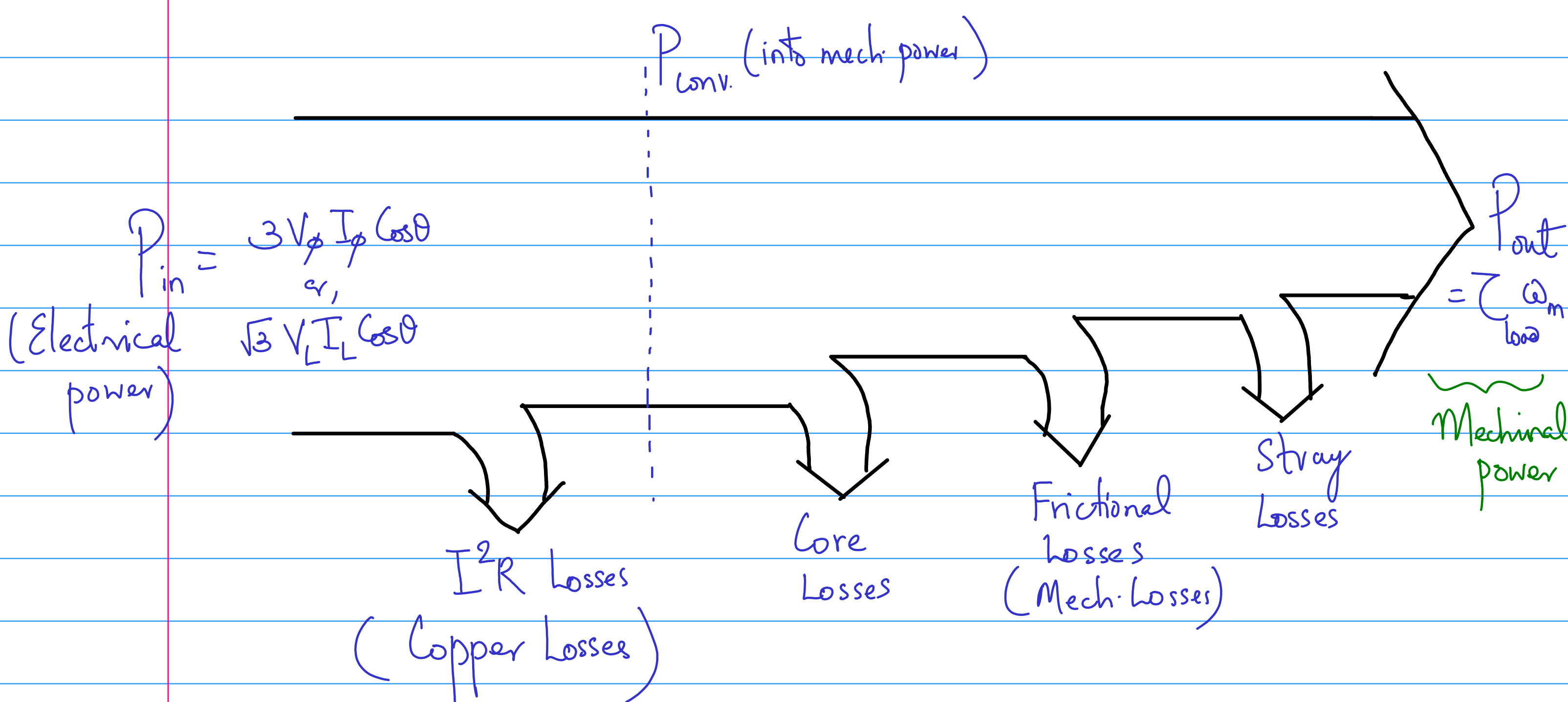
16.07.2021

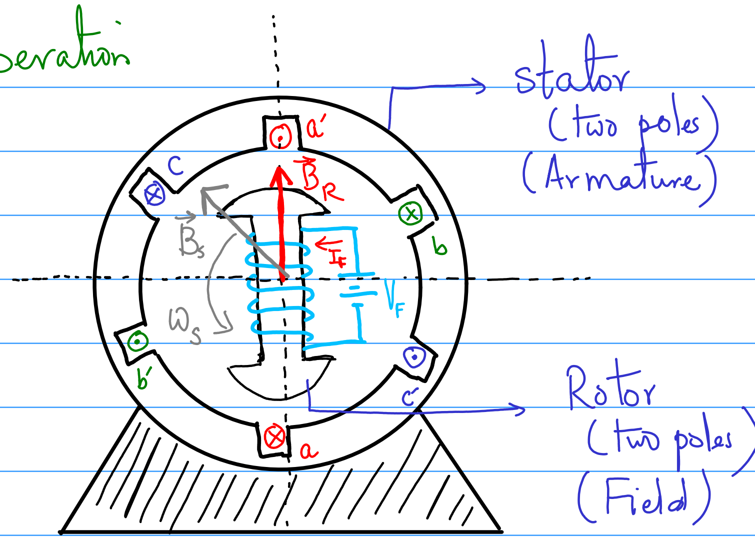
Synchronous Motors

(Ref. Chapter 6)

- Conversion of electrical power to useful mechanical power.
- A sync. motor is the "SAME" physical machine in all respect as a sync. generator.
- Except the direction of power flow is "REVERSED".
- Also, all basic understandings (deductions) of speed, torque eq^n apply to sync. motor as well.



Basic principle of Operation of sync. motor:



- $\vec{B}_R$ = steady-state magnetic flux density produced by the field current I_F.

- 3ϕ set of currents in the stator (Armature) windings produces uniform rotating magnetic flux density.

