} = \frac{N_1}{N_2} = a}$

• $P = \tau \cdot \omega$

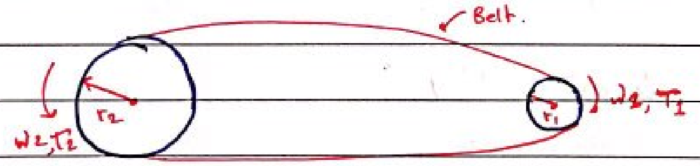
$\frac{\omega_1}{\omega_2} = \frac{N_2}{N_1}$

$\tau_1 = \tau_2' = T_2 \frac{N_1}{N_2} = a T_2$

• $\boxed{J_2' = \left(\frac{N_1}{N_2}\right)^2 J_2}$

* the only Problem in Gear-coupling is its losses.

②



• low radius is usually at the motor side.

Motor { high speed. / low torque.

$\frac{\tau_1}{\tau_2} = \frac{r_1}{r_2} = \frac{D_1}{D_2}$ (radius, diameter)

$\frac{\omega_1}{\omega_2} = \frac{r_2}{r_1}$, $J_2' = \left(\frac{r_1}{r_2}\right)^2 \cdot J_2$

* the problem of belt-coupling is it's elasticity, vibration, slippage.

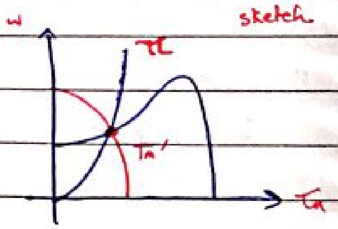
→ to avoid slippage: use teethed belt.

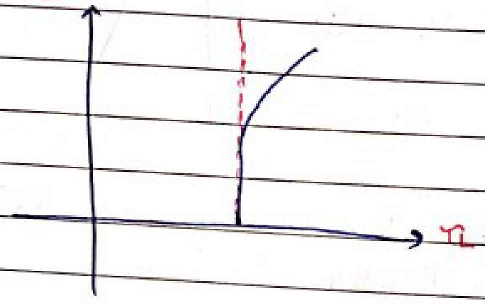
Thursday 3/10/2019

* Main types of mechanical loads:

① compressors.

T_L is almost independent of speed.





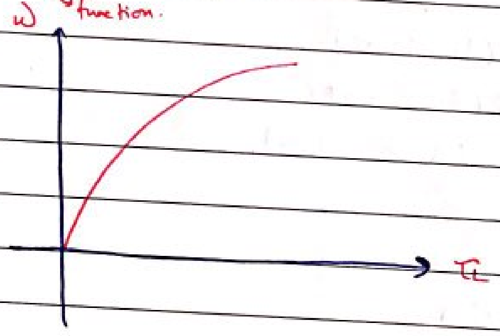
(linearized to be constant) practically.

- this load is unidirectional & works in Q_1, Q_3 only. (cannot be reversed).

(Zero speed / high starting torque for compressors).

② Fan-type load.

$T_L = \underset{\text{function.}}{f}(\omega^2) = K\omega^2$

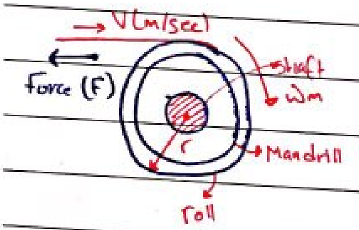


starting Torque = 0

$P = K.\omega^3$

(works in Q_1, Q_3 only).

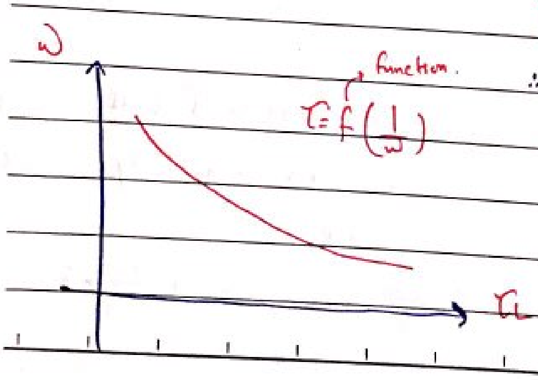
③ constant Power load.



$T_L = F.r$

$\omega_m = \frac{V}{r}$, $r = \frac{V}{\omega_m}$ $\therefore T_L = F * \frac{V}{\omega_m}$

$\underbrace{(T_L * \omega_m)}_{\text{Power}} = F.V$



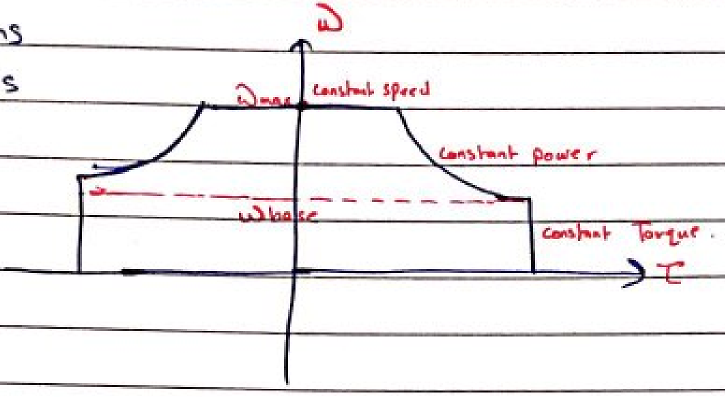
$T = \overset{\text{function.}}{f}\left(\frac{1}{\omega}\right)$

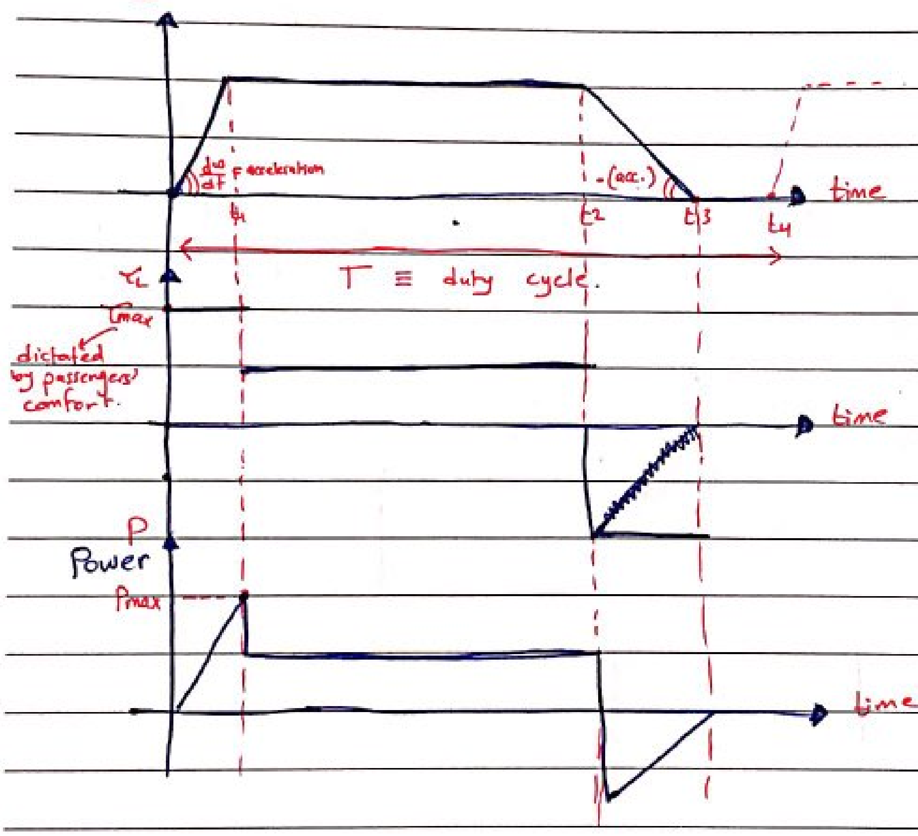
$\therefore P = T_L * \omega_m = \underbrace{F.V}_{\text{must be constants}} \equiv \text{constant.}$

④ Transportation loads.

- Subway trains
- street cars

:





$$\underbrace{T_m}_{\text{motor's torque}} = \underbrace{T_L}_{\text{load's torque}} + \overbrace{J\frac{dw}{dt}}^{\text{acceleration Torque}}$$

maximum Power ≡ rated Power.
but it's very large so
we take the rms value of powe

Sunday 13/10/2019

* Transportation

① Torque - speed limits

$\omega b \triangleq$ base speed

Max speed: load max. limits.

Max Torque: Max. motor Torque during acceleration.

$$\tau_{motor} = \tau_{Load} \text{ (constant speed)} + J.\frac{d\omega_m}{dt}$$

$$\tau_{motor} = \tau_L + \tau_{acc.}$$

- J (transporation) $\gtrsim$ 20 (normal loads) or Motor

- power limits :

Limits of the supply and converter.

* Station-to-station duty cycle :

$\omega = f(t)$, $\tau = f(t)$, $P = f(t)$

$$\omega = \frac{v}{r}$$

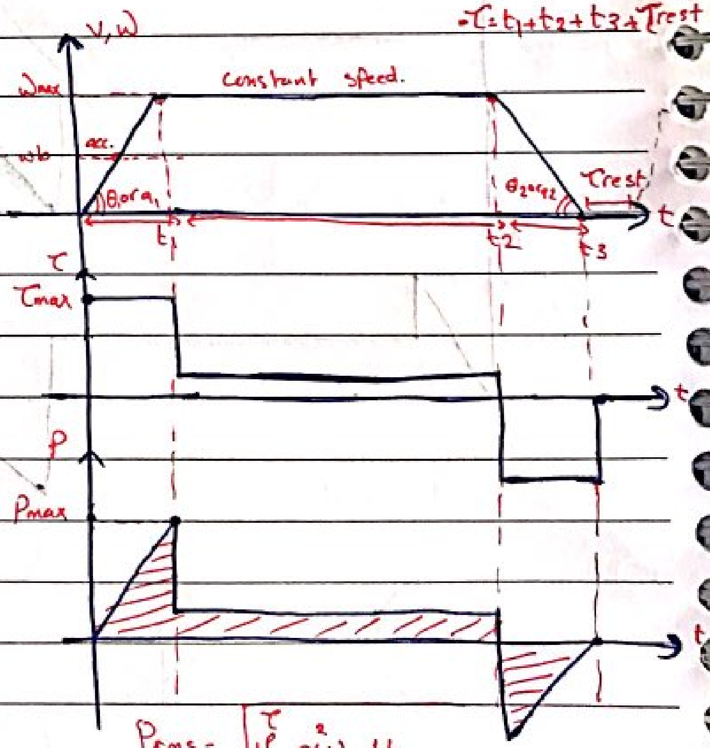
Linear acceleration $a = \frac{dv}{dt}$ (m/s^2)

$\theta = \frac{d\omega}{dt}$ (rad/s)

$$\theta = \frac{d(v/r)}{dt} = \frac{1}{r}\frac{dv}{dt} = \frac{a}{r}$$

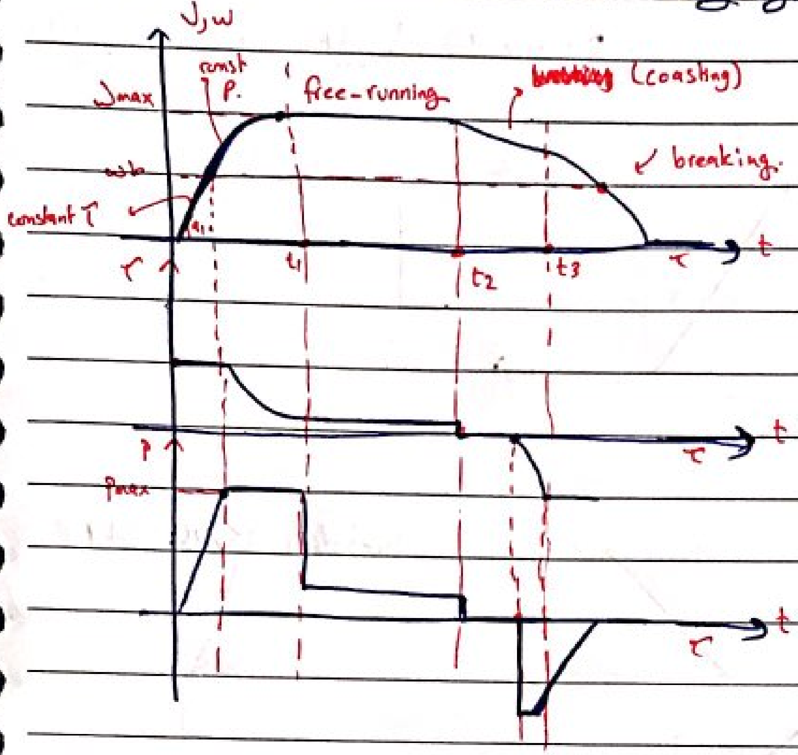
angular acceleration $\boxed{\theta = \frac{a}{r}}$ r : wheel's radius.

- $\tau = t_1 + t_2 + t_3 + \tau_{rest}$



$$P_{rms} = \sqrt{\frac{1}{\tau}\int_0^{\tau} p^2(t)\, dt}$$

* Modified station-to-station duty cycle: → for power to be less than the maximum scale.

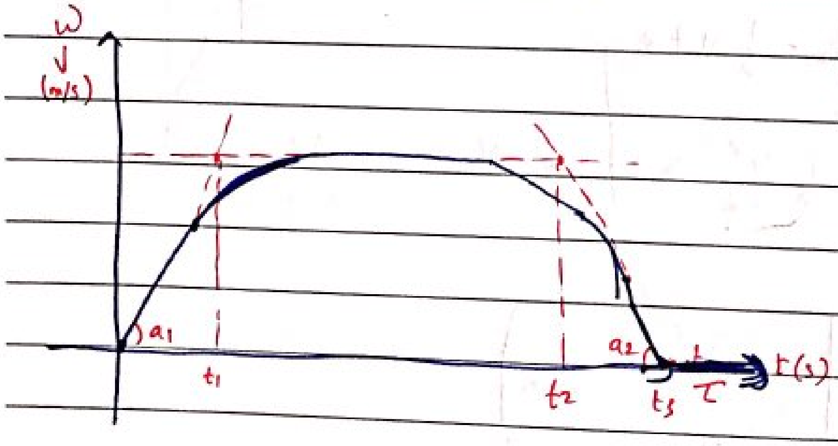


* the aim of modified version:

to reduce the maximum power limit of the converter/supply → and motor.

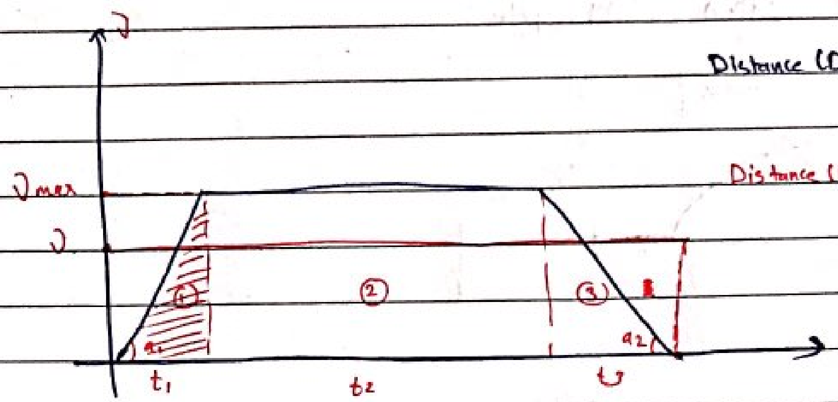
(acceleration at max Torque only up to the base speed).

* Speed/time Trapezoidal envelope



speed

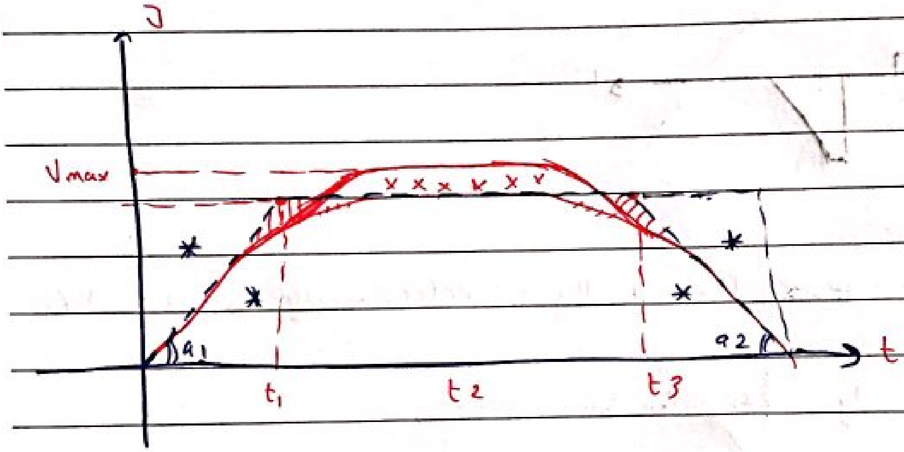
$$V_{avg} = \frac{\text{Distance}}{(t_1 + t_2 + t_3)}$$



$$\text{Distance (D)} = \overset{①}{\frac{1}{2}\vartheta_{max} t_1} + \overset{②}{\vartheta_{max} t_2} + \overset{③}{\frac{1}{2}\vartheta_{max} t_3}$$

$$\text{Distance (D)} = (t_1 + t_2 + t_3) \times \vartheta_{max} - \frac{1}{2}\vartheta_{max}^2\left(\frac{1}{a_1} - \frac{1}{a_2}\right)$$

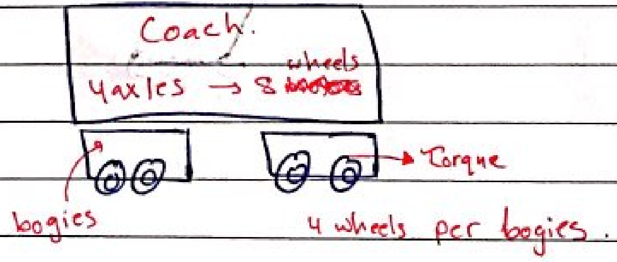
Tuesday 15/10/2019



Distance :

$$D = (t_1 + t_2 + t_3) * \vartheta - \frac{1}{2} v t_1 - \frac{1}{2} v t_3$$

$$D = (!t_2) * V + \frac{1}{2}\frac{V^2}{a_1} + \frac{1}{2}\frac{V^2}{a_2} \quad ; \quad V_{av.} = \frac{D}{t_1 + t_2 + t_3}$$



$n \equiv$ gear ratio

$n_1 \equiv$ # of motors.

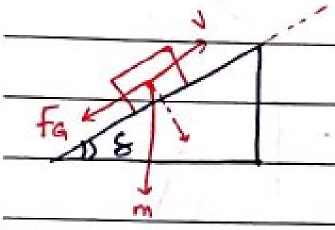
$n2 \equiv$ # of wheels.

$J_w \equiv$ Inertia for one wheel.

$J_w = \frac{1}{2} m r^2$

$J_m = \frac{1}{2} m r_a^2$

↳ armature of the motor's radius.



$\sin\delta \equiv G \equiv$ Gradient

$\sin\delta \leq 0.05$

- $F_G = mg \sin\delta$

$\tau = mg \cdot r$

* Required Torques during acceleration:

acceleration rate $\left(\begin{matrix} a_1 & acc \\ a_2 & dec \end{matrix}\right)$

① $\tau_{acc.} = m \cdot a \cdot r * \underline{\underline{n}}$ (for all motors)

↳ to refer to the motor side.

Acceleration (+,-) Torque.

② Torques to accelerate the rotating elements.

a) wheels ; $\tau_{wheel} = J_w * \frac{dw}{dt} = J_w * r\frac{dV}{dr} = J_w * \frac{a}{r}$ θ: Rotational (angular) acc.

$$\tau_W = J_w \cdot \frac{a}{r} \cdot n2 \cdot n$$; for all motors.

b) $\tau_{motor}(acc) = J_a \cdot \frac{a}{r}$; for one motor $\tau_{motor}(acc) = J_a \cdot \frac{a}{r} \cdot n_1$; for all motors.

③ Gradient Torque.

$$\underset{gradient}{\tau_G} = m \cdot g * r \cdot \sin\delta * n$$; for all motors.

④ Resistance to motion (friction + windage) during acceleration.

Assume to be : 20 Newton / Tonne

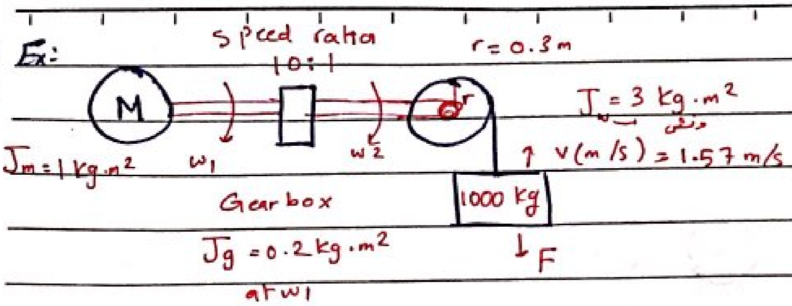
- 1000 kg → 20 Newton.

$$\tau_R = \frac{20 * \overset{mass\ (kg)}{m}}{1000} * r * n.$$; for all motors.

* $\tau_{shaft} = \tau_{acc} + \tau_w + \tau_R + \tau_{max}(acc.)$

Sunday 20/10/2019

Ex:



ⓐ Calculate Equivalent Inertia in motor side.

ⓑ Select suitable motor ratings $(P_r, \omega_m(r) \longrightarrow N_m(r))$, Assume 100 % efficiency for all system's elements.

Sol:

$$\frac{N_1}{N_2} = \frac{1}{10} = n$$

$$\frac{w_1}{w_2} = \frac{1}{n} = 10$$

$$\frac{T_1}{T_2} = n = \frac{1}{10} \quad , \quad \frac{J_1}{J_2} = n^2$$

ⓐ $J_{equ.}$ (m.side) $= J_m + J_g + J_w' + J_L'$

$$J_w' = n^2 J_w = \frac{1}{10^2} \times 3 = 0.03 \quad kg\,m^2$$

$J_L = m.r^2$ when Linear ; but when circular $\frac{1}{2} m r^2$

$$J_L = 1000 * (0.3)^2 = 90 \quad kg.m^2$$

$$J_L' = n^2 \times J_L$$

$$= \left(\frac{1}{10}\right)^2 \times 90 = 0.9\ kg.m^2$$

$$J_{equ} = 1.0 + 0.2 + 0.03 + 0.9 = 2.13\ kg.m2$$

$$J_L = J_L \cdot \theta = J_L \cdot \frac{a_L}{r}$$

$$J_L = T_L * \frac{r}{a_L}$$

$$= F.r \cdot \frac{r}{a_L}$$

$$= \frac{m\cancel{a_L}}{\cancel{a_L}} \cdot r \cdot r = m.r^2$$

3000 rpm
1500 rpm → synch. motor
:

1410 rpm
2820 rpm → Induction AC motors.
:

$F_L = m \cdot g = 1000 \times 9.81 = 9810 \text{ N}$

ⓑ $w_2 = \frac{v}{r} = \frac{1.57}{0.3} = 5.236 \text{ rad/s}$

$w_1 = \frac{w_2}{a} = \frac{5.236}{0.1} = 52.36 \text{ rad/sec.}$

$N_m \text{(motor)} = \frac{60 \times w_m}{2\pi} = \frac{60 \times 52.36}{2\pi} = 500 \text{ rpm}$

$\Longrightarrow \frac{T}{r} \cdot v = T_w = \text{Jequ.}$

$P_L = F \cdot v = w \times T$

$T = F \cdot r$

$F = \frac{T}{r}$

$P_L = F \cdot v = w \times T = 9810 \times 1.57 = 15401.6 \text{ W}$

$P_L = \frac{15401.6}{746} = 20.3 \text{ hp}$

$w_2 = 52.36 \times a = 5236$

$P_L = T_L \times w_2 = 15401 \text{ W}$

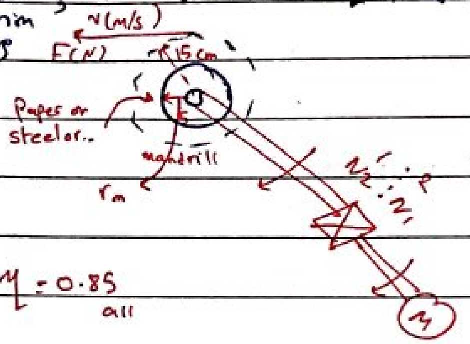
$\hookrightarrow F \cdot r = 9810 \times 0.3$

* if η was given in the question, we must divide the power by the η each shaft, but don't divide the motor's η unless we want to know the input power of the motor, as the output power is the considered one here. (Previous ex assumed all 100% η).

