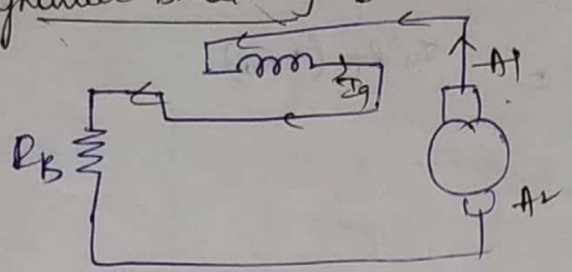
Dynamic braking :- (... change the field) ... so



Three phase Induction motor :-
Induction motor (copper will be there)

→ Squirrel cage Induction " (Distributed winding is there)

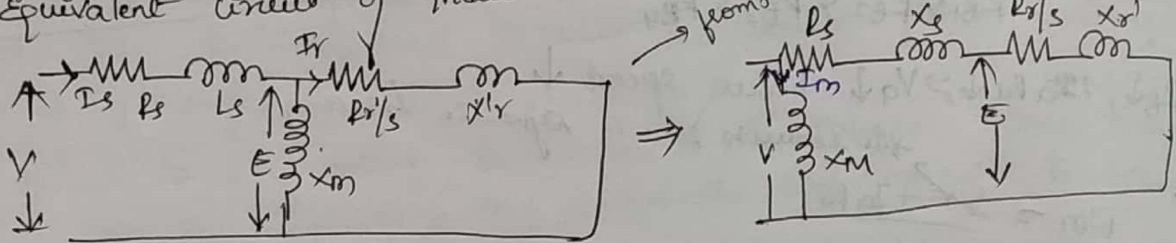
→ wound rotor "

slip $(s) = \dfrac{\omega_{ms} - \omega_m}{\omega_m}$

ω_{ms} → synchronous speed ; ω_m → rotor speed

$\omega_{ms} = \dfrac{4\pi f}{P}$ f → frequency, P → no of poles.

Equivalent circuit of Induction motor :- from this to this we assumed that stator Impedance losses are negligible



$\omega_m = \omega_{ms}(1-s)$

$$I_r' = \frac{V}{(R_r'/s + R_s) + j(X_s + X_r')}$$

Power transferred to rotor $P_g = 3 I_r'^2 R_r'/s$

Rotor copper loss $P_{cu} = 3 I_r'^2 R_r$

$$P_m = P_g - P_{cu} = \frac{3 I_r'^2 R_r'(1-s)}{s}$$

(derivation is HW) $T = \dfrac{P_m}{\omega_{ms}}$

$$T = \frac{3 I_r'^2}{\omega_{ms}} \cdot \frac{R_r'}{s} = \frac{3}{\omega_{ms}}\left[\frac{V^2 R_r'/s}{(R_s + R_r'/s)^2 + (X_s + X_r')^2}\right] \quad -①$$

$$T = \frac{P_g}{\omega_{ms}} = \frac{P_m}{\omega_m}$$

$$S_{max} = \frac{dT}{ds} = 0$$

$$\frac{dT}{ds} = 0 = \frac{d}{ds}\left[\frac{3 I_r'^2}{\omega_{ms}} \cdot \frac{R_r'}{s}\right]$$

$$= \frac{3}{\omega_{ms}} \Big[\big[(R_s + R_r'/s)^2 + (x_s + x_r)^2 \big] \cdot V^2 \cdot R_r' \cdot (-1/s^2) - V^2 R_r'/s \; 2\big[(R_s + R_r'/s) \cdot (-R_r'/s^2) + 0\big] \Big]$$

$$= \frac{3}{\omega_{ms}} \Big[\big[(R_s + R_r'/s)^2 + (x_s + x_r)^2 \big] \Big(-\frac{V^2 R_r'}{s^2}\Big) + 2V^2 R_r'/s \,(R_s + R_r'/s) \cdot \frac{R_r'}{s^2} \Big]$$

$$\Rightarrow \frac{\frac{3}{\omega_{ms}} \Big[-V^2 \frac{R_r'}{s^2} \cdot (R_s + R_r'/s)^2 - \frac{V^2 R_r'}{s^2}(x_s + x_r)^2 + \frac{2V^2 R_r'^2}{s^3}(R_s + R_r'/s) \Big]}{\big[(R_s + R_r'/s)^2 + (x_s + x_r)^2 \big]^2} = 0$$

$$S_m = \pm \frac{R_r}{\sqrt{R_s^2 + (x_s + x_r)^2}} \quad \text{— ②}$$

Substituting ② in ①

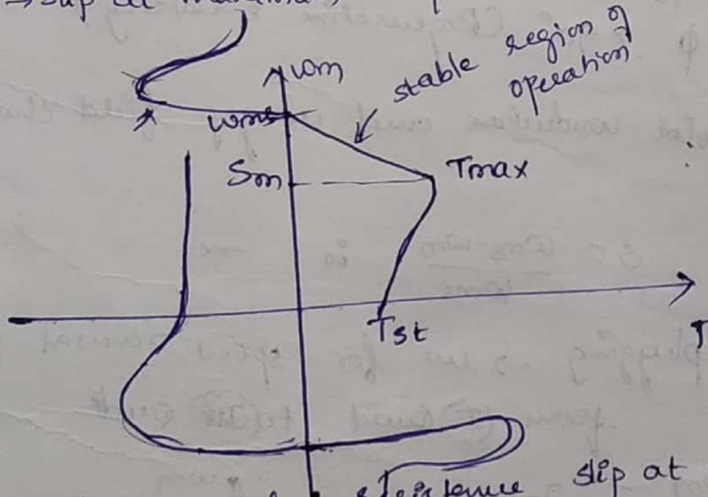
$$T_{max} = \frac{3}{2\omega_{ms}} \left[\frac{V^2}{R_s \pm \sqrt{R_s^2 + (x_s + x_r')^2}} \right] \quad \text{— ③}$$

①/③ and substituting in ②

$$\frac{T}{T_{max}} = \frac{2\big(1 + \overset{<1}{\frac{R_s}{R_r'} S_m}\big)}{\frac{s}{S_m} + \frac{S_m}{s} + \frac{2R_s}{R_r' S_m}} \Rightarrow \frac{2}{\frac{s}{S_m} + \frac{S_m}{s}}$$

neglect

$S_m \to$ slip at maximum torque



if $s < S_m$

$$\therefore \frac{T}{T_{max}} = \frac{2s}{S_m}$$

if $s > S_m$

$$\therefore \frac{T}{T_{max}} = \frac{2S_m}{s}$$

→ if we change rotor resistance slip at max torque (S_m) will change

→ stable region of operation bcoz as speed ↑'s Torque ↓'s.

→ $s > S_m$ and becomes −ve (applied frequency is less) $\omega_m > \omega_{ms}$

→ slip is −ve in the case of regenerative braking

and slip (s) becomes '−ve' eq② ①, ②, + ③ holds.

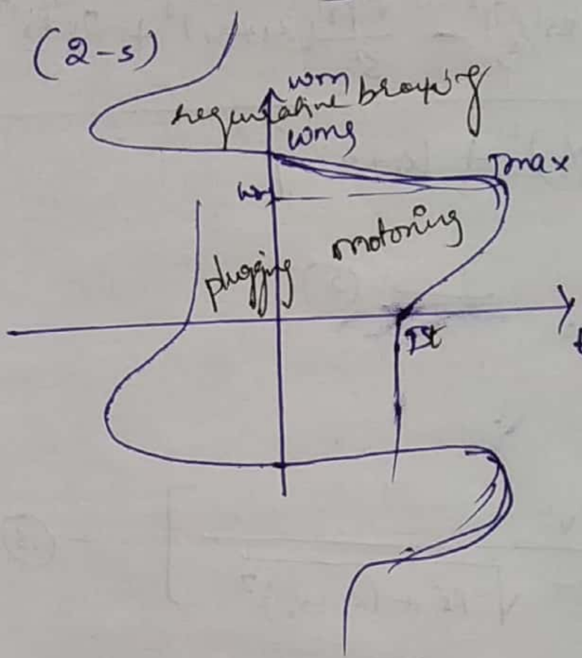
$\left(S = \frac{\omega_{ms} - \omega_m}{\omega_{ms}} \right.$ which is −ve)

Plugging :-

$$s = \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}}$$

$$s = \frac{-\omega_{ms}}{-\omega_{ms}} - \frac{\omega_m}{-\omega_{ms}}$$

$$s = (2-s)$$



28/03/22

Plugging :-

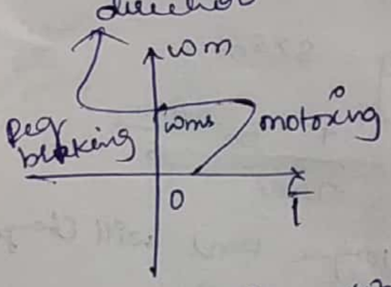
$$S_n = 2-S$$

$$s = \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}} = \frac{\omega_{ms} + \omega_m}{\omega_{ms}}$$

Regenerative braking :-

$P = 3VI_s \cos\phi_s$ $\phi_s < 90^\circ$ (motoring)
$\phi > 90^\circ$ (Regenerative braking)

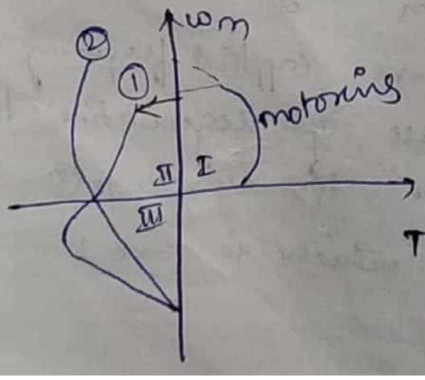
Relative speed between rotor conductors and airgap field changes direction

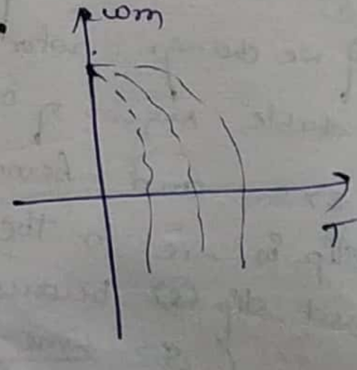


$s = \frac{\omega_{ms} - \omega_m}{\omega_{ms}}$ is -ve

plugging → use for speed reversal from from (I) Quad to (III) Quad

$$s = \frac{-\omega_{ms} - \omega_m}{-\omega_{ms}} = 2-s$$

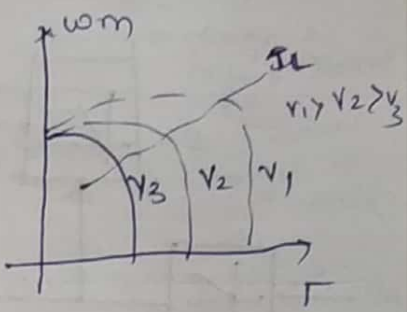




Speed control :-

Stator Voltage control

$$T = \frac{3}{\omega_{ms}}\left[\frac{V^2 R_r'/s}{(R_s + R_r'/s)^2 + (X_s + X_r')^2}\right]$$

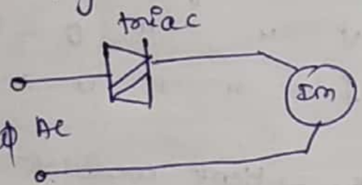


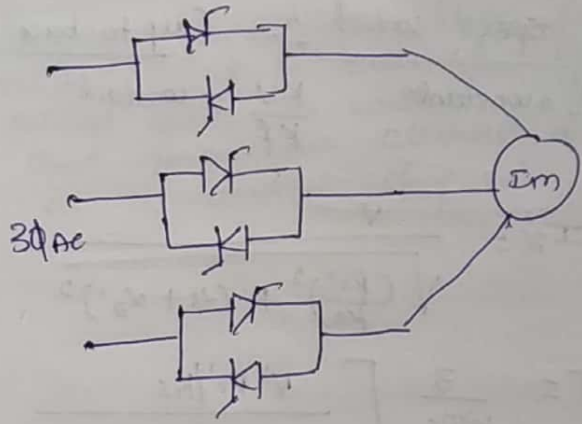
$$I_r' = \frac{V}{(R_s + R_r'/s) + j(X_s + X_r')}$$

useful in fan & pump drives

$$T = \frac{P_m}{\omega_m} = \frac{P_g}{\omega_{ms}}$$

$$\eta = \frac{P_m}{P_g} = 1-s$$





V.

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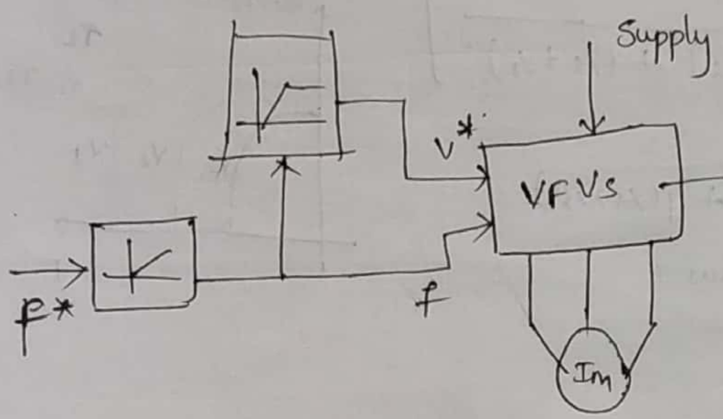
Open loop V/F control :-



→ Variable frequency Variable Voltage Source.