- The two fields, ie, $\vec{B}_s$ & $\vec{B}_R$ interacts.

$$\vec{\tau}_{ind} = k \, \vec{B}_R \times \vec{B}_s \quad \text{... in counterclockwise direct}^n.$$

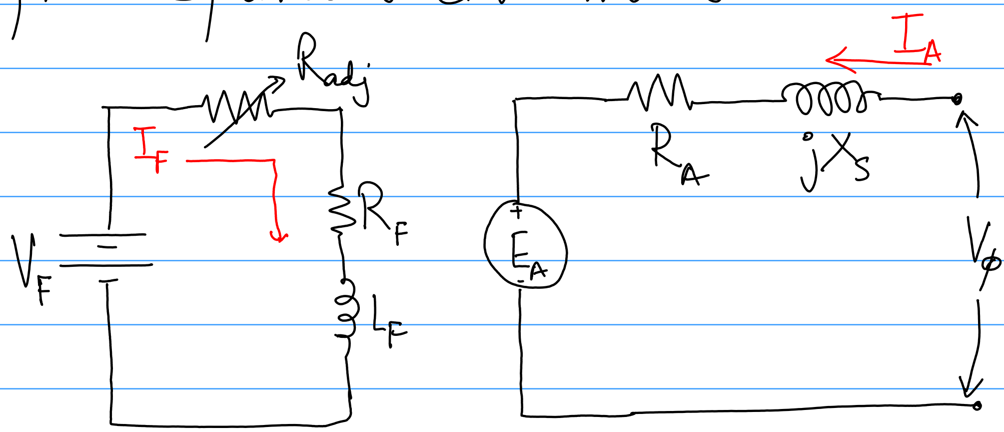
- As a result of this interaction, the rotor field ($\vec{B}_R$) will tend to "Line Up" with the stator field ($\vec{B}_s$)

- Therefore, $\vec{B}_R$ trying to never ending catchups with $\vec{B}_s$.

Equivalent ckt. model of Sync. Motor.

- Since it is the same machine as sync. generator, the equivalent ckt. model remains the same.
- However, the direction of current flow in armature winding (I_A) is "REVERSE".

per-phase equivalent ckt. model.



Apply KVL to the armature ckt.