Tuesday 22/10/201

* Ex:

Motor is required to drive atop roll on a plastic strip line, the mandrill which the strip is wound $(r_m = 5cm)$, the strip emerges from the line at $V = 20 m/sec.$, strip tension $= 10$ kg ↳ $10 \times 9.81 N.$; the motor is coupled to the mandril by 1: 2 reduction gearing, the gear 85% η at all speeds.



$\eta_{all} = 0.85$

find speed & power ratings of the motor required for this system?

• $a = \frac{N_1}{N_2} = 2$

→ the strip's builds up to a roll of (30 cm) in diameter.

Sol:

• $F = m \times g = 10 \times 9.81 = 98.1 \ N.$

$P = \tau . \omega$ ← • $P = F . V = 98.1 * 20 = 1962$ watts

ثابتة بال transformer only T, J

$P_{motor} = \frac{P_{Load}}{\eta} = \frac{1962}{0.85} = 2308.23$ Watts.

at starting of rolling:

$\omega_2 = \frac{V}{r_m} = \frac{20}{5 \times 10^{-2}} = 400$ rad/s

$\omega_1 = \frac{400}{2} = 200$ rad/s

motor side

$N_{motor} (rpm) = \frac{60 * \omega_2}{2\pi} = \frac{60 \times 200}{2\pi} = 1910.8$ rpm.

$\tau_{st.} = F . r$ (عزم ال load)

$= 98.1 * 5 * 10^{-2}$

$= 4.9$ N.m.

$\tau_m = 2 \times 4.9 = \frac{9.8}{0.85}$ N.m (عزم ال motor) or $\tau = \frac{P}{\omega} \frac{2308}{200}$ $\frac{P_{motor}}{\omega_{motor}}$

at the end of rolling :

$W_2 = \frac{20}{15 \times 10^{-2}} = 133.33$ rad/s

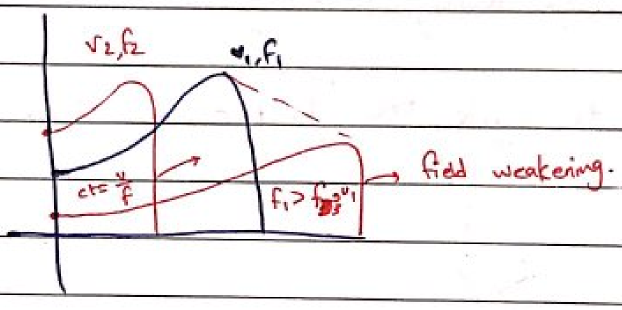
$\omega_{1\,motor} = \frac{W_2}{a^2} = \frac{133.33}{2} = 66.665$ rad/s $\rightarrow \frac{60 \times 66.665}{2\pi} = 955.4$ rpm $= N_m$ (rpm).

$P_{motor} = 2308$ watts. , $T_{end} = \frac{2308}{66.665}$

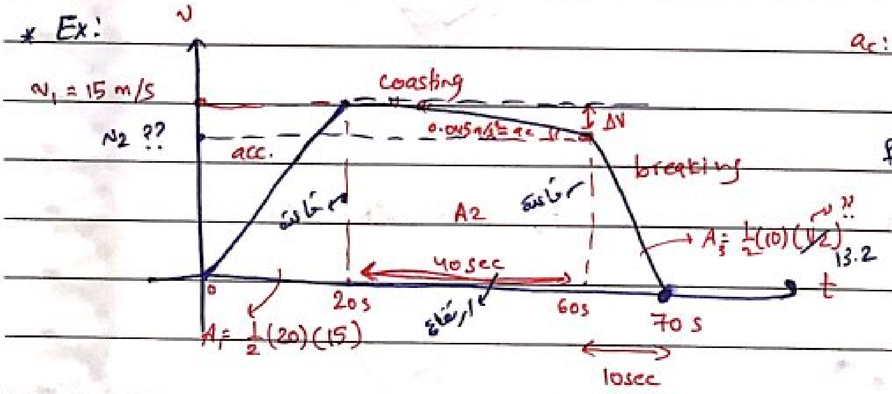
- Motor ratings ($\overset{\approx}{2308}$ W , $\overset{\approx}{1910}$ RPM)

$0 \leq N_{motor} \leq N_{motor}$ (rated) ⇒ Armature voltage control.
$N_{motor} \geq N_{motor}$ (rated) ⇒ field - weakening voltage control. } DC-motor.

$0 \leq N_{motor} \leq N_{motor}$ (rated) ⇒ vvvf
$N_{motor} \geq N_{motor}$ (rated) ⇒ voltage control (above) only → field weakening. } AC-motor



* Ex:



a_c: a coasting.

find the average speed ?

$a_c = \frac{\Delta V}{40} \rightarrow \Delta V = 40 * 0.045 = 1.8$ m/s

$V_2 = 15 - 1.8 = 13.2$ m/s

a deceleration rate $= \frac{V_2}{10} = \frac{13.2}{10} = 1.32$ m/s²

Sol: $V_{avg.} = \frac{D(m)}{70sec}$ → areas.

a acceleration rate $= \frac{15}{20} = 0.75$ m/s

$A_1 = \frac{1}{2}(15)(20) = 150$ m

$A_2 = \left(15 + 13.2\right) * \frac{40}{2}$ مج القاعدتين × الارتفاع / ٢
$= 564$ m.

$A_3 = \frac{1}{2}(10)(13.2) = 66$ m
v_2 t_3

$\Sigma D = A_1 + A_2 + A_3 = 780$ m ⟹ $V_{avg} = \frac{780}{70} = 11.14$ m/sec.

$V\left(\frac{Km}{hr}\right) = \frac{11.14 * 3600}{1000} = 40.1$ km/hr.

Five Apple

Scanned with CamScanner

Thursday 24/10/2019

* Example:

(gear)

Train with $m = 96 \times 10^3$ kg , nc : # of coaches = 3 ; each coache has 3 ~~bogg~~ bougies, each bougie has 2 axles.

(# of axles = 12 , # of wheels =

m_w = 455 kg ; r_w = 0.54 m

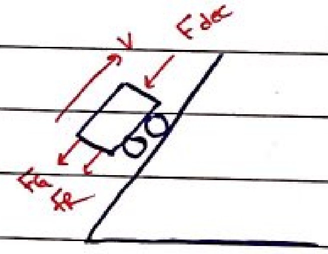
m_{ar} = 502 kg , ra = 0.225 m

- Train operates between two stations 1500 apart.
- between two stations a uniform gradient of 1 in 80
- scheduled average speed is 20 m/s up the gradient.
- scheduled average speed is 22.5 m/s down the gradient
- Control setting of acceleration on a level track = 1.25 m/sec²
- control setting of deceleration on a level track = 1.5 m/sec²
- Regenerative braking is used
- Train resistance during acc/dec = 20 N/1000 kg.

. Required:

① draw, to scale, the trapezoidal v/t curve.

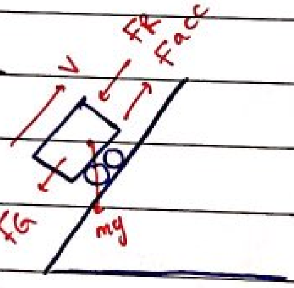
2



braking upword.

$F_t = F_{dec} + F_R + F_G$

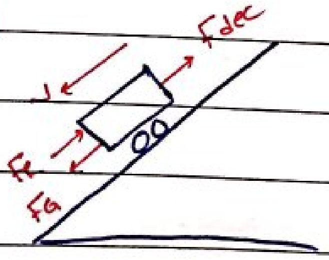
1



accelerates upward.

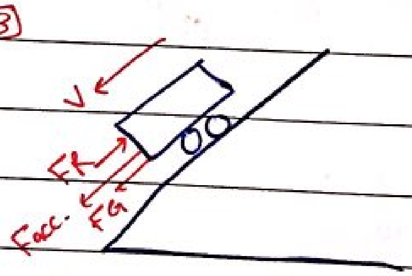
$F_t = F_{acc} - F_R - F_G$

4



$F_t = F_{dec} + F_R - F_G$

3



باتجاه الأرض

لا يتأثر ب Facc. dec.

$F_t = F_{acc} + F_G - F_R$

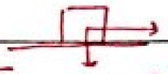
→ we have to cumend the mass first:

m acc = m + meq.(w) + mequ. (ar)

↳ equivalent (Fictions)

→ $m\,equ.(w) = m + \frac{Jw * nw}{rw^2} + \frac{Jar * nm}{ra^2 n^2}$ ↳ # of wheels. ↳ # of motors.

* Note: acceleration on Linear



$F_{acc} = m \cdot a$ → in case Linear.

m equ.(w) = ?

→ $J_w = 1/2\ r_w^2\ m$

$= \frac{1}{2}\ 455 * 0.54^2 = 66.34\ kgm^2$

* Note: $F = ma$

$\frac{T}{r} = ma$

$\frac{J}{r}\ \frac{dw}{dt} = ma$

$\frac{J}{rr}\ \frac{dv}{dt} = ma$

$\frac{J\alpha}{r^2} = mA$

$\boxed{m = \frac{J}{r^2}}$

→ $J_{ar} = 1/2 * ra^2 * m$

$= \frac{1}{2} \times 502 * 0.225^2 = 12.707\ kg \cdot m^2$

→ $m\,equ.(w) : \frac{66.34 * 24}{0.542} = 5.46\ kg$

→ $m\,equ.(ar) : \frac{12.707 * 12}{0.225^2 * 0.356^2} = 4.126\ kg$ ↳ $n^2 = \frac{N1}{N2} = 0.356$

∴ $m\,acc\,(equ) = 96 \times 10^3 + 5.46 \times 10^3 + 4.126 \times 10^3 = 105.59 \times 10^3\ kg.$

$\overset{macc}{}\qquad \overset{* a}{}$

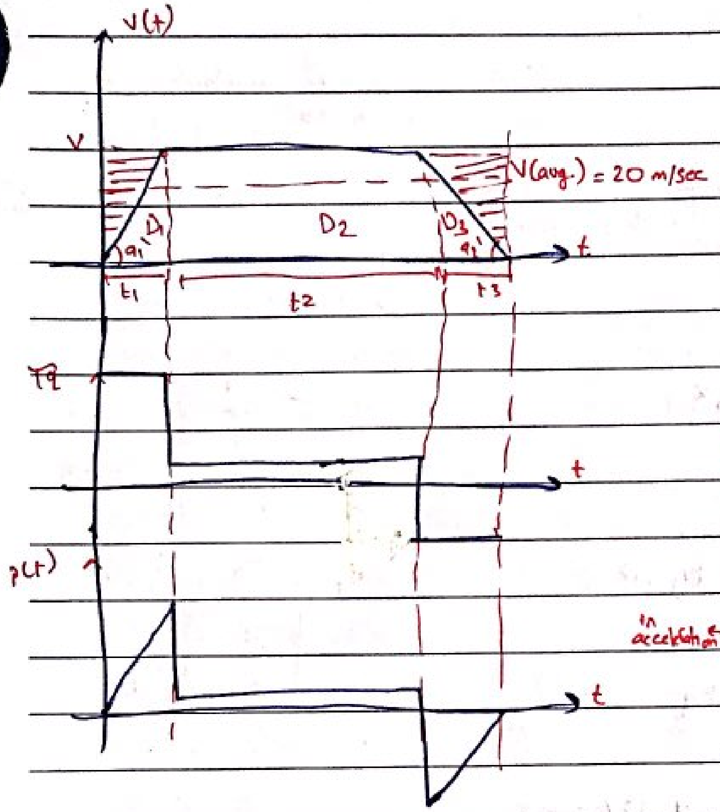
→ $F_{acc} = 105.59 \times 10^3 * 1.25 = 132\ kN$

↳ equ. (acc).

→ $F_{dec} = 105.59 \times 10^3 * 1.5 = 158.4\ kN$

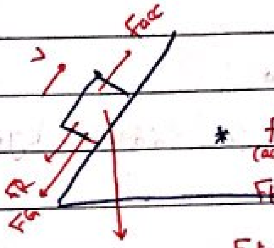
Sunday 27/10/2019

Completing the example:



* equivalent acceleration rate a_1'
* equivalent deceleration rate a_2'

} upward motion



* $F_{t(acc)} = F_{acc} - F_R - F_G$

$F_t = (131.98 - 142 - 11.772) \times 10^3$

$F_t = 118.29 \times 10^3$ N.

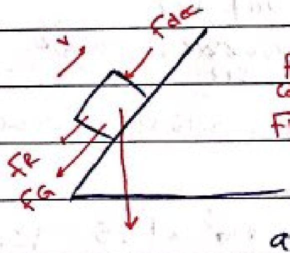
in acceleration • $a_1' = \frac{F_{t(acc)}}{105.6} = 1.12$ m/s² (105.6 ↳ mass)

; Vav = 20 m/sec

; D = 1500 m

∴ T = $\frac{1500}{20}$ = 75 s

• $a_2' = ??$



$F_{t(dec)} = F_{dec} + F_R + F_G$

$F_t = 172.071 \times 10^3$ N

$a_2' = \frac{F_{t(dec)}}{105.6} = 1.63$ m/s²

>> 1.5

* upward motion مساحة المثلث ① – مساحة المثلث ②

$D = 1500 = V * T - \frac{1}{2}\frac{V^2}{a_1'} - \frac{1}{2}\frac{V^2}{a_2'}$

مساحة المستطيل بالكامل

$1500 = 75V - \frac{1}{2}V^2\left(\frac{1}{1.12} + \frac{1}{1.63}\right)$

$V_{acc}^2 - 99.6\,V_{acc} + 1991.7 = 0$

V = 71.9 m/sec ; 27.71 m/sec

X neglected.

; V(avg) = 20 m/sec

∴ we'll take V = 27.71 m/sec

Five Apple

$$D_1 = \frac{V_1^2}{2a_1} = \frac{1}{2} \times \frac{27.71^2}{1.12} = 342.7 \text{ m}$$

$$D_3 = \frac{1}{2}\frac{V^2}{a_2} = \frac{1}{2} \times \frac{27.71^2}{1.65} = 235.6 \text{ m}$$

$$D_2 = D - D_1 - D_3 = \underline{\underline{921.7}} \text{ m}$$

$t_1, t_2, t_3 \Rightarrow t_2 = \frac{D_2}{V} = \frac{921.7}{27.71} = 33.26$ sec.

to find $t_1 \longrightarrow D_1 = \frac{1}{2} V t_1 = \frac{1}{2} \times 27.71 \times t_1$

$\therefore t_1 = 24.73$ sec.

$t_3 = \frac{2D_3}{V} = \frac{2 \times 235}{27.71} = 17$ sec.

or $75 - (t_1 + t_2)$

* Downward motion:

a_1'' , a_2'' ??

downward acceleration

downward deceleration

$$a_1'' = \frac{F_{acc} + F_G - F_R}{m_{acc}} = 1.343 \text{ m/sec}^2$$

$$a_2'' = \frac{F_{dec} - F_G + F_R}{m_{dec}} = 1.407 \text{ m/sec}^2$$

$$T_{dec} = \frac{D}{V_{avg(dec)}} = \frac{1500}{22.5} = 66.67 \text{ secs.}$$

$$V_{dec} \times T_{dec} - \frac{V_{dec}^2}{2}\left(\frac{1}{a_1''} + \frac{1}{a_2''}\right) = 1500$$

$$V_{dec}^2 - 91.62 V_{dec} + 2061.4 = 0$$

$V_{dec} = 51.9$ m/sec ; 39.72 m/sec

neglected

; $V_{avg)_{dec}} = 22.5$ m/s

$\therefore V = 39.72$ m/sec

• $D_1 + D_2 + D_3 = 1500$ m

$D_1 = 587.23$ m ; $D_2 = 352$ m ; $D_3 = 560.8$ m

$t_1 = 29.57$ sec ; $t_2 = 8.861$ sec ; $t_3 = \overset{28}{\cancel{29}}.24$ sec

• $t_1 + t_2 + t_3 = 66.67$

* upward $\underset{(\text{Load})}{\omega_{max}} = ?? \quad \frac{v}{r} = \frac{27.71}{0.54} =$

$\omega_{max}(\text{motor}) = \frac{\omega_{max}(\text{load})}{\underset{\hookrightarrow \text{transf. ratio}}{n}} = \boxed{144.146 \text{ rad/sec.}}$ to find Power.

$N_{motor} = \frac{144.146 \times 60}{2\pi} = 1376$ RPM (looks like $\overset{\text{AC}}{\text{induction}}$ motor)

rating : 1500 assuming 50 Hz frequency.

~~[illegible]~~ slip ≈ 8.1

↳ D-class motors, T_{max} ↑↑ very high

slip > 5% ↙

(8% → 12%) D class

losses عالية

Tuesday 29/10/2019

* Torque / Power verus time curves.

* Forces in the following cases:

Ⓐ upward motion:

1) During acceleration

2) constant speed running

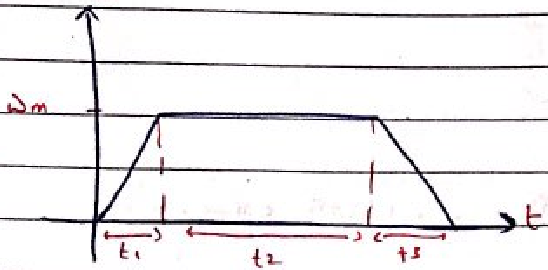
3) Deceleration

Ⓑ downward motion:

1) acceleration

2) constant speed

3) deceleration



$A_1 = F_{acc} + F_G + F_R$

$A_2 = 0 + F_G + F_R'$

↳ free running.

F_R': Resistance to motion force during constant speed running.

$F_R' = m(4.1 + 0.123V)\times10^{-3} + A_c . V^2 [151\,K + 2.16\,n_c . L_c] \times 10$

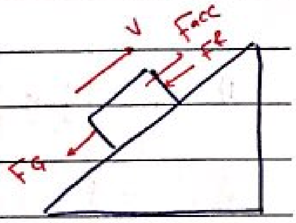
$V \equiv$ speed m/sec

$A \equiv$ Area of the front edge of the first coach.

$K \equiv$ shape of the front edge.

$n_c \equiv$ # of coachs

$L_c \equiv$ length of each coach.



$m = 96\times10^3\,kg$, $k = 1$, $n_c = 3$, $A_c = 11.5\,m/s^2$, $L_c = 23\,m$

$F_G = m . g . \frac{1}{80}$

$* F_G = 11.772\,kN$

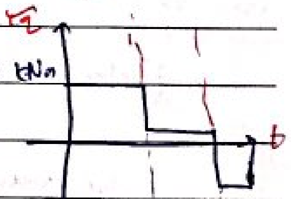
$* F_R = 20\times96 = 1.92\,kN$

F_R' (upward) = 3.37 KN

F_R' (downward) = 6.306 kN

upward cases

- $\overset{A_1}{F_{motor}}$ (upward-acc.) [all motors] = (131.98 + 11.772 + 1.92) kN = 145.6745 kN (Motoring action).



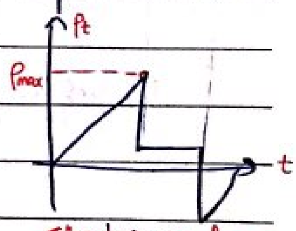
T_{motor} (upward-acc) [Per-motor] $= \frac{F * r * n}{n_1} = \frac{145.6745 \times 0.54 \times 0.356}{12} = 2.333,707\,kNm$

n_1 ↳ # of motors

$\rightarrow = \frac{V_{upward}}{r . n} = \frac{27.71}{0.57\times0.35} = 144.15$ rad/sec

$P_{max\,(up\_acc)} = T_m * \omega_{max}$ [motor] (upward)

$P_{max} = 2.333 \times10^3 \times 144.15 = 336.4$ Kw/motor



Either design on Pmax or Prms.

- $\overset{A_2}{F_{motor}}$ (up-ward) constant speed $= 0 + F_G + F_R = 15.142\,kN$

T_{motor} (upward constant speed) [Per-motor] $= \frac{15.142 \times 0.54 \times 0.35}{12} = 242.58$ Nm/motor

P_{motor} (upward constant speed) $= 242.58 * 144.15 = 34.967$ KW.

- F_{motor} (upward-dec) = $-F_{dec} + F_R + F_G$

deceleration

$= \ominus 144.6787$ KN.

↳ Generation of power.

