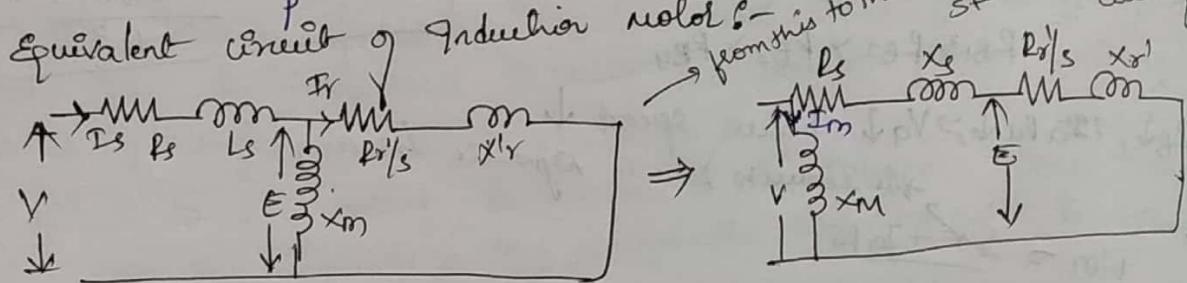


Three phase Induction motor :-
 → Squirrel cage Induction motor
 → wound rotor

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

$\omega_m \rightarrow$ synchronous speed ; $\omega_m \rightarrow$ rotor speed

$$\omega_{ms} = \frac{4\pi f}{p} \quad f \rightarrow \text{frequency}, \quad p \rightarrow \text{no. of poles}$$



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

$$I_d' = \frac{V}{(R_d'/s + R_s) + j(X_s + X_d')}$$

$$\left. \begin{aligned} \text{Power transferred to rotor } P_g &= 3 I_d'^2 R_d'/s \\ \text{Motor copper loss } P_{cu} &= 3 I_d'^2 R_s \end{aligned} \right\}$$

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

(Assumption is true) $T = \frac{P_m}{\omega_{ms}}$

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

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

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

$$\frac{dT}{ds} = 0 = \frac{d}{ds} \left(\frac{3 I_d'^2}{\omega_{ms}} \cdot \frac{R_d'}{s} \right)$$

$$= \frac{3}{\omega_{rms}} \left[[(R_s + R_s'/s)^2 + (x_s + x_r)^2] \cdot V^2 \cdot R_s \cdot (-Y_s) - V^2 R_s' s \right]$$

$$2 [R_s + R_s'/s] \cdot (-R_s'/s^2) + 0 \right]$$

$$= \frac{3}{\omega_{rms}} \left[(R_s + R_s'/s)^2 + (x_s + x_r)^2 \left(-\frac{V^2 R_s'}{s^2} \right) + 2V^2 R_s' s (R_s + R_s'/s) \cdot \frac{R_s'}{s^2} \right]$$

$$\Rightarrow \frac{3}{\omega_{rms}} \left[-\frac{V^2 R_s'}{s^2} \cdot (R_s + R_s'/s)^2 - \frac{V^2 R_s'}{s^2} (x_s + x_r)^2 + \frac{2V^2 R_s' s}{s^2} (R_s + R_s'/s) \right] = 0$$

$$\boxed{\left[(R_s + R_s'/s)^2 + (x_s + x_r)^2 \right]^2}$$

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

Substituting (2) in (1)

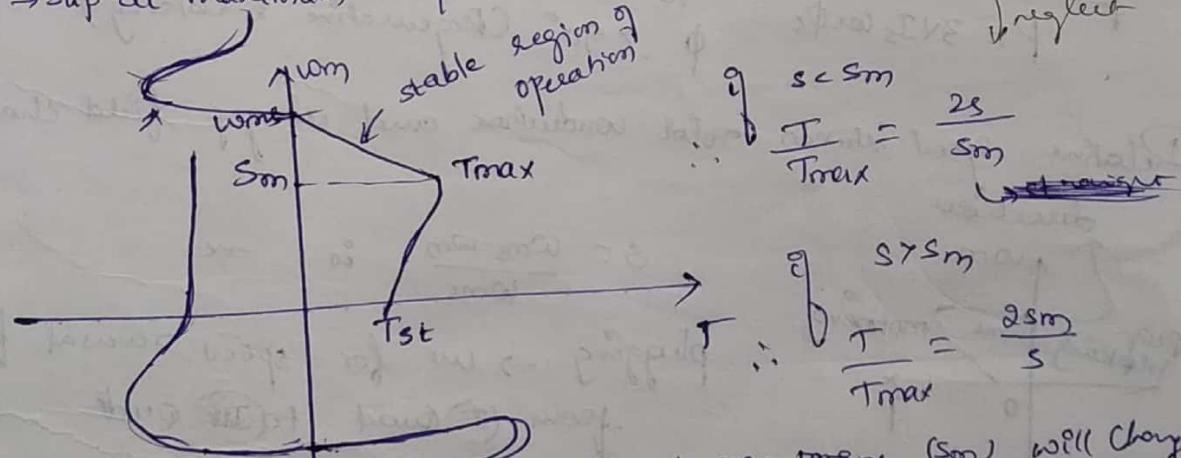
$$T_{max} = \frac{3}{2\omega_{rms}} \left[\frac{V^2}{R_s \pm \sqrt{R_s^2 + (x_s + x_r)^2}} \right] \quad \text{--- (3)}$$

(1)/(3) and substituting in (2)

$$\frac{T}{T_{max}} = \frac{2 \left(1 + \frac{R_s}{R_s'} \frac{s_m}{s} \right)}{\frac{s}{s_m} + \frac{s_m}{s} + \frac{2R_s}{R_s' s_m}}$$

$$\frac{2}{\frac{s}{s_m} + \frac{s_m}{s}}$$

$s_m \rightarrow$ Slip at maximum torque



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

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

→ if we change motor resistance slip at max torque (s_m) will change as speed n/s Torque & s.

→ stable region of operation bcz as speed n/s Torque & s.

→ $s > s_m$ and becomes -ve (applied frequency is less)

→ slip is -ve in the case of regenerative braking

and slip (s) becomes -ve \therefore (1), (2), + (3) holds.

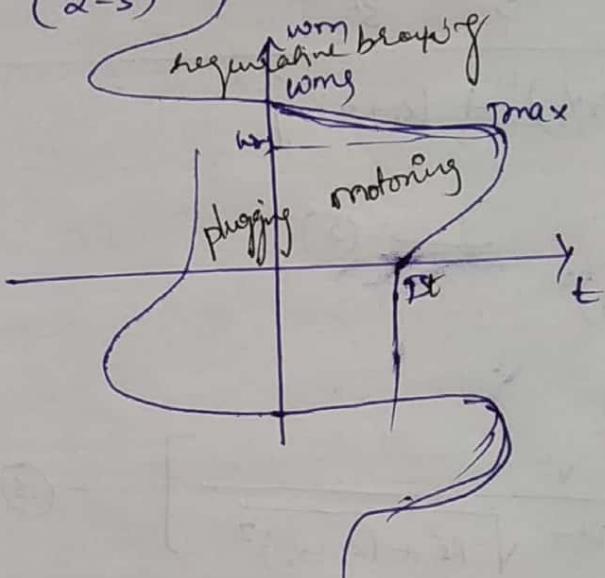
$$(s = \frac{\omega_{max} - \omega_m}{\omega_m}) \text{ which is -ve}$$

Plugging :-

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

$$s = \frac{\omega_m - \omega_m}{\omega_m} - \frac{\omega_m}{\omega_m} \quad \cancel{= 0}$$

$$s = (2-s)$$



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Plugging :-

$$s_n = 2-s$$

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

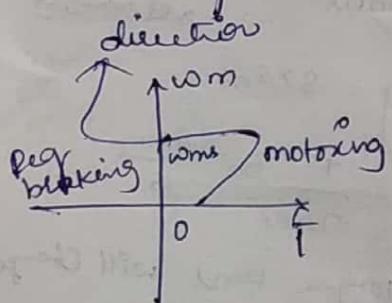
Regenerative breaking :-

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

$\phi_s < 90^\circ$ (motoring)

$\phi > 90^\circ$ (Regenerative breaking)

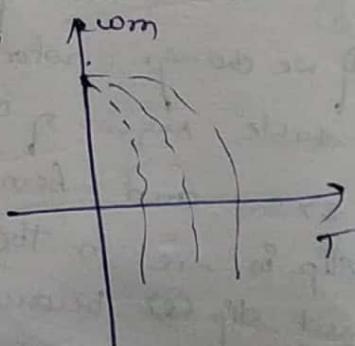
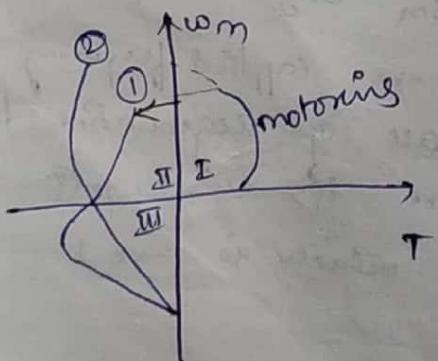
Relative speed between rotor conductors and airgap field changes direction



$$s = \frac{\omega_m - \omega_m}{\omega_m} \text{ is } -ve$$

plugging \rightarrow use for speed reversal from quadrant I to quadrant III

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



speed control :-

stator voltage control

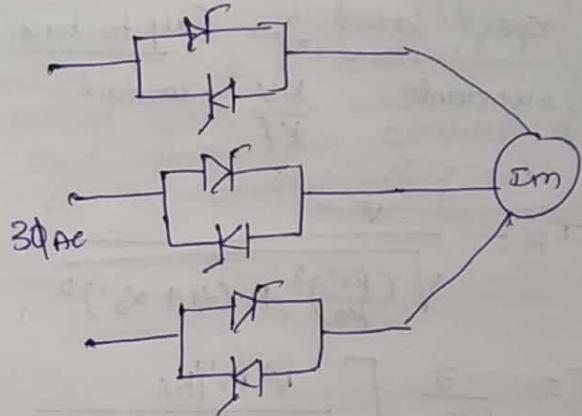
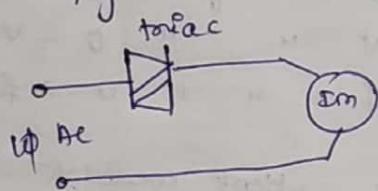
$$T = \frac{3}{\omega_m} \left[\frac{V^2 R_s' / s}{(R_s + R_s' / s)^2 + (x_s + x_s')^2} \right]$$

