Lecture-38

On

INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

- Single-phase induction motor.
- Stepper motor.

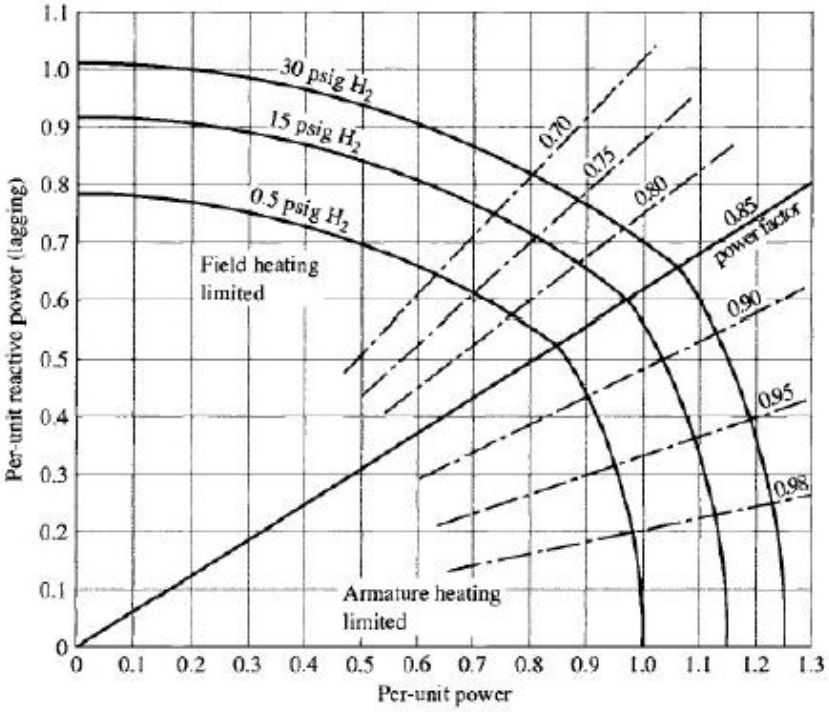
Synchronous Machine Parameters (Cont…)

❑ Capability Curve:

- Synchronous generators are usually rated in terms of the maximum apparent power (kVA or MVA) load at a specific voltage and power factor (often 80, 85, or 90 percent lagging), which they can carry continuously without overheating.

- Capability curves provide a valuable guide both to power system planners and to operators. As system planners consider modifications and additions to power systems, they can see if the various existing or proposed generators can safely supply their required loadings.

- Similarly, power system operators can quickly see whether individual generators can safely respond to changes in system loadings which occur during the normal course of system operation.



Capability curves of an 0.85 power factor, 0.80 short-circuit ratio, hydrogen-cooled turbine generator. Base MVA is rated MVA at 0.5 psig hydrogen.

Synchronous Machine Parameters (Cont…)

❑ Drawing Capability Curve:

- Condition of constant terminal voltage and maximum allowable armature current:

$$P^2 + Q^2 = (V_a I_a)^2$$

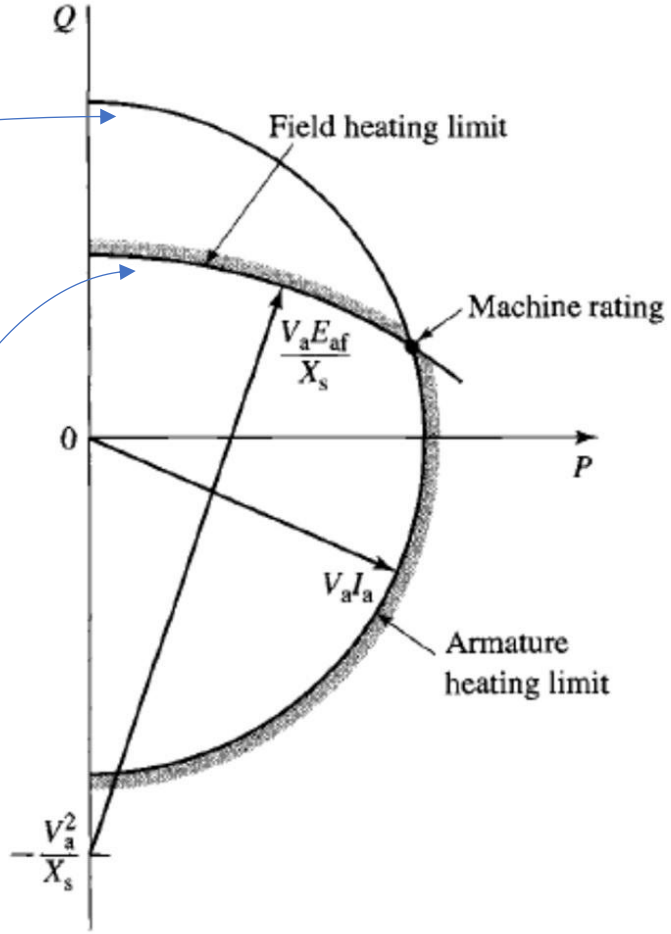
- When the field current is limited to its maximum value, the field voltage E_{af} is constant and so is $\frac{V_a E_a}{X_s}$