Slip speed control :- (upto base speed i.e synchronous speed)

$\frac{V}{f}$ = constant $\frac{KV}{Kf}$ = constant

K Varies from 0 – 1
V " " 0 – V
f " " 0 → f

$$I_r' = \frac{V}{\sqrt{\left(\frac{R_r'}{K_s}\right)^2 + (X_s + X_r')^2}}$$

K_s → Kept constant

$$T = \frac{3}{\omega_{ms}}\left[\frac{V^2 R_r'/K_s}{(R_r'/K_s)^2 + (X_s \pm X_r')^2}\right]$$

$\frac{R_r'}{SK} >> (X_s \pm X_r')$
↳ bcoz slip is small

$\therefore I_s = \sqrt{I_r'^2 + I_m^2}$
= constant

$$T = \frac{3V^2}{R_r' \omega_{ms}}(K_s)$$

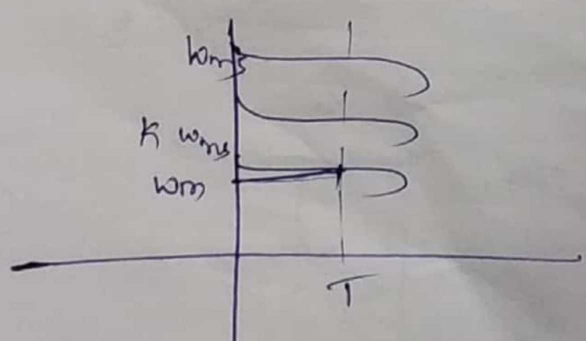
= constant.(ω_{sl})

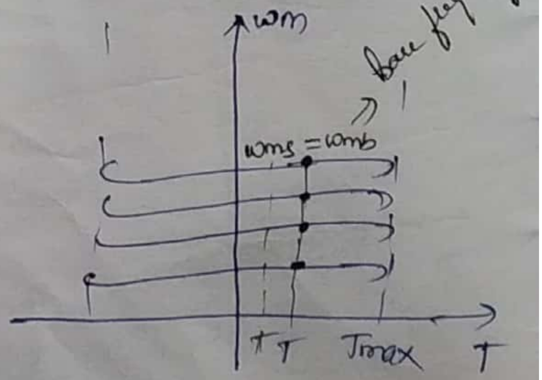
slip $s = \frac{K\omega_{ms} - \omega_m}{K\omega_{ms}}$

$$K_s = \frac{K\omega_{ms} - \omega_m}{\omega_{ms}} = \frac{\omega_{sl}}{\omega_{ms}}$$

$\omega_{sl} = K\omega_{ms} - \omega_m$

If ω_{sl} is Varies T → also Varies





→ Torque is constant upto base speed.

Beyond base speed :- (operation above base speed with $K>1$, V = constant)

$$I_r' = \frac{sV}{R_r'} = \frac{V}{R_r'} \frac{(K\omega_{ms} - \omega_m)}{K\omega_{ms}}$$

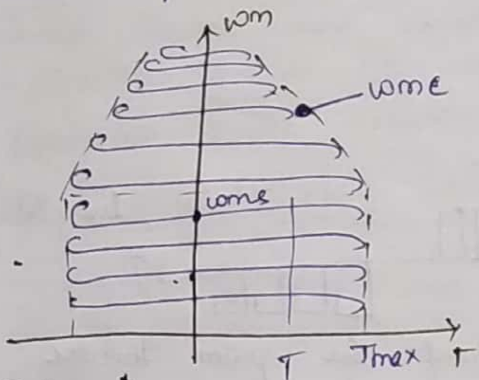
V = constant we can't change V_g beyond rated

$$(K\omega_{ms} - \omega_m) = \omega_{sl} = \frac{R_r'}{V} \omega_{ms} (K I_r')$$

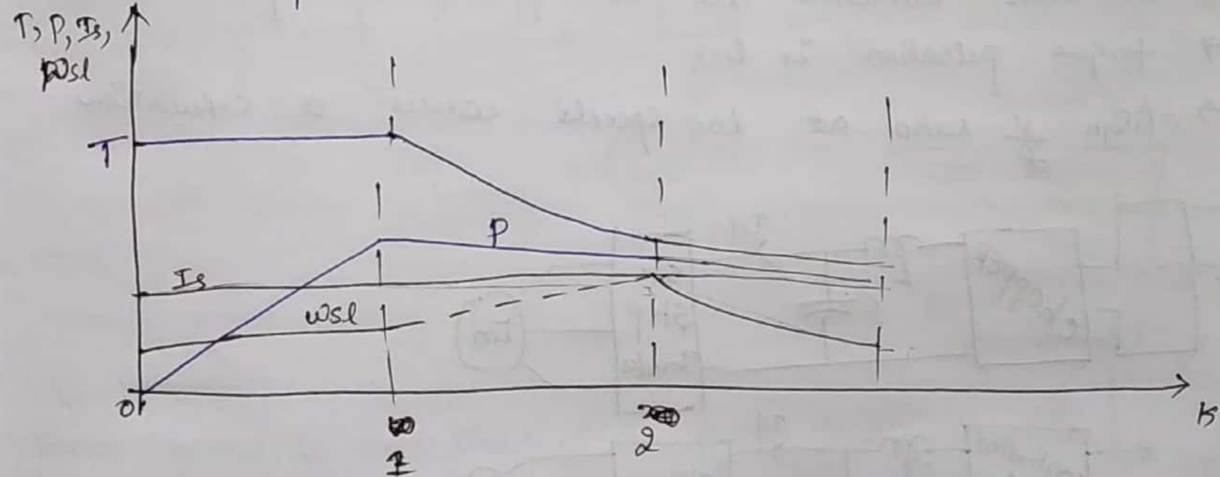
$K s \neq$ constant flux control is not there

$$P_m = 3V I_r'$$

* beyond base speed voltage is constant and I_r' kept constant at particular value therefore ω_{sl} the slip speed varies linearly with 'K' for a particular I_r' it works in constant power mode.

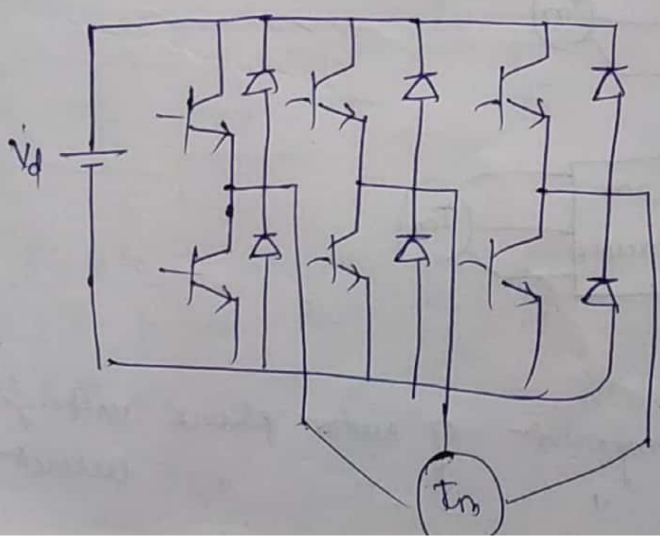


→ constant power mode happends. till critical speed is reached. beyond critical speed the current, power, and torque are allowed to fall at a constant slip

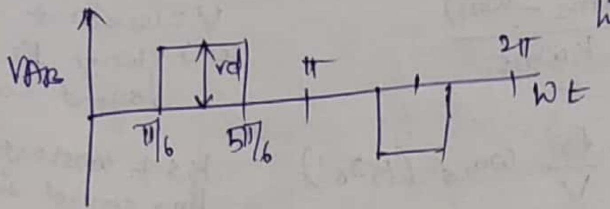


19/04/22

VSI fed induction motor drives :-



Six Stepped



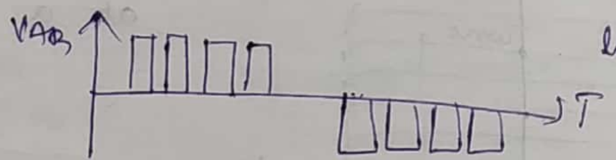
$$V_{AB} = \frac{2\sqrt{3}\,V_d}{\pi}\left[\sin\omega t - \frac{1}{5}\sin 5\omega t - \frac{1}{7}\sin 7\omega t + \frac{1}{11}\sin 11\omega t + \frac{1}{13}\sin 13\omega t\right]$$

$$V_{AN} = \frac{2V_d}{\pi}\left[\sin\omega t + \frac{1}{5}\sin 5\omega t + \frac{1}{7}\sin 7\omega t\right]$$

Rms value $V = \frac{\sqrt{2}\,V_d}{\pi}$

PWM Inverter :-

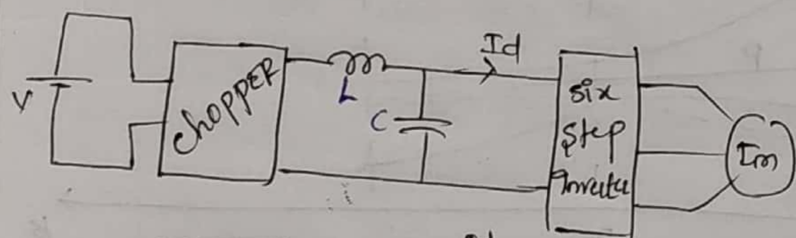
$$V = m\frac{V_d}{2\sqrt{2}}$$

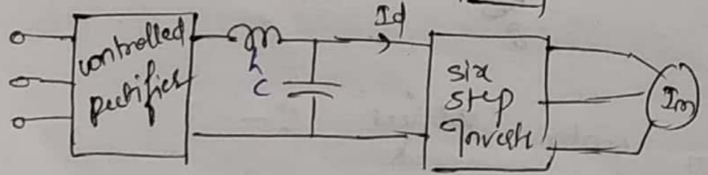


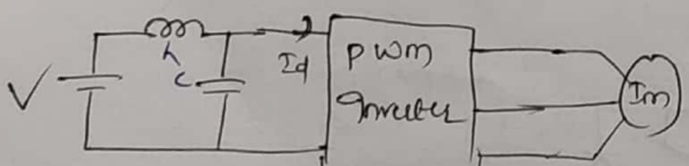
→ low order harmonics are not present in pwm Inverter

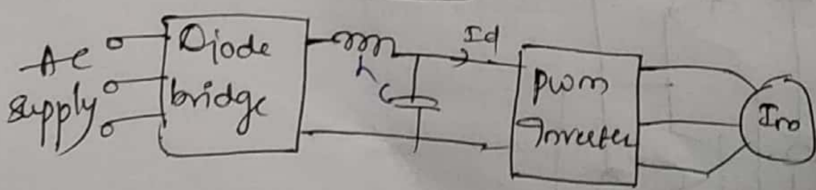
→ torque pulsation is less

→ high $\frac{V}{f}$ ratio at low speeds causes a saturation









$P = 3V I_s \cos\phi$

$V \Rightarrow$ fundamental component of motor phase voltage

$I_s \Rightarrow$ " " " " current

ϕ = angle b/w V & I_s

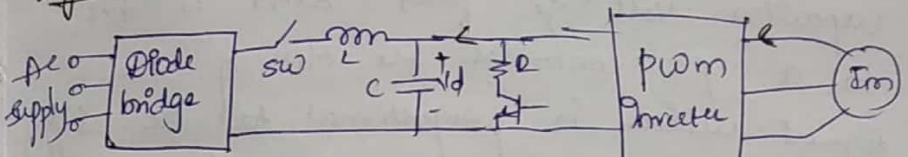
$\phi < 90°$ motoring (power flows from Inverter to motor)

$\phi > 90°$ braking (power flows from motor to Invert)

$f < f_s$ → relative speed changes so power direction changes

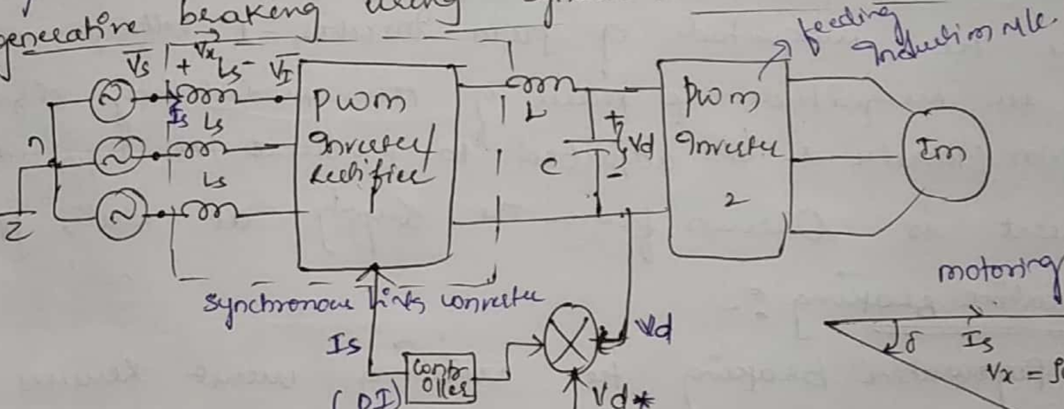
→ two pwm current can be made lag (or lead? (Ned Mohan)

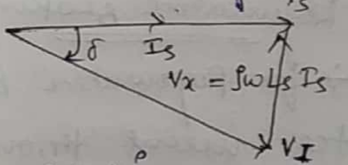
Dynamic braking in Induction motor :-



→ this reverse current cannot flow through diode rectifier so capacitor charges (SW - open) transistor turn ON. the power is Dissipated in the resistance 'R'.