$$R_s' = \frac{V}{(R_s + R_s' / s) + j(x_s + x_s')}$$

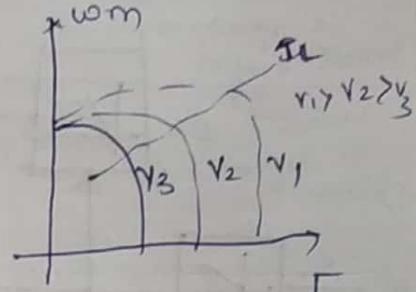
useful in fan & pump drives

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

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

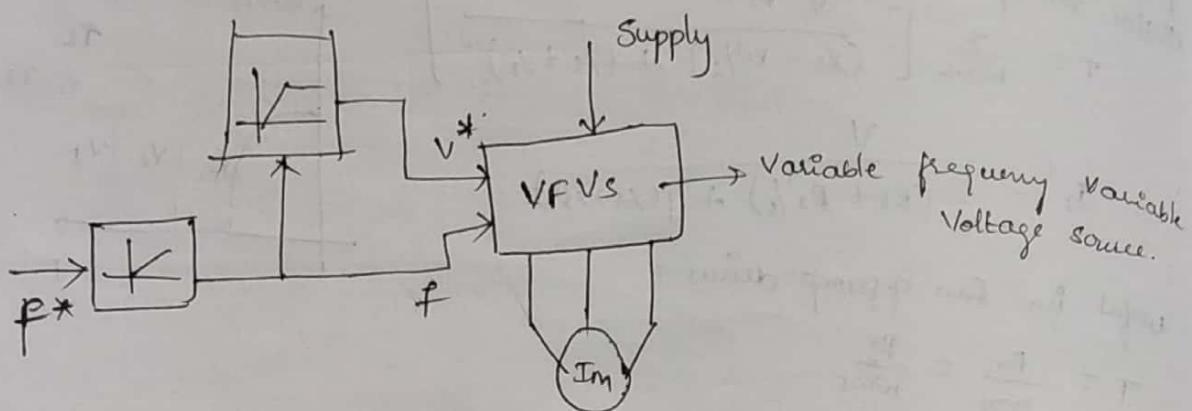


V.



10/4/22

Open loop V/F control :-



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

$$\frac{v}{f} = \text{constant} \quad \frac{kv}{kf} = \text{constant} \quad k \text{ varies from } 0-1$$

$$v \quad " \quad " \quad 0-v$$

$$f \quad " \quad " \quad 0 \rightarrow f$$

$$I_{\delta'}^1 = \frac{v}{\sqrt{\left(\frac{R_{\delta'}}{k_s}\right)^2 + (x_s + x_{\delta'})^2}} \quad k_s \rightarrow \text{kept constant}$$

$$T = \frac{3}{\omega_{ms}} \left[\frac{\frac{N^2 R_{\delta'} / k_s}{(R_{\delta'} / k_s)^2 + (x_s + x_{\delta'})^2}}{(R_{\delta'} / k_s)^2 + (x_s + x_{\delta'})^2} \right]$$

$$\frac{R_{\delta'}}{sk} \gg (x_s + x_{\delta'}) \quad \therefore I_s = \sqrt{I_{\delta'}^{12} + I_{\delta''}^2} \\ \text{↳ blog slip is small} \quad = \text{constant}$$

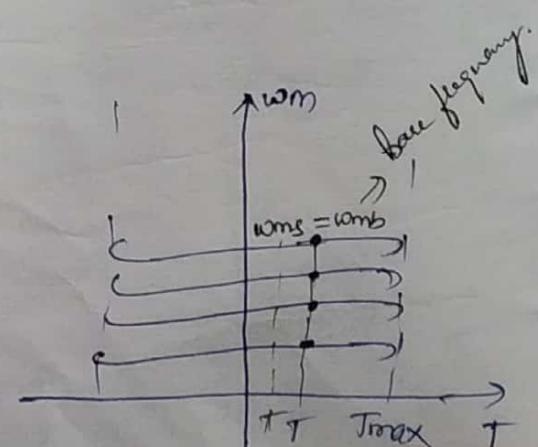
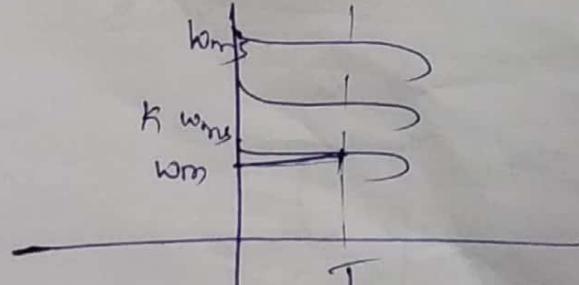
$$T = \frac{3}{R_{\delta'} \omega_{ms}} \quad (\text{constant})$$

$$\text{Slip} \cdot s = \frac{k \omega_{ms} - \omega_m}{\omega_{ms}}$$

$$k_s = \frac{\omega_{ms} - \omega_m}{\omega_{ms}} = \frac{\omega_f}{\omega_{ms}}$$

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

If ω_{sl} is varies $T \rightarrow$ also varies



→ Torque is constant upto base speed.

Beyond base speed :- Operation above base speed with $V = \text{constant}$

$$I_{\delta'} = \frac{SV}{R_{\delta'}} = \frac{V}{R_{\delta'}} \frac{(K_{wms} - w_m)}{K_{wms}}$$

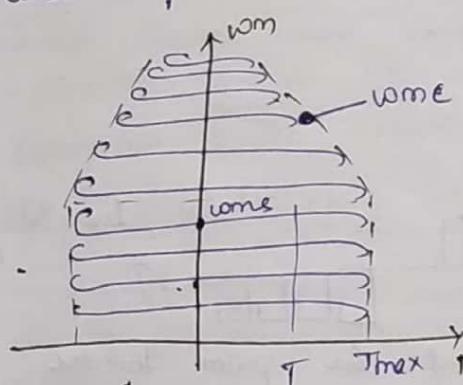
$V = \text{constant}$ we can't change K_B beyond rated

$$(K_{wms} - w_m) = w_{sl} = \frac{R_{\delta'}}{V} w_{ms} (K I_{\delta'})$$

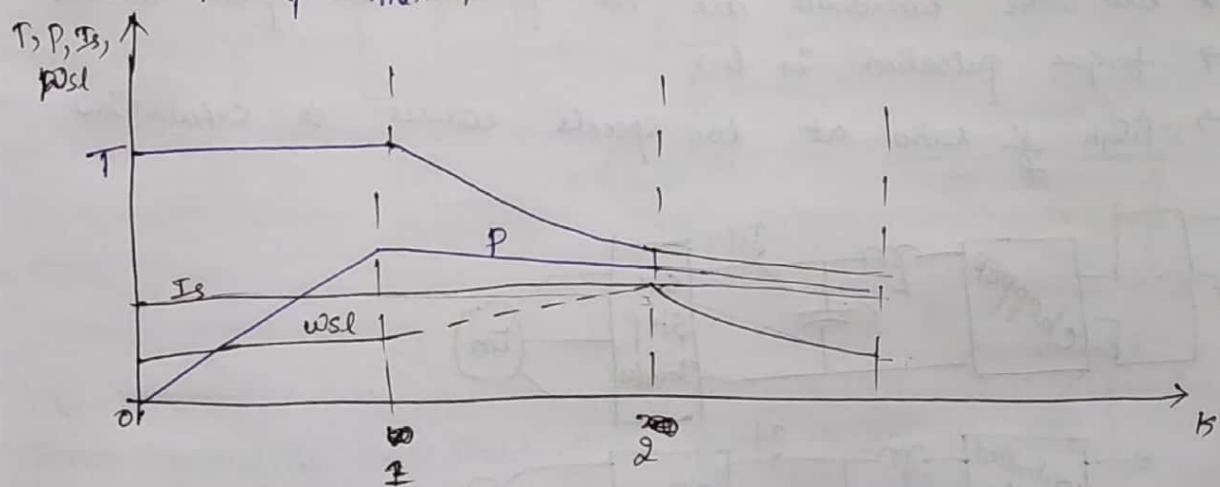
$$P_m = 3V I_{\delta'}$$

$K_B \neq \text{constant}$
flux control is not there

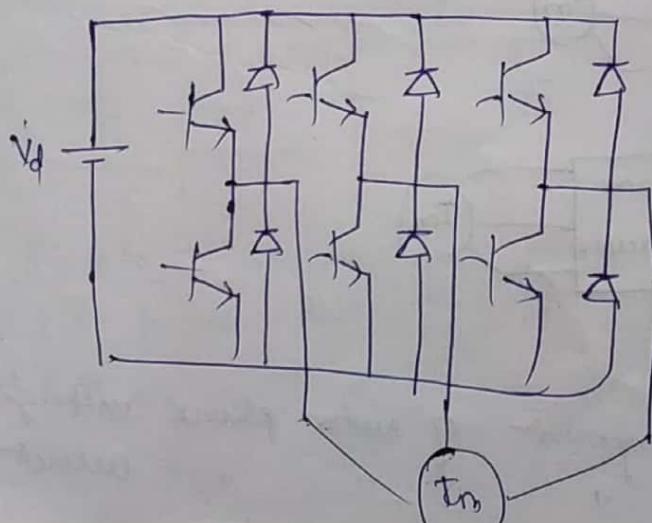
* beyond base speed voltage is constant and $I_{\delta'}$ kept constant at a particular value therefore w_{sl} the slip speed varies linearly with $I_{\delta'}$ for a particular $I_{\delta'}$ it works in constant power mode.