- From the output equations

$$P = \frac{V_a E_a}{X_s}\sin\delta \qquad Q = \frac{V_a E_a}{X_s}\cos\delta - \frac{V_a^2}{X_s}$$

Hence $P^2 + \left(Q + \frac{V_a^2}{X_s}\right)^2 = \left(\frac{V_a E_a}{X_s}\right)^2$

- Machine rating is commonly specified as the intersection of the armature current limiting and field current limiting curves.



Construction of synchronous generator capability curve

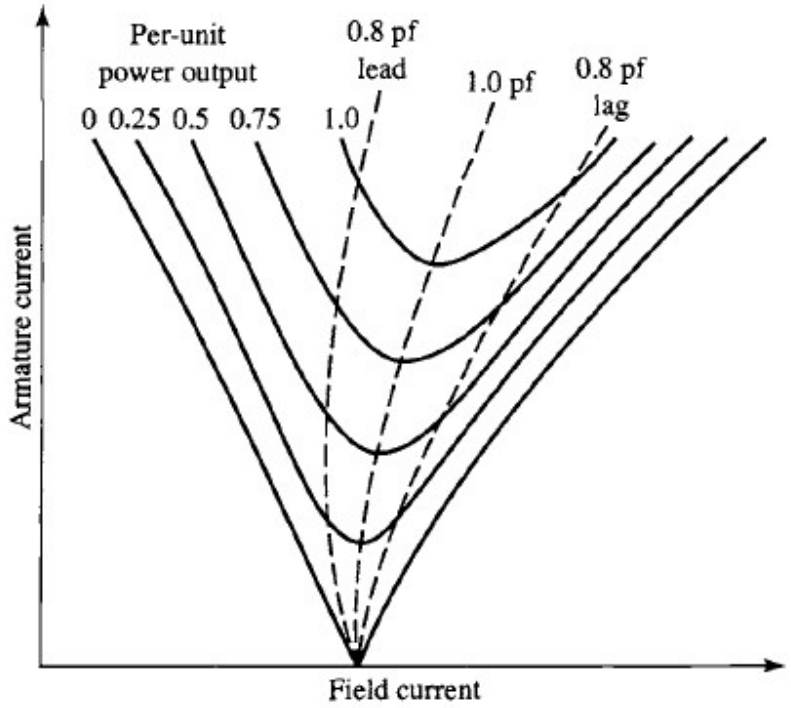
Synchronous Machine Parameters (Cont…)

❑ V-Curves:

- For a given real-power loading, the power factor at which a synchronous machine operates, and hence its armature current, can be controlled by adjusting its field excitation.

- The curve showing the relation between armature current and field current at a constant terminal voltage and constant real power is known as a V-curve, because of its characteristic shape.

- For constant power output, the armature current is minimum at unity power factor and increases as the power factor decreases.



Typical form of synchronous generator
V-curve

Synchronous Machine Parameters (Cont…)

❑ Synchronous Motor:

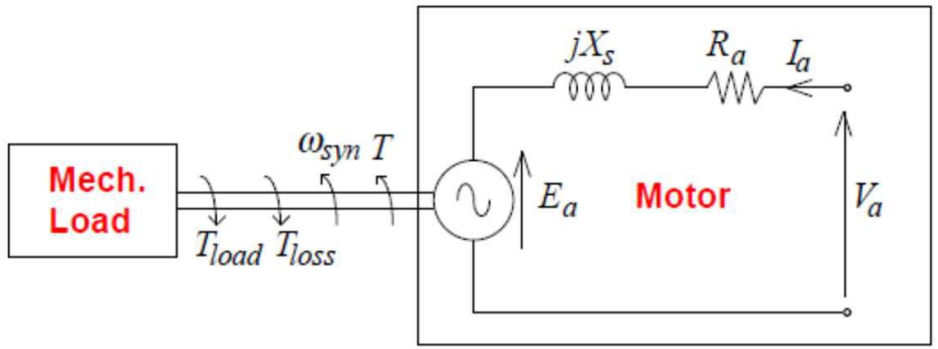
- The field (rotor) current of the motor produces a magnetic field B_R .
- A 3-phase voltage is applied to the armature (stator), which produces a rotating magnetic field B_S.
- Therefore, there are 2 magnetic fields in the machine, and the rotor field tries to line-up with the stator field. Since the stator field is rotating, the rotor field constantly tries to catch up with it (but never really succeeds!!).
- The induced torque is given by,

$$\boldsymbol{T} = k\boldsymbol{B}_R \times \boldsymbol{B}_S$$

- The basic principle of synchronous motor is that the rotor always chases the Rotating magnetic field produced by the stator.