T_{motor} (upward-dec) = $\dfrac{-144.687 \times 0.54 \times 0.35}{12} = -2.317885$ KNm

[per-motor]

P_{max} (upward-dec) = $-2.317885 \times 10^3 \times 144.15$

$P_{max} = -334.11$ KW

to find the energy :

per motor

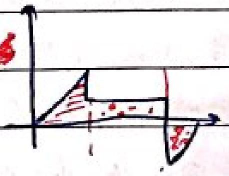
$\times 12$ to get Joule

$\times 12$

$P_{max}(dec) \times t_3$

$\times 12$

$W(up) = \left[\frac{1}{2} \times P_{max\,(acc)} \times t_1\right] + [t_1 \times P] + \left[-\frac{1}{2} \times 334.11 \times 17\ldots\right]$



$= \left[\frac{1}{2} \times 336.4 \times 24.7\right] + [\overset{34.967}{\cancel{[illegible]}} \times 33.26] + \left[-\frac{1}{2} \times 334.11 \times 17\ldots\right] = \cancel{[illegible]}$

49.923×10^6 J $\quad 13.9567 \times 10^6$ J $\quad -34.087 \times 10^6$ J

29.9721 MJ

for all motors.

define specific energy factor :

$\underset{(upward)}{SEF} = \dfrac{W_t\,(Joule)}{\underset{(kg)}{m} \times \underset{(m)}{D}} = \dfrac{49.923 + 13.9567 - 34.087}{96 \times 10^3 \times 1500} = 0.2069 \quad \dfrac{J}{kg \cdot m}$

كل ما كان أقل بكون أحسن وهو التميز بسبب قطر وقطا ،

downward case :

- F_{motor} (downward-acc) = $F_{acc} + F_R - F_G$

- F_{motor} (downward-constant speed) = $0 + F_R - F_G$

- F_{motor} (downward-dec) = $-F_{dec} + F_R - F_G$

Thursday 31/10/2019

completing downward motion:

A) acceleration:

$T = 1.9565$ kNm/motor

$P_{max} = 404.25$ kw/motor

$W = 71.72$ MJ

$F = 122.13$ kw

B) Constant speed:

$F = -5.466$ KN

$T = -87.56$ kN.m/motor

$P = -18.09$ kW

$W = -1.924$ MJ

C) deceleration:

$F = -148.527$ kN

$T = -2379.4$ N.m

$P_{max} = -491.624$ kW

$W = -83.29$ MJ

W_{tot} (run down) $= -13.4946$ MJ

$$S.P.E = \frac{-13.4946 \times 10^{6}}{1500 \times 96 \times 10^{3}} = \boxed{-}0.0937 \text{ J/Kg.m}$$

↪ توفير

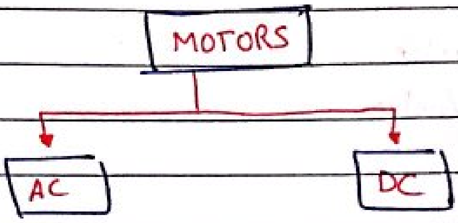
* RMS kW rating of the motor:

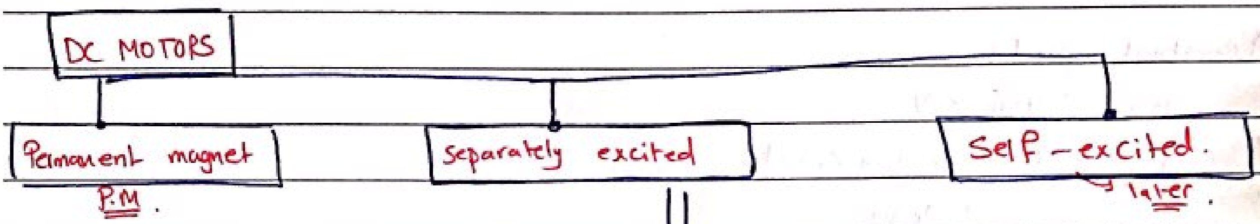
$$kw_{(rms)} = \sqrt{\frac{1}{T}\int_{0}^{T} P^{2}(t)dt}$$

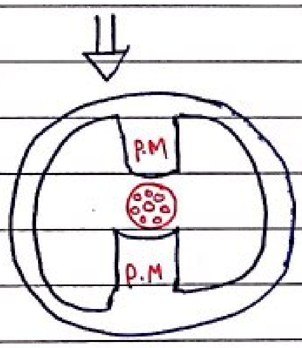
نحسب الطاقة لكل مرحلة لحال
ونجيب مقدار الرقم الأكبر

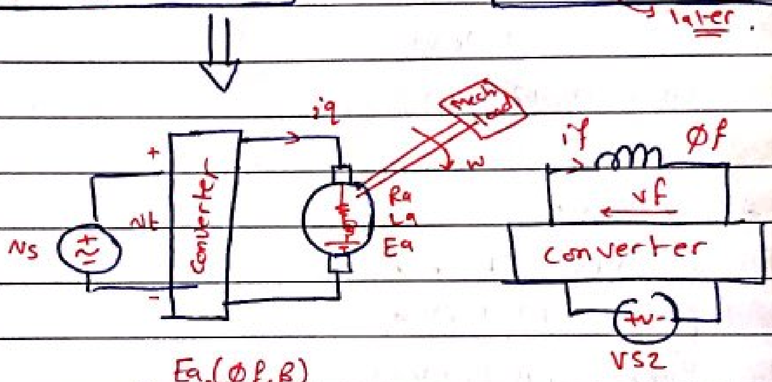
* Drive system:

1. Load
2. Motors
3. converters

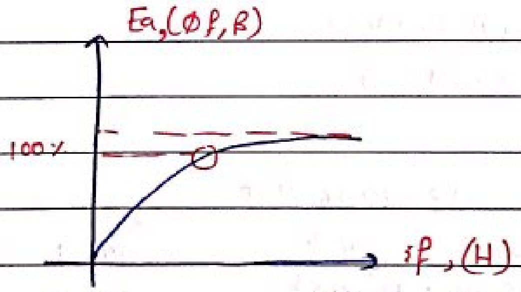








* up to 1 kw power.
* more reliable.
* no field winding
* very expensive
* servo systems.



B/H curve, no load characteristics;

in BH curve → slope = μ

$e = ka * \emptyset f * w$

ka = design constant $= \frac{Z}{\pi} * \frac{P}{n}$

A = 2 → wave winding

A = 2p → lap winding

(λ, if) → slope = L

compleliy separately excited:

$A = 2$	wave winding	high voltage low current
$A = 2P$	Lap winding	low-medium Voltge medium-high current

motor time constant = $\tau = \frac{L_a}{R_a}$

high $\tau \longrightarrow$ higher inductance

advantage $\longrightarrow$ better current filtration

(converter controlled systems)

disadvantage $\longrightarrow$ lower response to control command.

high T ⟶ higher inductance

advantage ⟶ better current filtration

(converter controlled systems)

disadvantage ⟶ lower response to control command.

Sunday 3/11/2019

* motors with rapid speed change:-

J : moment of inertia

$J = \frac{1}{2} m r^2$

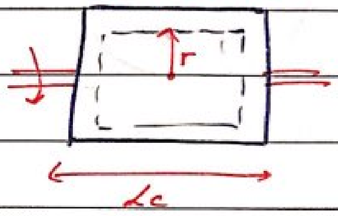
power rating of a motor is a function of (mass, r, ℓ_r)

rotor's radius

↳ armature's & rotor's length

in DC mech. stator.

Motor enclosure



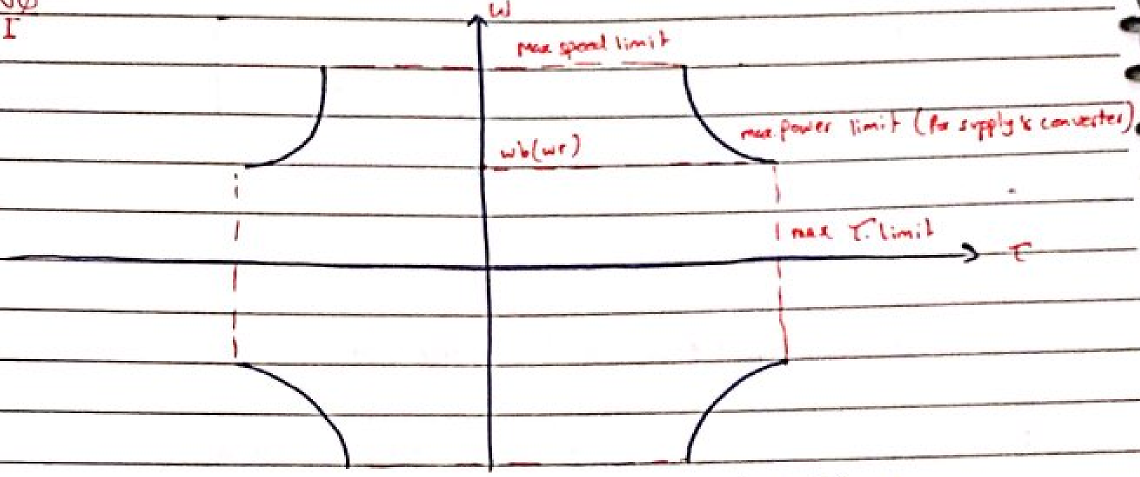
Fast response: low inertia leading to low (r) design

⟹ to keep the power unaffected, the length of the rotor (ℓ_r) should be higher to compensate.

• interia is for the rotating elements. , so it's for the rotor in motors.

* Envelope of T/w characteristic of the motor :-

$L = \frac{N\phi}{I}$



wb: linear speed to wb & then constant Torque.

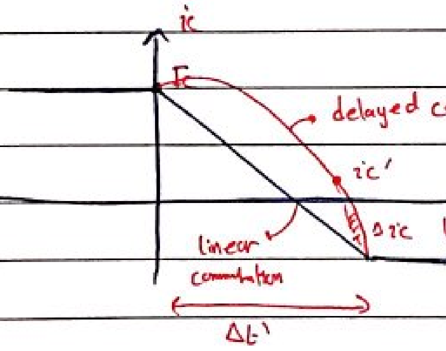
* Speed Limits :-

① Mechanical design.

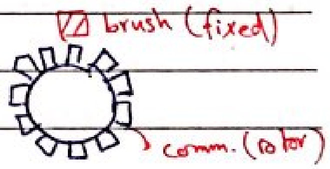
② Air-gap length should be as small as possible.

with air gap larger MMF in needed to create same flux

③ Armature reaction + Commutation (& sparking between the brushes and commutator segments.



large $L_c \frac{di_c}{dt}$ → large EMF → sparking.



* higher rotor speeds leads to higher change in $i_c \rightarrow L_c \frac{di}{dt}$

$e_c \rightarrow$ large $\rightarrow$ sparking

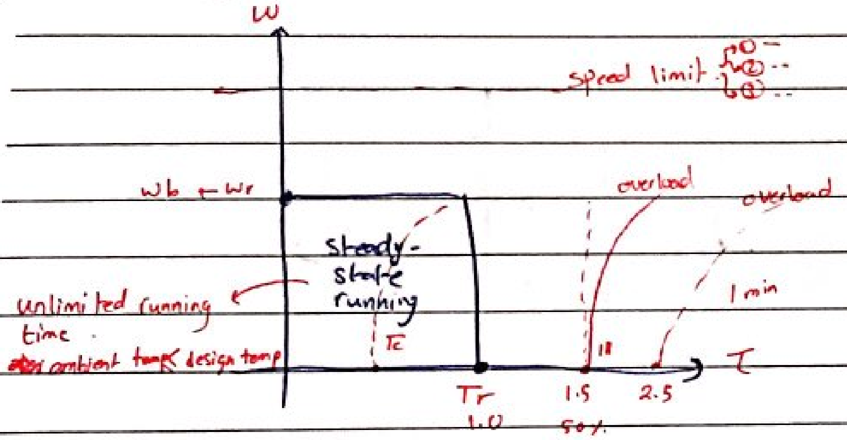
* ϕ over brushes isn't zero by the effect of Armature reaction.

* $\omega_m \leq (2 \rightarrow 3)\,\omega_m$ (rated)

ω_m (base)

Tuesday 5/11/2019

* overloading



① steady-state:

can run 24-H a day without overheating, assuming that:

a) No current harmonics

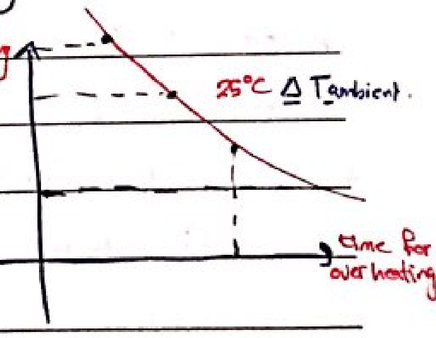
b) The ambient temperature is below design value

limits → Rated Torque / rated speed

② over-loading: restricted with the required time of overloading.

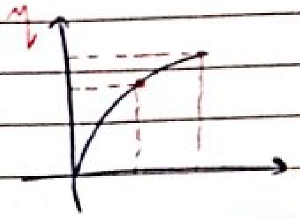
over-loading includes: load Torque overload & harmonics overload.

↳ caused by harmonics.



$$I_{harmonics} = \sqrt{I_{av}^2 + \sum_{n=1}^{\infty} I_{rms}^2(n)}$$

Solution ?? for continuous running $\Rightarrow$ oversize the motor.



think.

When do we do intentional over-load ??

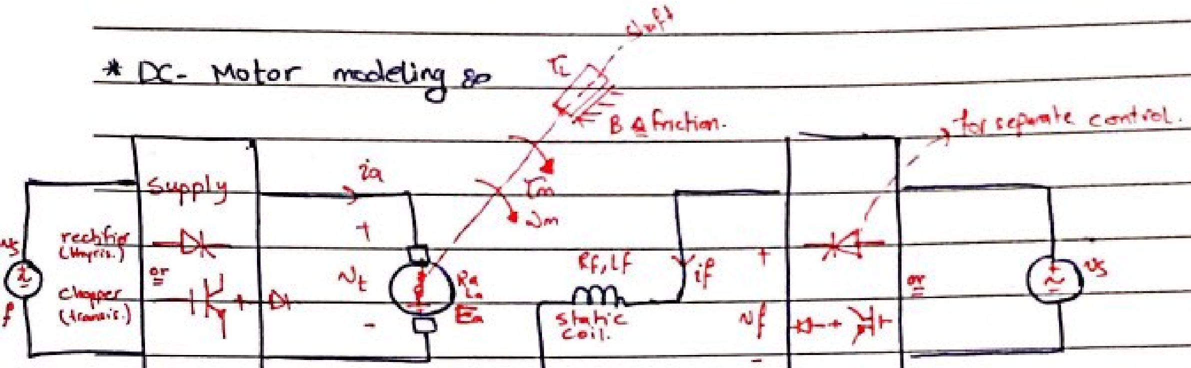
i.e: bridges (machines which work periodically).

→ designed by humans for low power rated motors.

(بسخن بس ما بتحرق باي الفترة لزمنية ، [illegible] بنفع كلمة أوفر).

better economies ↙

* DC- Motor modeling :-



field ckt.

$v_f = i_f \cdot R_f + L_f \cdot \frac{di_f}{dt}$ } static coil

$i_f = k_f \cdot \phi_f$ } Now

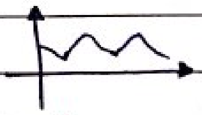
↳ magnetization curve.

E_a or $e_a = k_a \cdot \phi \cdot \omega$ (Induced emf).

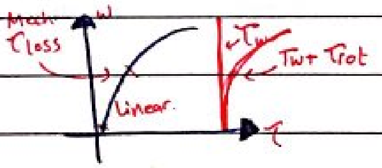
$T_m = \underline{k_a} \cdot \phi \cdot i_a$

↳ design parameter

$v_t = i_a \cdot R_a + L_a \frac{di}{dt} + k_a \cdot \phi \cdot \omega$



$T_m = k_a \cdot \phi \cdot i_a = T_L + B \cdot \omega$



* $E_a = k_a \cdot \phi_f \cdot \omega$ under steady state conditions, with no harmonics.
* $T_m = k_a \cdot \phi_f \cdot I_a$ "
* $v_t = I_a R_a + k_a \phi_f \cdot \omega$ "
* $T_m = T_L + B \cdot \omega$ "
* $v_f = I_f R_f$ "

$\therefore E_a = V_t - R_a I_a$

$K_a.\phi . \omega = V_t - R_a \overset{\frac{T_a}{K_a.\phi}}{I_a}$

$(K_a.\phi_f)^2 \omega = K_a.\phi_f . V_t - R_a(T_L + B.\omega)$

$\omega((K_a\phi_f)^2 + R_a.B) = K_a.\phi_f V_t - R_a.T_L$

$$\boxed{\omega = \frac{K_a.\phi_f V_t - R_a . T_L}{(K_a\phi_f)^2 + R_a.B}}$$ ⊛ very important.

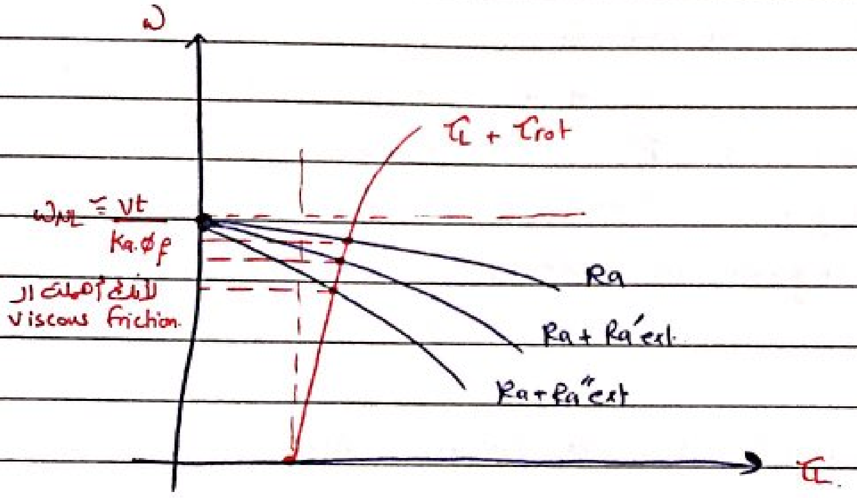
$\to \omega = \frac{K_a\phi_f . V_t}{(K_a\phi_f)^2} = \frac{V_t}{K_a\phi_f}$ if we neglect viscous friction

* Methods of speed control:

1 Armature resistance control. (Ra)

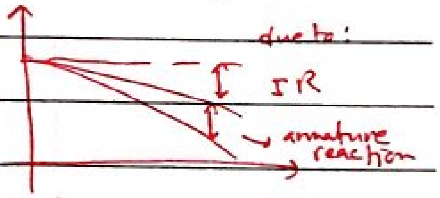
range of speed control.

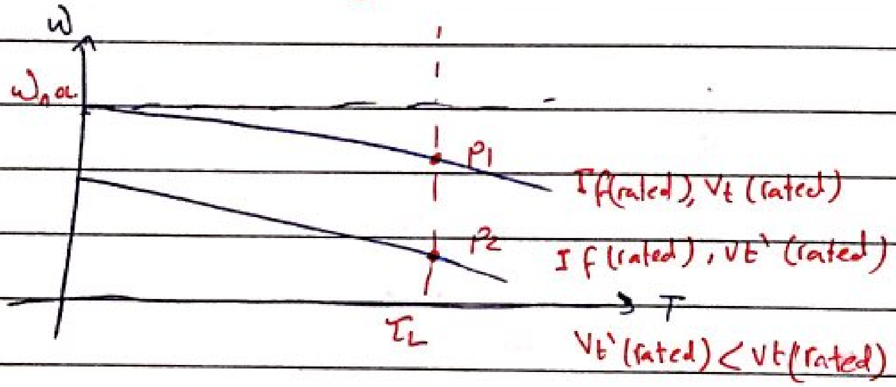
$\boxed{0 \leq \omega \leq \omega_{rated}}$



Thursday 7/11/2019

2 Armature voltage control





$V_t'(\text{rated}) < V_t(\text{rated})$

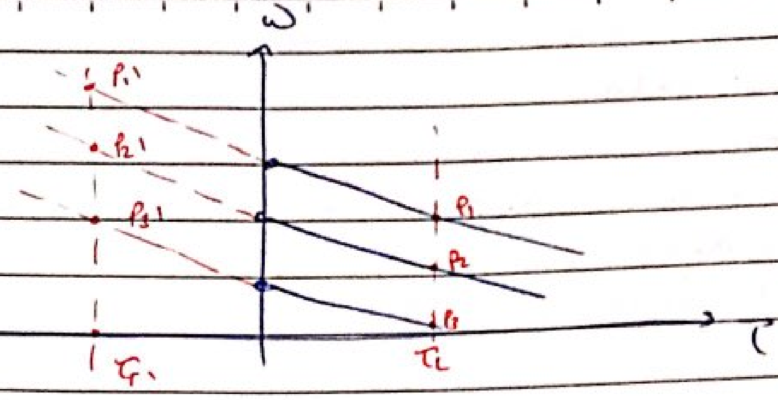
$\omega_{NL} = \frac{V_t}{K_a\phi}$ → neglect B at no load

$= \frac{V_t}{K_a . K_f . I_f}$

$0 \leq V_t \leq V_t(\text{rated})$

$0 < \omega_m \leq \omega_m(\text{rated})$

If, vt
→ same sign
Ia is (-ve)



* with variable vt, speed varies below rated value.

* curves are almost parallel with vt variations.

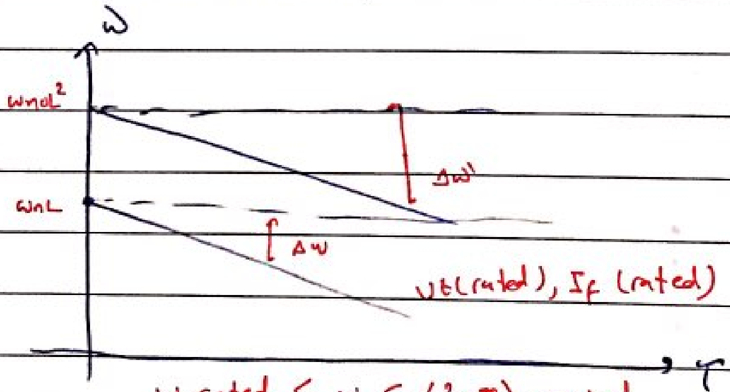
* if the torque has a negative sign (acceding), then, speed increased in the second quadrant assuming vt & If are unchanged in Polarity.
In this case (Ia) is changing direction.
P is (-ve). this is regeneration process.

[3] Field weakening control.

If can only be controlled below its rated value.

$I_f \leq I_f(\text{rated})$

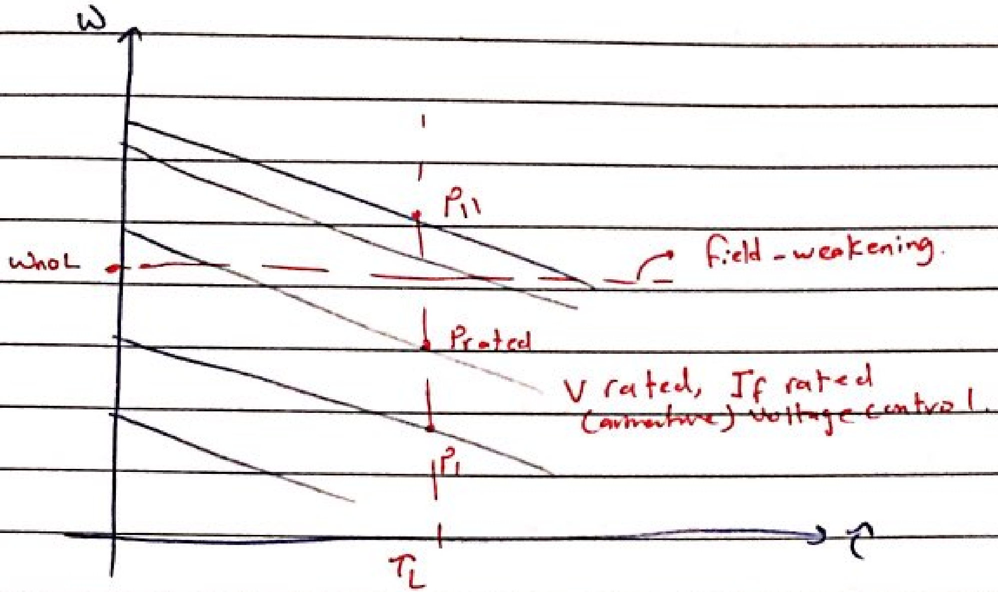
$$\omega = \frac{v_t}{k\phi} - \frac{R_a T}{(k\phi)^2}$$



w rated ≤ w ≤ (2-3) w rated

operation is constant power profile

$P = \tau \cdot \omega \quad , \quad \omega \uparrow \rightarrow \tau \downarrow$



Q) supply : $0 \leq V_t \leq 600V$

to supply a motor when $V_t = 600V \Rightarrow 1600$ RPM

a) load torque 420 N.m, calculate I_a??

b) field weakening is applied such that the Power is constant, calculate the torque, if speed is 4000 RPM

c) Power rating of the supply.