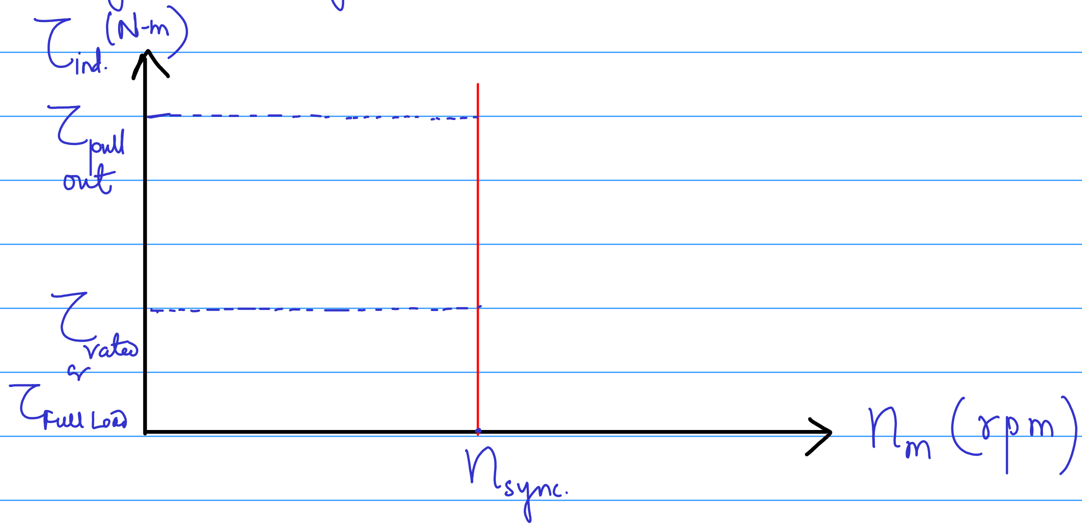
$$V_\phi = E_A + jX_S I_A + R_A I_A$$

$$\Rightarrow \quad \boxed{E_A \text{ (sync. motor)} = V_\phi - jX_S I_A - R_A I_A}$$

$\Rightarrow$ Recall $\boxed{E_A \text{ (sync. gen.)} = V_\phi + jX_S I_A + R_A I_A}$

Torque-speed characterstics of Sync. Motor

- It is a "CONSTANT-SPEED" machine.
- That is, the speed of the motor is locked to the applied electrical frequency.
- Therefore, the mechanical speed remains constant regardless of variation in the mechanical load.



$$\text{Speed regulation, } SR = \frac{n_{NL} - n_{FL}}{n_{FL}} \times 100\,\%$$

Since speed = constant (Regardless of mech. Load)

$$SR = 0\ \%$$

Recall;

$$\tau_{ind} = k B_R B_{net} \sin\delta$$ (where 'δ' is the torque angle)

$$\tau_{ind} = \frac{3 V_\phi E_A \sin\delta}{\omega_m X_s}$$ (in terms of Electrical Comp.)

the maximum $\tau_{ind} = \dfrac{3 V_\phi E_A}{\omega_m X_s}$ when $\delta = 90^\circ$

Typically, $\delta \sim 15^\circ - 20^\circ$

typically, $\tau_{pull\text{-}out} \sim 3$ times $\tau_{rated/Full\ Load}$

"Think about what happens when the torque on the shaft of a sync. motor exceeds the $\tau_{pull\text{-}out}$".

Ques: What happens when the mechanical load is varying?

If load $\uparrow$ $\Rightarrow$ The rotor speed $\downarrow$ (momentarily) $\Rightarrow$ Torque angle δ $\uparrow$

$\tau_{ind} \uparrow$

This eventually speeds up the rotor and it gains the sync. speed.

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STARTING A SYNC. MOTOR

Ques: How does the sync. motor get to sync. speed?

- Supplying DC field current $\rightarrow \vec{B}_R$
- Supplying 3-ϕ ac currents in stator $\rightarrow \vec{B}_s$ rotating

$\vec{\tau}_{ind} = k\, \vec{B}_R \times \vec{B}_s$

$f_e = 60\,Hz$

$\Rightarrow$ # oscillations in 1 sec = 60

$\Rightarrow$ for one complete osc., it takes $= \frac{1}{60}$ sec

Divide $\frac{1}{60}$ sec into four time instants

$t = 0$ sec, $\frac{1}{240}$ sec, $\frac{1}{120}$ sec, $\frac{3}{240}$ sec, $\frac{1}{60}$ sec