Regenerative braking using synchronous links converter :-



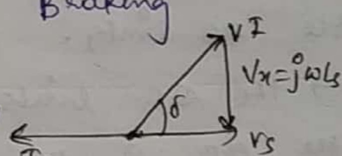


motoring

pwm-2 takes energy from 'C' (vd)

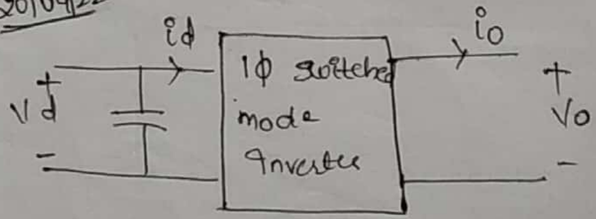
Vd = constant

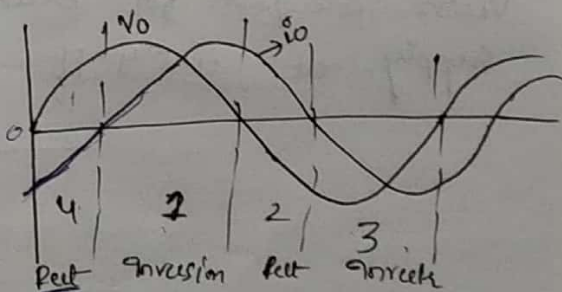
power supplied by pwm Inverter ① = power taken by pwm Inv ②



→ when Im → taking more power so Vd ↓'s so to maintain Vd = constant pwm Invert-1 draw more power from source.

20/04/22





$P = V_o i_o$

① + ③ P = +ve Power flows from DC to AC side

④ + ② P = -ve " " " AC to DC side.

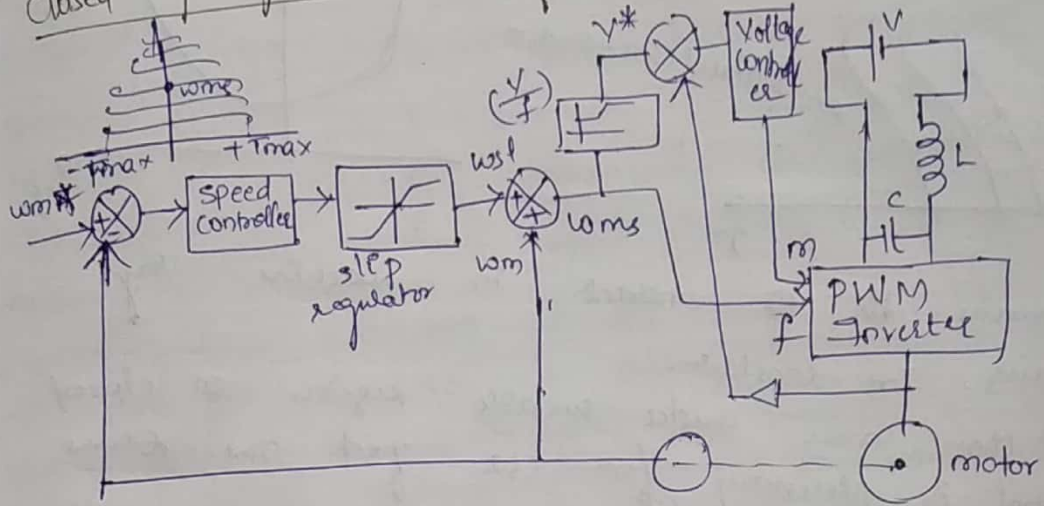
→ In synchronous link converter there are two Inverters PWM-1 & PWM-2 connected back to back through a common DC link.
→ PWM-2 supplies the Induction motor to meet its load torque. the control scheme is inherent V/f control which is normally employed.
→ when load on the IM rises it takes more power from PWM Inverter-2 which inturn takes from the DC link capacitor.
→ the DC link capacitor voltage falls Error is +ve and it is fed to a PI controller. the o/p of the controller is a signal which is proportional to the supply current (Is) which has to be taken from supply.
→ the voltage which has to be produced by Inverter-1 is calculated based on the vector Diagram for the motoring.
→ once the magnitude of PWM Inverter-1 voltage is gone the magnitude & phase of the modulating signal of PWM Inverter-1 is adjusted to produce the required Vg.
→ current is Drawn from the supply at unity pf

Regenerative Braking :-

→ for Regenerative braking the motoring current reverses the current through PWM Inverter-2 reverses and feeds the DC link.
→ the DC link voltage rises the Error become -ve the o/p of PI controller gives a signal proportional to the current to be given back to the supply.
→ PWM Inverter-1 synthesizes a voltage according to the vector diagram for braking and current is fed back to the supply. at unity pf.

22/4/22

Closed Loop speed Control of VSI fed Induction motor :-

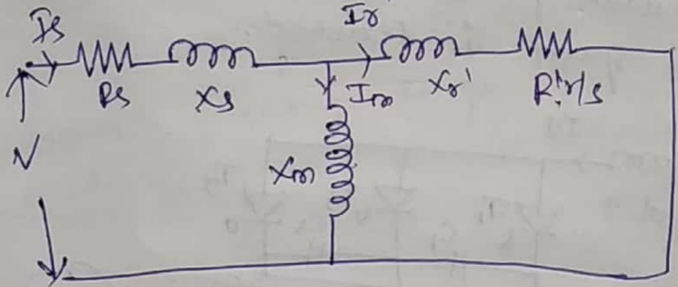


wsl → slip speed
wm → rotor speed
wms → synchronous speed.

Critical speed → max speed that rotor can run
Base speed → Rated speed

25/04/22

Variable frequency control from current source :-



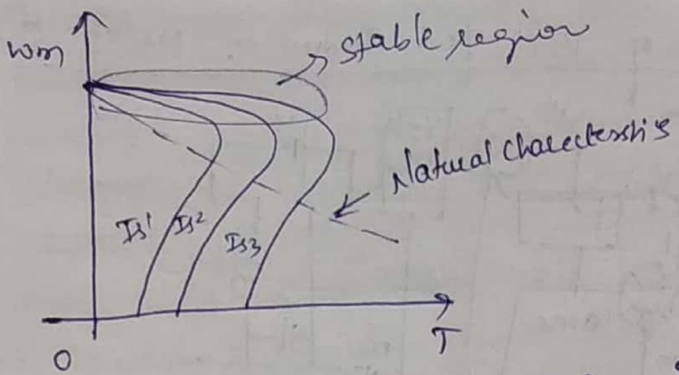
$$I_r' = \frac{X_m I_s}{\sqrt{(R_r'/s)^2 + (X_m + X_r')^2}}$$

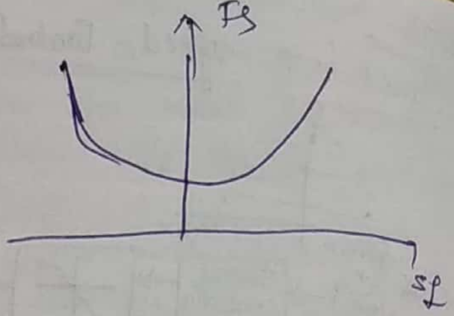
$$T = \frac{3}{\omega_{ms}} I_r'^2 \frac{R_r'}{s}$$

$$= \frac{3}{\omega_{ms}} \left[\frac{I_s^2 X_m^2 R_r'/s}{(R_r'/s)^2 + (X_m + X_r')^2}\right]$$

$$I_m^2 = \left[\frac{(R_r'/s)^2 + (X_r')^2}{(R_r'/s)^2 + (X_m + X_r')^2}\right] I_s^2$$

$$= \left[\frac{(R_r'/sf)^2 + (2\pi L_r')^2}{(R_r'/sf)^2 + [2\pi L_m + 2\pi L_r']^2}\right] I_s^2$$



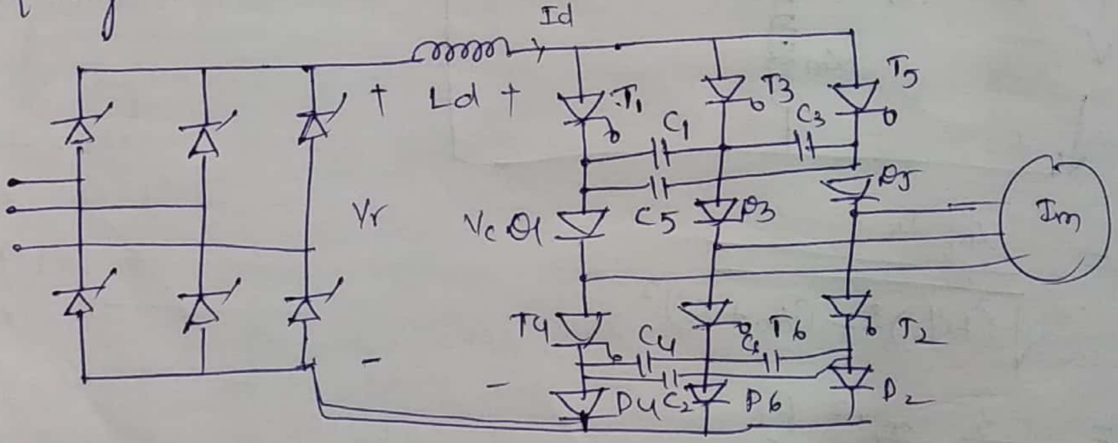


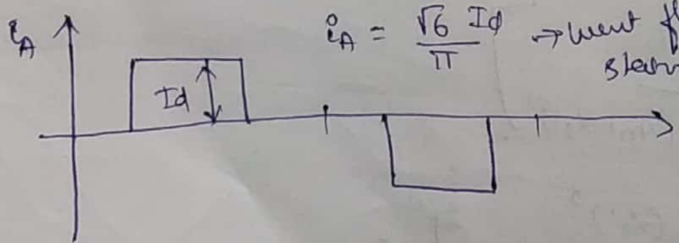
→ flux remains constant in machine by maintaing Im constant.

→ Natural char comes under unstable region so closed loop control is necessary for CSI fed IM drives

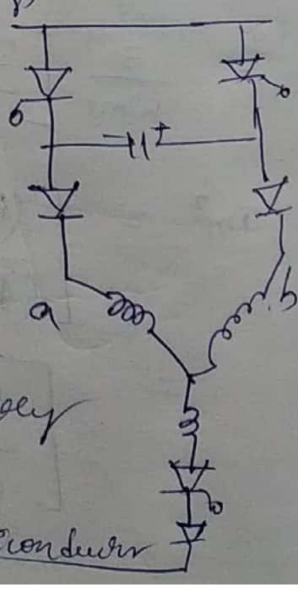
→ since motor is constraint to operate at constant flux i/p steady state behaviour is similar to variable frequency variable voltage source. thus at a given slipspeed the motor draws a constant current and develops a constant torque at all frequencies.

→ motor works in constant torque mode from 'O' to base frequency and constant power mode above base frequency till the critical speed is reached.





$i_A = \frac{\sqrt{6}\, I_d}{\pi}$ → current flowing through stator phase A



→ In case of VSI a commutation failure will cause two devices in the same leg to conduct. this connects conducting devices directly a/c the source consequently current through devices suddenly rises to dangerous values. Expensive high semiconductor fuses are required to protect the Devices.

→ In case of CSI conduction of two devices in the same leg doesnot lead sudden rise of current through them due to presence of large Inductor Ld, this allows time for commutation to takeplace and Normal operation to get ~~restored~~ restoring in subsequence.

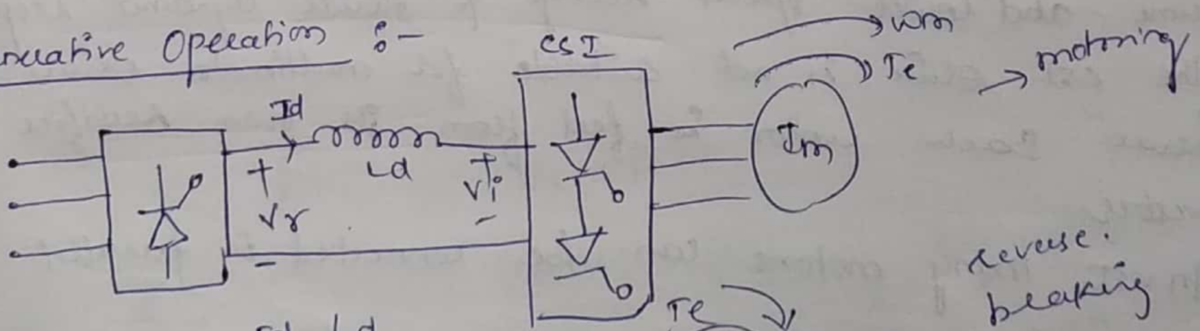
→ motor current rise and fall are very fast such a fast rise and fall of current in leakage 'L' produce a large Voltage spikes ∴ the motor with low leakage 'L' is used.