Sol: a) $P = \omega . T = VI$

b) $V_t = I_a = T^{\downarrow} \omega^{\uparrow}$

c) $P = I_a \times \overset{\rightarrow (600)}{V}$

Sunday 10/11/2019

Solution:

$P = W \times T = V . I_a$

$V_{rated} = 600\,V$, $N_r = 1600$ rpm neglect losses.

$T_d = 420\,Nm \rightarrow I_a = ??$

$w_m = \frac{2\pi \times 1600}{60} \rightarrow P_d = V_t . I_a$

$P_d = T_d \times w_m = 420 \times 2\pi \times \frac{1600}{60} = \underset{\hookrightarrow 600}{V_t} . I_a$

$I_a = 117.3\,A$

Field weakening → constant power

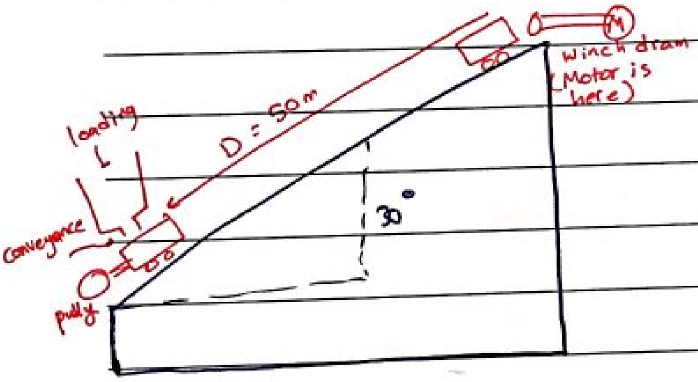
$P_d = 600 * 117.3 = w_m' * T' = \frac{2\pi \times 4000}{60} \times T_d'$

$T_d' = 168\,Nm$

$\frac{168}{420} \overset{!}{=} \frac{1600}{4000} \leftarrow$

- if P_{rot} were given → $P_{rot} = K . w_m$ → calculate K

$\tau_\omega = \tau_\omega'$ → can use this when there's no rational losses.



empty convey = 400 kg

load = 1600 kg

$n = 2u = \frac{w_m}{w_L}$

$V(up) = 5\,m/sec$

$V_{dram} = 10\,m/sec$

DC Motor :

230 V

$I_a(r) = 2460\,A$

75 Hp

115 rpm

$J_m = 1.94\,kg.m^2$

$L = 2mH$

$R_a = 0.0237\,\Omega$

Motor's preparation :-

T_{max} (and $I_a(max)$) is limited to 200%. (during acceleration).

Solution:

$E_a = V_t - I_a R_a$ } $a^2 T_L = T_L'$ (referred) $= J_m = 1.94$

$\hookrightarrow k = \frac{E_a}{\omega_m(r)}$ $J_L = 1.94 \times \frac{24^2}{\boxed{n\,2}}$

$T_d = k . I_a(r) = 464.7$ Nm

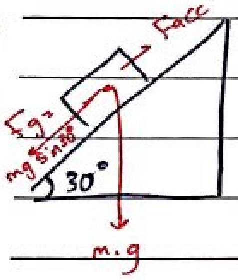
$T_d(r) = T_{sh} = \frac{P_o(r)}{\omega_m(r)}$

$T_{motor}(max) = 2 \times 464.7 = 929.4$ Nm.

$T_{load}(max) = 24 \times 929.4 = 22305.6$ Nm

$F_{load}(max) = \frac{T_L(max)}{r} = 23205.6$ N

$I_a = \frac{T_a}{K}$



$F_g = (1600 + 400) * 9.81 * \sin 30°$

$= 9810$ N

$T_g = F_g . r = 9810 * 1 = 9810$ N

$P_g = F_g * V = 9810 * 5 = 49050$ W.

$P(Hp) = \frac{40050}{746} = 765.75$ hp $\longrightarrow$ Selected $P(hp) = 75$ hp

$\omega_m(L) = \frac{V}{r} = \frac{5}{1} = 5$ rad/sec.

$W_m(motor) = 24 * 5 = 120$ rad/sec

$N_{motor}(rated) = \frac{120 \times 60}{2\pi} = 1150$ rpm

Tuesday 12/11/2019

$F_{max} = 22305.6\ N$

$\tau_{max} = 22305.6\ Nm$

$\tau_{acc}(motor) = 2\,J_m \frac{d\,\omega_{Motor}}{dt} = 2\,J_m . d = 2J_m \times \frac{n}{r}\frac{dv}{dt} = \frac{2n}{r} J_m . a$

$= \frac{2 \times 24}{1} \times 1.94 \times a = 93{,}12\,a$

$\rightarrow \omega_{motor} = n \times \omega_{tot}$

$= n \times \frac{v}{r}$

$= 24 \times \frac{v}{r}$

Load side:

$\tau_{acc}(load) = n \times \tau_{acc}(motor) = 24 \times 9312 \times a$

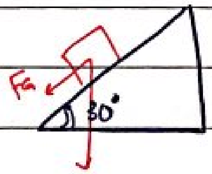
$= 2234.88a$ → for rotating elements (not the train's pulie)

$F_{acc} = \frac{2234.88}{1} = \frac{\tau_{acc}(load)}{r} = 2234.88\,a$

upward Journey → m = 1600 + 400 = 2000

a) acceleration:

$F_t = F_{acc} + F_g$



$F_g = m.g \sin 30°$

$= 200 \times 9.81 \times \frac{1}{2} = 9810\ N$

$\underset{F_{max}}{F_t} = (\underbrace{m.a + 2234.88\,a}_{F_{acc}}) + 9810$

$22305.6 = (2000\,a + 2234.88\,a) + 9810$

Scanned with CamScanner

$a = \frac{12495.6}{4234.88} = 2.95\ m/sec^2$

$t(acc.up)\,tr = \frac{V}{a} = \frac{5}{2.95} = 1.694\ sec$

$D_{acc}(up) = \frac{1}{2} \cdot a \cdot t^2_{acc(up)} = \frac{1}{2} \times 2.95 \times 1.694^2$
$= 4.236m$

$P_{motor} = \left(\underset{\tau_{mot}}{\frac{22305.6}{24}}\right) \times \underset{\omega_{mot}}{120.4} = 111899\ W \simeq 150hp$

b) constant speed (No. accelecktion)

$F_t = F_g = 9810\ N$

$D_{zero\ acc}$??

$P_m = \left(\frac{9810 * r}{n}\right) \times \frac{120.4}{0.746} = 65.75\ hp$

↳ upward journey (DEC)

c) $F_t = -F_{acc} - F_g$ (decelarition (upward motion))

$22305.6 = -(2000a + 2234.88a) - 9810$

$a = \left(\frac{22305.6 + 9810}{4234.88}\right) = -7.5836\ m/sec$ → dec.

$t_{dec(up)} = ??$

$\underset{0}{V_f} : \underset{5m/sec}{V_i} - a \times t_{dec(up)}$

$a = \frac{V_i}{t_{dec}(up)}$

$t_{dec}(up) = \frac{V_i}{a} = \frac{5}{7.5836} = 0.66\ sec$

$D_{dec}(up) = \frac{1}{2} \cdot a \cdot t^2_{dec}(up) = 1.65$ meter

$D_{constant\ speed} = 50 - 4.236 - 1.65 = 44.1158$

downward journey :-

$F_t = F_{acc} - F_g$

field weakening ⟶ constant power profile

$\tau = k . \phi . I$

200 % → 80 %

ϕ → 0.5

$\omega_m (down) =$

$V_{down} = 10 \ m/sec$

$\omega_m (down) = 2 \times 120.4 = 240.4 \ rad/sec$

$P = \omega . T$

P → Constant

ω → 200 %

T → 100 %

كم بالنسبة لل current رح تكون

؟ 50 %

$$T_{max\ down} = \frac{2230.6}{2} = 1115.28 \ N.m$$

$$F_{max\ down} = \frac{T_{max\ down}}{r} = 11152.8$$

$m = 400 \ kg \rightarrow F_g = 400 \times 9.81 \times \frac{1}{2} = 1962 \ N.$

Thursday 14/11/2019

* Downward:

ⓐ Acceleration:

$$F_t = F_{acc} - F_g$$

$$11152.8 = a \times 400 + 2234.88 \times a - 1962$$

$$a = 4.977 \ m/s^2$$

$$t' = \frac{V}{a} = \frac{10}{4.977} = 2.01 sec$$

$$D_1 = 1/2 a t^2 = 10.05 m$$

ⓑ Deceleration:

$$F_t = F_{acc} + F_g$$

$$11152.8 = -(a \times 400 + 2234.88 a) + 1962$$

$$a = -3.488 \ m/sec^2$$

$$t^2 = \frac{V}{a} = \frac{10}{3.488} = 2.867 sec.$$

$$D_2 = \frac{1}{2} a t^2 = 14.34 m$$

ⓒ Constant speed:

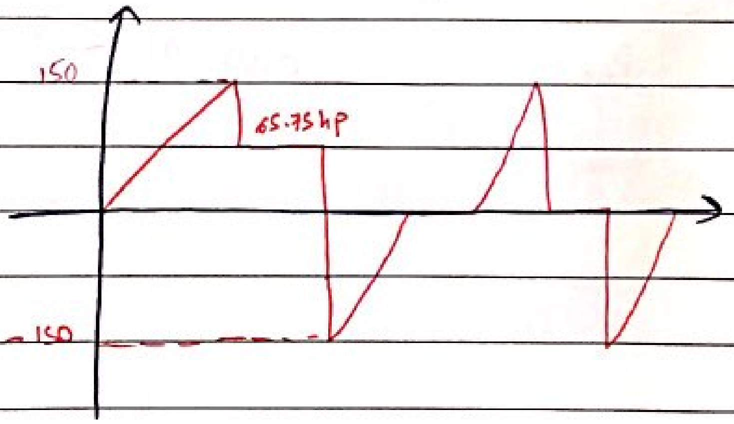
$$F_t = F_g$$

$$D_3 = D - D_1 - D_2$$

$$= 50 - 14.34 - 10.05 = 25.61 m$$

$$t_{correspond} = \frac{25.61}{10} = 2.561 sec$$

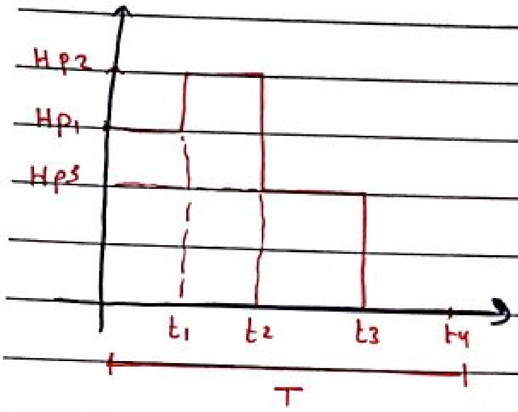
$$P_m = F \times V = 1962 \times 10 = 19.62 \ kw \longrightarrow 26.3 hp$$



* RMS Horse power

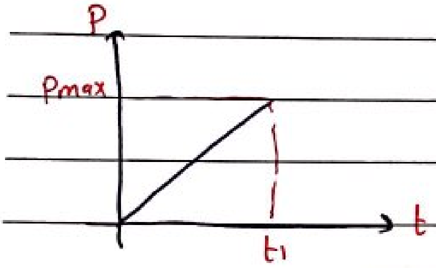
RMS : kW

Assume power duty cycle of the shape below



$$RMS(HP) = \sqrt{\frac{t_1 Hp_1^2 + (t_2 - t_1) HP_2^2 + (t_3 - t_2) HP_3^2 + (t_4 - t_3) \times 0 + \cdots}{t_3 + \frac{(t_4 - t_3)}{k}}}$$

k : related to ventilation ; $k \geq 1$



$$P(t) = P_{max} \frac{t}{t_1}$$

RMS HP = ?!

$$P_{rms} = \sqrt{\frac{1}{t_1} \int_0^{t_1} P^2_{max} \cdot \left(\frac{t}{t_1}\right)^2 dt}$$

$$= \sqrt{\frac{P^2_{max}}{t_1^3} \left[\frac{t^3}{3}\right]_0^{t_1}}$$

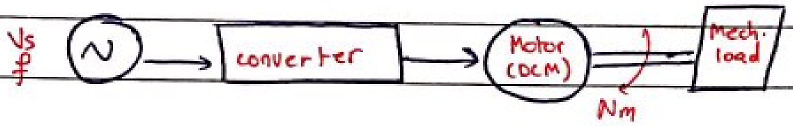
$$= \sqrt{\frac{P_{max}^2}{3 t_1^3} \cdot t_1^3}$$

$$\boxed{P_{rms} = \frac{P_{max}}{\sqrt{3}} = 0.57 \; P_{max}}$$

$$\text{rms hp} = \sqrt{\frac{\sum P^2(n)\, t_n}{T}}$$

Case	hp	time	$hp^2 \times t$
up acceleration	150	1.694	
up constant speed	65.75	8.823	
up deceleration	150	0.659	
unloading		5	
down acceleration	26.3	2.01	
down constant speed	150	2.561	
down deceleration		2.868	

* Converters:



• Supply ⟹

Vs & f are fixed

240 V/ph 50 HZ

110 V/ph 60 HZ

Motor Vrated 400 V

Supply 240 Vrms, 50 HZ

Converter rectifier / single Ph or 3-phase.

Single phase rectifier:

$$V_{av}(Max) = \frac{2V_m}{\pi} \cos 0^\circ = \frac{2\sqrt{2}}{\pi} \times 260 = 216V$$
$(\alpha = 0^\circ)$

3 phase rectifier:

$$V_{av}(max) = \frac{3\sqrt{3}\,V_m}{\pi} \cos\alpha = \frac{3\times\sqrt{3}}{\pi} \times \cos 0 \times 240\sqrt{2} = 561.3\ V.$$

a transformer is needed to transform 216 V to 400 V.

Sunday 17/11/2019

Converters for DC Drive:

Ⓐ Rectifiers (controlled)

single phase or 3ϕ.

Ⓑ choppers (DC to DC)

\# of phases: (load Power)

① $P_o < 2\,kW$ → single-ph is almost a must.

↳ load Power

② $2kW < P_o < 5kW$ → Preferred to be 3-ph, but single phase is possible.

③ $P_o > 5kW$ → 3-ph is almost a must.

* supply / load voltage.

$$V_{o(av)} = f(V_s) = \frac{2V_m}{\pi} = \frac{2\sqrt{2}}{\pi} V_{s(rms)} \simeq 200V$$

$$V_{o(av)3ph} = \frac{3\sqrt{3}\sqrt{2}\,V_{s(rms)}}{\pi} = \frac{3\sqrt{6}}{\pi} V_{s(rms)}/ph = 500$$

$V_{s(rms)}$: per phase.

$$I = \frac{\overset{\rightarrow P}{2000}}{\underset{V_{av}\,\leftarrow}{200}} = 10\,A$$

$$I_{single} = \frac{5000}{\underset{V_{av}\,\leftarrow}{200}} = 25\,A$$

$$I_{3ph} = \frac{5000}{\underset{V_{av}\,\leftarrow}{500}} = 10\,A$$

ⓐ load voltage

ex: V_{rated} (DC) motor = 230V

$V_o(av)_{1\phi}$ = 200 ⤳ not sufficient

solution: ① use step up transformer a = 200/230

② 3-ph rectifier

$V_o(av) = 514 \simeq 500$

This voltage is sufficient but a rectifier should run at high firing angle that generates 230 V, the system will suffer from the harmonics and ripple and power factor.

$\alpha \uparrow$ P.F $\downarrow$

→ in this case ($V_{load} << V_o(av)_{max. rectifier}$), use a step-up transformer.

- about 20% tolerance is acceptable.

* Converter Selection:

Selected type of converter.

if DC voltage is available : use choppers.

ex: existed DC generator or PV systems.

if Not → [Choppers .
[controlled rectifier.

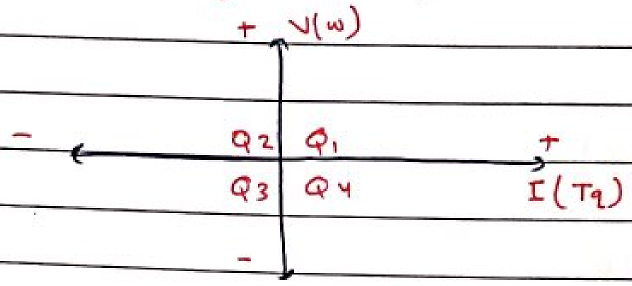
Tuesday 19/11/2019

* Converter Selection:

Controlled rectifiers or choppers.

Voltage & power capability are both in favor of rectifiers (using SCRs) rather than choppers (using transistors).

* The type & requirements of load:



$T_a = k_a . \phi . i_a$

$V_L \approx E = k_a \phi . w_m$

# of quadrants:

ⓐ $V^+, I^+ \longrightarrow Q1$

ⓑ $V^+, I^- \longrightarrow Q2$

ⓒ $V^-, I^- \longrightarrow Q3$

ⓓ $V^-, I^+ \longrightarrow Q4$

* Can a single rectifier work in Q1? yes.

〃 〃 〃 〃 〃 〃 Q2? Never, thyristors can't have a reversed current.

〃 〃 〃 〃 〃 〃 Q3? Never, runs at negative voltage when α > 90°, but current negative NO.

〃 〃 〃 〃 〃 〃 Q4? yes, α > 90°.

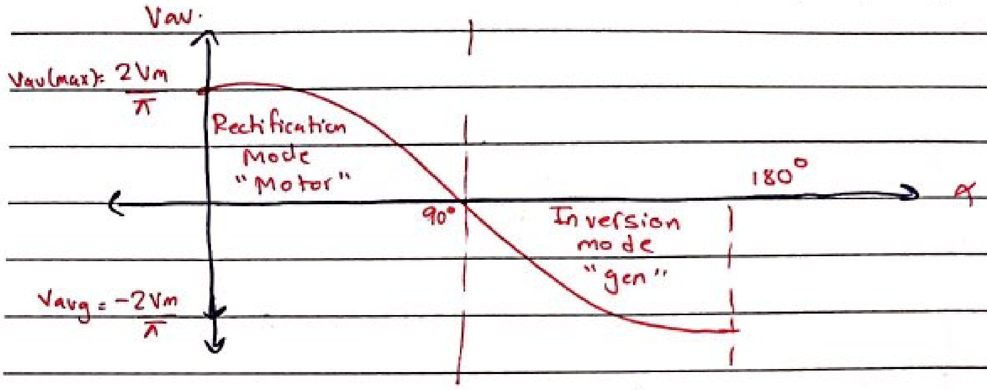
* for running in 4 quadrants, we need another converter that is possible to run in Q2, Q3.

when the two converters are connected to run together, the equivalent converter is known as the Dual converter.

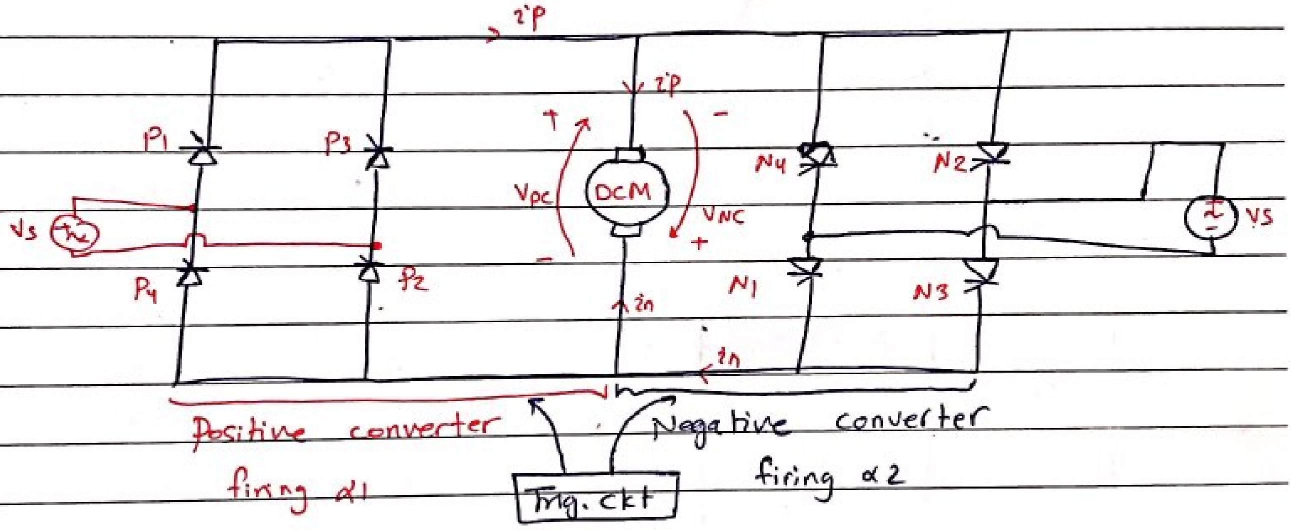
* A single converter (rectifier) can run in Q1 & Q4 in a drive system.

for motoring

for plugging.



Dual converters are required for reversable variable-speed DC Drive.



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

PC : $\alpha = \alpha 1$

$$V_{PC} = \frac{2V_m}{\pi} \cos\alpha_1$$

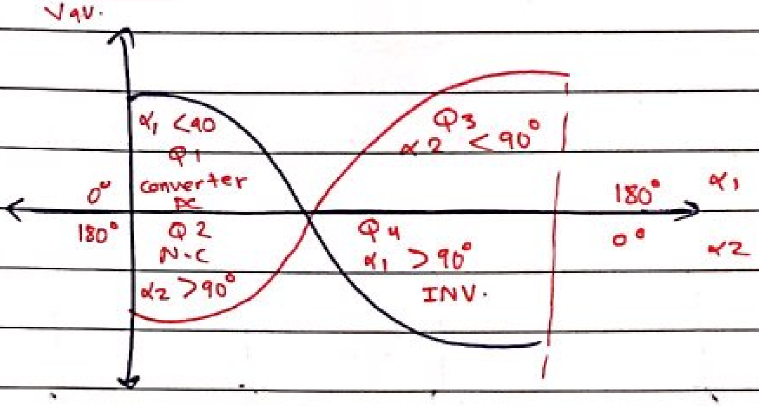
NC : $\alpha = \alpha 2$

$$V_{NC} = \frac{2V_m}{\pi} \cos\alpha_2$$

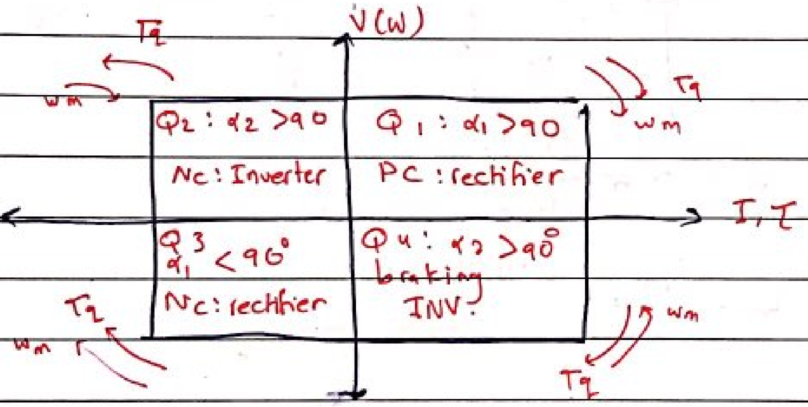
$V_{PC} = -V_{NC}$

$$\frac{2V_m}{\pi}\cos\alpha_1 = \frac{-2V_m}{\pi}\cos\alpha_2$$

$$\boxed{\alpha_1 + \alpha_2 = 180^0}$$



Thursday 21/11/2019

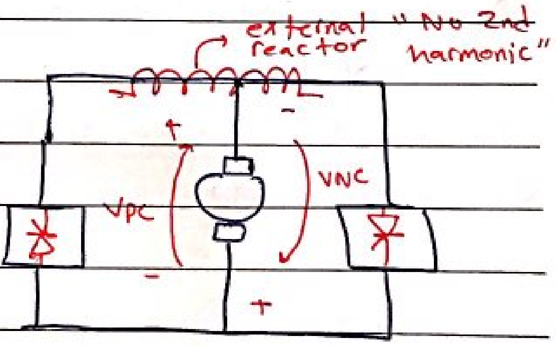


Q1: motoring action

Q2: Inversion Act
generation Act

Q3: motoring action

Q4: braking inversion



* Dual converters Modes!

