SNS COLLEGE OF TECHNOLOGY

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COIMBATORE-35

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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

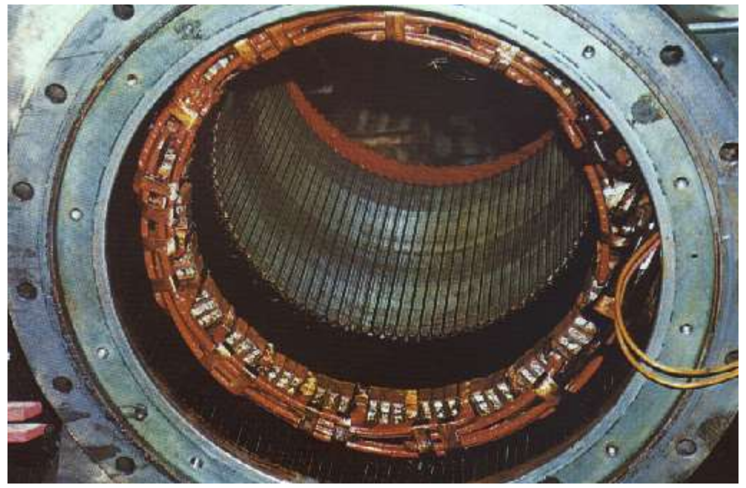
COURSE NAME: 23EET204/ ELECTRICAL MACHINES II

II YEAR / IV SEMESTER

Unit 2 – SYNCHRONOUS MOTOR

Topic 2: Torque Equation

GUESS THE TOPIC NAME…

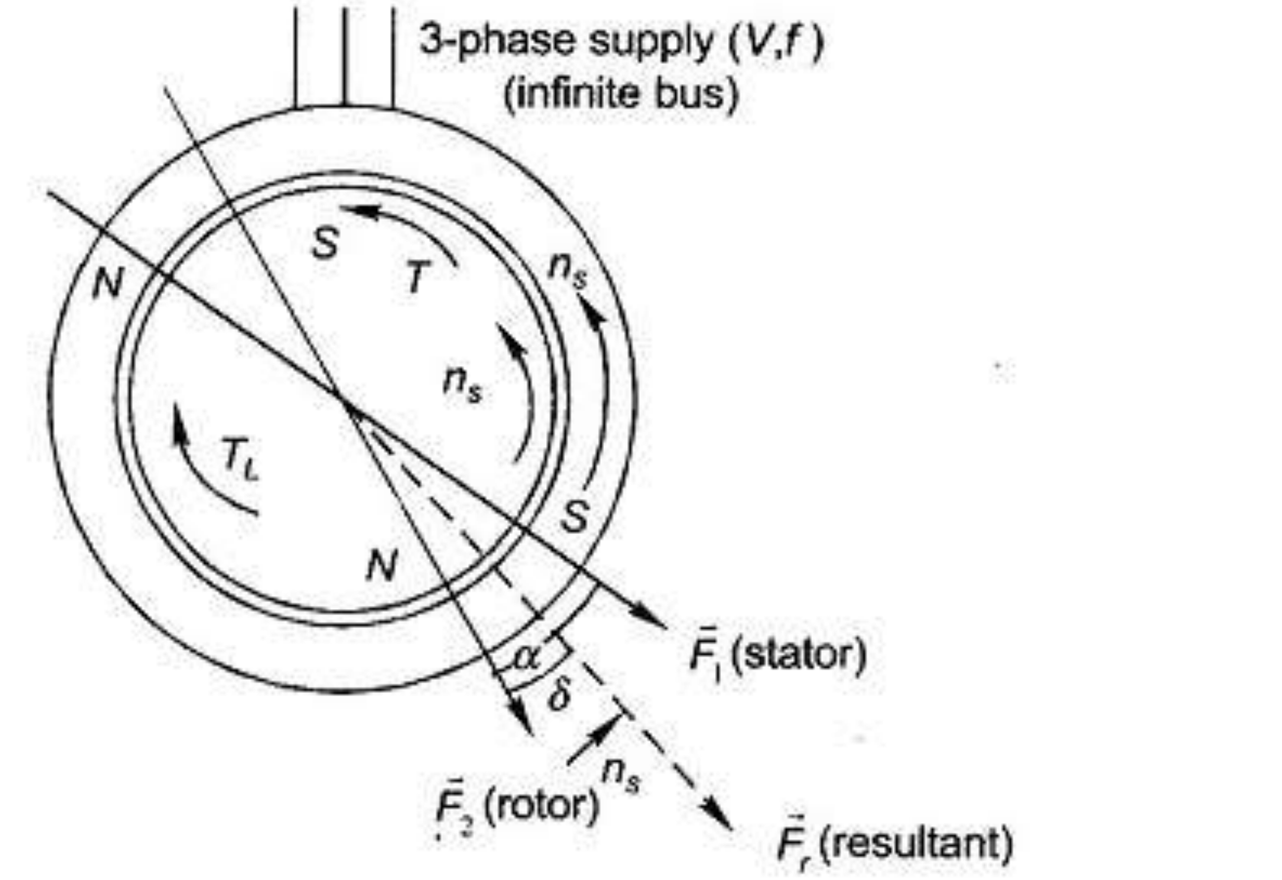


Synchronous Motor- Torque Equation

- The rotor is initially stationary with fixed north-south poles created by dc excitation. Let the 3-phase winding of the stator be connected to a 3-phase supply of fixed voltage V (line) and fixed frequency f (this is known as the infinite bus).