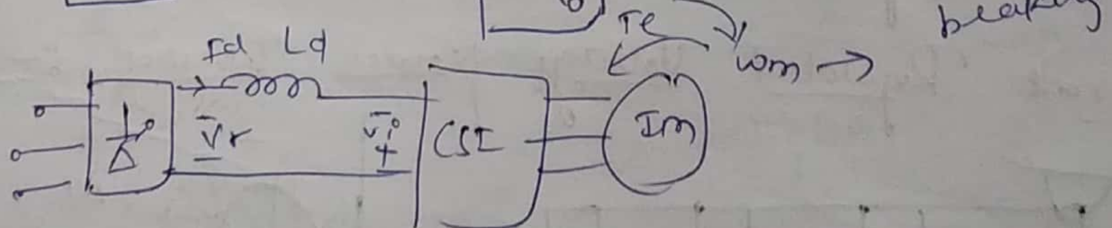
→ Even though the Voltage spikes have large values commutation 'C' → C_1 to C_6 reduce the voltage spike by reducing rate of rise of fall of current.

→ large value of 'C' is required to sufficiently reduce the volltage spikes.

→ large commutation C's have the advantage that cheap converter grade thyristor can be used then the inverter and ∴ they reduce frequency range of the speed range of the Devices.

Regenerative Operation :-

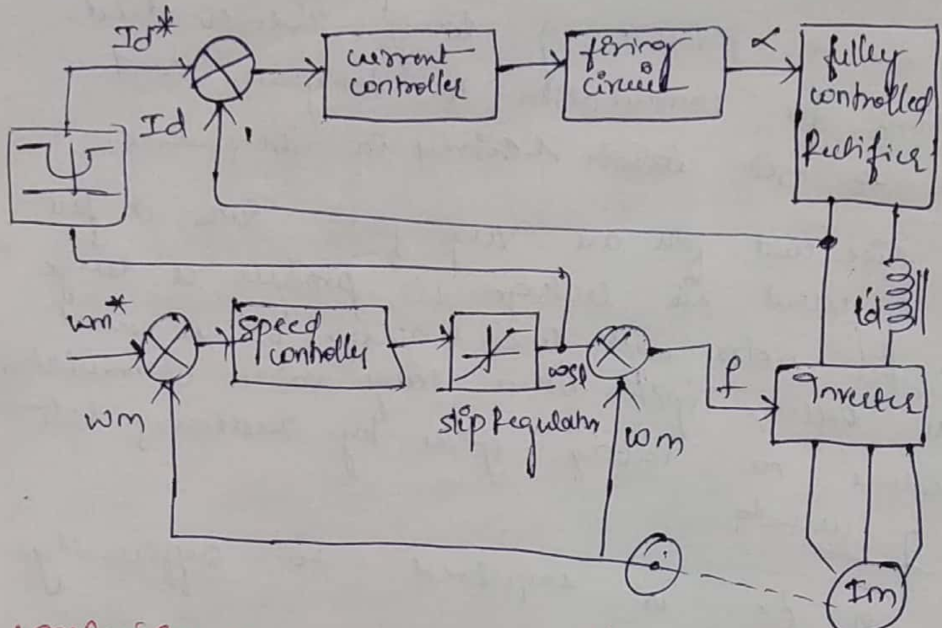




→ for reverse motoring we have to change phase sequence

27/04/22

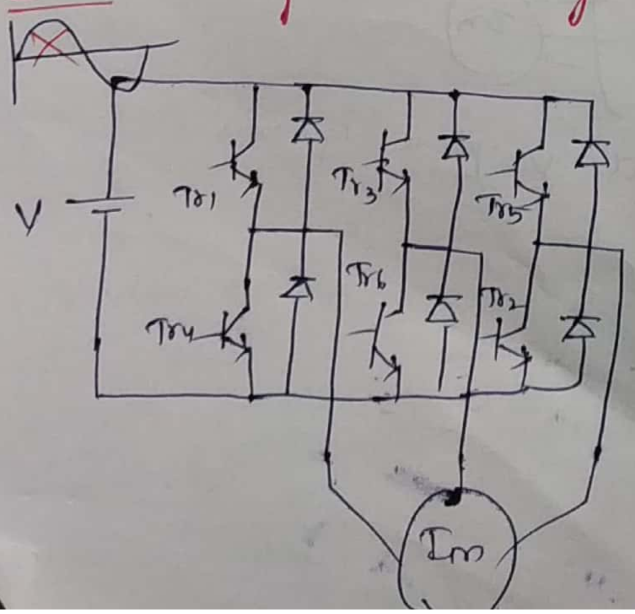
Closed loop of current source Inverter fed Induction motor

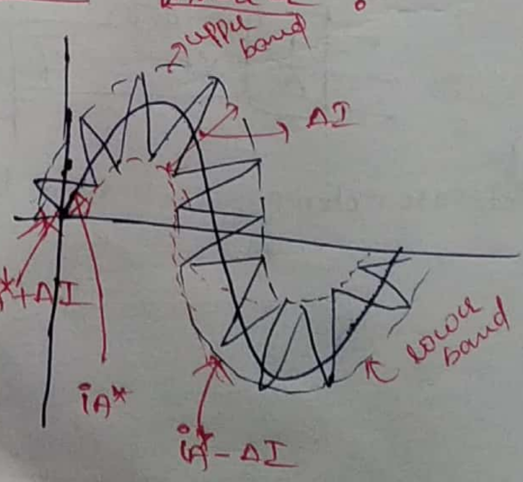


Comparision of CSI & VSI fed Drives :-

- CSI is reliable than VSI, commutation failure doesnot occur in CSI. it has inherent protection against short ckt a/c motor terminals.
- Bcoz of large Inductance in the DC links and large Inverter capacitors CSI drive has higher cost, weight & Volume and lower speed range & slower dynamic responce.
- the CSI drive is not suitable for multimotor drives & hence each motor is fed from its own rectifier & Inverter
- In VSI many motors can be connected in parallel