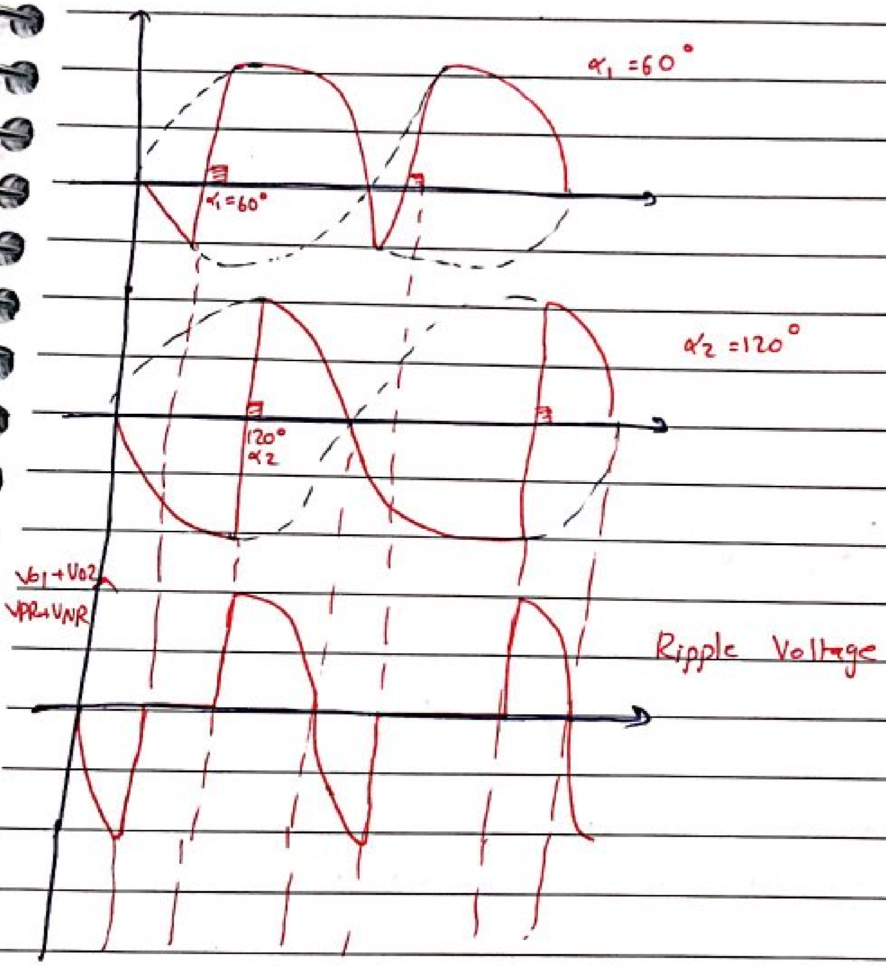
① without circulating current.

② with circulating current

$\alpha_1 + \alpha_2 = 180$

$V_{o1}(avg) = -V_{o2}(avg)$

$\alpha_1 = 60°$, $\alpha_2 = 120°$



* So an external rector is added in case of circulating current mode.

① without circulating current:

a) The triggering of PC SCRs & NC SCRs are separate (No overlapping) with a separation time of (10-20) msec. when PC SCRs are triggered, NC SCRs aren't triggered.

Result : No circulating current.

b) One single triggering circuit is enough to control both converters.

② with circulating current:

ⓐ both converters are simulataneously triggered but with $\alpha_1 + \alpha_2 = 180^\circ$.
which implies that two separate triggering circuits are required.

ⓑ a circulating current flows between the two converters due to the ripple voltage. To reduce this current an external reactor is added to the system, this will add to the cost PF, η, weight of the system:

cost → more expensive
PF → lower PF
η → lower η
weight → more weight & space requirements.

ⓒ advantage: No current cut-off, simpler control circuit (not cheaper).

* To select proper converter (In terms of controllability -- un controlled, fully controlled, semi controlled).

uncontrolled: just to run a motor at a certain fixed loading condition. (No braking, No speed control, No direction reversing.)

fully-controlled: when 4- quadrant or two quadrant operation is required, speed control, direction control, --- Reg braking.

Semi- controlled: only positive voltage (rectified) is possible so; No regenerating braking, a speed control is possible in one quadrant.
→ better harmonics on load.
→ better load current waveform.

Sunday 24/11/2019

Semi-controlled → only V^+, only I^+ → Q1

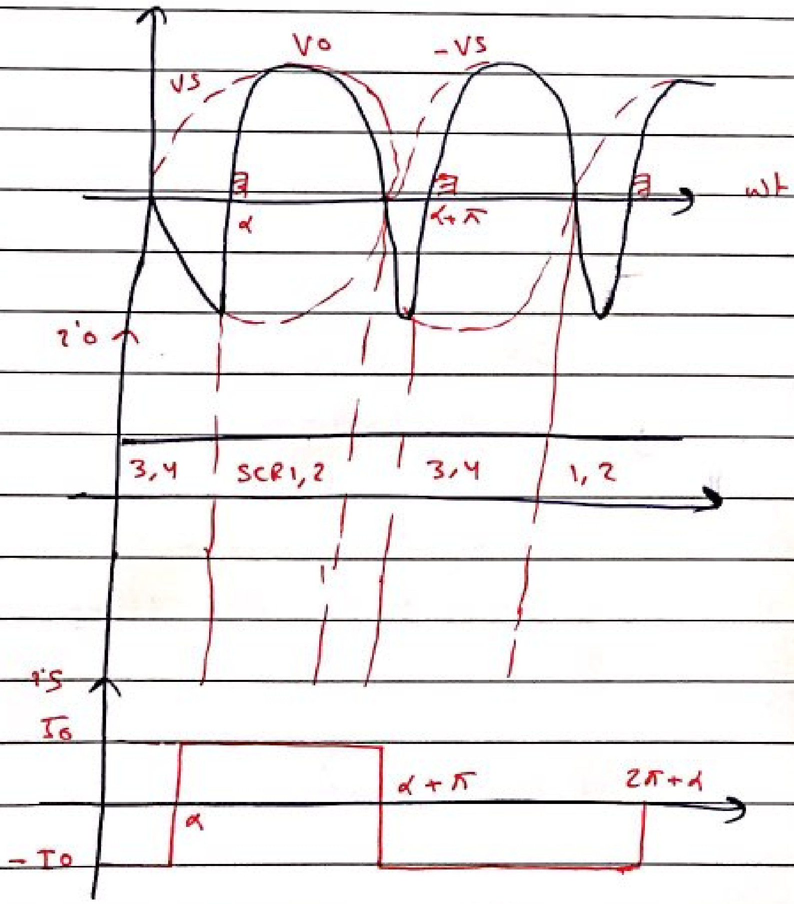
Semi-controlled dual converter → V^+ only → I^+, I^- → Q 4, Q2

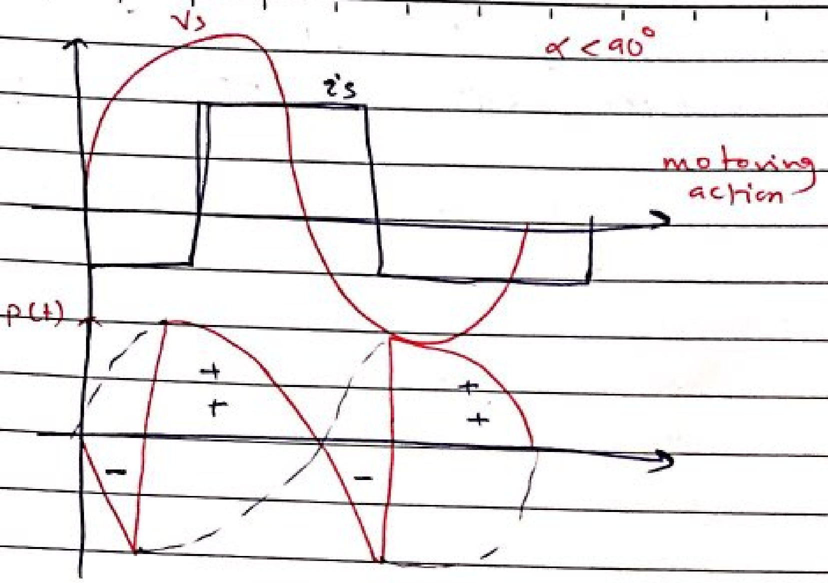
In all rectifier circuits, Iload (motor current) is assumed to be ripple free.

La is large enough (either by motor design or by adding external L in series with motor armature) (Assuming that response speed isn't critical)

in this case, the system always operates in CCM.

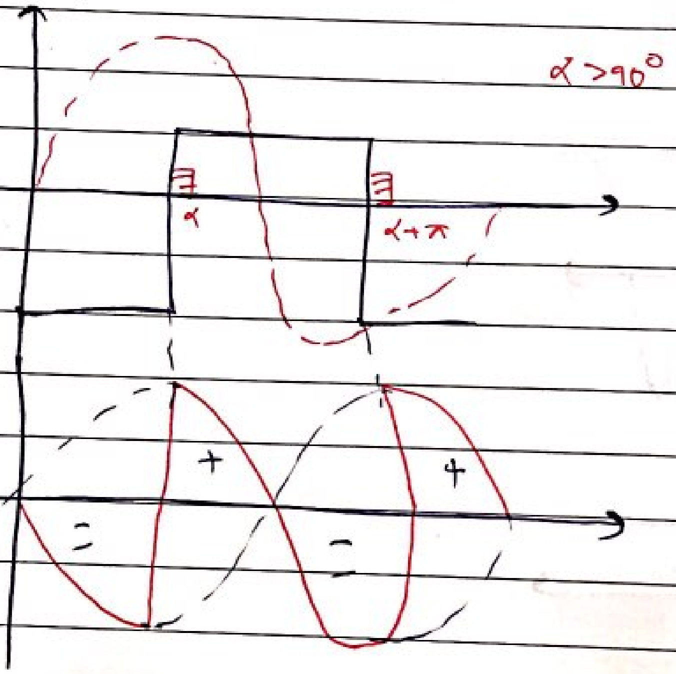
ⓐ single phase F.W.R fully controlled.





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

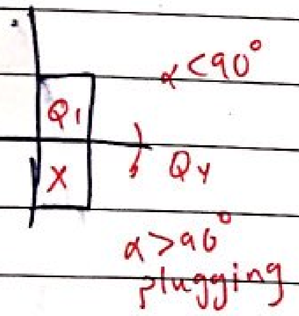
P_{in} (avg) = +



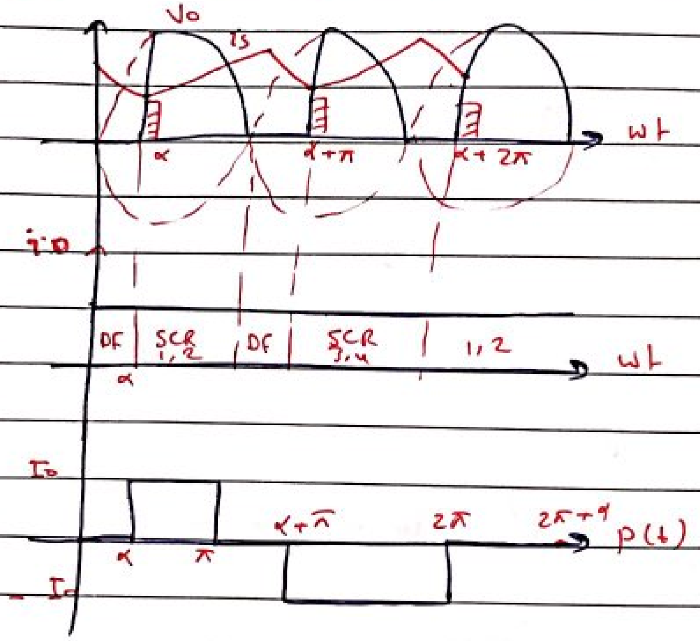
Q4 Vo (avg) is -ve

P (avg) = −

Drive with plugging : only two modes (Q) → (Q_1, Q_4)



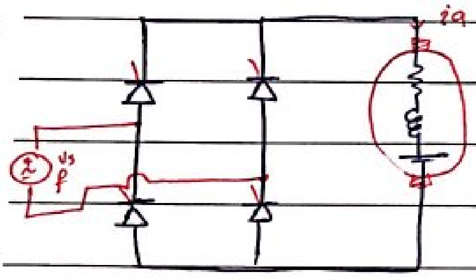
(b) Semi- controlled F.W.R

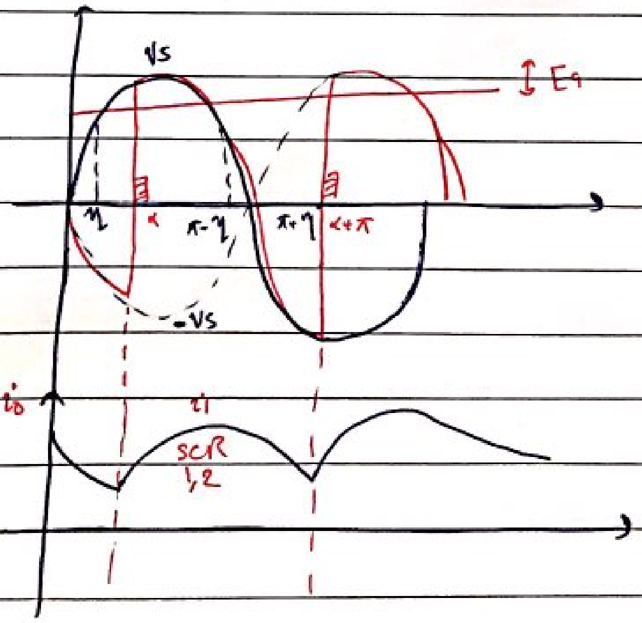


H.W: 3ϕ Rectifier La → ∞ , α > 90 , α < 90

Vo , iu, in , ic

Tuesday 26/11/2019





$Ea = ka . \phi . wm$

to find η →

$Ea = Vm \sin \eta$

$$\boxed{\eta = \sin^{-1} \frac{Ea}{Vm}}$$

$$Vs = Ea + i.R + L\frac{di}{dt}$$

$$i = I_m \sin(\omega t - \phi) - \frac{Ea}{R} + A e^{\rho \omega t}$$

Icc at $\omega t = \alpha_1$, $i_1 =$

$$I_1 = I_m \sin(\alpha - \phi) - \frac{E_a}{R} + A e^{\rho\alpha}$$

$$A = \left[I_1 + \frac{E_a}{R} - I_m \sin(\alpha - \phi) \right] e^{-\rho\alpha}$$

$$i = I_m \sin(\omega t - \phi) - \frac{E_a}{R} \left[I_1 + \frac{E_a}{R} - I_m \sin(\alpha - \phi) \right] e^{-\rho\alpha} \cdot e^{A\omega t}$$

Fcc at $\omega t = \alpha + \pi$, $i = I_1$

$$I_1 = I_m \sin(\pi + \alpha - \phi) - \frac{E_a}{R_a} + \left[I_1 + \frac{E_a}{R_a} - I_m \sin(\alpha - \phi) \right] \underbrace{e^{-\rho\alpha} \; e^{\rho(\pi + \alpha)}}_{e^{\rho\pi}}$$

$$I_1 - I_1 e^{\rho\pi} = - I_m \sin(\alpha - \phi) - \frac{E_a}{R_a} + \frac{E_a}{R_a} e^{\rho\pi} - I_m \sin(\alpha - \phi) e^{\rho\pi}$$

$$I_1 (1 - e^{\rho\pi}) = - \frac{E_a}{R_a} (1 - e^{\rho\pi}) - I_m \sin(\alpha - \phi) \left[1 + e^{\rho\pi} \right]$$

$$I_1 = - \frac{E_a}{R_a} - I_m \sin(\alpha - \phi) \cdot \left[\frac{1 + e^{\rho\pi}}{1 - e^{\rho\pi}} \right] \text{ -- } ⊛$$

given $N_m \longrightarrow \omega_m = \frac{2\pi N_m}{60}$

$E_a = k . \omega_m$

$k = \frac{E_a \text{ (rated)}}{\omega_m \text{ (rated)}}$

$I_m = \frac{V_m}{Z}$

$Z = \sqrt{R_a^2 + \omega L_a^2} \measuredangle \phi$

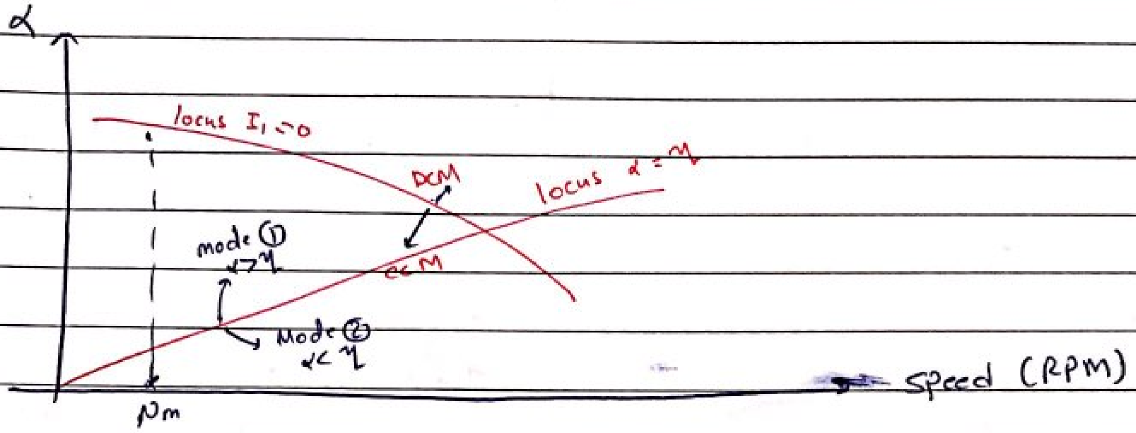
$\phi = \tan^{-1} \frac{\omega L_a}{R_a}$

$\rho = - \frac{1}{\tan\phi} = - \cot\phi \longrightarrow - \frac{R_a}{\omega L_a}$

Scanned with CamScanner

* critical operation between CCM & DCM , $\boxed{I_1 = 0}$

Write a report:



change speed & find α value from I_1 equation ⓧ

$$V_o(av) = \frac{2V_m}{\pi} \cos\alpha \quad \leftarrow \alpha$$

$$I_o(av) = \frac{V_o(av) - E_a}{R}$$

& we find α_{st}

speed ↑ → α ↓

$$I_o(av)_{st} = \frac{V_o(av) - 0}{R_a} = \frac{V_o(av)}{R_a} \quad \text{direct}$$

↓

to start at $I_{st} \simeq 200\%\ I_{rated}$

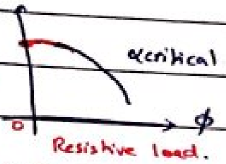
$$I_{st} = 2\ I_{rated} \ \frac{V_o'(av)}{R_a}$$

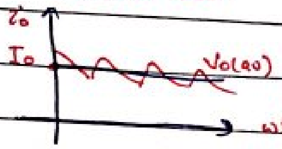
Thursday 28/11/2019

Ex: H.W : $V_{o(av)}$ $= \frac{3\sqrt{3}\,V_m}{\pi} \cos\alpha$
Sol. ccm.

I_o is ripple free.

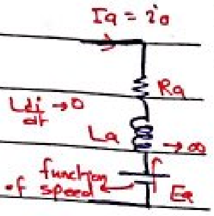
$\alpha > 90° \rightarrow -$
$\alpha < 90° \rightarrow +$





$= I_oR_a + E_a$

$\downarrow$



$* \; \frac{3\sqrt{3}\,V_m}{\pi} \cos\alpha = I_o R_a + E_a$

$\omega_m = \frac{2\pi}{60} \times rpm$ rad/sec

Quiz on Sunday.

$*PF_{in} = \frac{I_o^2 R_a + I_o E_a}{3\,V_{s\,ph(rms)} \times I_{sph(rms)}}$

$I_o\sqrt{\frac{2}{3}}$

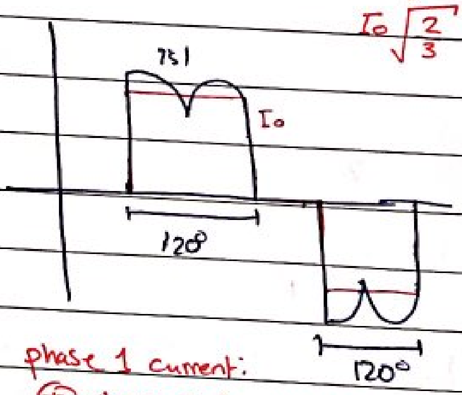
Peak/phase

$V_r = (E_{a(r)} + I_{a(r)} * R_a)$

$\hookrightarrow E_{a(r)} = V_r - I_{a(r)}(R_a)$

$K_a \cdot \phi = \frac{E_{a(r)}}{\omega_{mech(r)}} \rightarrow$ rated

•at any speed $\omega_m \rightarrow E_a = k\phi * \omega_m$



$T_d = k_a \cdot \phi * I_{a(av)}$.

$\hookrightarrow T_d = T_{shaft} + T_{rotational\ losses}$.

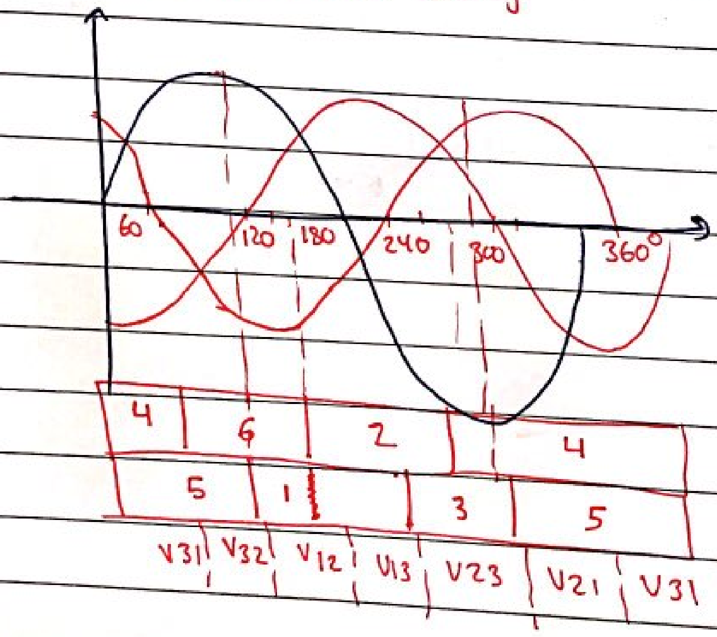
phase 1 current:

⊕ when SCR_1 running.