- As a result, 3-phase currents flow in the stator winding creating a rotating magnetic field rotating at synchronous speed ns (= 120 f/P) in the counter-clockwise direction (say)

- Since the rotor is stationary and cannot pick up speed instantaneously (inertia effect), the two fields move relative to each other resulting in zero average torque. As such the motor is non-self-starting.



Torque production in synchronous machine (motoring)

Synchronous Motor-Torque Equation

- Consider now that the rotor is run by auxiliary means to a speed close to synchronous in the direction of rotation of the stator field
- The two fields now have the opportunity of locking into each other or, in other words, the rotor pulls into step with the stator field and then on runs at exactly synchronous speed
- It is easily seen from Fig that the electromagnetic torque developed (T) acts on the rotor in the direction of rotation of rotor and balances the load torque T_L
- The mechanical power therefore flows to the load (motoring action) and, by the principle of conservation of energy, an equal amount of electrical power (plus losses in the device) are drawn from the electric supply
- It is also seen from Fig that for a given T_L, the rotor field lags behind the stator field by an angle α or behind the resultant field by an angle δ

Synchronous Motor-Torque Equation

The torque developed by the synchronous motor is given by the expression

$$T = \frac{\pi}{2}\left(\frac{P}{2}\right)^2 \Phi_r F_2 \sin\delta$$

If the stator winding resistance and leakage reactance are assumed negligible (a fair assumption), the induced emf of the stator winding balances the terminal voltage

$$V \approx \sqrt{3} \times 4.44\, K_w f \Phi_r N_{ph} \text{ (series)}$$

For a fixed terminal voltage, therefore, the resultant flux/pole is almost constant, independent of the shaft load. F_2, the peak of rotor mmf wave being dependent upon the rotor current (dc), is constant for fixed excitation.

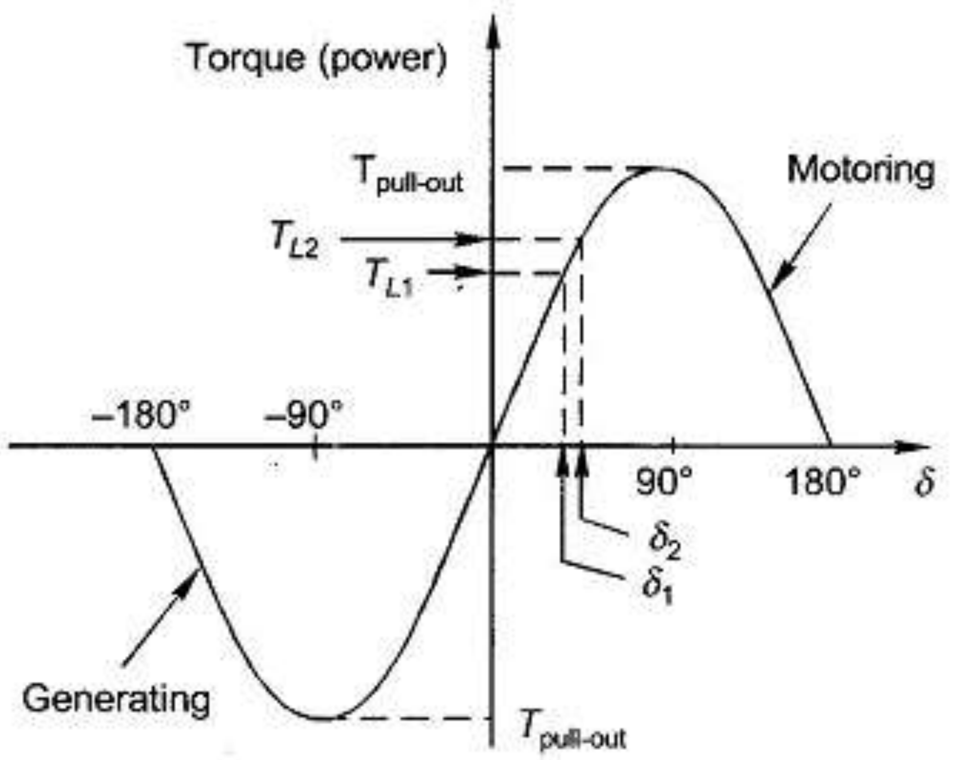
under conditions of constant terminal voltage and constant rotor excitation can therefore be written as

$$T = K \sin\delta$$

where δ is positive when the rotor field lags behind the resultant field and would be negative otherwise. The angle δ is known as the **torque angle** or **power angle**.