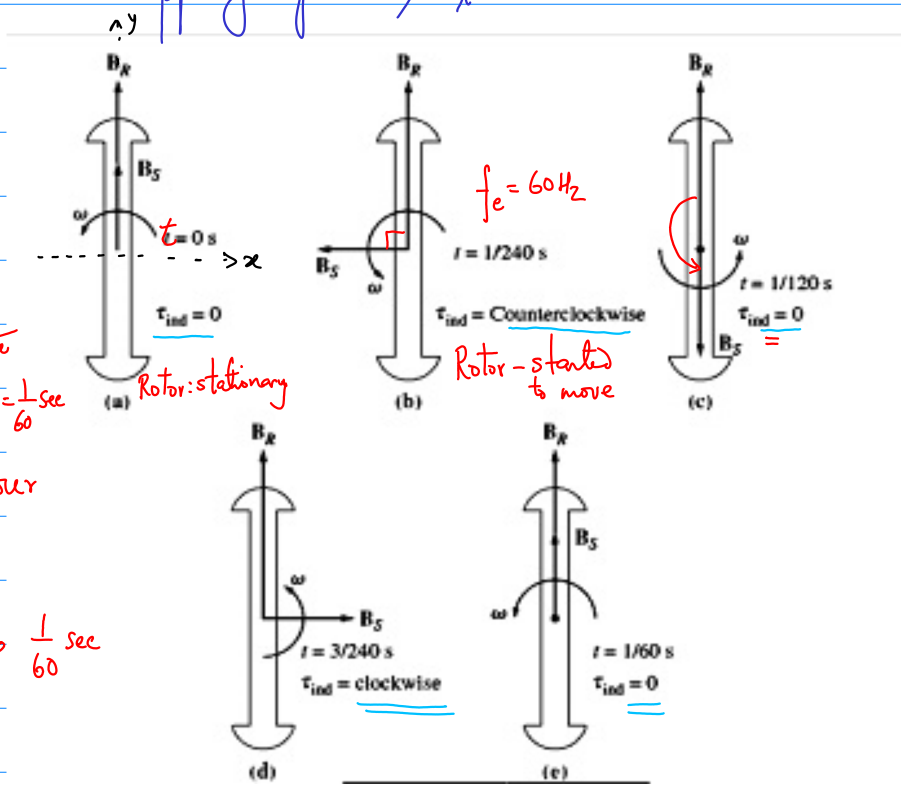


Fig 6.16

Observation:

- During 1st half cycle of electrical frequency:

  τ_{ind} = Counterclockwise direction.

- During 2nd half cycle of the elec. freq.

  τ_{ind} = clockwise direction.

As a result – $\tau_{ave,ind.}$ (in one cycle) $= 0$

$\Rightarrow$ Rotor of sync. motor does not move.

To start a sync. motor, the basic approaches are:

1) Reducing the speed of the rotating magnetic field produced by the stator.

For it, we need to reduce the electrical frequency.

$\Rightarrow$ We need extra-arrangement in the machine.

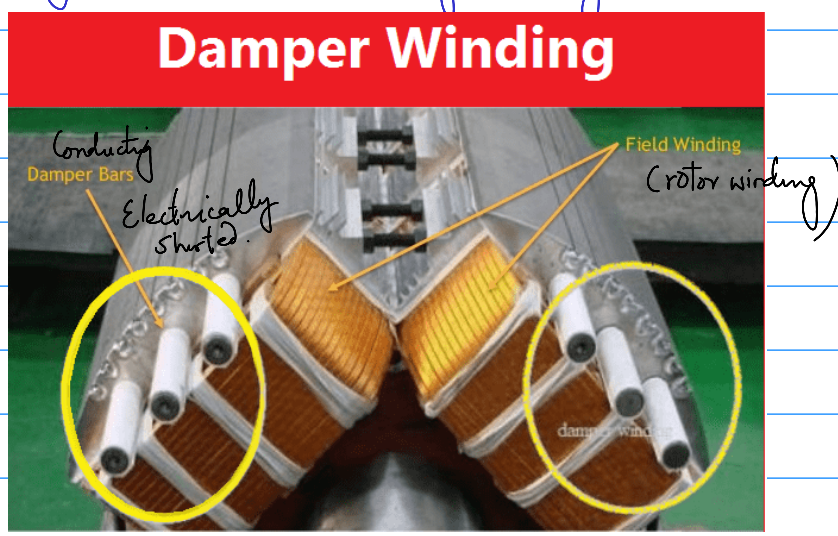
$\Rightarrow$ There are solid-state variable electrical drives available which can vary the input electrical frequency (50Hz/60Hz) from fraction to 50Hz/60Hz.