Current Regulated Voltage Source Inverter :-



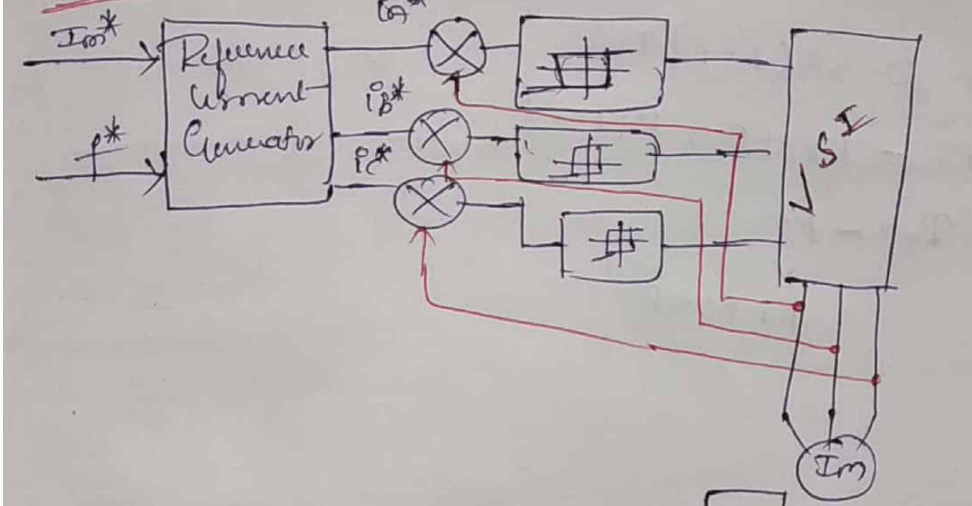


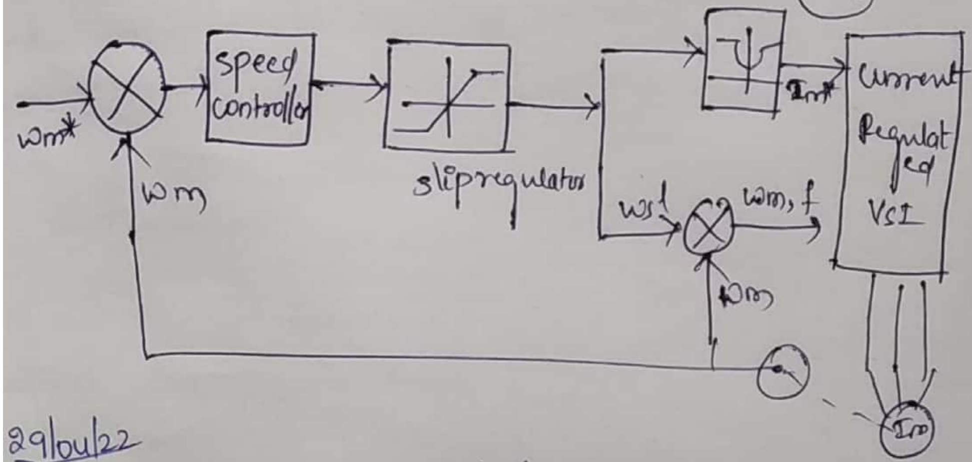
$i_A^* = I_m \sin \omega t$

$i_B^* = I_m \sin(\omega t - 120^\circ)$

$i_C^* = I_m \sin(\omega t - 240^\circ)$

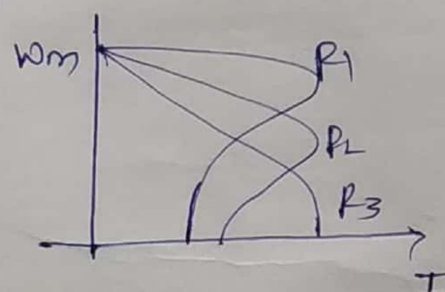
closed loop





29/04/22

Rotor Resistance control :-



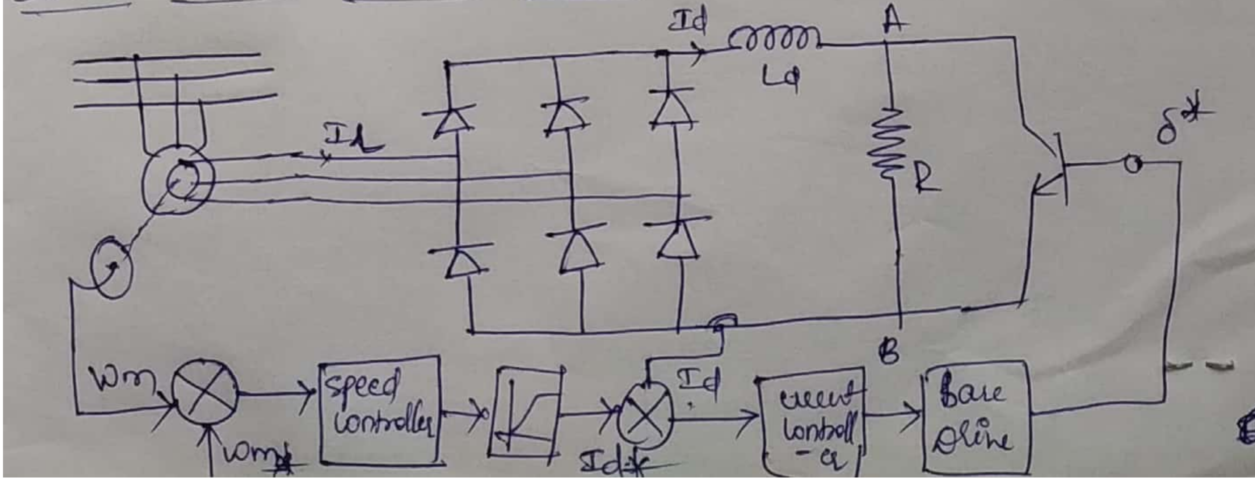
$R_1 < R_2 < R_3$

Variable frequency - Expensive

Variable Resistance - cheap

→ low η%, heating loss

Static Rotor resistance control :-



$$I_r = \sqrt{\frac{2}{3}}\, I_d$$

$$R_{AB} = (1-\delta) R$$

$$P_{AB} = I_d^2 R_{AB} = I_d^2 R_{AB} = I_d^2 R (1-\delta)$$

$$\frac{P_{AB}}{3} = 0.5R(1-\delta) I_r^2$$

$$R_{rT} = R_r + 0.5\, R(1-\delta)$$

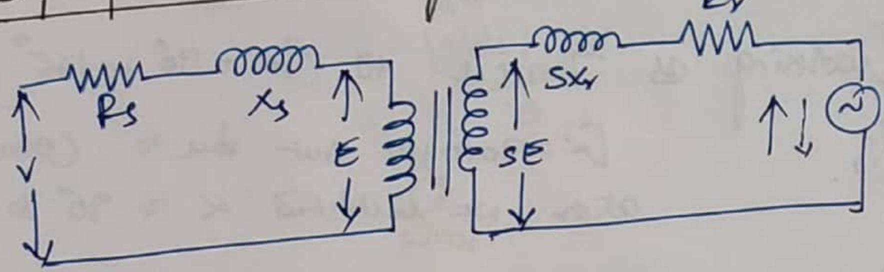
$$R_{rT} - R_r$$

$$\downarrow$$

$$R_r + 0.5R$$

1/5/22 PED

Slip power recovery :-

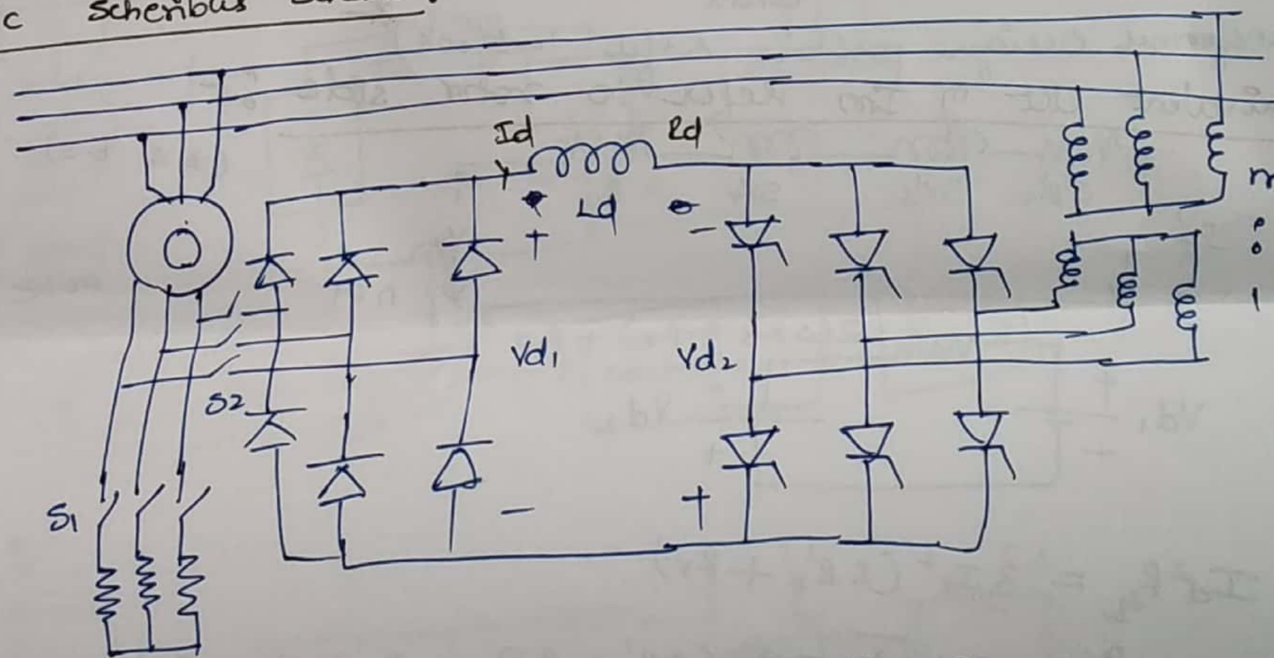


$P_m = P_g - P_r$ P_g = airgap power

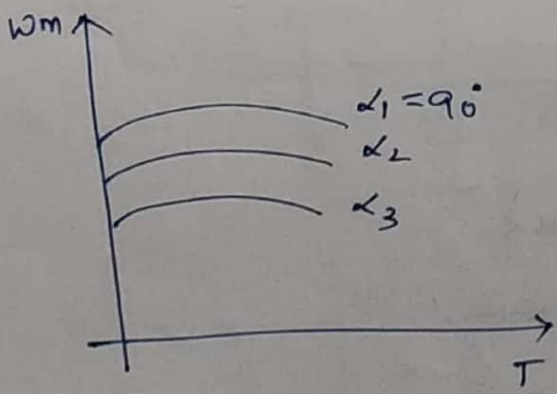
P_r = Power of injected source

$P_m = P_g \Rightarrow$ motor run in a Natural Characteristics.

Static Scheribus Scheme :-



$Vd_1 + Vd_2 = 0$



$Vd_1 = \frac{3\sqrt{6}}{\pi} \frac{sV}{n}$

n = stator to rotor turn ratio

s ⇒ slip

$Vd_2 = \frac{3\sqrt{6}}{\pi} \frac{V}{m} \cos\alpha$

$\frac{3\sqrt{6}}{\pi} \frac{sV}{n} + \frac{3\sqrt{6}}{\pi} \frac{V}{m} \cos\alpha = 0$

m ⇒ turns ratio of transformer.

$\frac{s}{n} = -\frac{\cos\alpha}{m}$

$\boxed{s = -\frac{n}{m} \cos\alpha}$

$s = \frac{-n}{m} \cos\alpha$

$s = a \cos\alpha \qquad a = \frac{-n}{m}$

[working as Inverter so α - 90° to 165°]

[$\alpha = 90$ to 180° but due to commutation we restricted α to 90° to 165°)

at s_{max} we get V_{d1} max

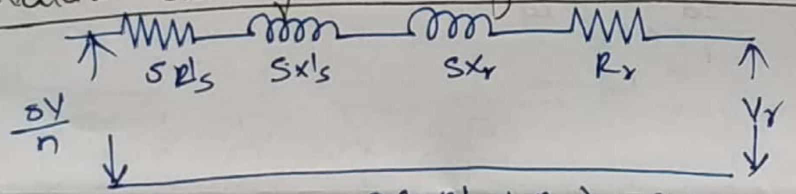
$$\frac{V s_{max}}{n} = \frac{-V}{m} \cos 165^\circ$$

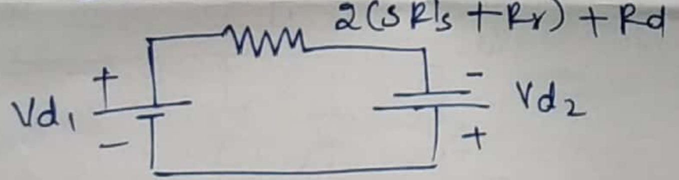
$$m = +0.966 \frac{n}{s_{max}}$$

(Transformer design problems refer textbook)*

Equivalent ckt of Im refer to rotor side :-

(* s b.s)





$$I_d^2 R_{Eq} = 3 I_r^2 (sR'_s + R_r)$$

$$R_{Eq} = 3 \times \left(\sqrt{\frac{2}{3}} I_d\right)^2 (sR'_s + R_r) = 2(sR'_s + R_r)$$

$$I_d = \frac{V_{d1} + V_{d2}}{2(sR'_s + R_r) + R_d}$$

$$= \frac{\frac{3\sqrt{6}}{\pi} \frac{sV}{n} + \frac{3\sqrt{6}}{\pi} \frac{V}{m} \cos\alpha}{2(sR'_s + R_r) + R_d}$$

$$= \frac{\frac{3\sqrt{6}}{\pi} V \left[\frac{s}{n} + \frac{\cos\alpha}{m}\right]}{2(sR'_s + R_r) + R_d}$$

If Rotor copper losses is Neglected.

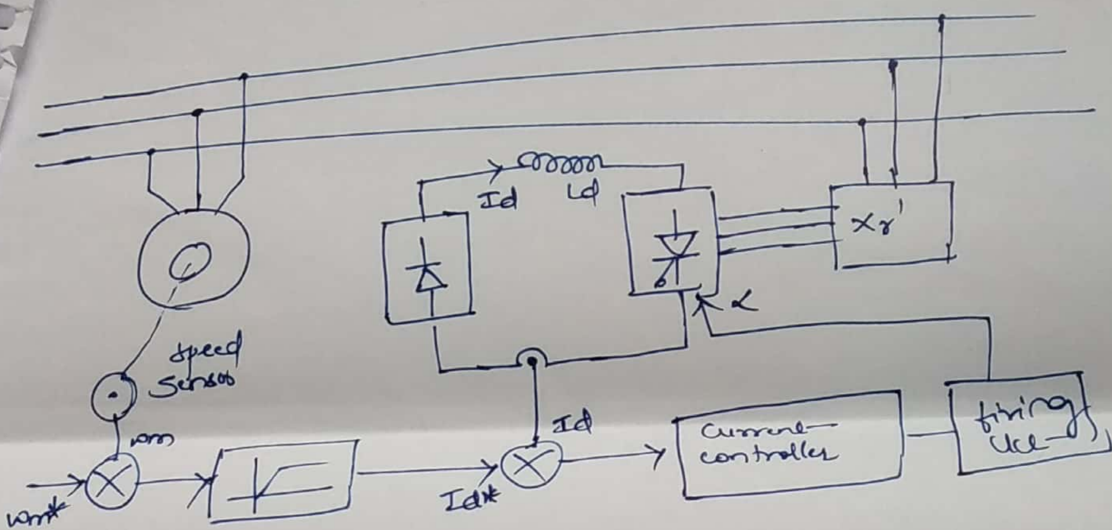
$$SP_g = |V_{d2}| I_d$$

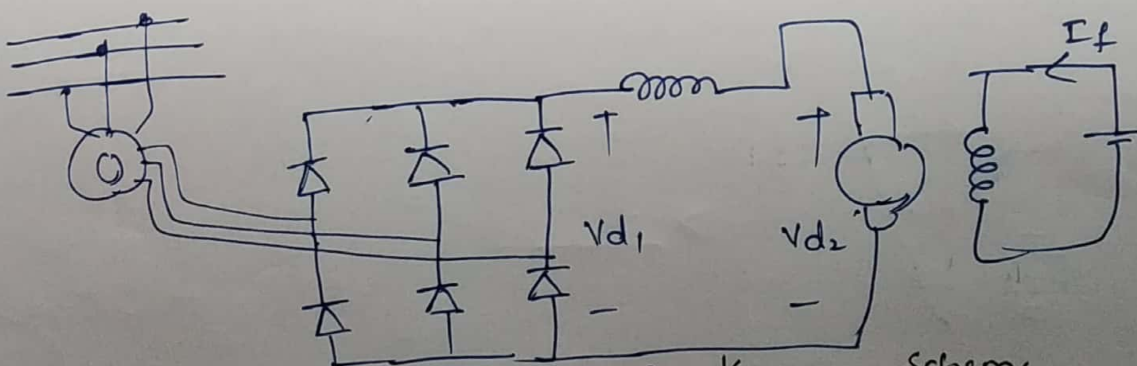
$$P_g = \frac{|V_{d2}| I_d}{s}$$

$$T = \frac{P_g}{\omega_{ms}}$$

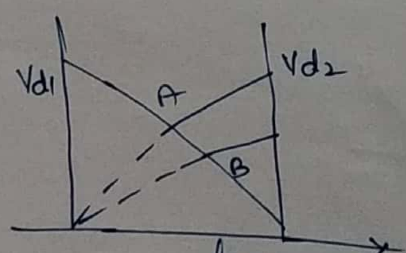
SP_g → slip power
↳ fed back to the supply

If $s = 20\%$ then rating of rectifier & Inverter should be 20% only.

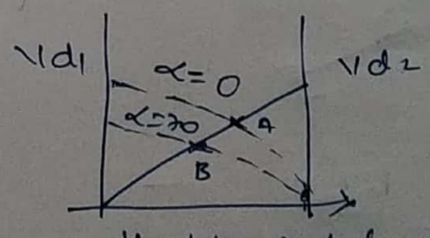




Static Kramer Scheme.



field control



thyristor control

Synchronous motors :- 9/5/22

→ pf can be varied either lag / leading / unity

1) wound field Synchronous motor → salient → ; → cylindrical → uniform airgap
2) Permanent magnet synchronous motor (PMSM)
3) Switch Reluctance motor (SRM)
4) Hysteresis motor

(1, 2: 3ϕ stator winding; 3, 4: 1ϕ stator winding)

cylindrical :→ uniform airgap → higher mechanical strength, high speed

Salient :→ poles are projected, low speed.

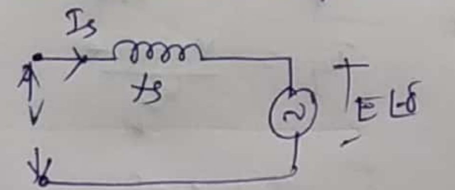
2) permanent magnetic synchronous motor (PMSM) (unity pf)
- → surface mounted → projecting type ; → inset
- → Interior

* high pf & high efficiency compared induction motor
* Pmsm has low losses and high efficiency bcoz of low losses it is possible to make motor with high power density and Torque to Inertia ratio.

3) Switch Reluctance motor (SRM) :-

Doesn't have field winding & no permanent magnet. Motor is driven by reluctance torque which is produced due to tendency of salient poles to allign themselves with synchronously rotating field produced by stator.