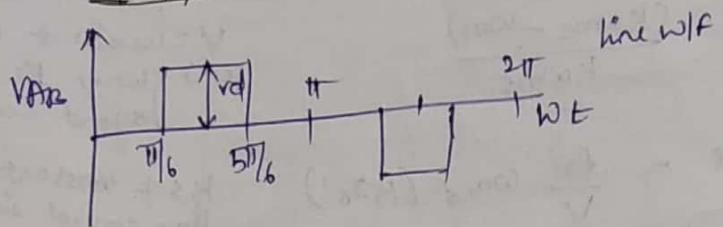
→ constant power mode happens till critical speed is reached. beyond critical speed the current, power, and torque are allowed to fall at a constant slip



19/04/22
VSI fed induction motor drives



Six Stepper



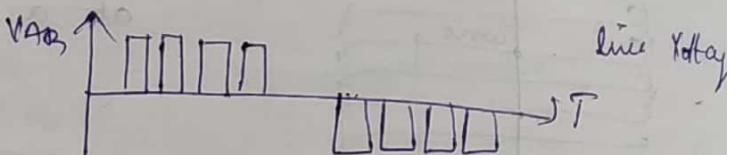
$$V_{AB} = \frac{2\sqrt{3}V_d}{\pi} \left[\sin \omega t - \frac{1}{5} \sin 5\omega t - \frac{1}{7} \sin 7\omega t + \frac{1}{11} \sin 11\omega t + \frac{1}{13} \sin 13\omega t \right]$$

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

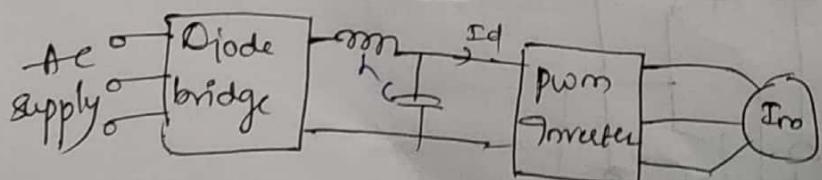
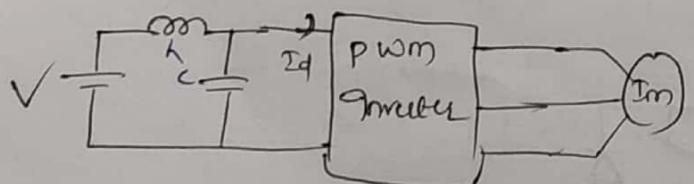
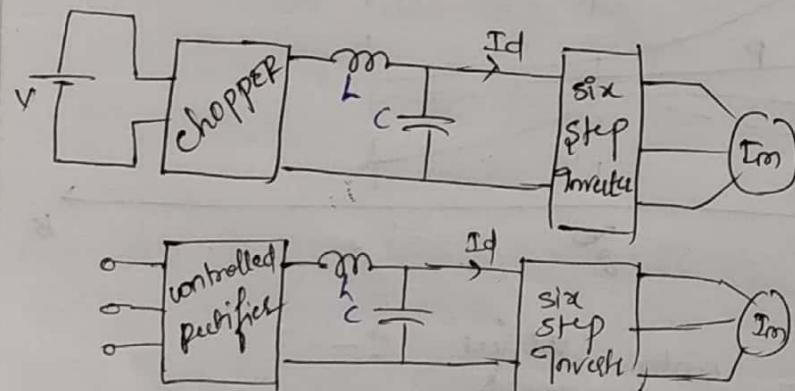
$$\text{Rms value } V = \frac{\sqrt{2}V_d}{\pi}$$

PWM Inverter :-

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



- 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 → fundamental component of motor phase voltage
 I_s → " " " " current

$\phi = \text{angle b/w } V + I_s$

$\phi < 90^\circ$ motoring

(power flows from inverter to motor)

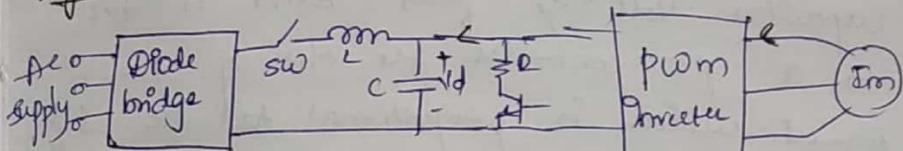
$\phi > 90^\circ$ breaking

(power flows from motor to inverter)

$f < f_s \rightarrow$ relative speed changes so power direction changes

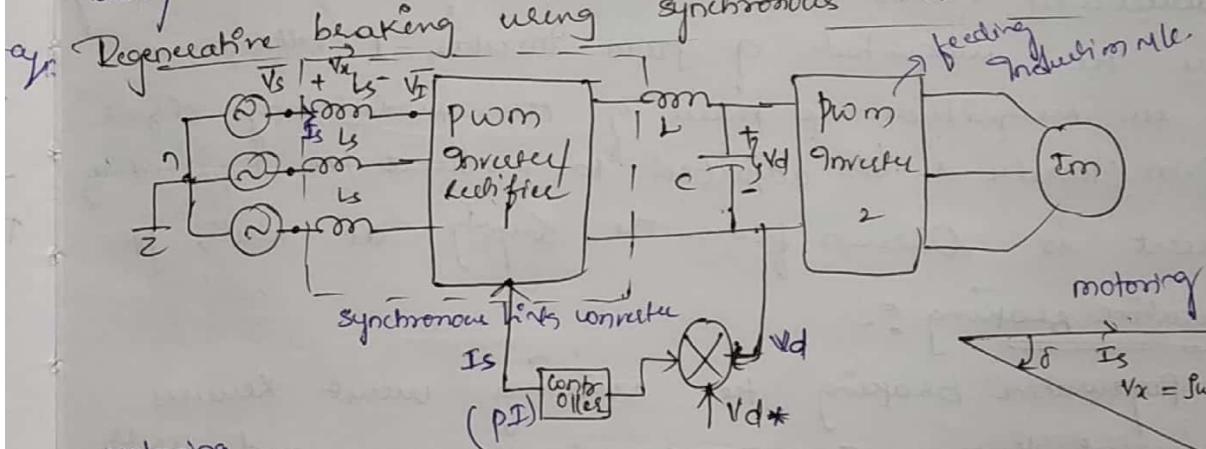
from user can be made lag (or lead) (wed notation)

Dynamic breaking in Induction motor



→ this reverse current cannot flow through diode rectifier 50
capacitor charges (SW open) transistor turn ON. the power is
dissipated in the resistance 'R'.

Regenerative braking using synchronous links converter :-



motoring

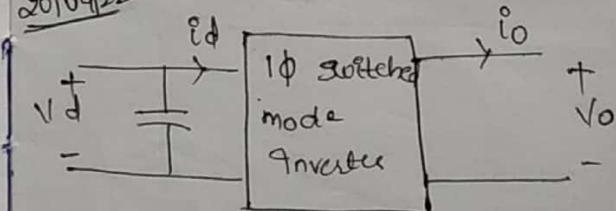
PWM-2 takes energy from 'C' (rd)

$V_d = \text{constant}$

power supplied by PWM Inverter ① = power taken by PWM Inverter ②

→ when $I_m \rightarrow$ taking more power so $V_d \downarrow$'s so to maintain $N_d = \text{constant}$ PWM Invert ② draw more power from source.

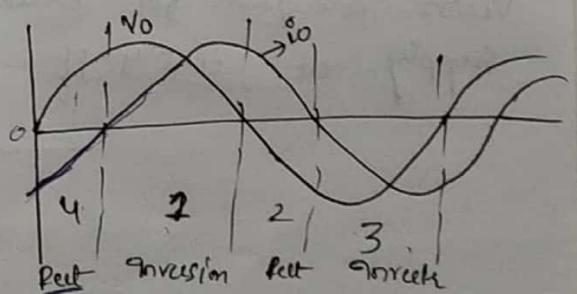
20/04/22



$$P = V_d i_0$$

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

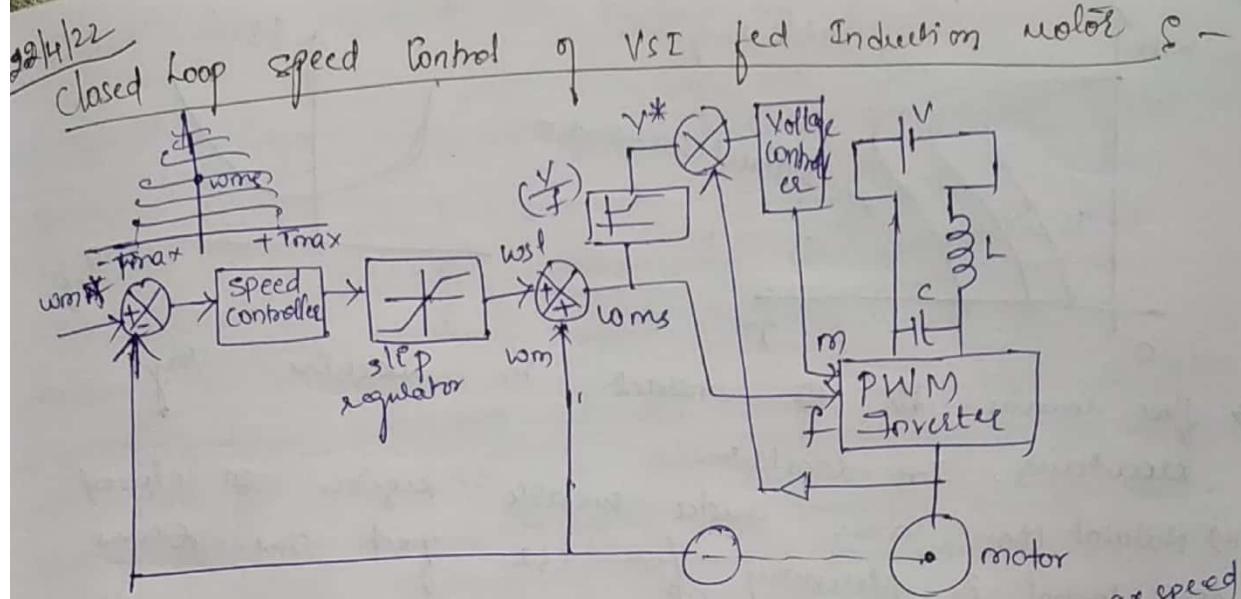
④ + ② P = -ve " " " " AC to DC side.



- In synchronous brief converter there are two inverters plm-1 & plm-2 connected back to back through a common DC link.
- plm-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 pls it takes more power from plm-2 which infers current 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 (I_s) 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 motor.
- once the magnitude of plm inverter-1 voltage is gone the magnitude & phase of the modulating signal of plm inverter-1 is adjusted to produce the required I_s .
- current is drawn from the supply at unity pf.

Regenerative breaking :-

- for regenerative braking the motor current becomes reverse the current through plm 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.
- plm inverter-1 synthesizes a voltage according to the vector diagram for breaking and current is fed back to the supply. at unity pf.

