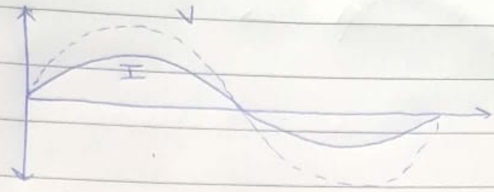
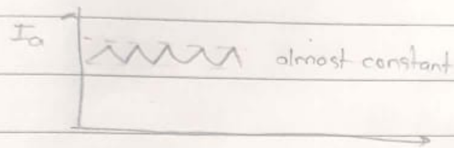
D] Inverter Current Control

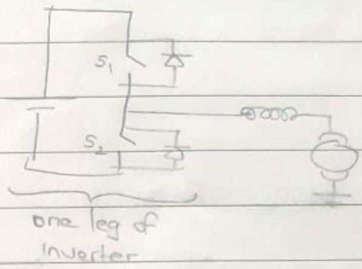
We want $PF = 1$
$S = P$

How to ensure that current flowing into the grid is in phase with V



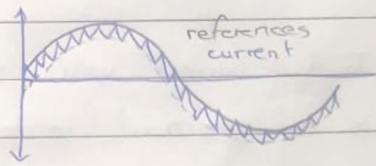
* Remember Regenerative braking





→ Hysteresis Band Current Controlled PWM.

Step 1 Generate reference sinusoid in phase with grid voltage V_2 and of required magnitude. (multiply by constant < 1)



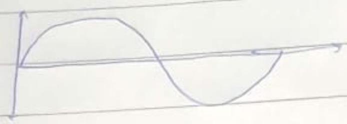
Step 2 Modulate S_1 such that current fits the reference

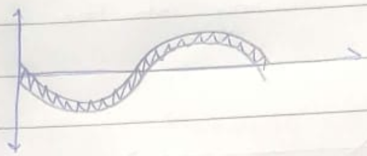
→ Can we use sinusoidal PWM to obtain unity PF?
- Yes, indirectly.
- Obtain $V_1 = V_m \sin(\omega t + \delta)$ using PWM

$$i = \frac{V_1 \angle \delta - V_2 \angle 0}{j X_L} \quad \Rightarrow L\frac{di}{dt} = V_m \sin(\omega t + \delta) - V_m' \sin$$

⇒ Current will be forced to be sinusoidal and in phase

→ We know now how to transfer power from DC to AC at UPF
We can do reverse (AC to DC at UPF) by reversing current direction.





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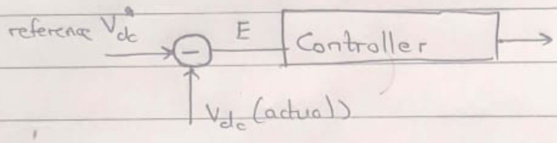
* Quiz Review



$E = V_{dc}^* - V_{dc}$
$= 0$ (steady state)

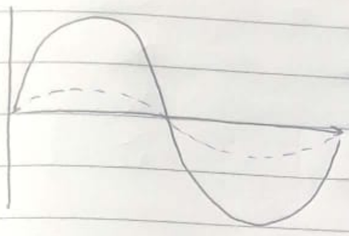
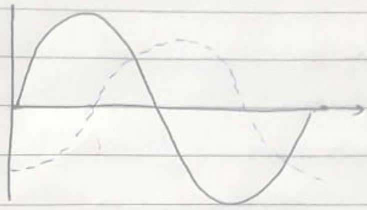
- To find correct value of δ, finding V_1, V_2, X and matching power is not practical in real time. Use a controller.

- If there is a power mismatch, V_{DC} will change
- When $E \neq 0$, we change $P = \frac{V_1 V_2}{X} \sin\delta$ as required to make $E = 0$

- Sinusoidal PWM :- If $V_{DC} < V_{DC}^*$, decrease P by changing (increase $|P|$)

- Current PWM :- $P = V_1 I_1$:- If $V_{DC} < V_{DC}^*$ decrease P by decreasing I.
  $(\cos\theta = 1)$

If $PF \neq 1$, Power transferred $\propto I \cos\theta$

 + 

In-phase current component	Quadrature current component
($I \cos\theta$)	($I \sin\theta$)
Non-zero power	Zero 'active' power

* Output voltage of sinusoidal PWM inverter $= \underset{\substack{\uparrow \\ MI}}{m} V_{DC} < V_{DC}$

'Buck operation'

* CSI :- ~~We~~ Boost operation

Close $S_1 S_4$ together $\Rightarrow$ current $\uparrow$, energy stored

↳ no short-circuit because of inductor

Open $S_1 S_4$ $\Rightarrow$ current $\downarrow$, energy transferred to output

Brushless DC machine :- Synchronous

Page No.:

SYNCHRONOUS MACHINES

	Stator I	Rotor
DC	DC	DC
Induction	AC	AC
Synchronous	3∅ AC DC	DC AC

- Steady state speed of synchronous machines = N_s = independent of load.