⊖ when SCR_4 running.

*HW #1 Solution: $\alpha = 60°$, $\alpha < 90°$

$SCR_1 \rightarrow 30 + 60 = 90° \xrightarrow{+120°} 210°$
2 +60° 150° → 270°
3 210° → 330°
4 270° → ~~390~~ 30°
5 330° → ~~450~~ 90°
6 ~~390°~~ 30° → 150°



Tuesday 3/12/2019

* Motor 230V, 5 Hp, 850 RPM, 20 A, $R_a = 1.19\,\Omega$, $L \rightarrow \infty$, P_{rot} = function of speed (Linear relation)

Supply: 240V, 50 Hz, 1ϕ. converter: 1ϕ fully controlled rectifier

Q1: does the supply's convecter capable of supplying the motor at cated conditions?

$$\underset{max.}{V_o(av)} = \frac{2\,V_m}{\pi}\cos\alpha = (2 \times 240\sqrt{2})/\pi \;\cos 0^\circ = 216.076\text{ V}$$

↳ $\alpha = 0^\circ$ (to get max. possible voltage).

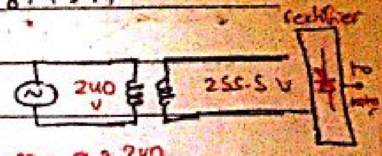
Since $\underset{load}{V_o(av)}\ (230V) > \underset{max}{V_o(av)}\ (216.076)$

∴ the supply's converter isn't capable of supplying the motor at rated conditios.

Solution: use a transformer (step-up); $a = \dfrac{216.076}{230} = 0.9394$

$240 \longrightarrow 216.076$

$?? \longrightarrow 230$



$0.9394 = a = \dfrac{240}{\boxed{255.5}}$?

$\rightarrow V_s'(rms) = 255.5\text{ V}$

$$\overset{rated}{E_a(r)} = V_t(r) - I_a(r) \times R_a$$

$$= 230 - 20 \times 1.19 = 206.2\text{ V}$$

$$K_a\phi = \frac{E_a(r)}{\boxed{\omega_m(r)}} = \overset{\omega_m(r)}{\boxed{\frac{2\pi \times 850}{60}}} = 89.01 \text{ rad/sec}$$

$$\therefore \frac{E_a(r)}{\omega_m(r)} = \frac{206.2}{89.01} = 2.3 \text{ V.sec/rad}$$

$T_d = K\phi \cdot I_a(r) = 2.3 \times 20 = 46$ Nm.

$T_d(r) = \dfrac{E_a(r)}{\omega_m(r)} \times I_a(r) = \dfrac{206.2 \times 20}{89.01} = 46$ Nm.

} 2 ways to find developed torque.

$P_{out} = P_{developed} - \boxed{P_{rotational}} \longrightarrow P_{rot}(r) = (206.2 \times 20) - 3730 = 394$ W.

↳ rated speed only = 850 RPM

↓

$P_o = 5 \times 746 = 3730$ N

$$P_{rot}\left(\underset{N_m}{\omega_m}{}^{or}\right) = P_{rot}(850) \times \frac{N_m}{N_m(r)} \text{ or } \frac{\omega_m}{\omega_m(r)}$$

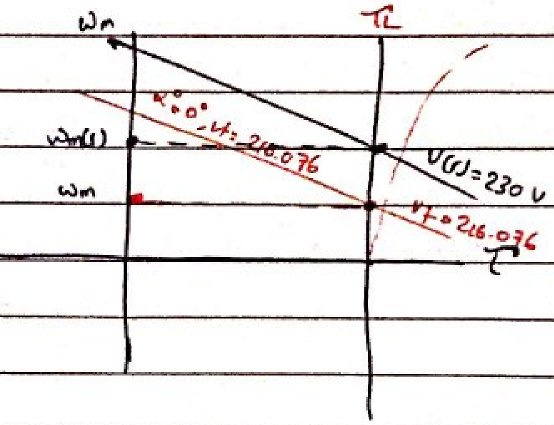
Q2:

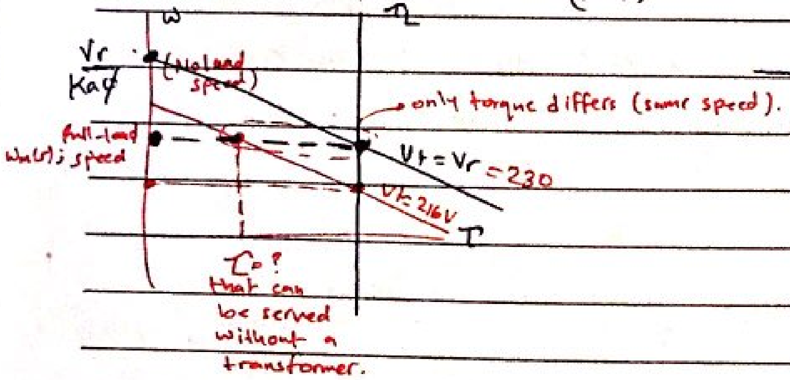
How much Power can the motor supply at rated speed without transformer?

$V_t = 216.076 = \{\omega_m(r) \times K_a\phi\} \rightarrow E_a(r) + I_a R_a$

↳ $V_{o(av)\,max}$ without Transformer.

$$\omega_m = \frac{V_r}{K_a\phi} - \frac{I_a R_a}{K_a\phi} = \frac{V_r}{K_a\phi} - \frac{R_a}{(K_a\phi)^2} \cdot T_a$$





$216.076 = 206.2 + I_a R_a + 1.19 I_a$

$\boxed{I_a = 8.3\ A}$ Instead of 20A.

$T_a = T_d = K_a\phi * I_a = 2.3 * 8.3 = 19.02$ Nm.

$P_a = T_a . \omega_m(r) = 1711.3$ Watts

$P_{rot} = P_{rot}(850) = 394.$

$P_{out} = 1711.3 - 394 = 1317.3$ Watt $= 1.7658$ hp

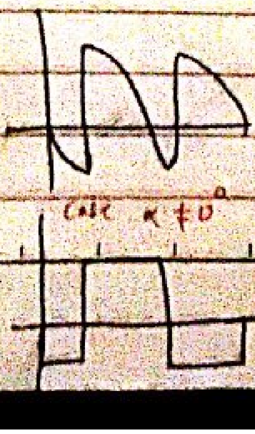
*loading ratio $= \frac{1.7658}{5\ hp} = 35,3\ \%$

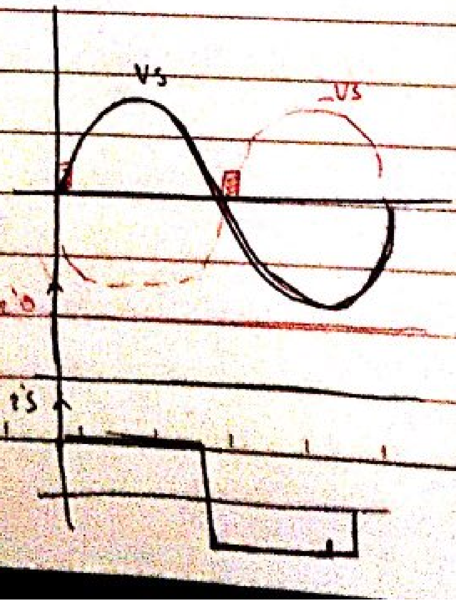
Q3: if running at rated conditions, (transformer is used).

$V_{supply} = 255.5$ V rms.

$V_t = V_r = 230$ V

$230 = \frac{2V_m'}{\pi} \cos \alpha \rightarrow 0°$





No -ve part cause α=0°.

Five Apple

to a t here

Ripple factor (RF)[Vo] = 48-43 %

RF(i0) = 0

$THDF_{(is)}$ = 48.43 %.

PFin = DPF × DTF

$= \frac{Vo(av)}{Vo(rms)}$ = 0.9 lag.

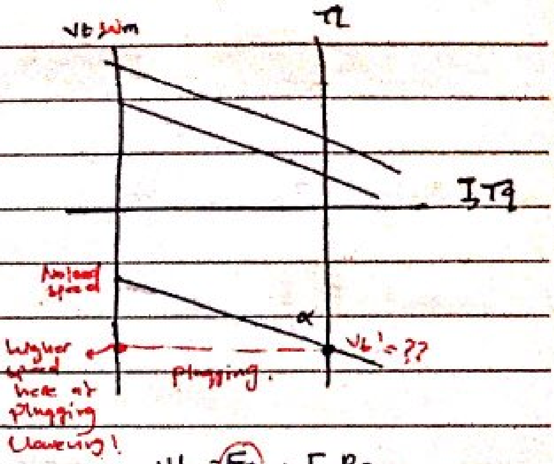
Qu: We need to do plugging.

Emf should be negative

$Ea \rightarrow Ia(\downarrow) \rightarrow Vt(\uparrow) \rightarrow \alpha$

$\omega m = \frac{Vt}{Ka\phi} - \frac{IaRa}{Ka\phi}$ → to find new speed.

& the find above



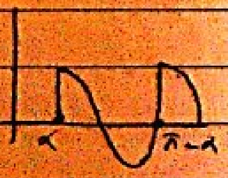
$Vt = \boxed{Ea} + IaRa$

↓ −Ea

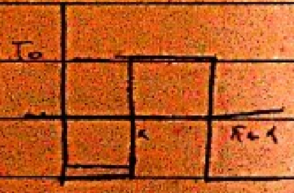
⊖

↳ : $\frac{2Vm}{\pi} \cos(\alpha)$

↳ α > 90°.



to find ripple factor from (α).



to find total harmonic distortion factor

PFin = DTF × DPF (general)

DTF ↳ $\frac{I_1(rms)}{Is(rms)}$

DPF ↳ $Cos\phi_1$

↳ Vs & $i_{fundamental}$.

PFin = $\frac{Vo(av)}{VS(rms)}$ (Special case of pure DC current).

↳ ⊖ inversion mode of operation (-ve Emf).

Thursday 5/12/2019

Starting of Antenna

↳ Discontinuous mode.

$\omega_m = 0 \rightarrow E_a = 0$

$\therefore V_t = \cancel{E_a}^{0} + \boxed{I_a R_a}$

↳ very low values.

- $V_{av}(critical) = \frac{2V_m}{\pi} \cos\phi$.

- $T_{motor} = \underbrace{J_{\cancel{tot}} \frac{d\omega_m}{dt}}_{T_{acc}} + T_{losses} + T_{Load}$; $J_{total} = J_{motor} + J_{load}$

  ↳ $2J_{motor}$

- $P_{rotational} = P_{in} - P_o - P_{cu}$

  ↳ $I_a^2 R_a$

* rotational losses ↓ viscous friction.

- $T_{rotational} = \frac{P_{rot}}{\omega_m}$; $T_{rot} = K . \omega_m$

Past paper * adding an external inductor to certain DC motors → comment on the statement.

go back to power electronics for relations & graphs.

$$\boxed{C(n) = \frac{4 I_o}{n\pi} \sin(-n\alpha)}$$

go back to check its square wave.

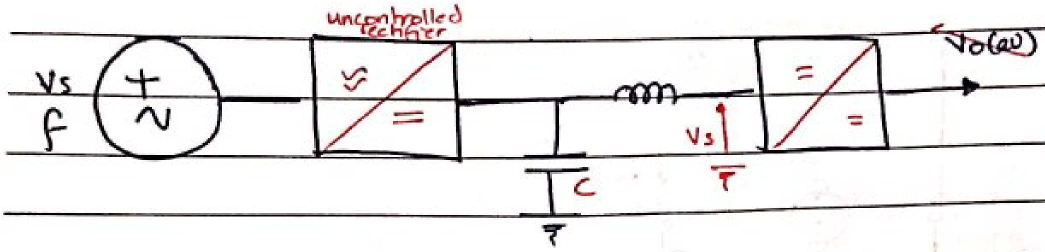
find * rms value kw of motor.

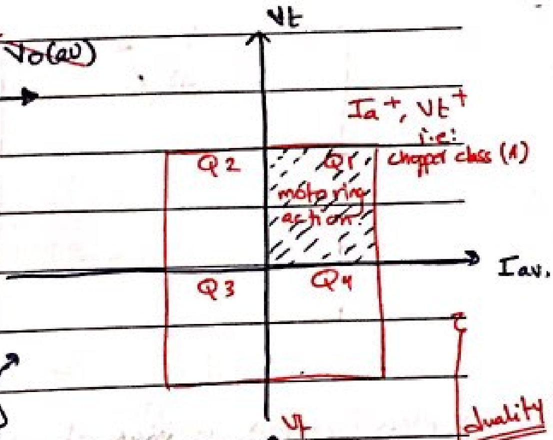
→ DCM relation with given α & β find Vo(avg.).

Sunday 8/12/2019

Final material.

* DC-to-DC (choppers) controlled Drive.

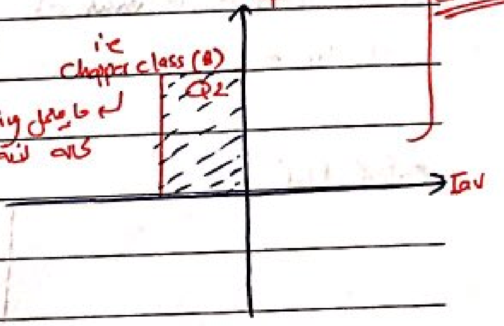




i.e. chopper class (A)

1

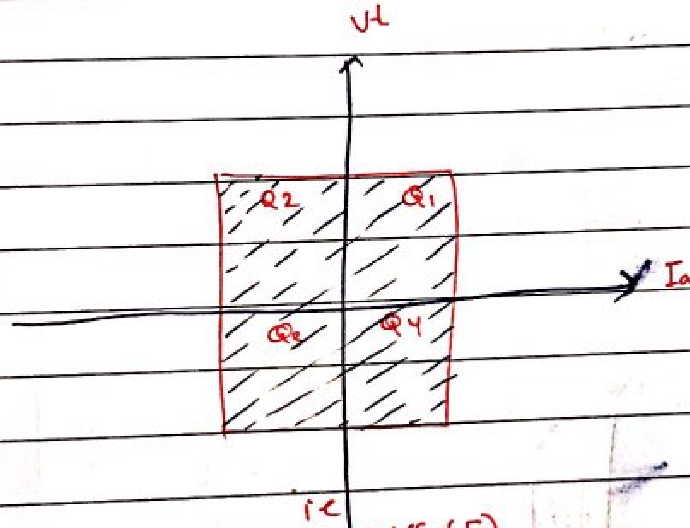
duality



i.e. Chopper class (B)

motoring ← ما بعمل

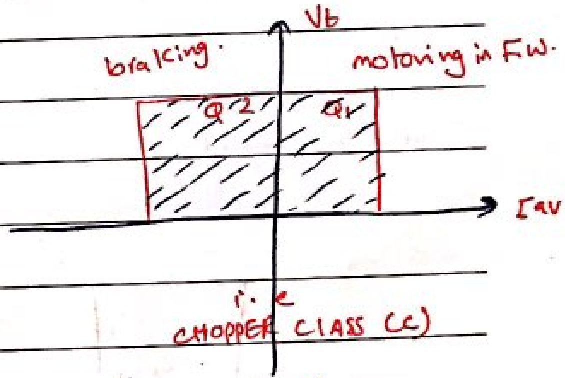
. I+ لأنه ما في



4

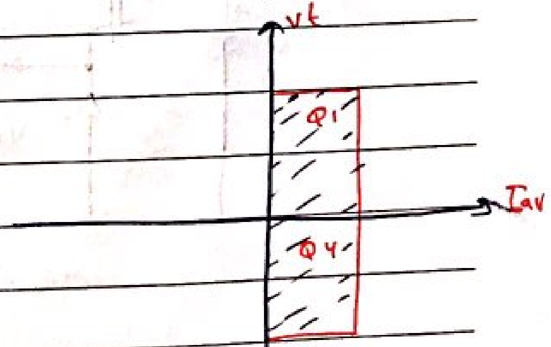
i.e. CHOPPER CLASS (E)
(works in all Qs)

2



i.e. CHOPPER CLASS (C)

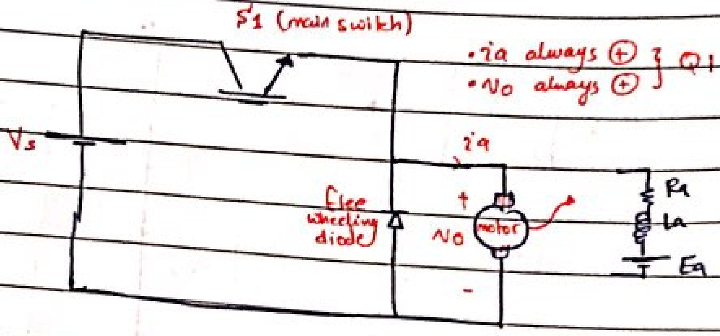
3



i.e. CHOPPER CLASS (D)
↳ such as fully controll
full wave rectifier

Chopper, Inverter → only transistors not thyristors.

*Chopper class (A):



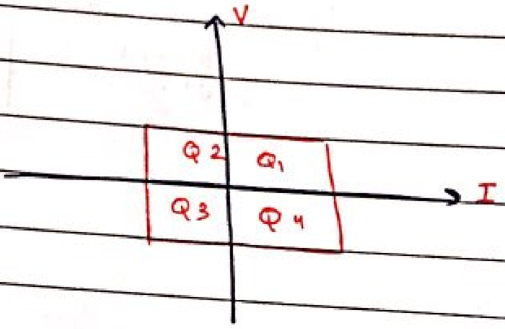
- ia always ⊕ } Q1 drive system.
- Vo always ⊕

* classification in terms of V, I directions:

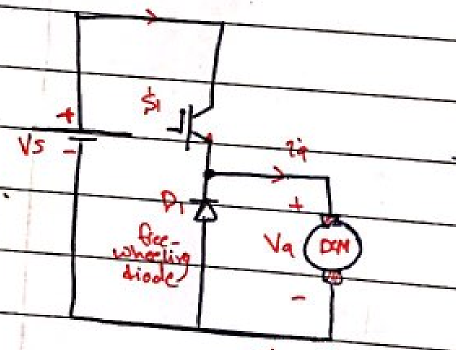
Tuesday 10/12/2019

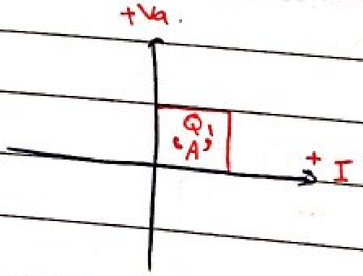
4-types:

A,B,C,D,E



[1] Type 'A' chopper.

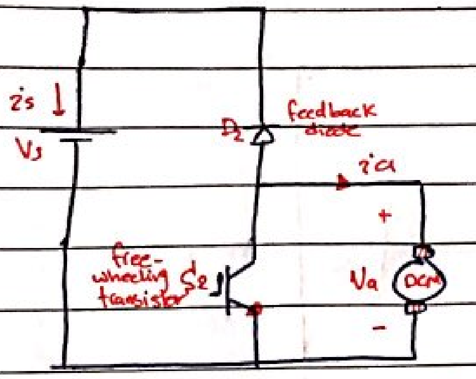


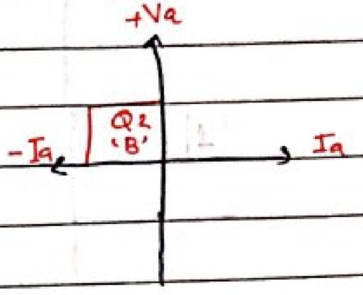


Va = Vt
armature ↲ ↳ terminal

[discharging → +ve I]

② Type 'B' chopper. → it does braking so it doesn't work alone.

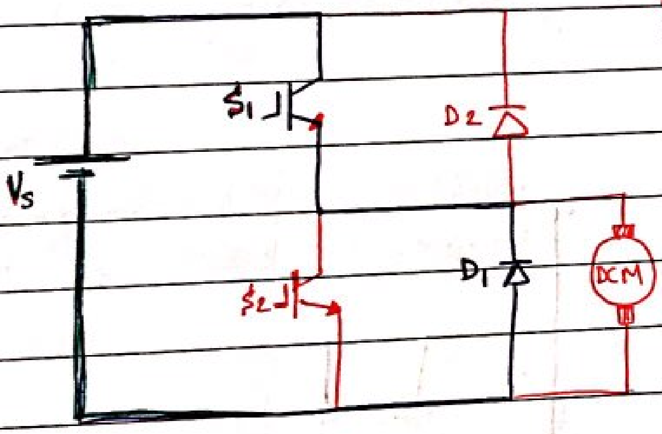




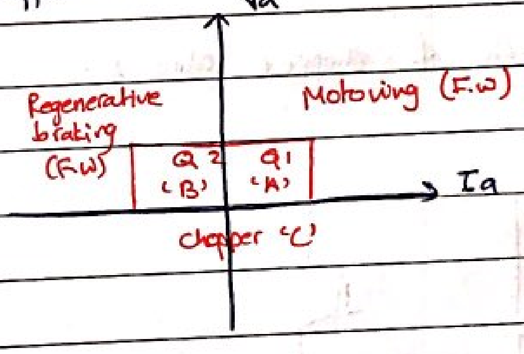
* class 'B' chopper isn't existing alone.

(the current will be negative)
[charging]

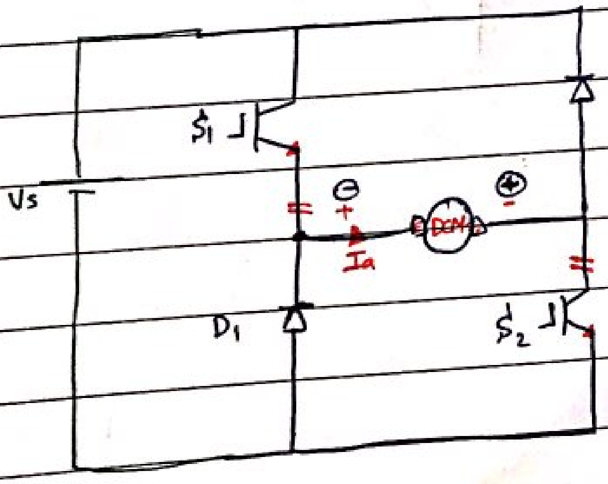
③ Type 'C' chopper.