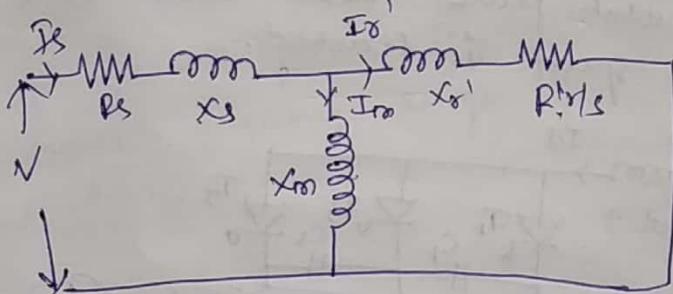


$w_{sl} \rightarrow$ slip speed
 $w_m \rightarrow$ rotor speed
 $w_{ms} \rightarrow$ synchronous speed.

critical speed \rightarrow max speed that motor can run
 base speed \rightarrow rated speed

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Variable frequency control from current source :-



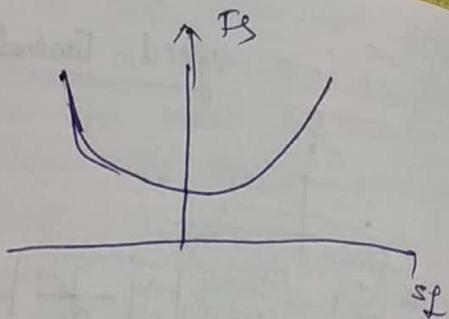
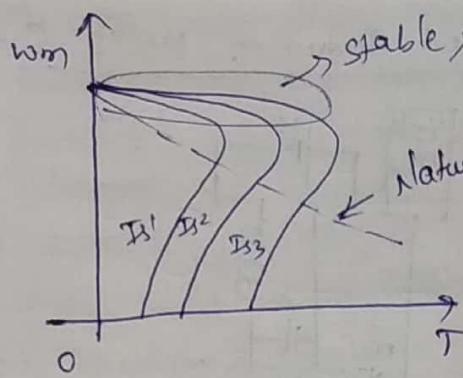
$$I_r' = \frac{X_m I_s}{\sqrt{(R_r'/s)^2 + (X_m + X_r')^2}}$$

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

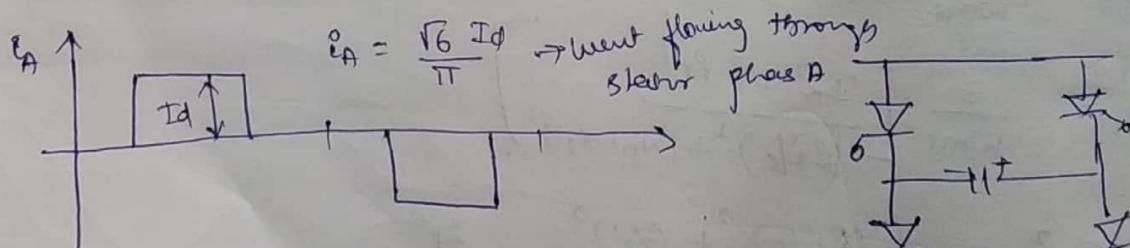
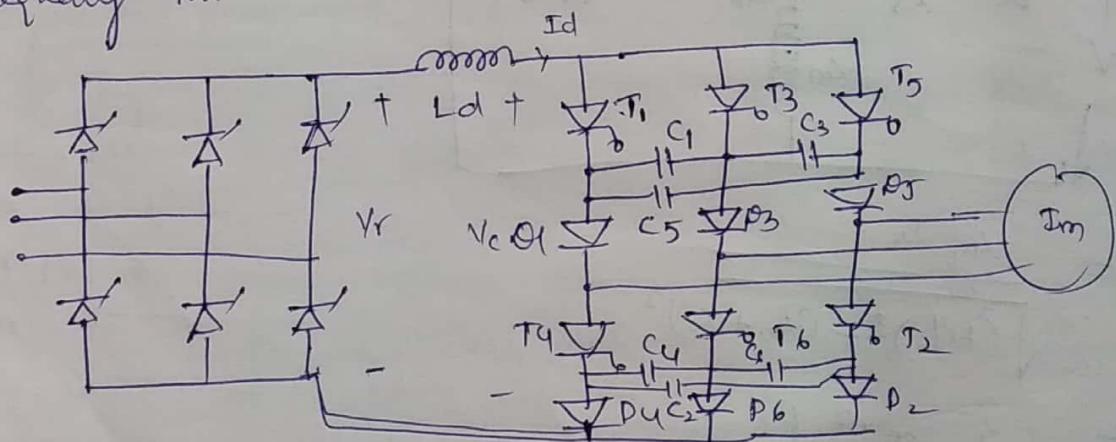
$$= \frac{3}{w_{ms}} \left[\frac{I_s^2 X_m^2 R_r'/s}{(R_r'/s)^2 + (X_m + X_r')^2} \right]$$

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

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



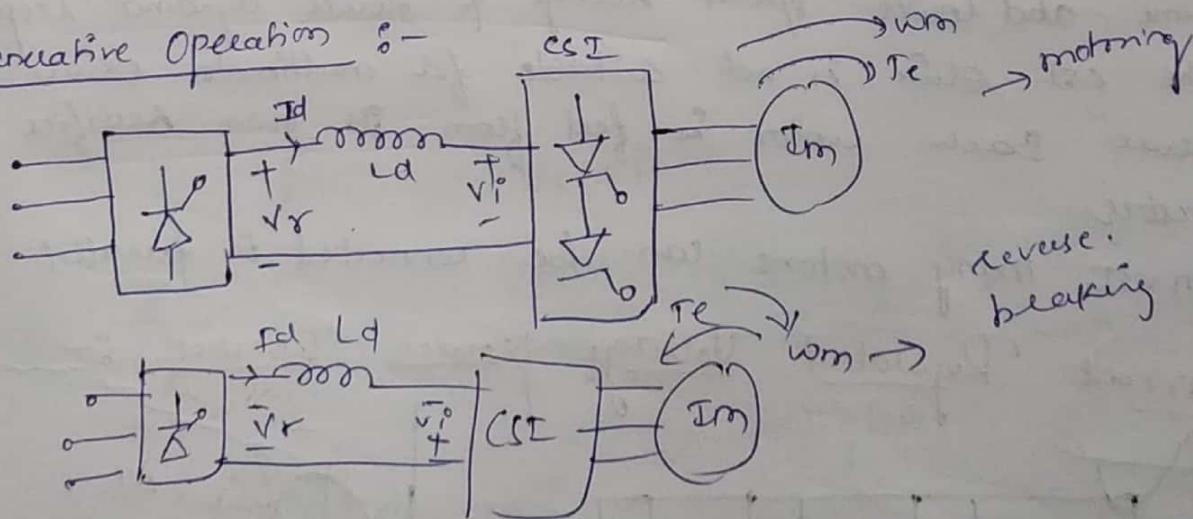
- flux remains ~~at~~ ~~at~~ constant in machine. by maintaining I_m constant.
- Natural char comes under unstable region so closed loop control is necessary for CSI fed IM drives
- since motor is constraint to operate at constant flux its steady state behaviour is similar to variable frequency Variable Voltage source. thus at a given slip speed the motor draws a constant current and develops a constant torque at all frequencies.
- motor works in constant torque mode from '0' to base frequency and constant power mode above base frequency till the critical speed is reached.



- In case of VSI a commutation failure will cause two devices in the same a leg to conduct. this connects conducting devices directly across the sources 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 does not lead sudden rise of current ~~of the~~ through them due to presence of large Inductor L_d , this allows time for commutation to take place and normal operation to get ~~smooth~~ ~~soft~~ restabilization in subsequent.
- motor current rise and fall are very fast such a fast rise and fall of current in leakage 'i' produce a large voltage spikes ∴ the motor with low leakage 'i' is used.
- Even though the voltage spikes have large values commutation voltage spike by reducing rate $C \rightarrow C_1$ to C_6 reduce the rate of fall of current, value of C is required to sufficiently reduce the voltage spikes.
- Large commutation c's have the advantage that can be used then for inverter and :.
- Large converter grade thyristor they reduce frequency range of speed range of the devices.

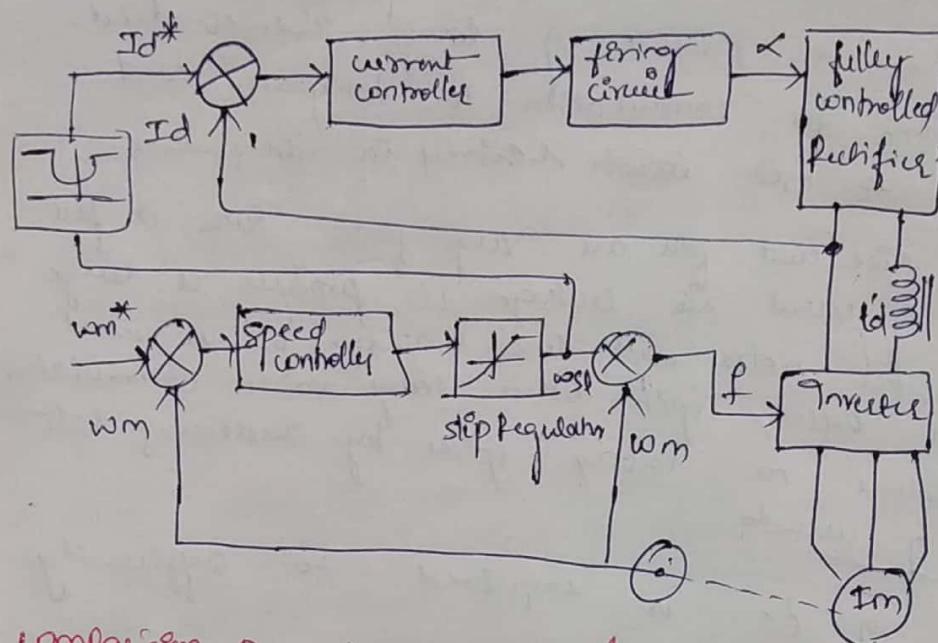
Regenerative Operation :-



→ for reverse motoring we have to change phase sequence

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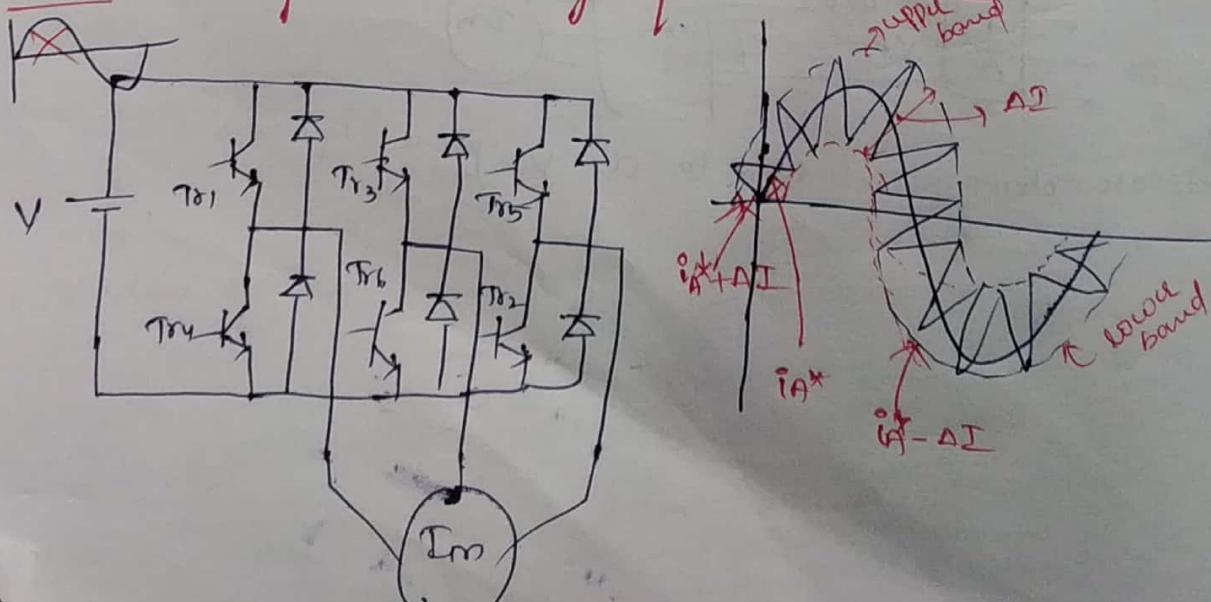
Closed loop of current source Inverter fed Induction motor



comparison of CSI & VSI fed Drives :-

- CSI is reliable than VSI, commutation failure does not occur in CSI. it has inherent protection against short at gic motor terminals.
- Due to large inductance in the dc links and large inverter capacitors CSI drive has higher cost, weight & volume and lower speed range & slower dynamic response.
- 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 :-