Equivalent circuit of cylindrical motor :-



$E \Rightarrow$ Excitation

$X_s \Rightarrow$ synchronous reactance

$P_{in} = 3 V I_s \cos\phi_s$

$$I_s = \frac{V\angle 0^\circ - E\angle -\delta}{jX_s}$$

$$= \frac{V}{X_s}\angle -90^\circ - \frac{E}{X_s}\angle -\pi/2 - \delta$$

$$I_s = \frac{V}{X_s}\angle -\pi/2 - \frac{E}{X_s}\angle -(\pi/2+\delta)$$

$\cos(-\theta) = \cos\theta$.

$$I_s\cos\phi_s = \frac{V}{X_s}\cos(\pi/2) - \frac{E}{X_s}\cos(\pi/2+\delta)$$

$$I_s\cos\phi = \frac{E}{X_s}\sin\delta$$

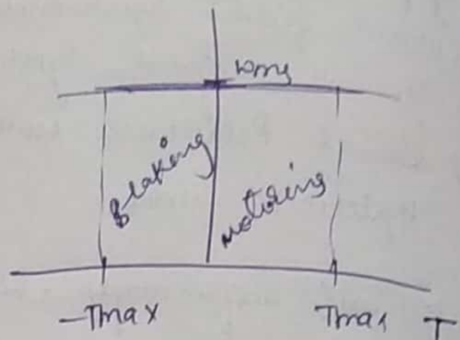
Neglecting stator copper loss

$$P_m = P_{in} = \frac{3VE\sin\delta}{X_s}$$

$$T = \frac{P_m}{\omega_{ms}}$$

Considering fixed frequency

$$T = \frac{3VE\sin\delta}{X_s\,\omega_{ms}}$$

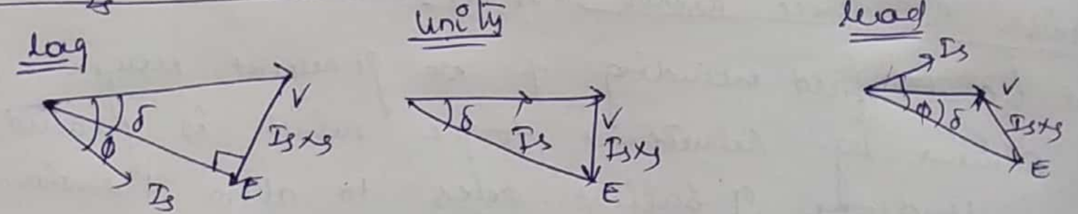


$\delta \rightarrow$ power angle / torque angle

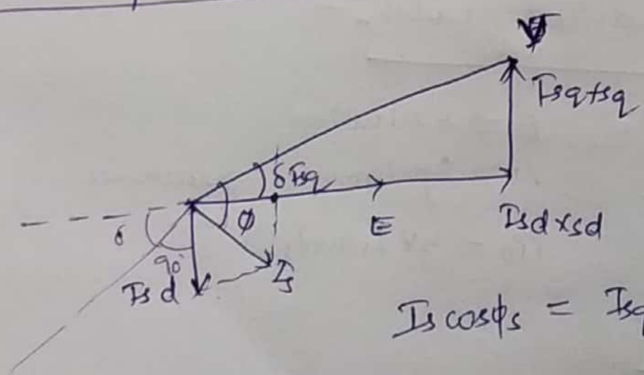
$\delta \rightarrow +ve$ when E lags V

$\delta \rightarrow -ve$ when E leads V

Phasor Diagram :-



Salient pole wound field motor :-



$$I_{sd} = \frac{V\cos\delta - E}{X_{sd}}$$

$$I_{sq} = \frac{V\sin\delta}{X_{sq}}$$

$$I_s\cos\phi_s = I_{sq}\cos\delta - I_{sd}\sin\delta$$

$$I_s\cos\phi_s = I_{sq}\cos\delta - I_{sd}\sin\delta$$

$$= \frac{V\sin\delta}{X_{sq}}\cos\delta - \left[\frac{V\cos\delta - E}{X_{sd}}\right]\sin\delta$$

$$= \frac{V\sin\delta}{2X_{sq}}\cos\delta - \frac{2V\cos\delta\sin\delta}{2X_{sd}} + \frac{E\sin\delta}{X_{sd}}$$

$$I_s \cos\phi_s = \frac{E \sin\delta}{X_{sd}} + \frac{V (X_{sd} - X_{sq})}{2 X_{sd} X_{sq}} \sin 2\delta$$

$$\left\{ \frac{V \cdot 2\sin 2\delta}{2X_{sq}} - \frac{V \sin 2\delta}{2X_{sd}} \right.$$

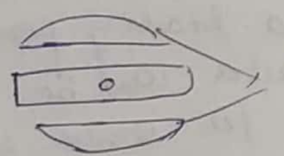
$$\left. \Rightarrow V \sin 2\delta \left[\frac{X_{sd} - X_{sq}}{2X_{sq} \cdot X_{sd}}\right] \right\}$$

$$P_m = 3 V I_s \cos\phi_s$$

$$= 3\left[\frac{V E \sin\delta}{X_{sd}} + \frac{V^2 (X_{sd} - X_{sq})}{2X_{sd} X_{sq}} \sin 2\delta\right]$$

$$T = \frac{P_m}{\omega_{ms}}$$

Hysteresis motor



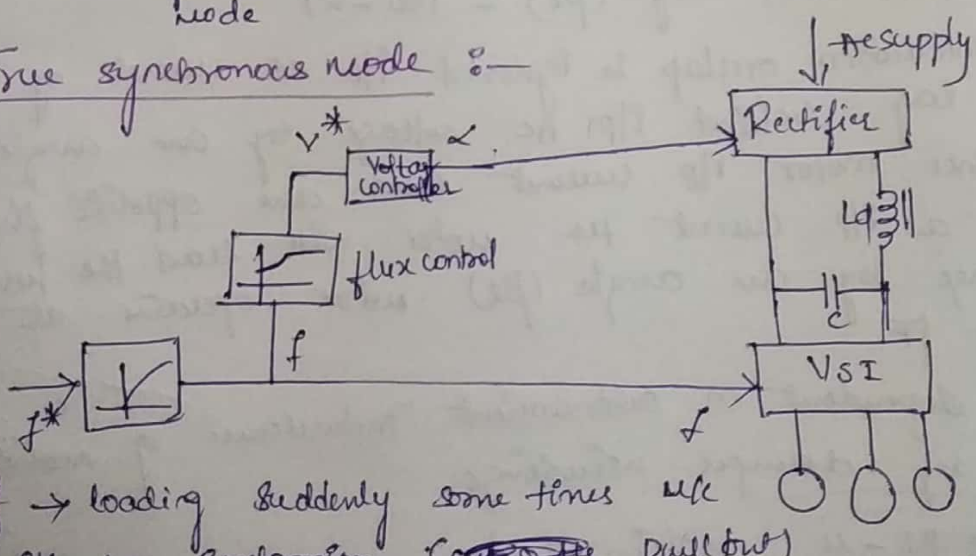
→ Hysteresis motor work as ~~synchronous~~ induction motor still synchronous speed.

18/5/22

Synchronous motor variable speed drives :-

- True synchronous mode
- Self controlled mode [damping winding is not required]

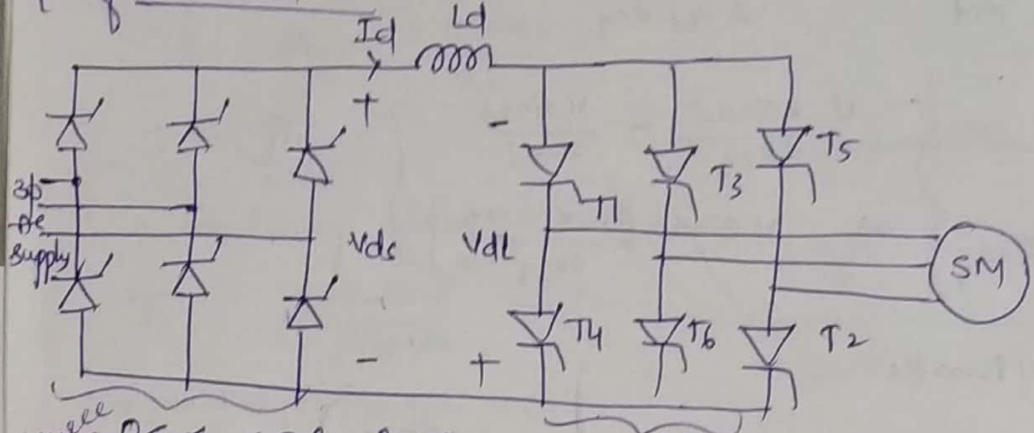
True synchronous mode :-



1) Synchronous reluctance motor
2) PMSM

~~Ex~~ → loading suddenly some times m/c will lose synchronism. (~~Cause of the~~ pull out)

Self controlled mode :-



source side converter $0 < \alpha_s < 90^\circ \rightarrow$ Rectifier
Vds +ve, Id +ve
$90^\circ < \alpha_s < 180^\circ \rightarrow$ Inverter

load side converter $90 < \alpha_l < 180^\circ \rightarrow$ Inverter
$0 < \alpha_l < 90^\circ \rightarrow$ Rectifier

→ $0^\circ < \alpha_s < 90^\circ \rightarrow$ line commutated rectifier
source side converter

→ ~~load side Inverter~~
when synchronous motor operates as a leading power factor thyristor of the load side converter can be commutated by motor induced voltages in the same way as thyristor line commutated converter, commutated by line voltages

→ $T \propto V_{ds} - V_{dl}$, speed can be change by control of load side converter firing angle.

→ commutation load angle $(\beta_l) = 180 - \alpha_l$

→ If commutation overlap is ignored i/p ac current of converter lag behind i/p ac voltage by an angle 'α_l'. Since motor i/p current has an opposite phase to convert a i/p current the motor will lead the terminal voltage by an angle (β_l) motor operates at leading PF.

→ β_l is dependent on subtransient inductance of motor reduced by damper windings

$\gamma = \beta_l - \mu$, margin angle
μ ← commutation overlap

$\beta_l \rightarrow$ kept minimum

$\gamma = \omega t_q$
t_q ← turn off time of thyristor

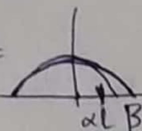
Constant margin angle control :—

→ μ is dependent on I_d

→ In a simple control scheme the drive is operated at fixed value of commutation lead angle $\beta_{critical}$ (β_c) for the load side converter working as Inverter, and $\beta = 0^\circ$ (or 180°) when working as a rectifier.

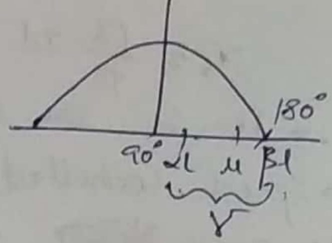
20/05/22

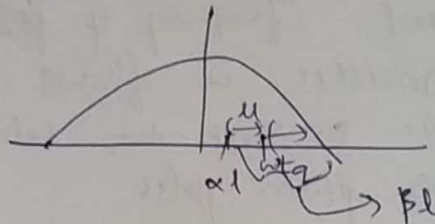
PED

$\beta l =$  $\alpha l \; \beta l = \min.$

$\beta l = 180 - \alpha l$

$\gamma = \beta l - \mu$





$\beta l <<$

So that αl is more

→ for the loadside Inverter 'αl' is the firing angle the stator current lags the stator Voltage by 'αl' motor current is opposite to stator current and it leads the terminal Voltage by 'βl' which is the commutation load angle.

→ βl has to be as low as possible so that the pf is near to unity. This can happen only ~~which~~ when 'αl' is maximum after providing allowance for turn off time of the thyristor and commutation overlap.

$\gamma = \beta l - \mu$

→ commutation overlap 'μ' depends on DC link current 'I_d' and $\gamma_0 = \omega t_q$, t_q is turn off time of the thyristor, ω = frequency of '~~ac~~' supply

→ βl is calculated after knowing 'γ' + 'μ' & βl is fixed at minimum value so that PF is near to unity which will reduce the converter rating

→ 'L_d' is used to reduce the ripple & I_d is constant for a particular load and combination of 'L_d' and Inverter acts as current source Inverter

→ thyristors are commutated by stator induced Voltages and it doesn't required special commutation ckts & process is known as load commutation.

Advantages of load commutation:-

→ doesn't required commutation ckts

→ a frequency of commutation can be higher

→ it can be used for medium power levels.

$I_s = \frac{\sqrt{6}}{\pi} I_d$

→ it is six step w/f.