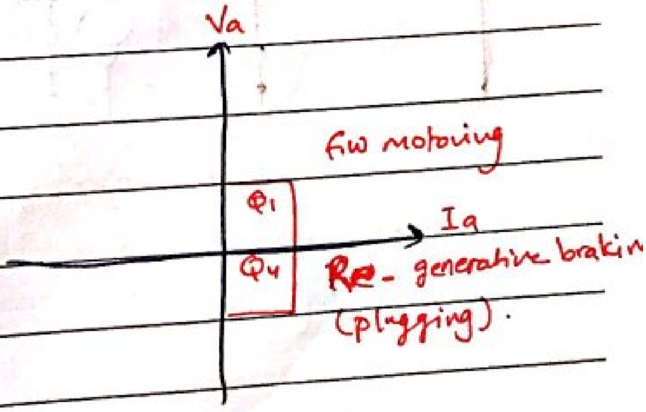


Red: chopper Class 'B' + } → Chopper class 'C'
blue: chopper Class 'A'

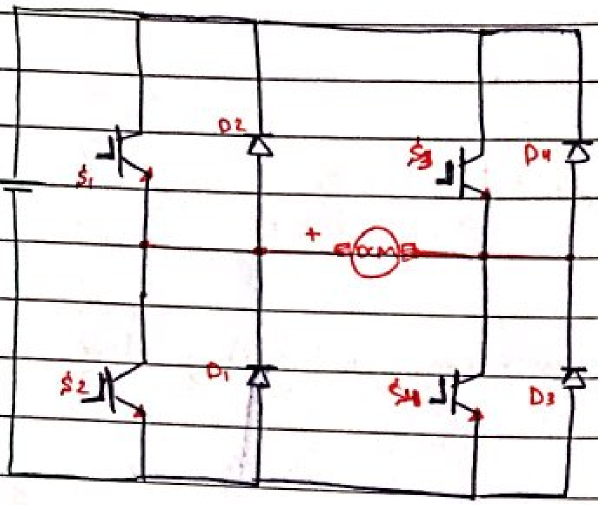


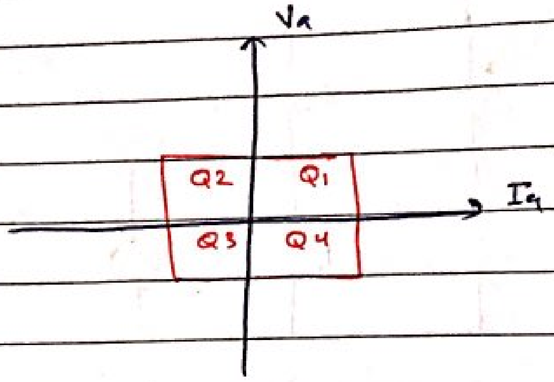
④ Type 'D' chopper.





⑤ Type 'E' chopper.

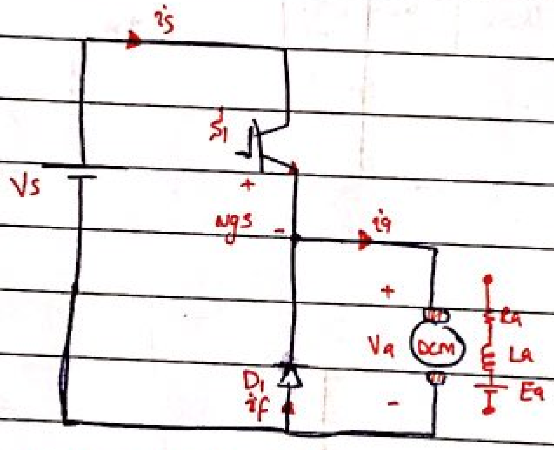




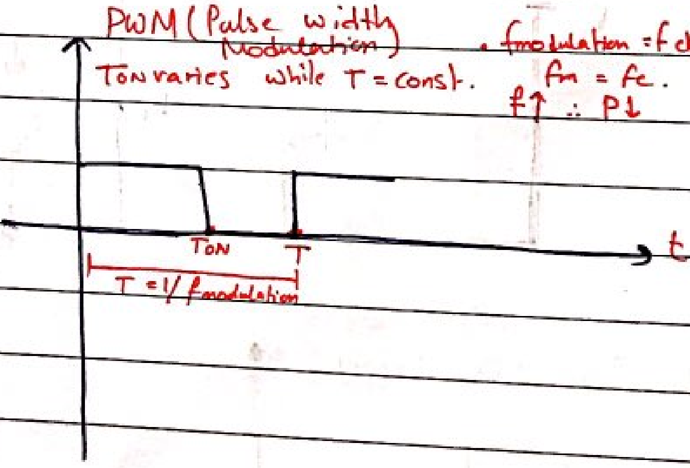
Q3+Q4 → braking in reversed direction.

Q2+Q3 → plugging in reversed direction.

*Analysis of chopper class A :



PWM (Pulse width Modulation)
Ton varies while T = const.



- fmodulation = f choppi
$f_m = f_c$.
f↑ ∴ P↓

*(La) very large if we dont care about the system's control.

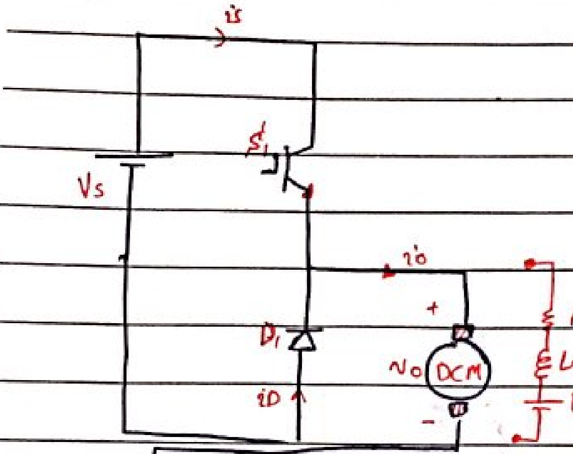
$\gamma = \frac{T_{ON}}{T}$ → γ: modulation index

$0 \leq \gamma \leq 1$

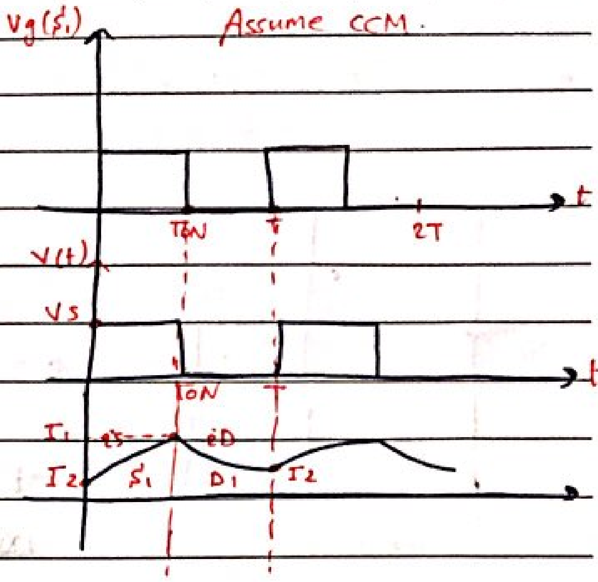
$V_o = 0$ ↲ ↳ $V_o = V_s$

Thursday 12/12/2019

* chopper class 'A'



$\boxed{E = K_a \phi . \omega_m}$



Assume CCM.

$T = \frac{1}{f_m} = \frac{1}{f_{ch}}$

modulation ↲ ↳ chopping

Assume CCM

TON → Variable

γ : Modulation index $= \frac{T_{ON}}{T}$

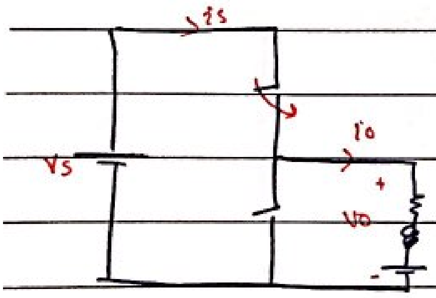
$0 \leq \gamma \leq 1$

$V_o = 0$ ↲ ↳ $V_o = V_s$

• begining of Analysis:

$0 < t \leq T_{ON}$

* $\tau = L/R$



$\boxed{V_o = V_s}$

$V_s = iR + L\frac{di}{dt} + E$

$V_s - E = iR + L\frac{di}{dt}$

$i = \underbrace{\frac{V_s}{R}}_{I_s} - \underbrace{\frac{E}{R}}_{I_E} + A e^{-t/\tau}$ ⇒ A= ?? Icc : where at $t=0$, $i = I_2$

$I_2 = I_s - I_E + A e^{-0/\tau}$

• $A = I_2 - I_s + I_E$

$iD = 0$, $i_o = i_s$

$i = I_s - I_E + I_2 e^{-t/\tau} - I_s . e^{-t/\tau} + I_E e^{-t/\tau}$

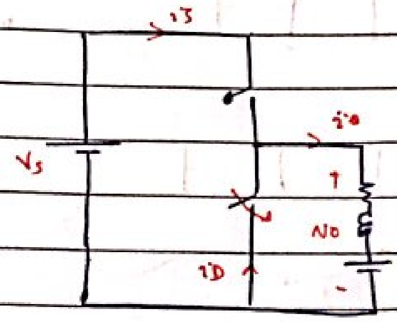
✱ $i_s = I_2 e^{-t/\tau} + I_s(1 - e^{-t/\tau}) - I_E(1 - e^{-t/\tau})$.

Fcc at $t = T_{ON}$, $i = I_1$

$$⊛\ I_1 = I_2 e^{-\frac{T_{ON}}{\tau}} + I_s\left(1 - e^{-\frac{T_{ON}}{\tau}}\right) - I_E\left(1 - e^{-\frac{T_{ON}}{\tau}}\right) \,--\, ①$$

$\cdot\ T_{ON} = \gamma \cdot T$

two unknowns. I_1 & I_2.



$i_s = 0$

$i_o = i_D$

$$0 = iR + L\frac{di}{dt} + E$$

$$-E = iR + L\frac{di}{dt}$$

$T_{ON} \le t \le T$

$$i_D = -I_E + Be^{-t/\tau}$$

at $t = T_{ON}$ Icc. $\longrightarrow i_D = I_1$

$$I_1 = -I_E + Be^{-\frac{T_{ON}}{\tau}} \Rightarrow B = (I_1 + I_E)\, e^{\frac{T_{ON}}{\tau}}$$

$$⊛\ \therefore i_D = -I_E + (I_1 + I_E) \cdot e^{\frac{T_{ON}}{\tau}} \cdot e^{-\frac{t}{\tau}}$$

Fcc at $t = T$, $i_D = I_2$

$$⊛\ I_2 = -I_E + (I_1 + I_E)\, e^{\frac{T_{ON}}{\tau}} \cdot e^{-\frac{T}{\tau}} \,--\, ②$$

Conclusion:

$$⊙\ I_1 = I_s\left[\frac{1 - e^{-\frac{T_{ON}}{\tau}}}{1 - e^{-\frac{T}{\tau}}}\right] - I_E$$

$$⊙\ I_2 = I_s\left[\frac{1 - e^{\frac{T_{ON}}{\tau}}}{1 - e^{\frac{T}{\tau}}}\right] - I_E$$

Critical condition:

$$\boxed{I_2 = 0}$$

$$T_{ON(cr.)} = \ln\left[1 + \frac{I_E}{I_s}\left(e^{\frac{T}{\tau}} - 1\right)\right] ⊛$$

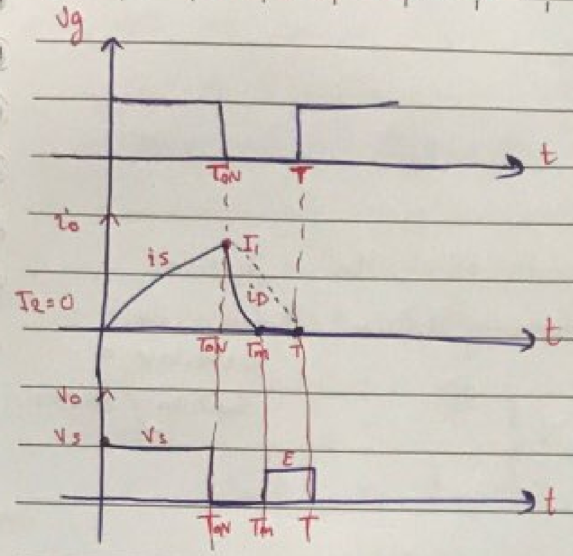
$$\gamma(cr) = \frac{T_{ON}(cr)}{T} ⊛$$

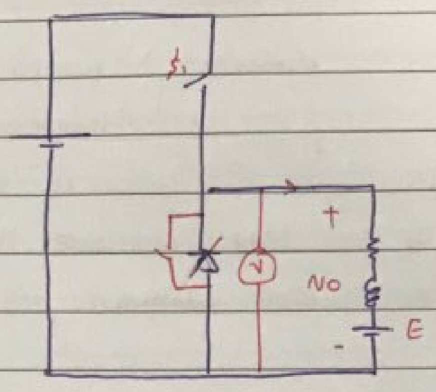
T_M ?? in DCM next lecture.

Sunday 15/12/2019

* DCM for chopper class 'A'

- class 'C' never works in DCM.





$$T_m = -\tau \ln\left[\frac{IE}{(IE + I_1)} \cdot e^{-\frac{T_{ON}}{\tau}}\right] \circledast$$

<u>Icr</u> ?

$$V_{o(av)_{CCM}} = \gamma V_s$$

$$V_{o(av)_{DCM}} = \sqrt{\frac{1}{T}\int_0^{T_{ON}}\left[V_s\,dt\right] + \frac{1}{T}\int_{T_m}^{T}\left[E\,dt\right]} = \gamma V_s + E(1 - \gamma_m)$$

- where $\gamma_m = \frac{T_m}{T}$

Voltage harmonics:

- $C(n)_{CCM} = \frac{2V_s}{n\pi}\sin(n\gamma\pi)$; $n = 1, 2, 3, ---$ [peak amplitude for nth harmonic]
- $\varphi(n) = \frac{\pi}{2} - n\gamma\pi$ [displacement angle for nth harmonic]

$$V_o(t) = \gamma V_s + \sum_{n=1,2,3,4,..} \frac{2V_s}{n\pi}\sin(n\gamma\pi) \cdot \sin\left(n\omega t + \frac{\pi}{2} - n\gamma\pi\right) \circledast$$

$$i_o(t) = \frac{\gamma V_s - E}{R} + \sum \frac{2V_s}{n\pi Z(n)}\sin(n\gamma\pi)\sin\left(n\omega t + \frac{\pi}{2} - n\gamma\pi - \phi(n)\right)$$

$\phi(n) = \tan^{-1}\left(\frac{2\pi n f_{ch} L_a}{R}\right)$

$Z(n) = R + \underset{j2\pi n}{\cancel{}} f_{ch} \times L_a$

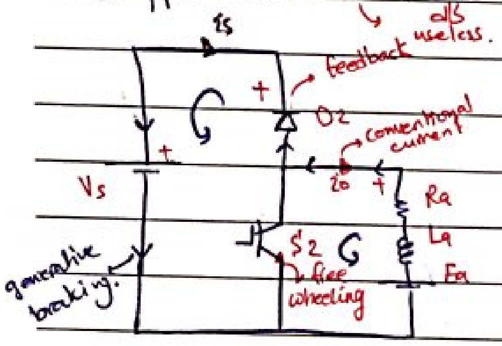
- $f_{ch} = f_m$

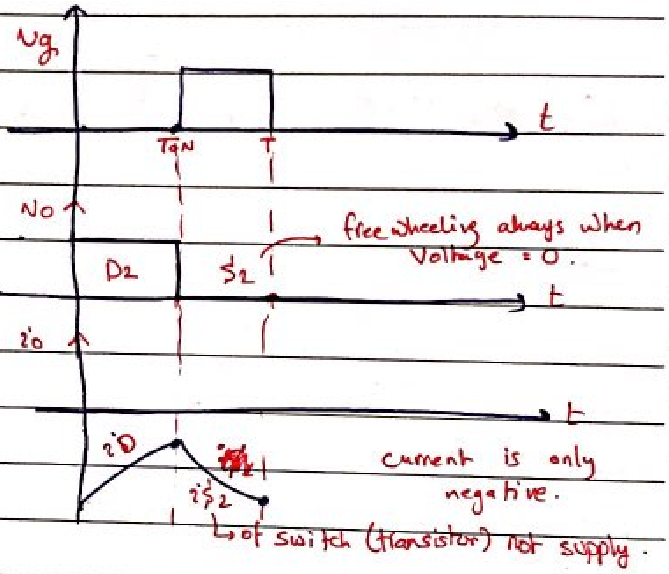
$$V_{o(rms)} = \sqrt{V_o^2(av) + \sum_{n=1,2,3,..}\left(\frac{2V_s}{\sqrt{2}\,n\pi}\sin(n\gamma\pi)\right)^2} \quad , \quad I_{o(rms)} = \sqrt{I_o^2(av) + \sum_{n=1,2,3,..}\left(\frac{2V_s}{\sqrt{2}\,n\pi Z(n)}\sin(n\gamma\pi)\right)^2}$$

* advantages :

- Much simpler analysis.
- harmonics elimination, is possible & simple.
  ↳ / reduction.
- extra degree of freedom to reduce the harmonics effect, that is besides to the load inductance, the chopping flequency (up-to a certain level) is an excellent solution.
  ↳ because of switching losses.

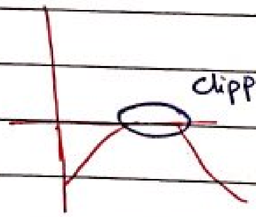
* chopper class 'B' :





* chopper (B) can be used alone if $\underline{\underline{E}}$ is coming from a $\underline{\underline{DC}}$ Generator or from a $\underline{\underline{PV}}$ system & in this case $E > V_s$.

*



clipping if we ever get +ve current with chopper (B).

Tuesday 17/12/2019

* Analysis of chopper (B):

Same equations for I_1, I_2 as Chopper (A) same analysis.

$0 < t < T_{ON}$ (D2 is conducting) → feedback.

$$V_s = i_D R + L\frac{di_D}{dt} + E$$

$T_{ON} < t < T$ (S_2 is conducting) → free wheeling.

$$0 = i_{S_2} R + L\frac{di_{S_2}}{dt} + E$$

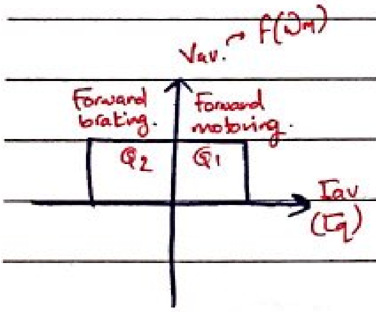
$$I_1 = I_s\left[\frac{1 - e^{-\frac{T_{ON}}{\tau}}}{1 - e^{-\frac{T}{\tau}}}\right] - I_E \quad ⊛$$

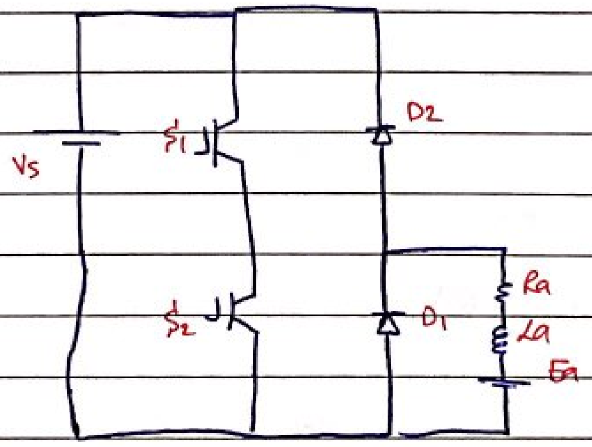
$$I_2 = I_s\left[\frac{1 - e^{\frac{T_{ON}}{\tau}}}{1 - e^{\frac{T}{\tau}}}\right] - I_E \quad ⊛$$

- $V_o(av) = \gamma V_s$. , $\gamma = \frac{T_{ON}}{T}$
- $I_o(av) = \frac{\gamma V_s - E}{R_a}$

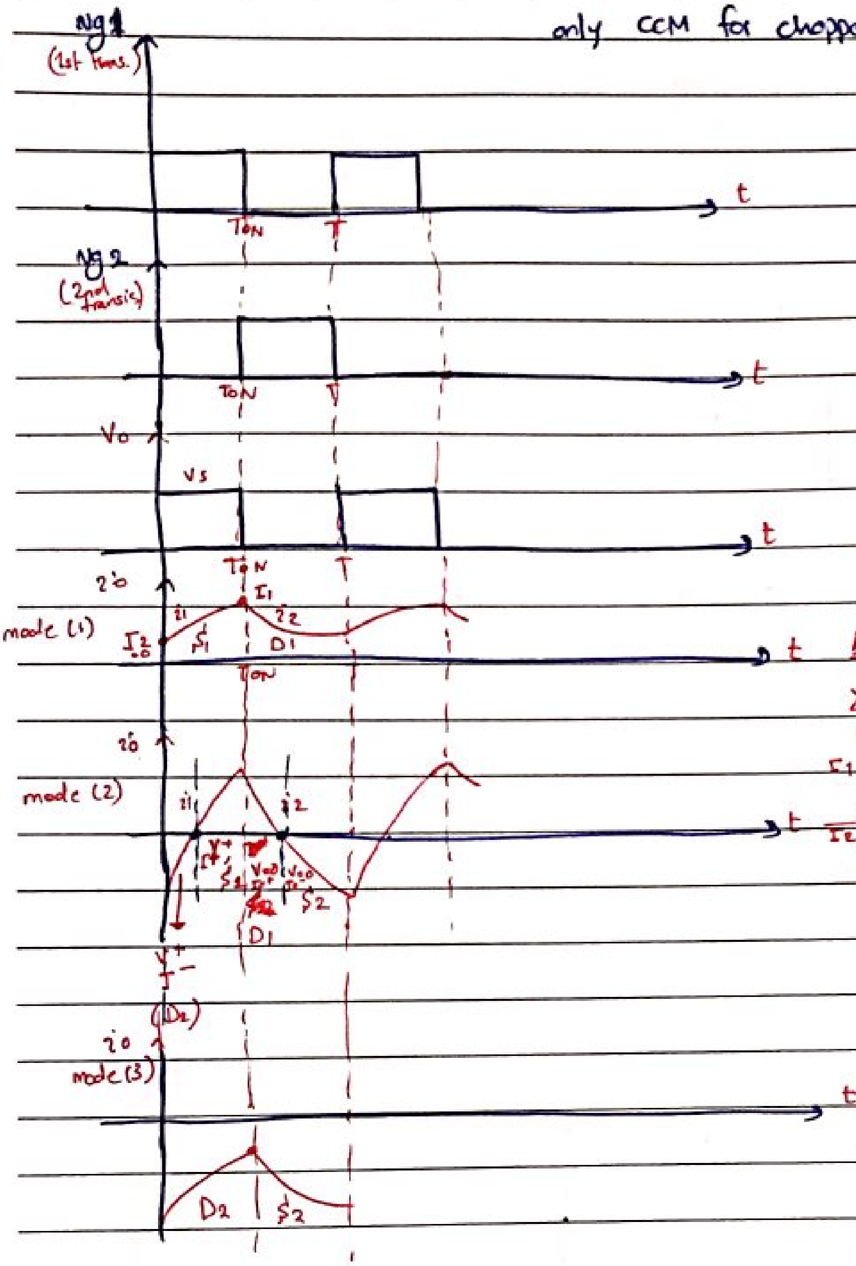
↓ always negative.

* chopper class 'c':



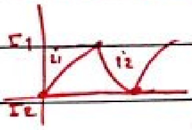


only CCM for chopper (C) NO DCM.