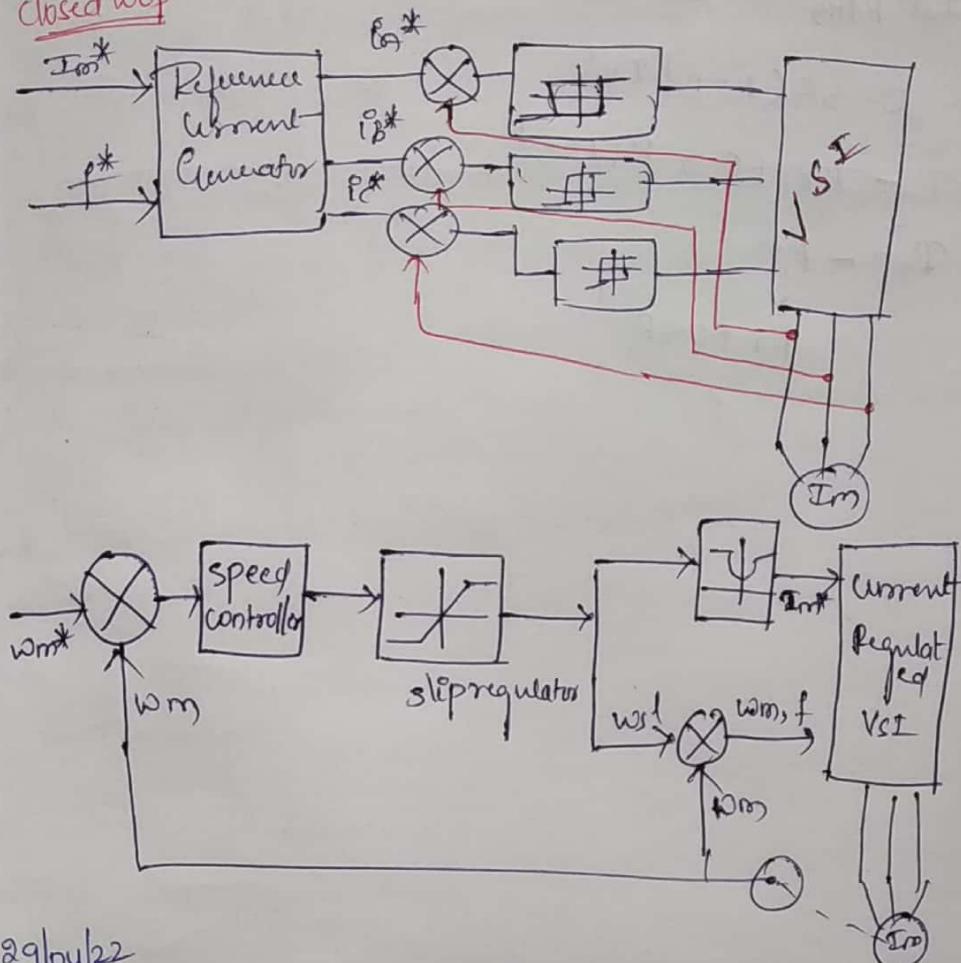


$$i_A^* = \text{Im} \sin \omega t$$

$$i_B^* = \text{Im} \sin (\omega t - 120^\circ)$$

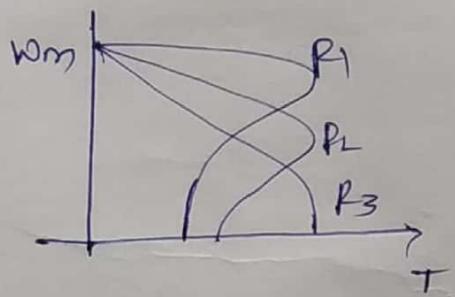
$$i_C^* = \text{Im} \sin (\omega t - 240^\circ)$$