Synchronous Motor-Torque Equation

- The plot of electromagnetic torque developed by the synchronous machine is shown
- The machine operates at fixed δ for a given mechanical load torque (say (δ_1 for T_{L1}) and runs at synchronous speed.
- As the load torque is increased to $T_{L2} > T_{L1}$, the rotor decelerates and the angle δ increases to a new steady value $\delta_2 > \delta_1$ as shown
- The machine settles at the new operating angle in an oscillatory manner and its steady speed is once again synchronous.
- The field coupling of the stator-rotor acts like a spring coupling and combined with rotor inertia, the system is oscillatory in nature.
- However, these oscillations die out after every disturbance because of the [damping]() contributed by the mechanical and electrical dissipative effects that are present in the machine.



Torque-angle (T – δ) characteristic of synchronous machine

Synchronous Motor-Torque Equation

- It is also observed from Fig. that the maximum torque developed by the motoring machine is at $\delta = 90°$ and is called the **pull-out torque** (or **pull-out power**); power being proportional to torque as the machine speed is synchronous, independent of load.

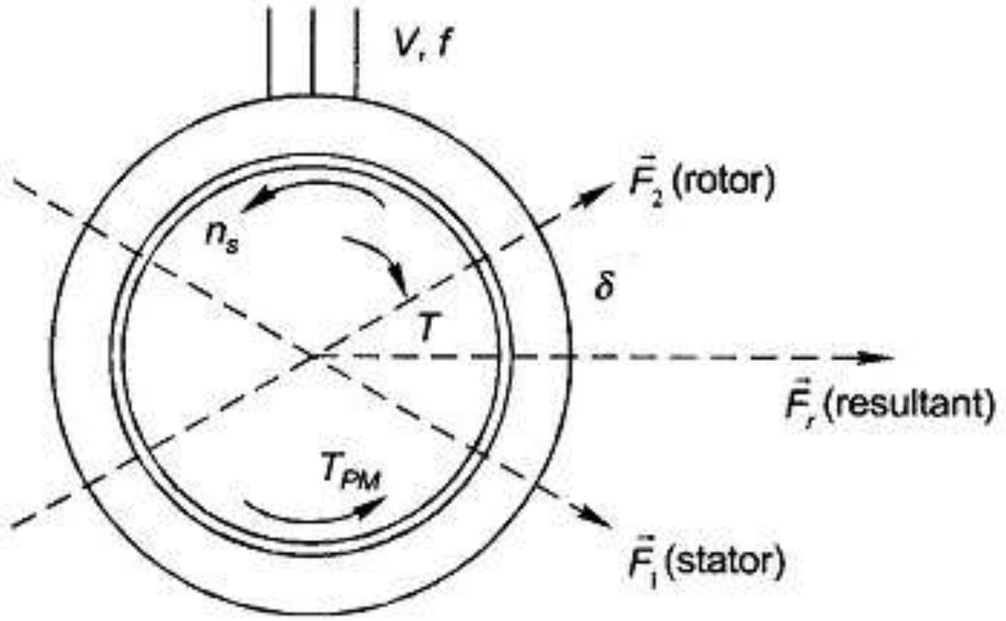
- If the motor is loaded with torque (power) more than $T_{pull\text{-}out}$, the developed torque reduces and the rotor lag angle increases monotonically till the rotor-stator field-bond snaps, i.e. the rotor falls out of step.

- The machine will finally come to a stop and must, as a precautionary measure, be disconnected from the supply much before that.

- It is easily seen from the expression of Equation that the pull-out torque can be increased by increasing the stator terminal voltage and/or rotor field excitation.

Synchronous Motor-Torque Equation

- With negative δ, i.e. rotor field leading the resultant field in the direction of rotation of the rotor, the electromagnetic torque as seen from Fig. is now developed in a direction opposite to that of the rotor rotation and must be balanced by an external mechanical torque T_{PM} (provided by a prime-mover) for the rotor to run at synchronous speed maintaining the locking of the rotor and stator fields.
- The mechanical power now flows into the rotor and the electrical power flows out of the stator to the infinite bus.
- The rotor readjusts its angle of lead such that the electrical output equals the mechanical input minus losses.
- If the mechanical input is more than the maximum electrical power developed (corresponding to generator pull-out torque, δ=90°), the rotor accelerates and falls out of step, i.e. the synchronism between the rotor and stator fields is lost



Torque production in synchronous machine (generating)

SUMMARY

Torque Equation, pull out torque

KEEP LEARNING..

Thank u

SEE YOU IN NEXT CLASS