A chopper class 'A'.

γ_{cr} (1-2) → when $I_2 = 0$



$$I_{av} = \begin{cases} + \text{ always (mode ①)} \\ +, \overset{or}{} - \text{ in mode ②} \\ - \text{ always (mode ③)} \end{cases}$$

$$I_{av} = \frac{V_{o(av)} - E}{R_a}$$; I_{av} (+ve) → Motoring. [mode ① and part of mode ②].

$V_{o(av)} = \gamma V_s$: $E(\omega)$

$\gamma V_s > E \rightarrow I_{o(av)}$ +ve , $\gamma V_s = E \rightarrow I_{o(av)}$ Zero

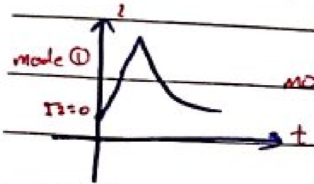
↳ No T_q & motor will start braking.

بيباطا بعدين.

Thursday 19/12/2019

* $\gamma_{cr}(1\to2) = \frac{\tau}{T}\ln\left[1-\frac{E}{V_S}\left(1-e^{\frac{T}{\tau}}\right)\right]$, $\gamma_{cr}(2\to3) = -\frac{\tau}{T}\ln\left[1-\frac{E}{V_S}\left(1-e^{-\frac{T}{\tau}}\right)\right.$

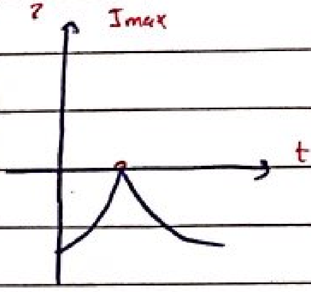
$I_2 \to 0$

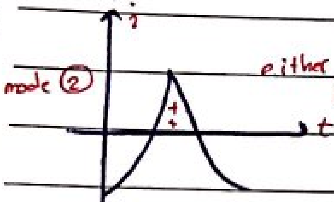


motoring

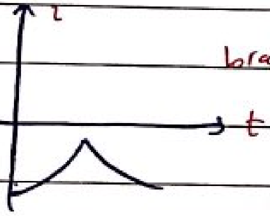
$I_1 \to 0$

Imax





either motoring or braking is Possible.



braking.

Thursday 26/12/2019

* frequency control of IM. (Major method)

• DC motor.
↳ limitations
(vibration, commutation spark & mech. limitations)

$\cancel{\omega_s} = \frac{60 f}{P}$; $0 \le f \le \underline{3 f_r}$
↳ Mechanical, limitation.
design.

$V_{ph} = 4.44 \; N_{ph} * f * \phi_m$

$V_{ph} = K` * f\downarrow * \phi\uparrow$
↳ constant.

• case ⓐ $f < f_r$. while keeping V_{ph} constant.

The machine will experience bad saturation.

[NEVER ACCEPTED]

Solution: to vary V_{ph} by the same ratio as f; such that $\frac{V}{f}$ = constant.

• This type of control is known as: VVVf. (variable voltage, variable freq. control).
↳ or Constant flux control.
(field).

• case ⓑ $V_{ph} = K` * f\uparrow . \phi\downarrow$

If, $f > f_r$. ; $\omega_m > \omega_{m(r)}$.

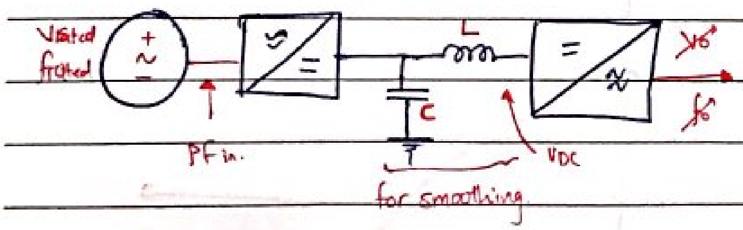
$\underset{(V_{ph})}{V_t}$ will never be able to be increased above rated (ratio). value.

$\underset{(V_{ph})}{V_t} = V_{rated}$; $\frac{V}{f}$ = [illegible] decreasing. ↓

$\phi = \frac{V_t}{K.f} = K'.\frac{V}{f}$; ϕ reduced while f increased.

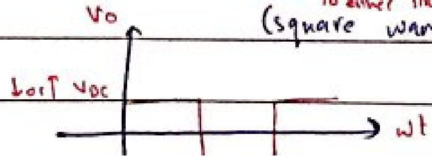
• This type of control is referred to field weakening control.

* Speed control Block:



. fo → only controlled by inverters, switching.

. Vo → a) by using controlled rectifier to either increase or decrease Vdc.
(square wave inverter).



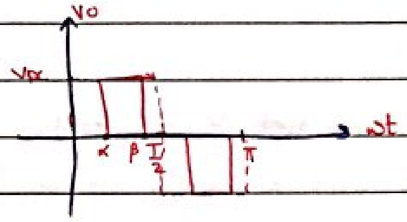
side note: $PF = \underbrace{DPF * DTF}_{\text{both are}}$ functions of α

higher $\alpha \rightarrow$ lower PF.

b) by using uncontrolled rectifier $\boxed{\alpha=0}$ leading to highest power factor.

Vo can be controlled by the inverter.

→ Pulse width modulation is to be applied.



Smaller width than the graph before.

Fourier transform.

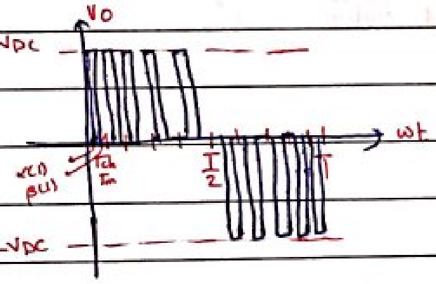
lots of harmonics so we use, multi-pulse PWM.

1. Uniform PWM.

2. Sinusoidal PWM.

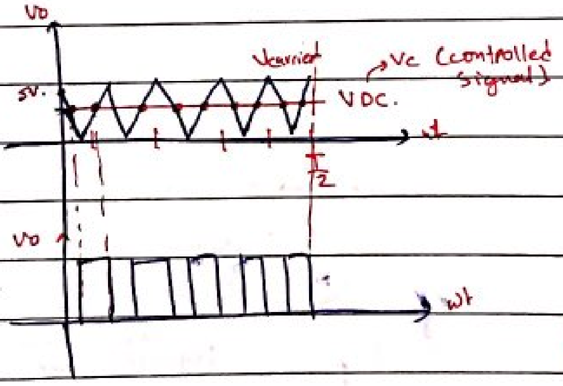
- Tch: chopping
- Tm: modeling.

① UPWM.



$f_o \triangleq$ Power frequency $= 1/T$

② SPWM.



comparator.

this first.

# of pulses per half cycles 5

$\boxed{f_o = \frac{1}{T}}$, $f_{ch} = \frac{1}{T_{ch}}$ $\boxed{= \frac{1}{\frac{T}{(10)}}}$

# of pulses of full cycle.

- $\frac{f_{ch}}{f_o} = \frac{\frac{1}{T/10}}{1/T} = 10$; $\boxed{f_{ch} = 10 f_o}$

Tuesday 31/12/2019

* frequency control of I.M:

$N_s = \left(\frac{60}{p}\right) f$ } → Synchronus speed
$V \simeq k . f . \phi$

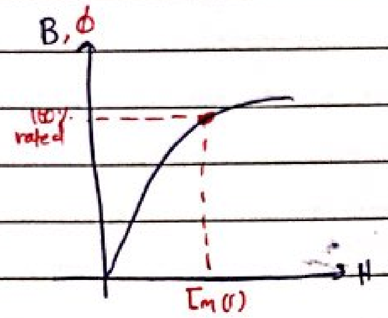
Criteria: $\phi \leq \phi_{nec.}$ ($= \phi_{rated}$)

$\phi = K'\left(\frac{V}{f}\right)$

ⓐ $f < f_r$

V should be reduced such that $\frac{V}{f}$ = const. → VVVf control

$\phi \triangleq$ constant at rated value.



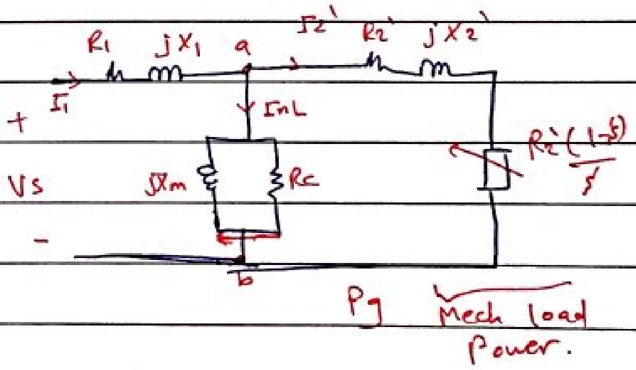
ⓑ $f > f_r$

$\frac{V}{f\downarrow}$ & can't be increased to keep ϕ = constant

$\phi\downarrow$ → (field weakening).

$N_{m(r)} \leq N_m \leq (2\text{-}3) N_{m(r)}$ → limitation is mechanical.

X not used. * $I_r = \frac{V_r}{\sqrt{\left(R_1 + \frac{R_2'}{s_r}\right)^2 + (X_1 + X_2')^2}}$ (not accurate unless you neglect Rc & Xm)



- P_g (air-gap power) $= 3 I_2'^2 \frac{R_2'}{s}$
- $\tau_g = \frac{P_g}{\omega_s} = \frac{3 I_2'}{\omega_s} \frac{R_2'}{s}$

at no load → $s = 0$ → $\frac{(1-0)}{0} = \infty$

∴ magnetization current = InL

- $P_{conv.} = 3 - I_2'^2 R_2' \left(\frac{1-s}{s}\right) = (1-s) P_g$
- $\eta \simeq (1 - s)$ → slip shouldn't be a large value.

- $\frac{P_{conv.}}{\omega_m} = \tau_{conv.} = \frac{P_g \cancel{(1-s)}}{\omega_s \cancel{(1-s)}} = \frac{P_g}{\omega_s} = \tau_g$

- $s = \frac{\omega_s - \omega_m}{\omega_s}$
- $\omega_m = (1-s)\,\omega_s$

- $T_{out} = \tau_g - \tau_{rot.\,loss}$

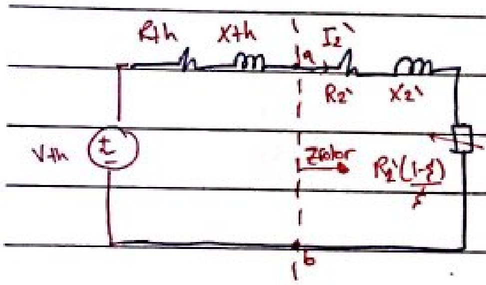
$I_{nL} \rightarrow$ Excitation (magnetization) branch current.

$I_{nL} \simeq 20 - 50\%\ I_{rated}$.

$\boxed{X_m} \lll R_c$
$\hookrightarrow$ core losses.

very small because of air gap.

; $L_m = \frac{N^2}{R_m} \downarrow$ (Reluctance).

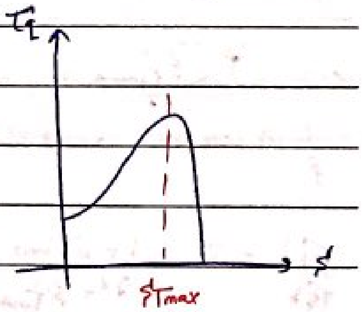


- $R_{th} \simeq R_1 \left(\frac{X_m}{X_m + \cancel{X_2}}\right)^2$
- $X_{th} \simeq X_1$
- $V_{th} = \left(\frac{X_m}{X_m + X_1}\right) V_s$

- $I_1 = \frac{V_{th}}{\sqrt{\left(R_{th} + \frac{R_2'}{s}\right)^2 + (X_{th} + X_2')^2}}$

- $I_{st} = \frac{V_{th}}{\sqrt{(R_{th} + R_2')^2 + (X_{th} + X_2')^2}}$

- $s_{T_{max}} = \frac{R_2'}{\sqrt{R_{th}^2 + (X_{th} + X_2')^2}}$



special case:

$Z_{th} \ll Z_{rotor}$.

$Z_{th} \longrightarrow 0 \quad (R_{th} \rightarrow 0,\ X_{th} \longrightarrow 0)$

- $s_{T_{max}\,(rated)} = \frac{R_2'}{X_2'} = \frac{R_2'}{2\pi f_{rated} L_2'} = \frac{R_2'}{2\pi(\lambda_f f_r) L_2'} = \frac{R_2'}{\lambda_f \cdot X_2'(1)}$

* $\lambda_v = \frac{V}{V_{rated}}$; $0 \leq \lambda_v \leq 1$

* $\lambda_f = \frac{f}{f_{rated}}$; $0 < \lambda_f \leq (2\text{-}3) f_{rated}$

- $I_{rated} = \frac{\lambda_v V_r}{\sqrt{\left(\frac{R_2'}{s_r}\right)^2 + [illegible](X_2'(1))^2}}$

if f variable, v variable :
$\hookrightarrow \therefore I_{st}' = \frac{V_r \lambda_v}{\sqrt{(R_2')^2 + (X_2'(1)\lambda_f)^2}}$

- $I_{st.\,(rated)} = \frac{\lambda_v V_r}{\sqrt{R_2'^2 + X_2'(1)^2}}$

$$\frac{I_{st}'(V,f)}{I_{st}(V_r, f_r)} = \frac{\lambda_v \sqrt{R_2'^2 + X_{2(r)}'^2}}{\sqrt{(R_2')^2 + \lambda_f^2 X_{2(r)}'^2}}$$

$$= \frac{\lambda_v \cancel{R_2'} \sqrt{1 + \left(\frac{X_2'(r)}{R_2'}\right)^2}}{\cancel{R_2'} \sqrt{1 + \lambda_f^2 \left(\frac{X_{2r}'}{R_2'}\right)^2}}$$

$$= \frac{\lambda_v \sqrt{1 + \frac{1}{s_{T_{max}}^2}}}{\sqrt{1 + \lambda_f^2 \frac{1}{s_{T_{max}}^2}}}$$

$$\frac{I_{st}'}{I_{st}} = \lambda_v \sqrt{\left(\frac{1 + s_{T_{max}}^2}{\lambda_f^2 + s_{T_{max}}^2}\right)}$$

ex: $\boxed{f < f_r} \rightarrow V < V_r$

$\frac{V}{f}$ Δ constant ; $\lambda_v = \lambda_f = \lambda < 1$

$$\frac{I_{st}'}{I_{st}} = \lambda \sqrt{\frac{1 + s_{T_{max}}^2}{\lambda^2 + s_{T_{max}}^2}}$$

usually (12 % – 20%)

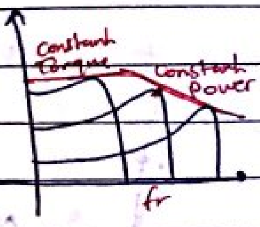
$\lambda = 0.5$; $\lambda < 1$, $s_{T_{max}} = 0.15$ try $\lambda > 1$!!

$$\frac{I_{st}'}{I_{st}} = 0.5 \sqrt{\frac{1 + 0.0225}{0.25 + 0.0225}} = 0.97$$

$\lambda = 0.8$

$$\frac{I_{st}'}{I_{st}} = 0.8 \sqrt{\frac{1 + 0.0225}{0.64 + 0.0225}} = 1.5$$ (starting current will increase).

$$\frac{\tau_{max}'}{\tau_{max}} =$$



$$\tau_{max} = \frac{3 V_{th}^2}{2 \omega_s \left[R_{th} + \sqrt{R_{th}^2 + (X_{equ})^2} \right]}$$

$$\tau_{max} = \frac{3 V_{th}^2}{2 \omega_s} \cdot \frac{1}{X_{equ.(r)}}$$

$$\omega_s = \frac{60 f_r}{P}$$

$$\omega_s(f) = \frac{60 \overset{\to \lambda f_r}{(f)}}{P}$$

ⓐ

$$\tau_{max}' = \frac{\cancel{3}\, \lambda_v^2 V_{th}}{2 \lambda_f \omega_s \lambda_f X_{equ(r)}} = \frac{\lambda_v^2}{\lambda_f^2} \quad ; \quad \lambda_v = \lambda_f \longrightarrow \frac{V}{f} = \text{constant}.$$

$$\boxed{\frac{\tau_{max}'}{\tau_{max}} = \left(\frac{\lambda_v}{\lambda_f}\right)^2}$$, τ_{max} will never be affected.

ⓑ $f > f_r$, $\lambda_v = 1$, $\lambda_f \geqslant 1$

$$\boxed{\frac{\tau_{max}'}{\tau_{max}} = \frac{1}{\lambda_f^2}}$$

- $$\tau_{st} = \frac{3 V_{th}^2 R_2'}{\omega_s \left[R_2'^2 + X_{2r}'^2 \right]}$$
- $$\tau_{st}' = \frac{3 \lambda_v^2 V_{th}^2 R_2'}{\lambda_f \omega_s \left[R_2'^2 + \lambda_f^2 X_{2r}'^2 \right]}$$

$$\frac{\tau_{st}'}{\tau_{st}} = \frac{\dfrac{\lambda_v^2}{R_2'^2 \left[1 + \dfrac{\lambda_f^2}{s_{Tmax}^2} \right]}}{\dfrac{1}{R_2'^2 \left[1 + \dfrac{1}{s_{Tmax}^2} \right]}}$$

$$\cancel{= \frac{(s_{Tmax}^2 + \lambda_f^2)\lambda_v^2}{\lambda_f (s_{Tmax}}}$$

$$\frac{\tau_{st}'}{\tau_{st}} = \frac{(s_{Tmax}^2 + 1)}{(s_{Tmax}^2 + \lambda_f^2)} \frac{\lambda_v^2}{\lambda_f}$$

ⓐ $\frac{V}{f}$ = constant $\lambda_v = \lambda_f$

$$\frac{\tau_{st}'}{\tau_{st}} = \lambda \frac{(s_{Tmax}^2 + 1)}{(s_{Tmax}^2 + \lambda^2)}$$

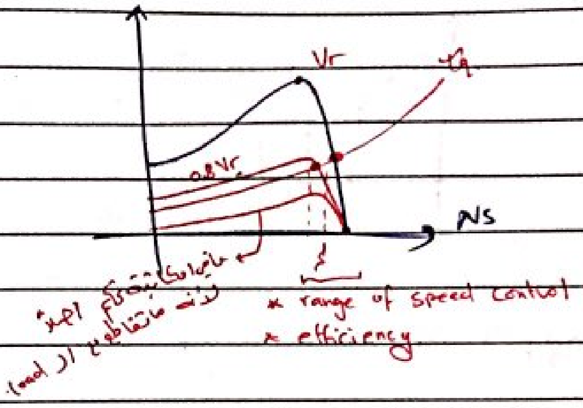
ex: $s_{Tmax} = 0.15$, $\lambda = 0.5$

Sol: $$\frac{\tau_{st}'}{\tau_{st}} = 0.5 \left(\frac{0.0225 + 1}{0.0225 + 0.25} \right) = 1.87$$

ⓑ $f > f_r$; $\lambda_v = 1$, $\lambda_f = 2$

↳ Can't be larger than 1 if $f > f_r$.

$$\frac{\tau_{st}'}{\tau_{st}} = \frac{1^2}{2} \frac{(0.0225 + 1)}{(0.0225 + 4)} = 0.127$$



advantages freq. control:

↳ can be used for soft starting.

speed control

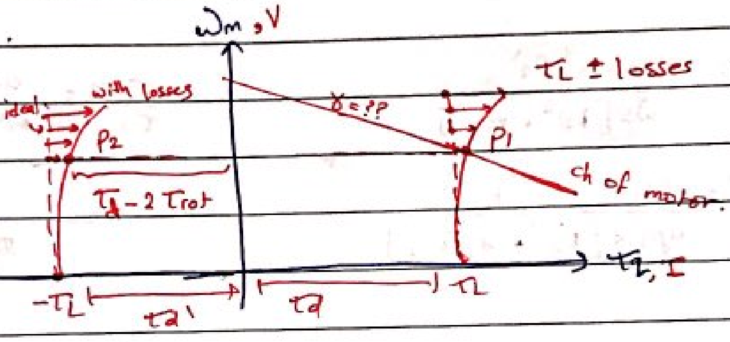
- Increased starting Torque below rated frequency.
- Increased maximum Torque.

last example:

DCM. 230 V, 750 RPM, 56A, $0.28\ \Omega = R_a$, $L_a = 2.81$ mH., 15 hp.

driven by chopper class C [A → B]

$V_s = 250$ V DC., $f_{ch} = 400$ Hz.



$\tau_d' = \tau_d - 2\tau_{rot}$.

Rated conditions:

$P_{out} = 15 \times 746 = 11190$ W

$P_{in} = 56 \times 230V = 12880$ W

$P_{cu} = 56^2 \times 0.28 = 878$ W

$P_{rot} = 12880 - 11190 - 878 = 812$ W

$\tau_{rot} = \frac{812}{\omega_{m(r)}} = 4.43$ N.m.

$E_a(r) = 230 - 0.28 * 56 = 214.3$ V

$K_a\phi = \frac{E_a(r)}{\omega_m(r)} = 1.169$

$\tau = \frac{2.81 \times 10^{-3}}{0.28} = 10.04$ msec

$\gamma = \frac{230}{250}$

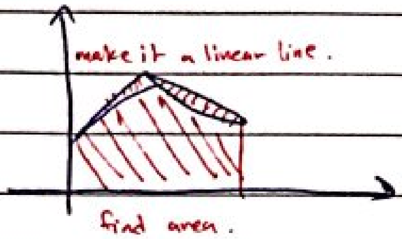
$T_0 = \frac{1}{f_{ch}} = \frac{1}{400} = 2.5$ msec, $T_{ON} = \gamma T = 2.3$ msec.

$I_1 = 63.81$ A

$I_2 = 50.3$ A.

[illegible] معادلة خط [illegible]

معطاة.



find area.

area = 56.

∴ class A (motoring action).

- $T_d = K_a \cdot \phi \cdot I_a$

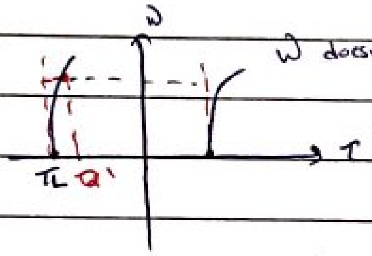
$T_d = 1.169 * 56 = 65.46$ N.m.

- $T_L = 65.46 - 4.43$

$T_L = 61.03$ N.m.

$I_a(av) = \frac{61.03}{1.169} = 52.2$ A.

braking action:



ω doesn't change instantly.

$T_d = -(61.03 - 4.43)$

$T_d = -56.6$ N.m

- $I(av) = \frac{-56.6}{1.169} = -48.42$ A.

[illegible]

- $E_a' = K_a . \phi . \omega_m = E_a(1) = 214.3$V

- $V_t' = 214.3 + (-48.42 * 0.28) = 200.7$V.

- γ $= \frac{200.7}{250} = 0.8$, • $T_{ON} = 0.8 \times T = 2,007$ msec.

$$\boxed{\begin{array}{l} I_1 = -31.35 \text{ A} \\ I_2 = -66.48 \text{ A} \end{array}}$$

both currents are -ve & avg current is -ve

So we are in braking condition.