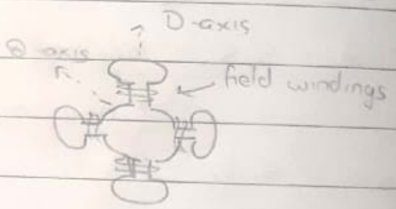
- High power applications (~ MW)

* Induction machine :- PF is always lagging because of magnetizing

- Stator of SM is like IM, but rotor is DC.

eg To generate 50 Hz, prime-mover should rotate 2-pole rotor at 3000 rpm.

- Rotors → Cylindrical (2 pole)
  → Salient pole (4 pole)



- Air gap is not uniform
- Unsuitable for high speed.
- Air gap is very small along field (direct (D)) axis
- Angle between direct axis and quadrature axis
  = 45° mechanical = 90° electrical
- Air gap is large along Q-axis
- ∴ Reluctance along Q >> Reluctance along D

$R_Q >> R_D$

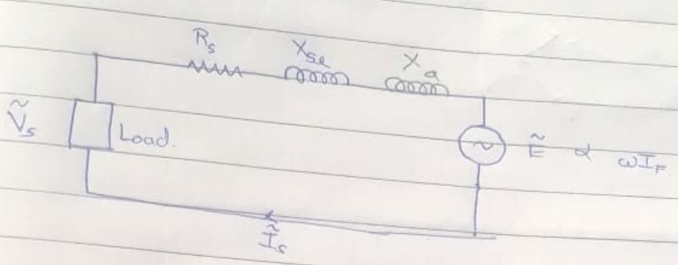
- ☆ $X_Q << X_D$

- When rotor is driven at 3000 rpm, DC field (of rotor) is rotating at 3000 rpm.

Voltage induced in stator is AC ∴ $E = 4.44 \phi f N$

$E \propto \omega I_f$

- Different characteristics are obtained when stator is connected to local load and grid.



- Flowing current I_s produces its own field, which interacts with original field.
- I_s can be lagging, leading, or in-phase depending on load.
- New field can oppose, aid or do nothing to original field.

aids in some places
opposes at others
"Cross Magnetization"

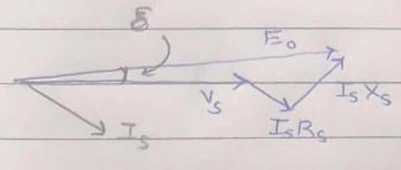
- We account for effect of stator flux on field flux by adding X_a to equivalent circuit. (only for representation)

$$X_a = \text{Armature Reaction Reactance (fictitious)}$$

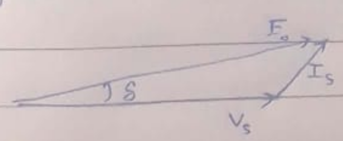
$$X_a + X_{s\ell} = X_s = \text{Synchronous reactance}$$

$$Z_s = \text{Synchronous Impedance} \approx jX_s$$

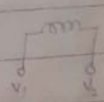
- If I_s is lagging V_s.



Ignore the resistance



$$P = \frac{E_0 V_s}{X_s} \sin\delta$$

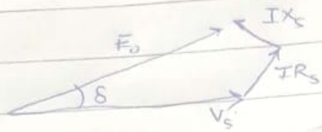


GBA derive without ignoring resistance

GBAFO formula for Q

What we have studied

- If I_s is leading



GBAFO In which of above cases does

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- $R_s << X_s$

→ When machine is connected to the grid, V and f cannot change.

- Since I/P Power is held constant, active component of current cannot change.
- Reactive current can change.
- PF can change
- Accordingly, $E_o \angle \delta$ can change.

GBAFO Locus of current

* DC Machine :- Projected poles on stator, cylindrical rotor
Synchronous rotor ?

Both have non-uniform air gaps.