2) Use an external prime-mover to accelerate the rotor to sync. speed.

Once the sync. speed is achieved, the prime-mover is disconnected.

3) Use of damper winding (conducting bars) or, Amortissuer winding

- Special conducting bars laid into notches carved in the face of the rotor and then they are electrically shorted on each end by a conducting ring.



Initially,

(i) Disconnect the dc field current in the rotor winding

$\Rightarrow \vec{B}_R = 0$

(ii) Supply 3-ϕ ac current in the stator winding

$\vec{B}_s$ = rotating

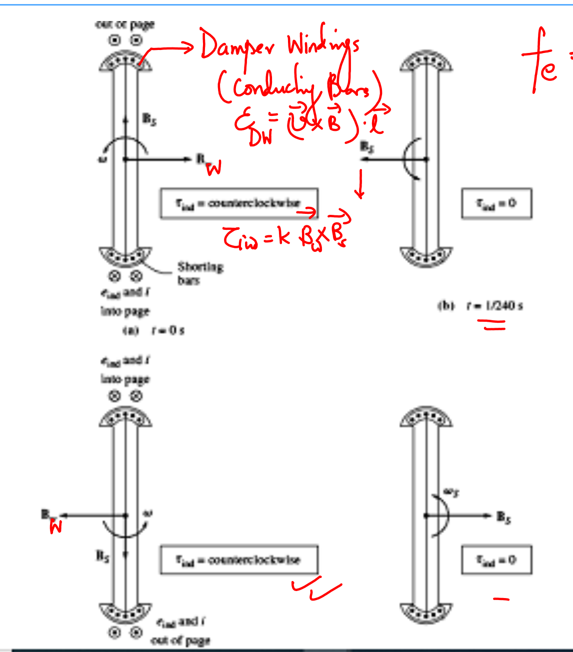


Fig 6.19

$f_e = 60Hz$

Observation: The is a "Unidirectional Torque" acting on the rotor.

$\Rightarrow$ This makes the rotor to catch up the sync. speed.

A sync. motor with damping rods:

1) Disconnect the field winding (ie $\vec{B}_R = 0$) from dc power supply & short the electrically.

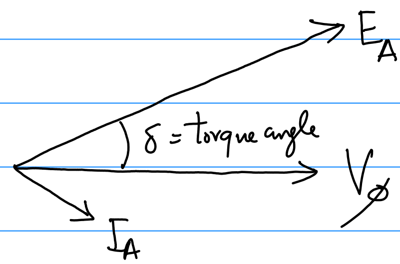
2) Apply 3ϕ voltage to the stator, and let the rotor to accelerate to near sync. speed.

3) Connect the dc field ckt, the motor locks into the sync. speed.

$\vec{B}_W = 0$ (ie, motional emf $= 0$ / Relative motion $= 0$)

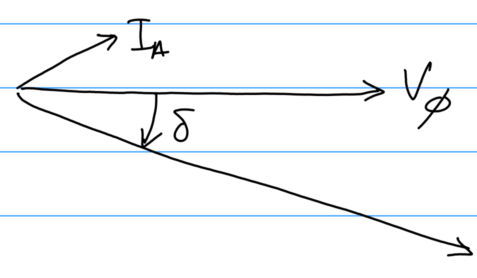
Comparison b/w Sync. Generator & Sync. Motor.

Supplies real power P (Generator)



E_A leads V_ϕ

Consumes real power P (Motor)



E_A lags the V_ϕ

Reactive Power, $Q = E_A \cos\delta > V_\phi$ (in both Sync. Generator & Motor)