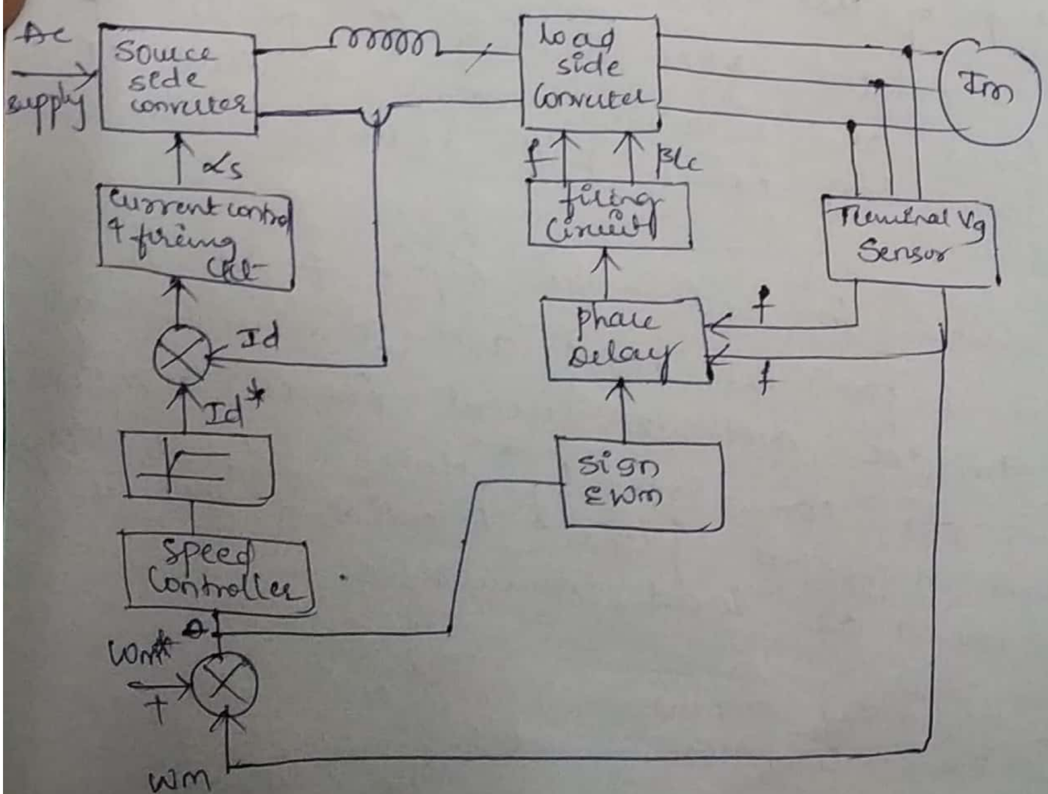
→ Speed controlled by self controlled mode by sensing the rotor induced emf. (frequency & phase is analysed) and the inverter is fired for the same frequency and phase. so that the rotor poles are themself alligning with stator poles.

→ Rotor sensors are placed at 60° interval to measure rotor induced voltage. the magnitude of the induced voltage in sensor is proportional to the frequency of the voltage & phase is proportional to the position of the rotor sensor with respect armature terminal voltage.

Pulsed mode:- <10% of synchronous speed.

→ pulsed mode is used for frequency less than 10% of base speed at the end of every 60° the source side converter is made to work as an inverter, 'Vdc' ~~reverses~~ reverses, the reverse voltage is applied to the conducting thyristors and thyristor current is ~~closed~~ forced to zero.

→ then the source side converter is made to work as rectifier this happens for every 60.



for regenerative braking $\beta l = 180°$

24/5/22 :-

Permanent magnet synchronous motors :- (PMSM) (PMAC)

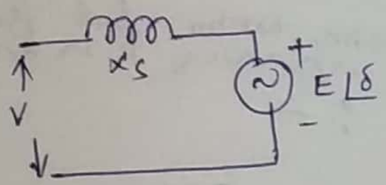
depending upone how the stator is excited it is classified into

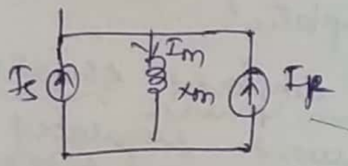
1) Sinusoidal 2) trapezoidal

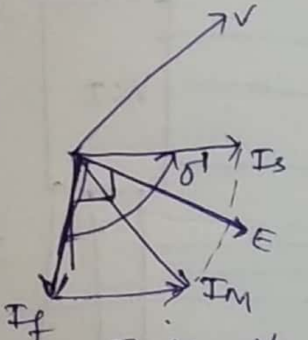
→ they are controlled by means of variable frequency voltage source (or) variable frequency current source.

→ they are controlled by self controlled manner by means of rotor position sensors.

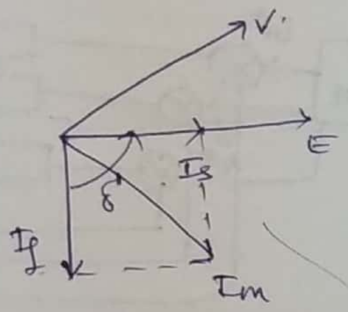
→ they are known as brushless DC motors.



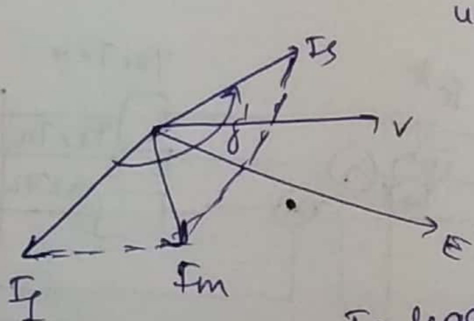




I_s lags V



I_f, I_s at 90°
unity pf



I_s leads V.

$$\bar{I}_f = \frac{\bar{E}}{jX_s}, \quad I_m = \bar{I}_f + \bar{I}_s$$

$$P_m = 3 E I_s \cos(\delta' - \pi/2) = 3 X_s I_s I_f \sin\delta$$

$[E = X_s I_f]$

$$T = \frac{P_m}{\omega_{ms}} = K I_s I_f \sin\delta \qquad K = \frac{3X_s}{\omega_{ms}}$$

$(T = T_{max}$ at $\delta = 90°)$ at upf $\quad \delta \to$ angle $\to I_s, I_f$

→ $\delta' = \pi/2$ for motoring operation and $\delta' = -\pi/2$ for regenerative operation.

→ up to base speed (V/f) = constant, ~~~~ to

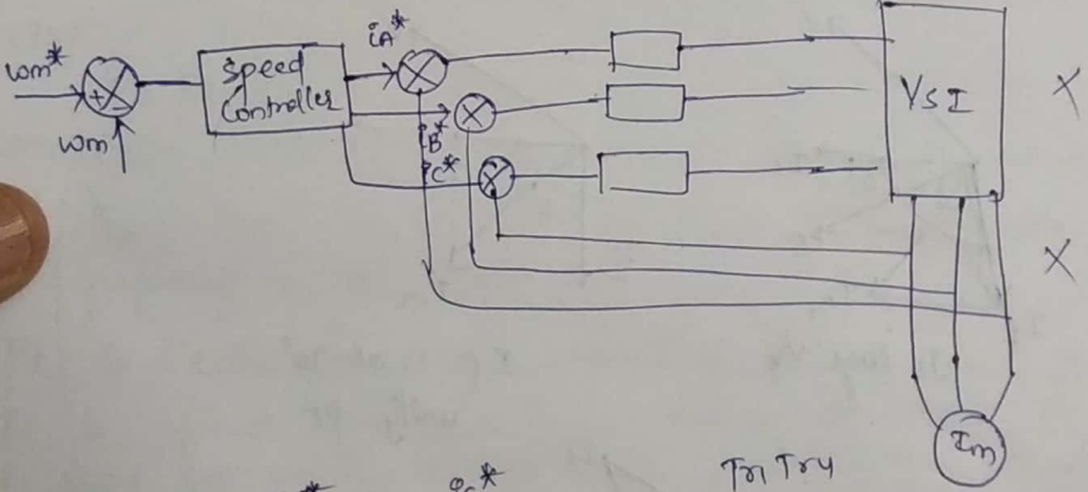
above " " $(V/f) \neq$ constant

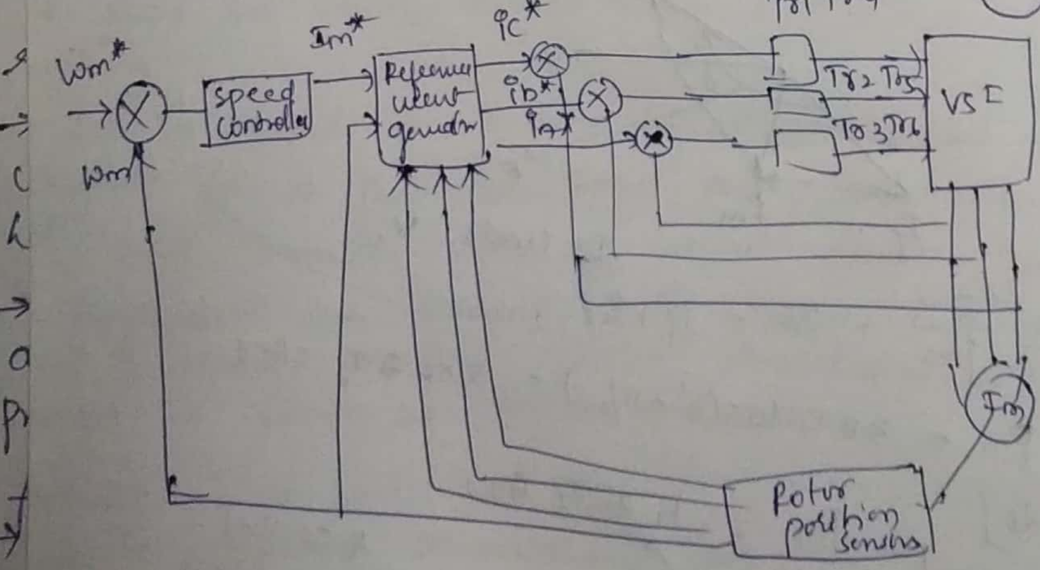
$f\uparrow$ so $\phi\downarrow$ so it is operated in flux weakening mode.

→ In flux weakening mode the angle between I_s & I_f is increased so that I_m is decreased.

→ Rotor south pole axies is 180° out of phase with the going zero crossing ~~of~~ stator phase-A current. this information is used ~~from~~ rotor position sensors to generate the reference ~~sine~~ sine templates.

Servo Drive Employed Sinusoidal PMAC Motor fed from a current regulated VSI :-





→ if Error +ve speed controller accelerates (or) if it is -ve it will decelerates.

→ it is a current regulated VSI

→ (Trapezoidal | vector controlled speed control) * exam (5M/10M)
PMAC M/C of IM

(from chopper controlled of DC till Now)

Speed will ↑se
When $\omega_m^* = \omega_m$

23/03/22

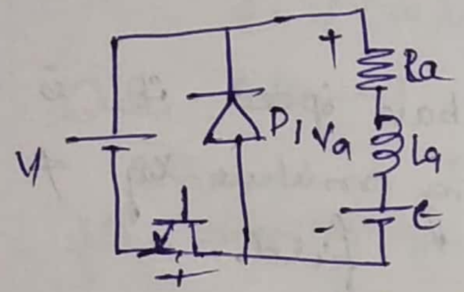
Chopper - DC-DC Converter :

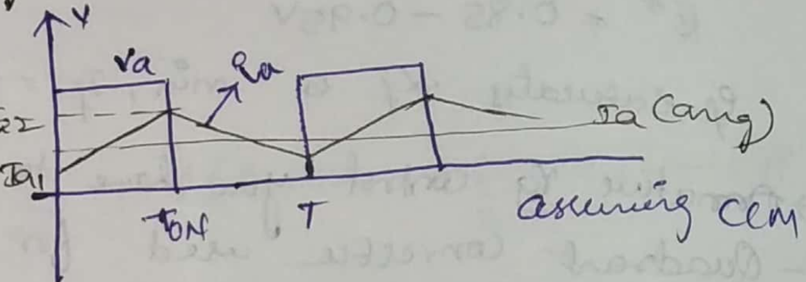
thyristor

1) MOSFET → low power applications
2) IGBT, Power transistor → Medium power
3) GTO, IGCT → high power

→ high frequency Devices
→ for low speed, Regenerative braking possible

Chopper control of Seperately excited motor :-





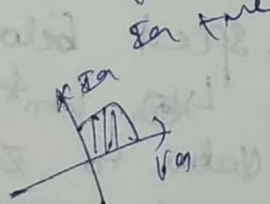
assuming CCM

Duty Interval - (0 - TON)

free wheeling interval - (TON - T)

Duty Interval :-

$$R_a I_a + L\frac{di_a}{dt} + E = V$$



Freewheeling Interval :-

$$R_a I_a + L\frac{di_a}{dt} + E = 0$$

$$V_a = \frac{1}{T}\int_0^{t_{ON}} V\,dt \Rightarrow V\frac{t_{ON}}{T} = \delta V$$

$\delta \rightarrow$ Duty ratio $\Rightarrow \frac{t_{ON}}{T}$

$V_a = E + I_a R_a$

$E = K\omega_m$.