I Synchronous Motor

- Three phase supply is given
- For steady torque, F_s and F_r should be stationary with respect to each other.

$$T \propto F_s F_r \sin\delta \qquad \delta \text{ should be constant}$$

- Speed of stator field (F_s) $= N_s$
  " " rotor " (F_r) $= N_r$ (initially zero)

- At smaller frequencies ($\downarrow N_s$), if inertia is small, rotor can catch up speed in spite of unsteady torque. If this happens we can very gradually keep increasing frequency, and rotor will accelerate (if inertia is small)
  We don't do this shizz.

- Rotor has two types of windings :- cage winding and field winding
- Because of cage winding, motor starts like an induction motor.
  However, this torque generated becomes zero at $N_r \to N_s$
- As $N_r \to N_s$, connect field winding.
  Now F_s & F_r are almost constant.
  N_r is brought up to N_s by this field torque

:) * Torque-producing losses of induction machine $(sP_{air\,gap})$ are absent in synchronous machine because $s = 0$

:(- But there still are (new) field copper losses

:) - To remove those, use permanent magnets instead of field winding ----- '~~PE~~ Permanent magnet motor'

:) - In normal synchronous machine, when $N_r = N_s$, if load is suddenly increased, $N_r \downarrow$. Then cage torque increases too. It tries to accelerate N_r.
Hence cage winding provides damping effect to N_r.

P.T.O

∴ - Since permanent magnet machines do not have cage winding, there is no damping. ⇒ Unstable.

- We can still use permanent magnet machines to drive fan/pump bec. $T_L \propto \omega_r^2$ does not change instantaneously.

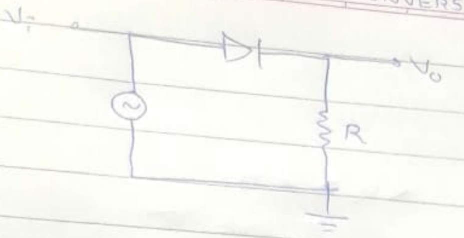
→ ~~Permanent magnet 'Synchronous' Machine~~

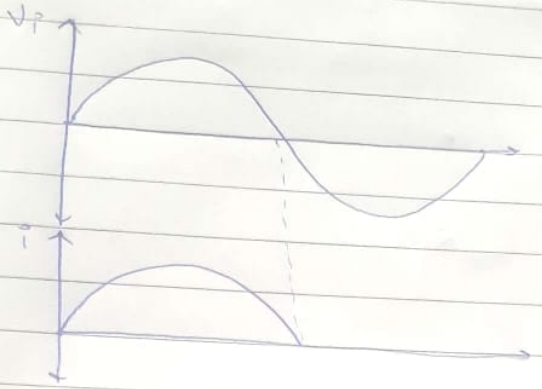
∵ • In general, stator frequency is independent of every disturbance. Keep stator frequency dependent on rotor speed, to overcome instability.

∴ - But we will not be able to maintain a single speed.

Use a brushless DC machine instead.

AC to DC Conversion





α = time when conduction starts = 0

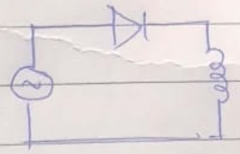
β = time when conduction ends = π

γ = time of conduction = π

- $\langle V_0 \rangle = \frac{V_m}{\pi}$
- Load current and source current has non-zero average value (DC current)
- The source may be coming from a transformer secondary

DC component of source current $\Rightarrow$ DC component of flux in core

$\rightarrow$ Replace R by L



Find nature of i
Integrate

- $\alpha = 0$
- $V_m \sin\omega t = L\frac{di}{dt} \Rightarrow i \uparrow$
- Current reaches peak at $\omega t = \pi \Rightarrow L\frac{di}{dt} = 0$
- After $\omega t = \pi$, $i \downarrow$ and becomes zero at $\omega t = 2\pi$

$\beta = 2\pi$

- Basically, $\langle V_L \rangle = 0$

→ Combination of R - L.

- $\alpha = 0$
- $\beta < 2\pi$, because now $\langle V_o \rangle \neq 0$.
- Current reaches peak between $\frac{\pi}{2}$ and π

$\uparrow$ when $L=0$ $\qquad$ $\uparrow$ when $R=0$

- $V_m \sin\omega t = iR + L\frac{di}{dt}$

When $i = i_{max}$, $V_m = i_{max} R$

- $\gamma < 2\pi$
- $\langle V_o \rangle$ is between $\frac{V_m}{\pi}$ and 0

when $L=0$ $\qquad$ when $R=0$

- When γ increases, $\langle V_o \rangle$ decreases.

This is because beyond $\omega t = \pi$, $V_m < 0$.