Closed loop



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Rotor Resistance control :-



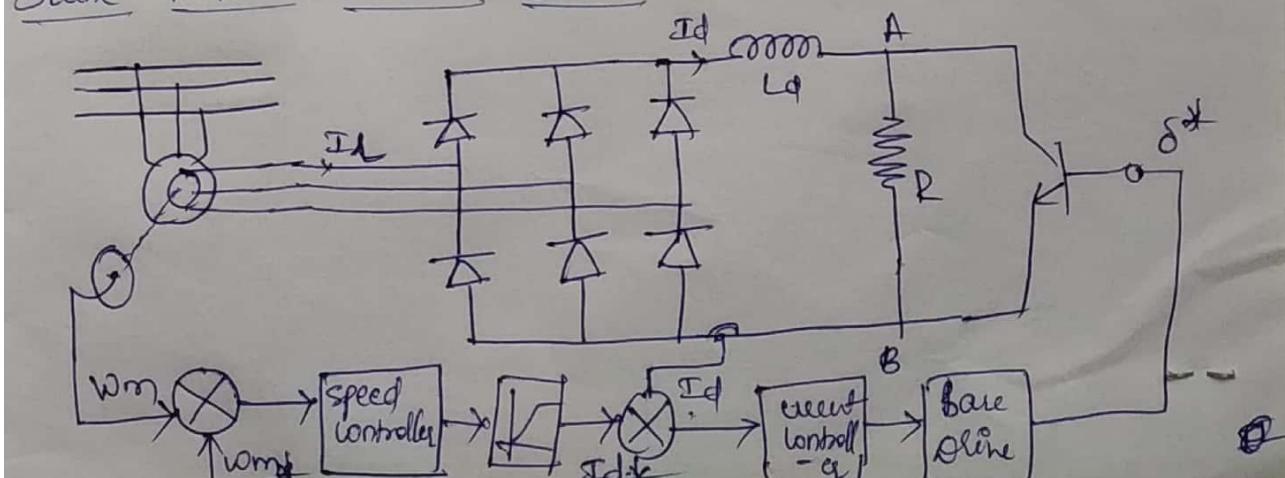
$$R_1 < R_2 < R_3$$

Variable frequency-expensive

Variable Resistance - cheap

low n.t., heating loss

Static Rotor resistance control :-



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

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

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

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

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

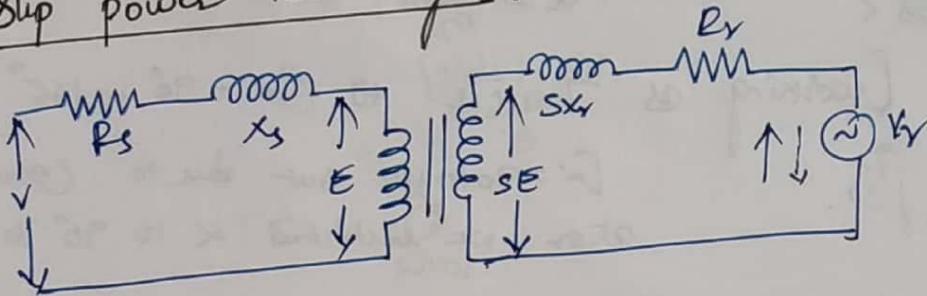
$$R_{rT} - R_r$$

$$\downarrow \\ R_r + 0.5R$$

10/5/22

PED

Slip power recovery :-

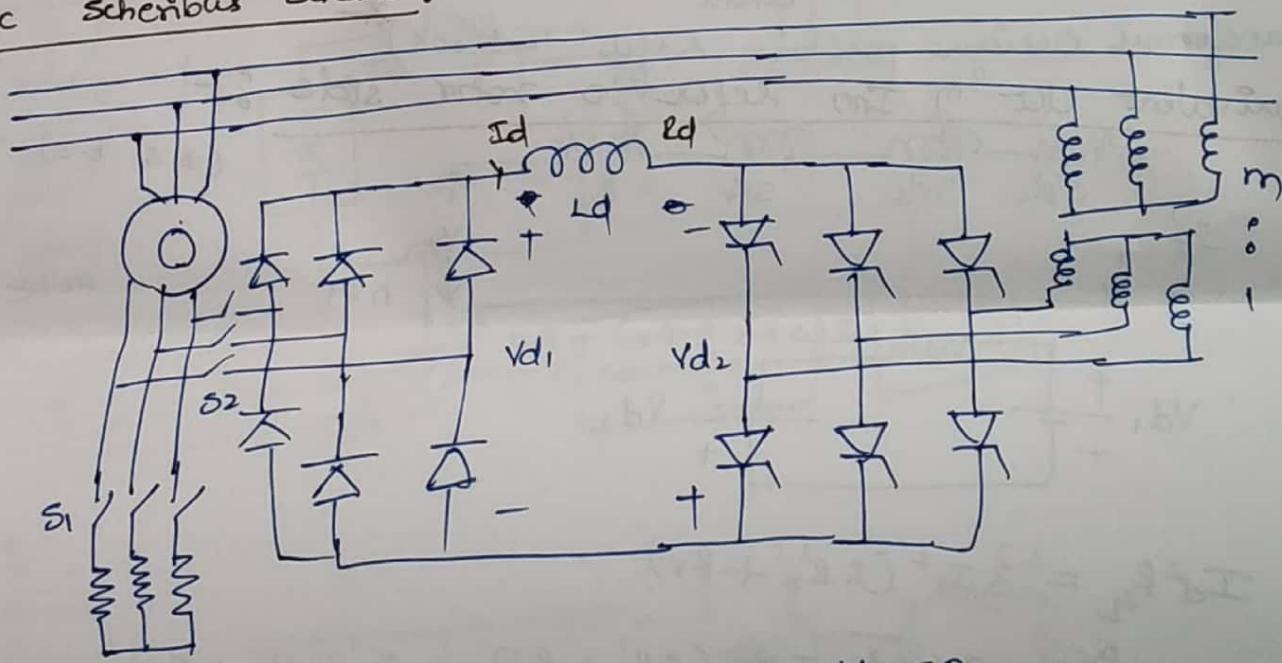


$$P_m = P_g - P_r \quad P_g = \text{airgap power}$$

P_r = Power of injected source

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

Static Schenibus Scheme :-



$$V_{d1} + V_{d2} = 0$$

$$V_{d1} = \frac{3\sqrt{6}}{\pi} \frac{S}{n} Y$$

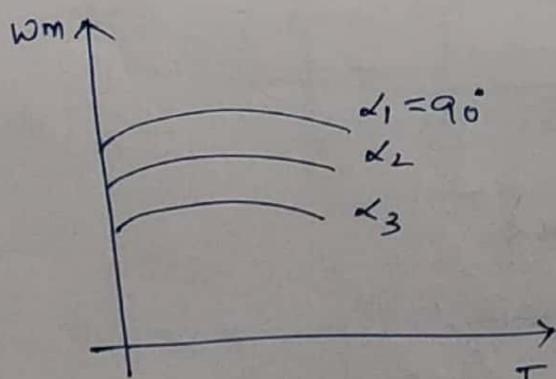
n = stator to rotor turn ratio

$s \Rightarrow \text{slip}$

$$V_{d2} = \frac{3\sqrt{6}}{\pi} \frac{Y}{m} \cos \alpha$$

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

m = turns ratio of transformer



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

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

$$S = -\frac{V}{m} \cos \alpha$$

$$S = a \cos \alpha$$

$$a = -\frac{V}{m}$$

[Working as Thruster so $\alpha = -90^\circ \text{ to } 165^\circ$]

$\alpha = 90 \text{ to } 180^\circ$ but due to constraint we restricted α to $90^\circ \text{ to } 165^\circ$

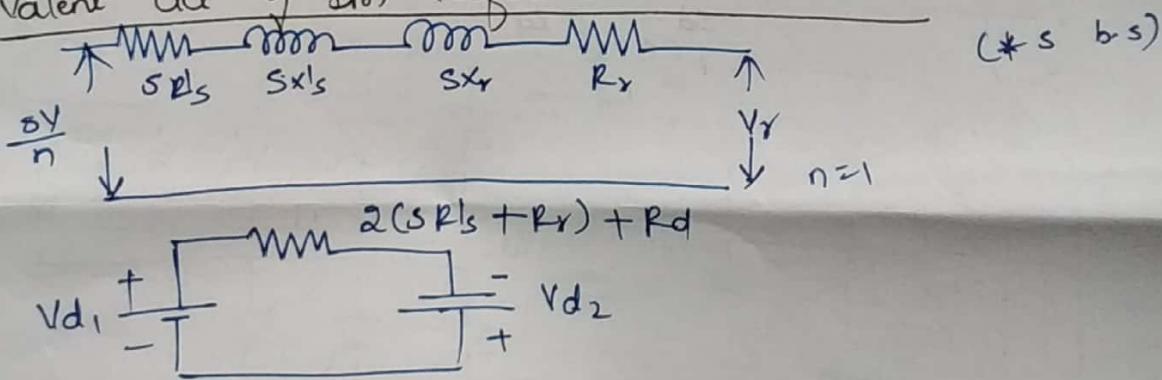
at S_{max} we get $V_{d1, max}$

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

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

(Transformer design problems refer textbook)*

Equivalent circuit of Im refer to rotor side :-



$$Id^2 R_s' = 3 Id^2 (S RL_s + R_r)$$

$$R_{eq} = 3 \times \left(\frac{2}{3} Id^2 (S RL_s + R_r) \right) = 2 (S RL_s + R_r)$$

$$Id = \frac{V_{d1} + V_{d2}}{2 (S RL_s + R_r) + Rd}$$

$$= \frac{\frac{3\sqrt{f}}{\pi} \frac{sy}{n} + \frac{3\sqrt{f}}{\pi} \frac{V}{m} \cos \alpha}{2 (S RL_s + R_r) + Rd}$$

$$= \frac{\frac{3\sqrt{f}}{\pi} V \left[\frac{3}{n} + \frac{\cos \alpha}{m} \right]}{2 (S RL_s + R_r) + Rd}$$

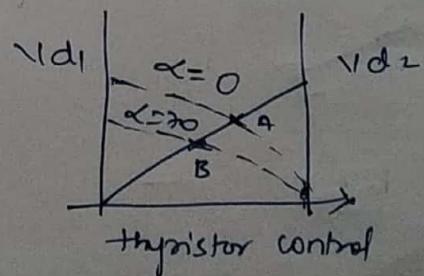
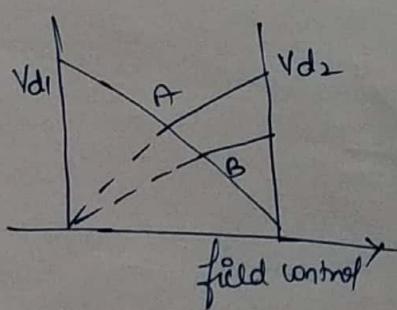
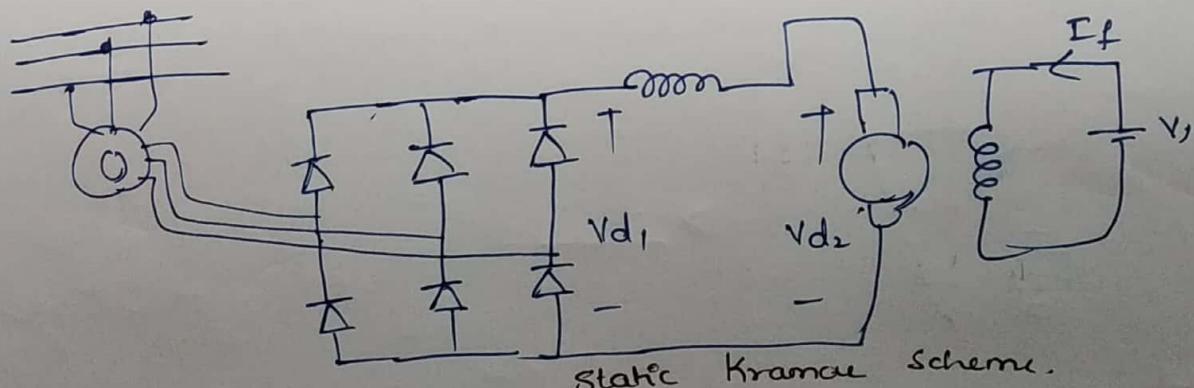
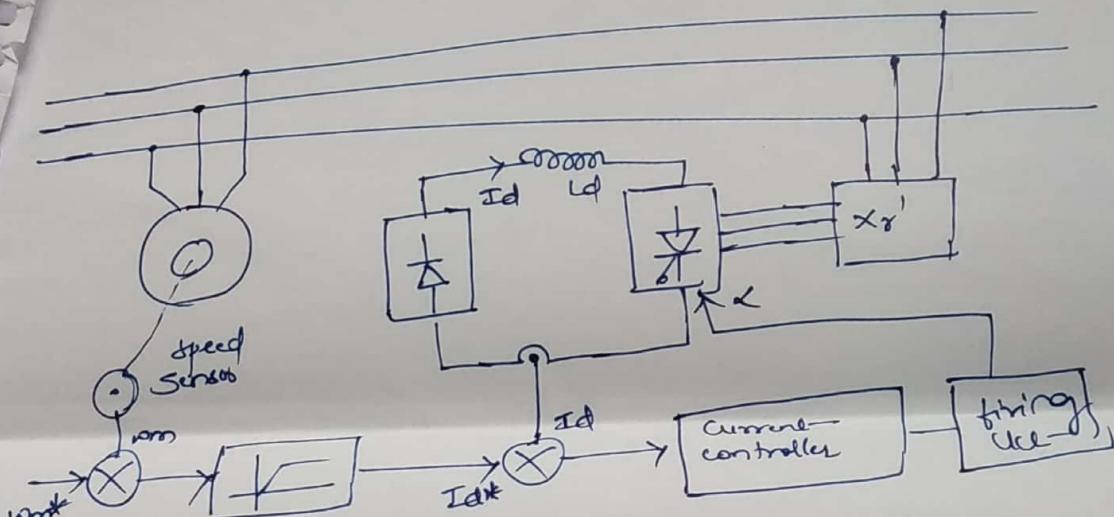
If rotor copper losses is Neglected.

$$SPg = |Vd_2| I_d$$

$$P_g = \frac{|Vd_2| I_d}{s}$$

$$T = \frac{P_g}{\omega_m s}$$

$SPg \rightarrow$ slip power
 ↳ fed back to ac supply
 $s=20\%$, then rating
 of generator + torque
 should be 20% only.



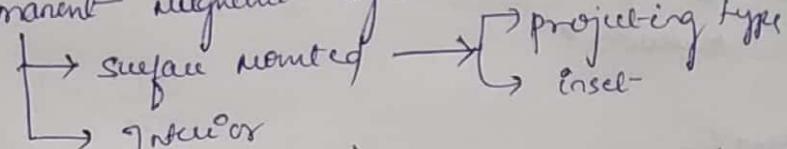
Synchronous motor :- PF can be unity lag | leading | unity | 9/5/22

- 1) wound field Synchronous motor salient pole → cylindrical → uniform airgap
- 2) Permanent magnet synchronous motor (PMSM) 3φ stator winding
- 3) Switch Reluctance motor (SRM) 1φ stator winding
- 4) Hysteresis motor

Cylindrical → uniform airgap → higher mechanical strength, high speed

Salient :→ poles are projected, low speed.

2) permanent magnetic synchronous motor (PMSM) (unity pf)



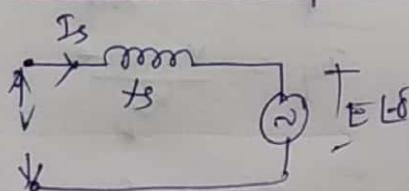
* high pf & high efficiency compared induction motor

* PMSM has low losses and high efficiency bcz of low losses
It is possible to make motor with high power density
and Torque to Friction 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 align themselves with synchronously rotating field produced by salar.