$V_a = K\omega_m + I_a R_a$

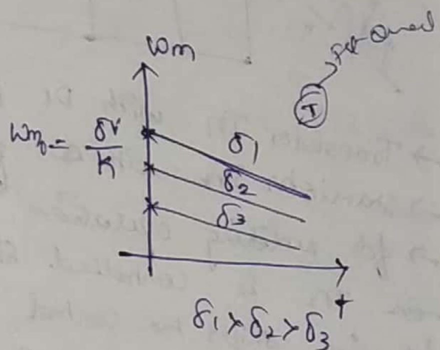
$$\omega_m = \frac{V_a - I_a R_a}{K} \Rightarrow \frac{V_a}{K} - \frac{I_a R_a}{K}$$

$T = K I_a$

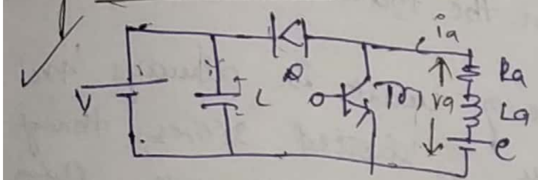
$I_a = T/K$

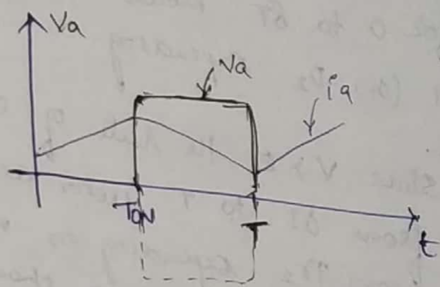
$$\omega_m = \frac{V_a}{K} - \frac{T R_a}{K^2}$$

$$\omega_m = \frac{\delta V}{K} - \frac{T R_a}{K^2}$$



Regenerative braking:-





$$V_a = \frac{1}{T}\int_{TON}^{T} V\,dt$$

$$\Rightarrow \frac{1}{T} V\,[T - TON]$$

$$\Rightarrow \frac{V\,[T-TON]}{T}$$

$\Rightarrow \delta V$

$\left(\frac{T-TON}{T}\right)$ (Not same for all the cases)

$V_a = E + I_a R_a$

$T = -K\phi i_a$

$I_a = -T/K\phi$

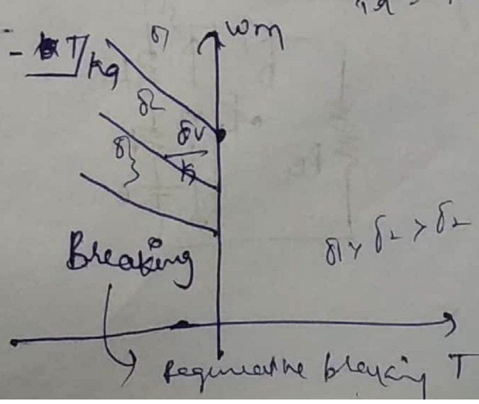
here I_a is $-$ve so $I_a = -T/K_a$

$$\delta V = K\omega_m + \left(-\frac{T}{K} R_a\right)$$

$$K\omega_m = \delta V + \frac{T}{K} R_a$$

$$\omega_m = \frac{\delta V}{K} + \frac{T}{K^2} R_a$$

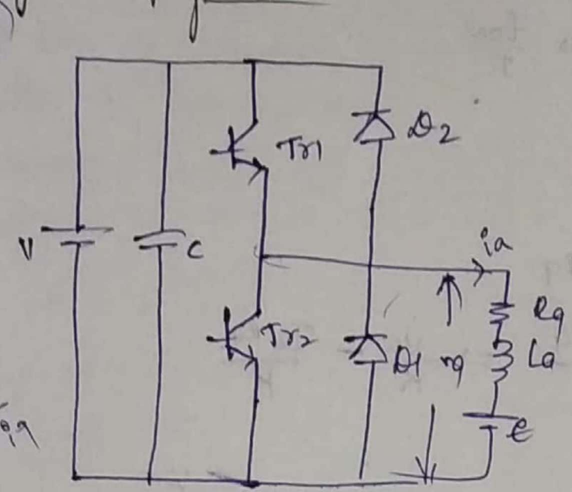
$E > \delta V$

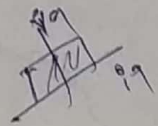


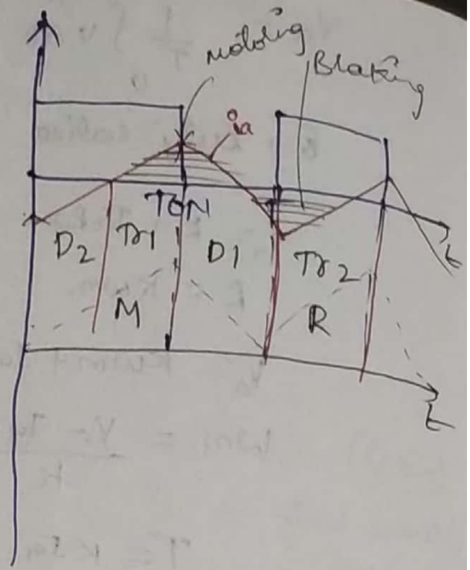
$\delta_1 > \delta_2 > \delta_3$

Motoring and braking
Regenerative

(type A 2 quad chopper)







→ Transistor Tr1 with D1 forms forwarding motoring operation
→ Transistor Tr2 with D2 forms regenerative braking operation
→ for motoring operation Tr1 is control and for braking operation Tr2 is controlled. Shifting the control from motoring to braking shifts the control from Tr1 to Tr2.
→ for 0 to δT motor is connected to source either through Tr1 (or) D2 depending on wether the motor current is +ve (or) -ve.
→ Since $V > E$ the rate of change of current is always '+ve'
→ from δT to T motor armature is shorted either through D_1 (or) Tr_2 depending on wether I_a is +ve (or) -ve. During this periode the rate of change of current is always '-ve'

$V_a = \delta V$

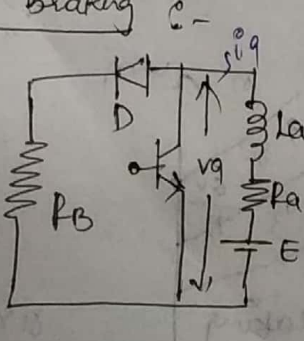
$I_a = \frac{\delta V - E}{R_a}$

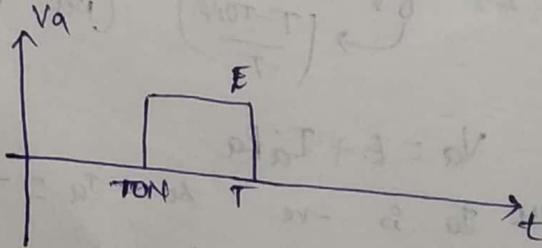
$\delta > \left[\frac{E}{V}\right]$ I_a is +ve

$\delta < \frac{E}{V}$ I_a is -ve.

$V_a = V$ if T_1 (or) D_2 ON
$V_a = 0$ if D_1 or T_2 ON
$i_a = +ve$ if Tr_1 (or) D_1 on
$i_a = -ve$ if D_2 & T_2

Dynamic braking :-





$E_N = I_a^2 R_B (T - T_{ON})$

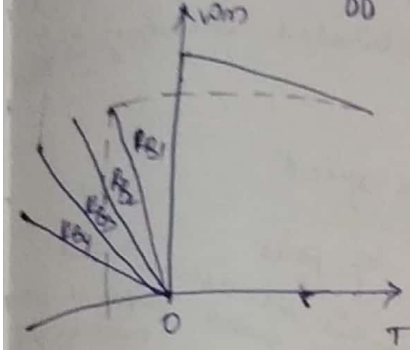
$P_N = \frac{E_N}{T} = \frac{I_a^2 R_B (T - T_{ON})}{T} = I_a^2 R_B (1-\delta)$

$\left(\delta = \frac{T_{ON}}{T}\right.$ Duty interval$\left.\right)$

$P_N = I_a^2 R_B (1-\delta)$

$R_{BE} = R_B (1-\delta)$

↳ effective resistance depends on 'δ'



$E = I_a^2 R_B (T - T_{ON})$

$\cancel{K\omega_m = I_a^2 R_B (T - T_{ON})}$

$\cancel{\omega_m = \frac{I_a^2 R_B (T - T_{ON})}{K}}$

$\cancel{\omega_m = \frac{(T/K)^2 R_B (T - T_{ON})}{K}}$

$\omega_m = \frac{T^2 R_B (T - T_{ON})}{K^3}$

$R_{B1} > R_{B2} > R_{B3} > R_{B4}$

$R_B \downarrow, \Rightarrow I_a R_a \downarrow, \Rightarrow V_a \downarrow$ hence speed ↓

this reduces to zero in dynamic braking

30/03/22

$\omega_m = \frac{\delta V + I_a R_a}{K}$

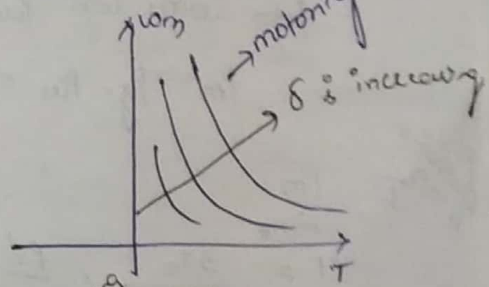
$R_{BE} = R_B(1-\delta)$

Chopper control of Series motor :-

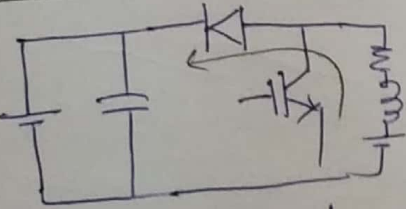
$E \propto K(i_a)\omega_m$, for ~~practical~~ particular δ, I_a is selected

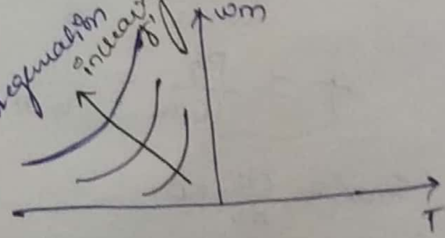
$\omega_m = \frac{\delta V - I_a R_a}{K}$ K is found from magnetization characteristic.

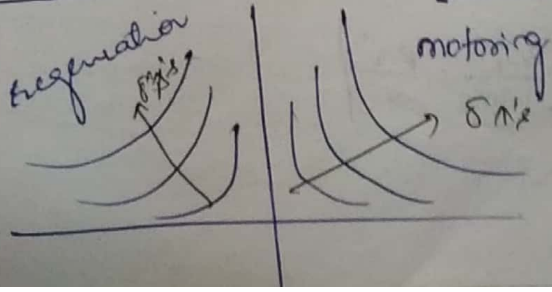
$T \propto I_a \phi$



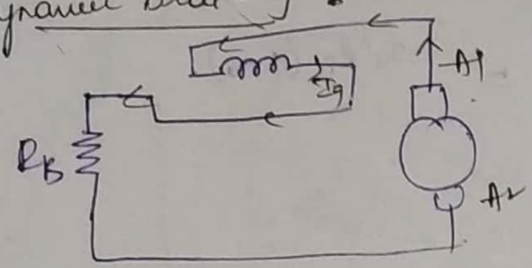
Regenerative braking :-







Dynamic braking :- (here also current reverses so change the field)



Induction motor :-

three phase Induction motor (copper will be there)

→ Squirrel cage Induction motor (Distributed winding is there)

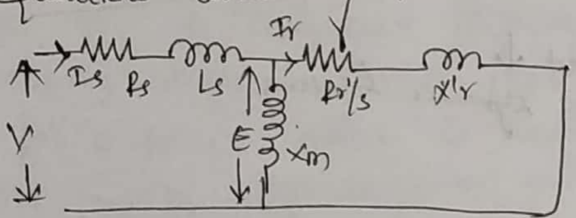
→ wound rotor " "

$$slip\ (s) = \frac{\omega_{ms} - \omega_m}{\omega_m}$$

ω_{ms} → synchronous speed ; ω_m → rotor speed

$\omega_{ms} = \frac{4\pi f}{P}$ f → frequency, P → no of poles.

Equivalent circuit of Induction motor :- from this to this we assumed that stator impedance losses are negligible



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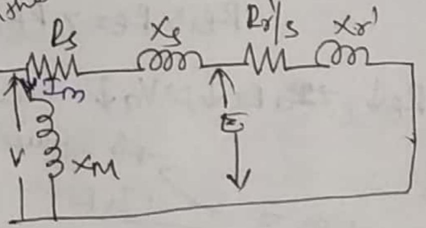

$$\omega_m = \omega_{ms}(1-s)$$

$$I_r' = \frac{V}{(R_r'/s + R_s) + j(X_s + X_r')}$$

Power transferred to rotor $P_g = 3 I_r'^2 R_r'/s$

Rotor copper loss $P_{cu} = 3 I_r'^2 R_r$

$$P_m = P_g - P_{cu} = \frac{3 I_r'^2 R_r' (1-s)}{s}$$

(derivation is this) $T = \frac{P_m}{\omega_m}$

$$T = \frac{3 I_r'^2}{\omega_m s} \cdot \frac{R_r'}{s} = \frac{3}{\omega_{ms}} \left[\frac{V^2 R_r'/s}{(R_s + R_r'/s)^2 + (X_s + X_r')^2} \right] \quad \text{—(1)}$$

$$T = \frac{P_g}{\omega_{ms}} = \frac{P_m}{\omega_m}$$

$$S_{max} = \frac{dT}{ds} = 0$$

$$\frac{dT}{ds} = 0 = \frac{d}{ds}\left[\frac{3 I_r'^2}{\omega_{ms}} \cdot \frac{R_r'}{s}\right]$$

Scanned with CamScanner