Equivalent circuit of cylindrical motor :-



$E \Rightarrow$ Excitation

$X_s \Rightarrow$ Synchronous reactance

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

$$I_s = \frac{V \angle -90^\circ - E \angle -\delta}{jX_s}$$

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

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

$$\cos(-\delta) = \cos\delta$$

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

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

Neglecting stator copper loss

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

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

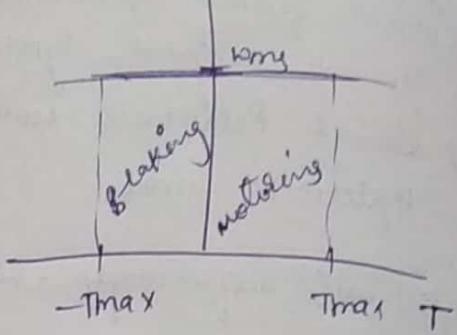
Considering fixed frequency

$$T = \frac{3VE \sin\delta}{x_s W_{ms}}$$

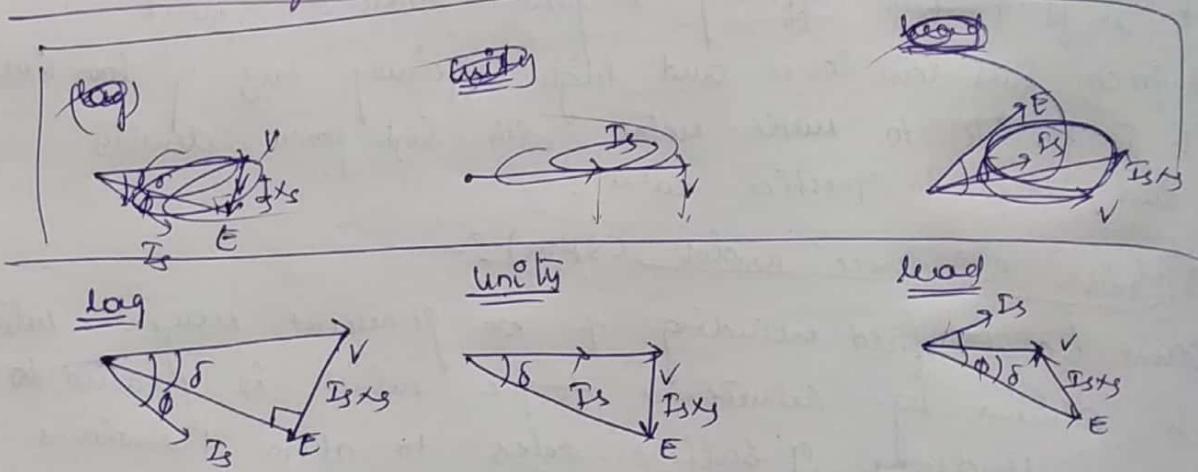
δ → power angle / torque angle

δ → +ve when E lags V

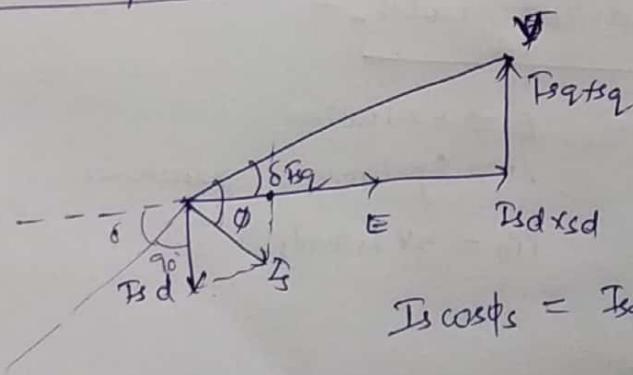
δ → -ve when E leads V



Phasor Diagrams :-



Salient pole wound field motor :-



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

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

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

~~$$= \frac{(V \cos\delta - E) \cos\delta}{x_{sd}} -$$~~

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

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

$$= \frac{V \sin\delta}{x_{sq}} \cos\delta - \underbrace{\frac{V \cos\delta \sin\delta}{x_{sd}}}_{+ \frac{E \sin\delta}{x_{sd}}}$$

$$T_{max} = \frac{E \sin \delta}{x_{sd}} + \frac{V^2 (x_{sd} - x_{sq})}{2 x_{sd} x_{sq}} \sin 2\delta$$

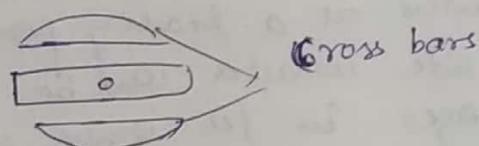
$$\left\{ \begin{array}{l} \frac{V \cdot E \sin 2\delta}{2 x_{sq}} - \frac{V \sin 2\delta}{2 x_{sd}} \\ \Rightarrow V \sin 2\delta \left[\frac{x_{sd} - x_{sq}}{2 x_{sq} \cdot x_{sd}} \right] \end{array} \right\}$$

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

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

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

Hysteresis motor



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

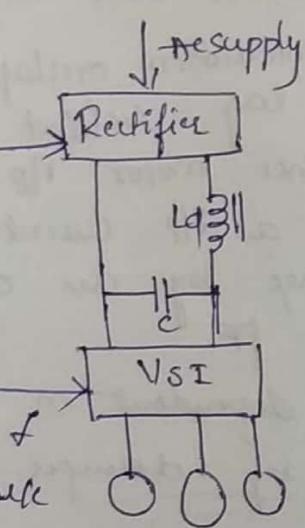
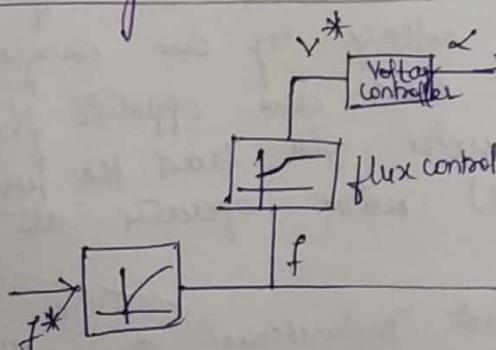
18/5/22 Synchronous motor Variable speed Drive :-

True synchronous node

self controlled mode

[damping winding is not required]

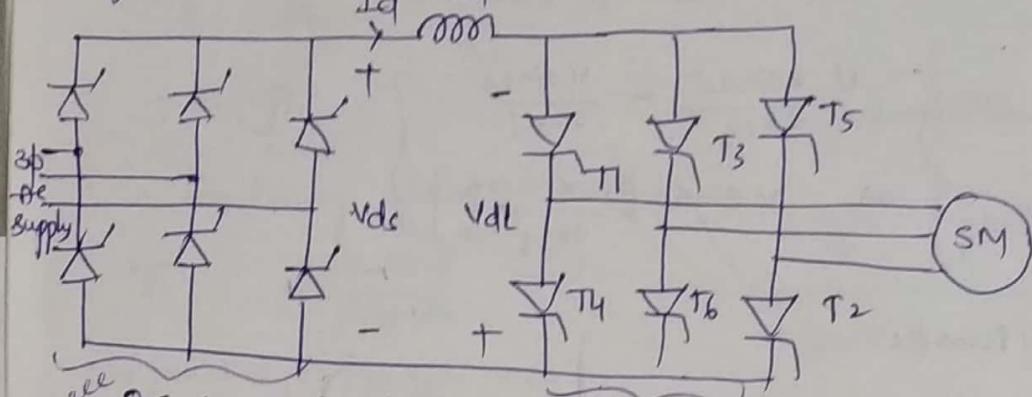
True synchronous node :-



~~Self~~ → loading suddenly some times we will lose synchronism. ~~Consequence~~ pull out

- 1) Synchronous reluctance motor
- 2) PMSM

Self controlled mode :-



source side converter $0^\circ < \alpha_s < 90^\circ \rightarrow$ Rectifier
 V_{d+ve}, I_{d+ve}
 $90^\circ < \alpha_s < 180^\circ \rightarrow$ Inverter

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

→ $0^\circ < \alpha_s < 90^\circ$ → line commutated rectifier

→ load side Inverter

when synchronous motor operates as a leading power factor
 thyristor of the load side converter can be commutated
 by motor induced voltage 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 (β_L) = $180^\circ - \alpha_L$

→ β_L commutation overlap is ignored. $\frac{1}{2} p$ ac current of
 converter lag behind $\frac{1}{2} p$ ac voltage by an angle
 α_L . Since motor $\frac{1}{2} p$ ac current has an opposite phase
 to convert a $\frac{1}{2} p$ ac current the motor will lead the $\frac{1}{2} p$ ac
 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
commutation overlap

$$\gamma = wt_q$$

↑ turn off time of thyristor

$\beta_L \rightarrow$ kept minimum

Constant Margin angle Control :-

- α is dependent on I_d
- In a simple control scheme the drive is operated at fixed value of commutation lead angle $\beta_{critical}$ (β_{lc}) for the load side converter working as inverter, and $\beta = 0^\circ$ or 180° when working as a rectifier.

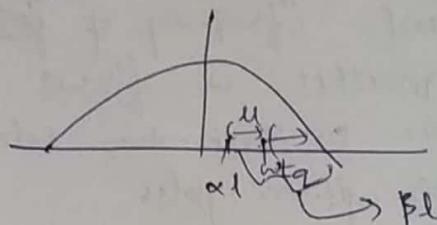
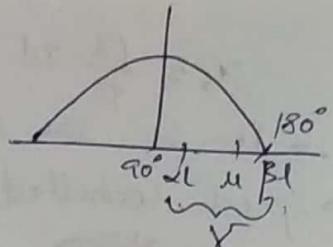
20/5/22

PED

$$\beta_L = \alpha_L + \beta_L = \min.$$

$$\beta_L = 180^\circ - \alpha_L$$

$$\gamma = \beta_L - \alpha_L$$



$\beta_L < \alpha_L$
so that γ is more

→ for the load side Inverter α_L is the firing angle
the stator current lags the stator voltage by α_L motor current is opposite to stator current and it leads the voltage by β_L which is the commutation load angle.

→ β_L has to be as low as possible so that the PF is near to unity. This can happen only when α_L is maximum after providing allowance for turn off time of the thyristor and commutation overlap.

$$\gamma = \beta_L - \alpha_L$$

→ commutation overlap γ depends on DC link current I_d and $\tau_q = \omega t_q$, t_q is turn off time of the thyristor,
 ω = frequency of supply

→ β_L is calculated after knowing γ + α_L if β_L is fixed at minimum value so that PF which will reduce the converter rating

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

→ thyristors are commutated by stator induced voltage and it doesn't require special commutation cells & process is known as load commutation.

Advantages of load commutation

- doesn't require commutation cells
- a frequency of commutation can be higher
- it can be used for medium power levels.

$$T_S = \frac{f_0}{\pi} I_d$$

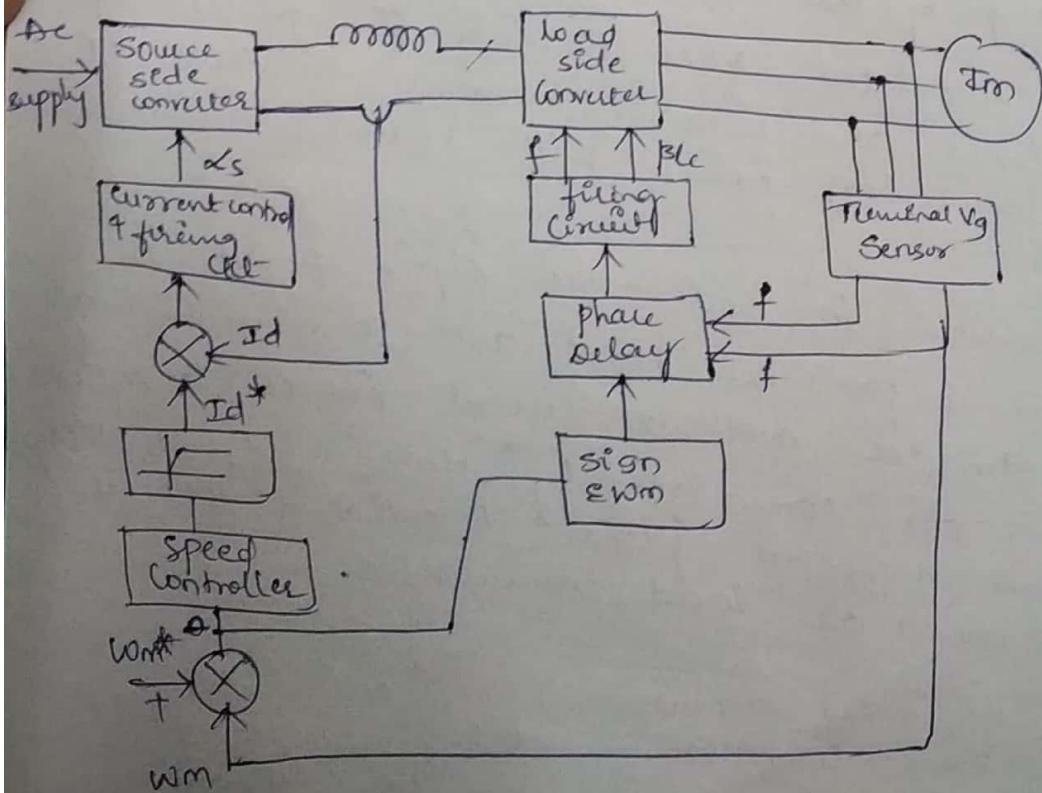
→ it is the step off.

→ speed controlled by self controlled mode by sensing the rotor induced emf. (frequency of ~~the~~ phase is analyzed) and the generator is fixed for the same frequency and phase so that the rotor poles are themselves aligning 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~~ position of the rotor sensor with respect armature terminal voltage.

~~Pulsed mode~~ Pulsed mode - 10% of synchronous speed.

→ ~~the~~ 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' across reverse, the reverse voltage is applied to the conducting thyristors and thyristor current is forced to zero. → then the source side converter is made to work as rectifier this happens for every 60° .

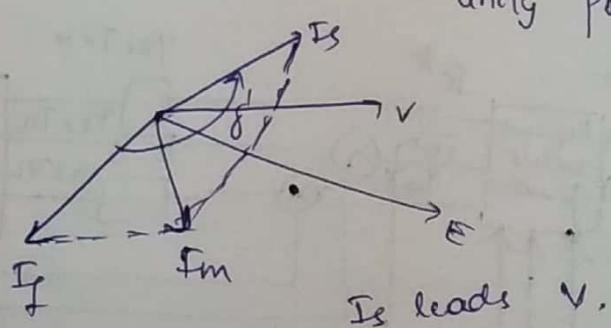
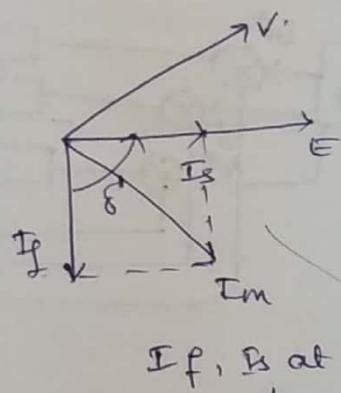
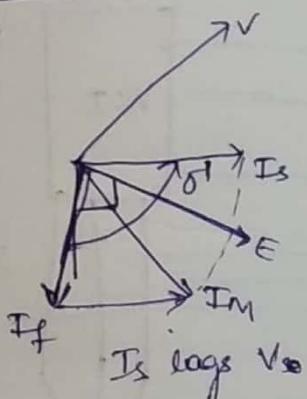
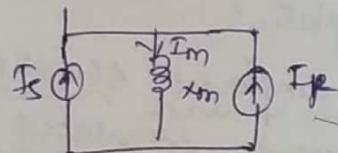
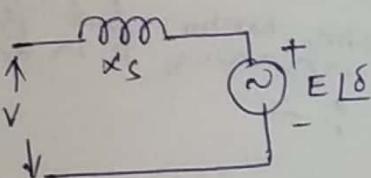


for regenerative braking $\beta_L = 180^\circ$

24/5/22
Permanent magnet synchronous motors :- (PMSM) (PMAC)
 Depending upon how the rotor is excited it is
 classified into

1) Sinusoidal \Rightarrow trapezoidal

- \rightarrow they are controlled by means of variable frequency voltage source or variable frequency current source.
- \rightarrow they are controlled by ~~or~~ self controlled manner by means of rotor position sensors.
- \rightarrow they are known as brushless motors.



$$I_f = \frac{E}{jX_s}, \quad I_m = I_f + I_s$$

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

$$[E = \pm I_f]$$

$$T = \frac{P_m}{\omega_{ms}} = K \propto I_f I_m \delta$$

$$K = \frac{3 X_s}{\omega_{ms}}$$

$$(T = T_{max} \text{ at } \delta = 90^\circ) \text{ at upf} \quad \delta \rightarrow \text{angle} \rightarrow \frac{\theta}{I_f}$$

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

\rightarrow Up to base speed (V_f) = constant, ~~Drop to~~

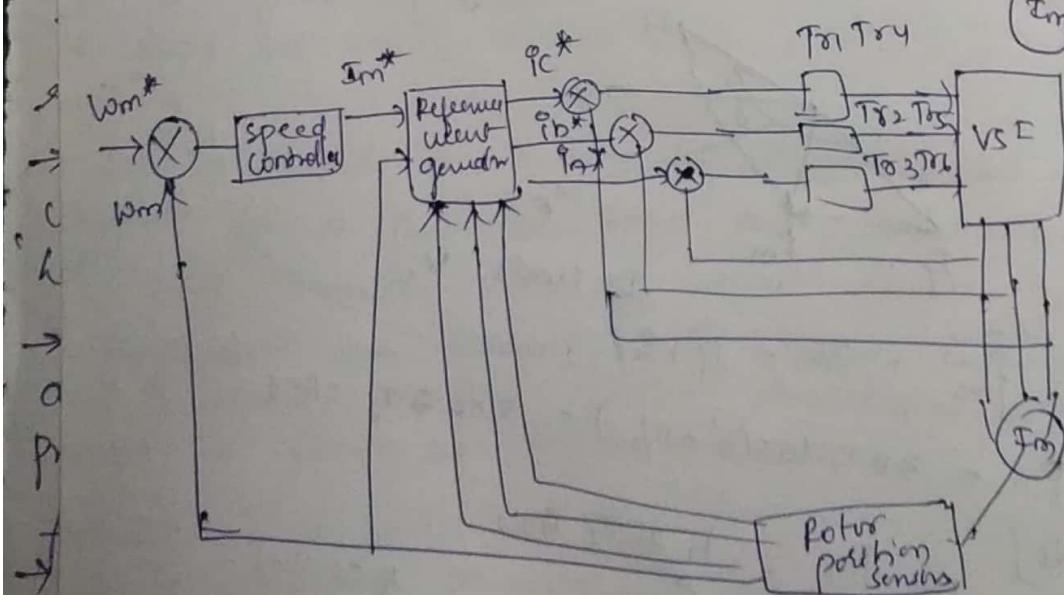
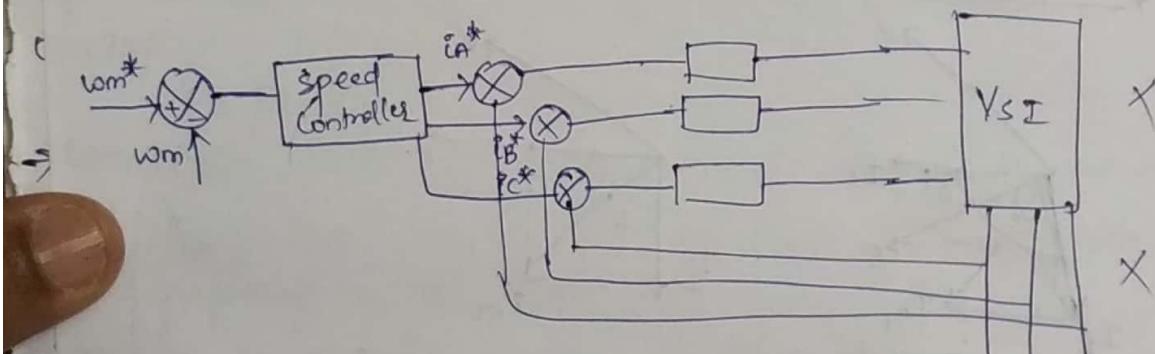
above " " (V_f) \neq constant
f \uparrow so $\phi \downarrow$ so it is operated in

flux weakening mode.

\rightarrow In flux weakening mode the angle between I_s & F_f is increased so that I_m is decreased.

\rightarrow Rotor south pole axis is 180° out of phase with the going zero crossing arm. stator phase-A current. This information is used from rotor position sensors to generate the reference sine template.

Servo Drive Employed Sinusoidal pulse motor fed from a current regulated VSI :-



- If error tre speed controller accelerates or if it is negative it will decelerate.
- It is a current regulated VSC
- Trapezoidal | vector controlled speed control) * exam
phase MLC (5M/10M)
from chopper controlled of DC till now)