Synchronous Machine Parameters (Cont…)

❑ Synchronous Motor Operation:



Motor operation of the synchronous machine

- The rotor field is synchronized (locks in) with the rotating stator field, which drags the rotor along (consequently, rotation occurs).

- Electrical energy is consumed to produce mechanical energy, and the mechanical torque T balances the load torque T_{load} and the loss torque T_{loss} due to friction and windage:

$$T = T_{load} + T_{loss}$$

Synchronous Machine Parameters (Cont…)

❑ Output Torque:

- Output power of the motor can be given by (similar to generators as before),

$$P = \frac{3V_a E_a}{X_s}\sin\delta \quad \text{(Considering 3 phases)}$$

- The output torque is given by,

$$T = \frac{3V_a E_a}{\omega_m X_s}\sin\delta$$

Where ω_m is the mechanical (Synchronous) speed of the rotor.

- Maximum torque is given by

$$T_{max} = \frac{3V_a E_a}{\omega_m X_s}$$

Synchronous Machine Parameters (Cont…)

❑ Example:

- A 480-V, 60 Hz, four-pole synchronous motor draws 50 A from the line at unity power factor and full load. Assuming that the motor is lossless. What is the output torque of this motor?

❑ Solution:

- If this motor is assumed lossless, then the input power is equal to the output power. The input power to this motor is

$$P_{in} = \sqrt{3} V_T I_L \cos\theta = \sqrt{3} \times 480 \times 50 \times 1.0 = 41.6kW$$

- Rotational speed in mechanical radians per second is given by,

$$\omega_m = \left(\frac{2}{p}\right)\omega_e = \left(\frac{2}{p}\right)2\pi f_e = \left(\frac{2}{4}\right)2\pi \times 60 = 188.4\ mech.rad./s$$

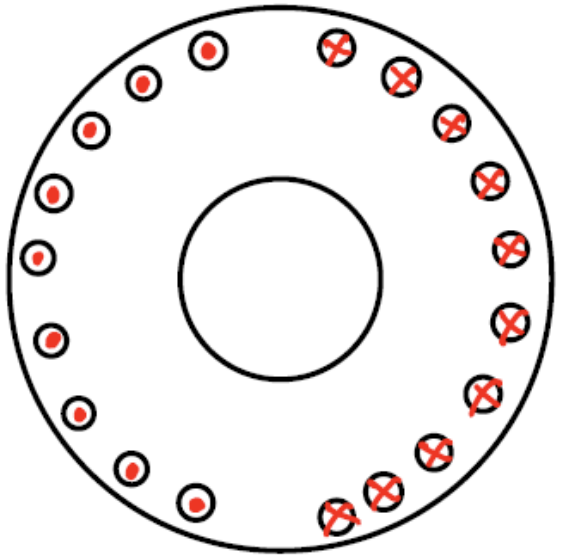
- The output torque is given by

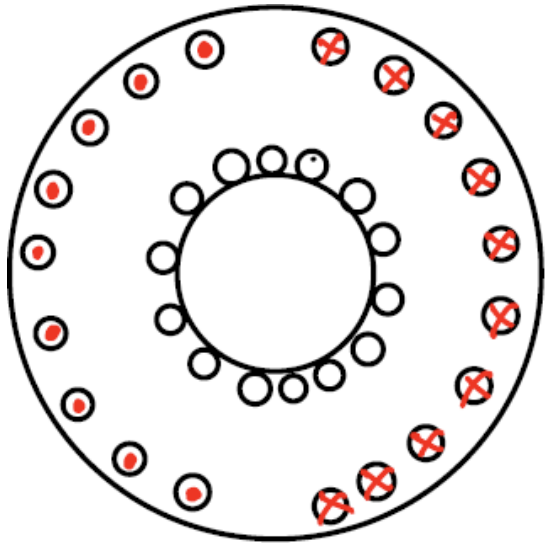
$$T_{out} = \frac{P_{out}}{\omega_m} = \frac{41.6kW}{188.4\ mech.rad./s} = 221\ Nm$$

Single-phase induction motor

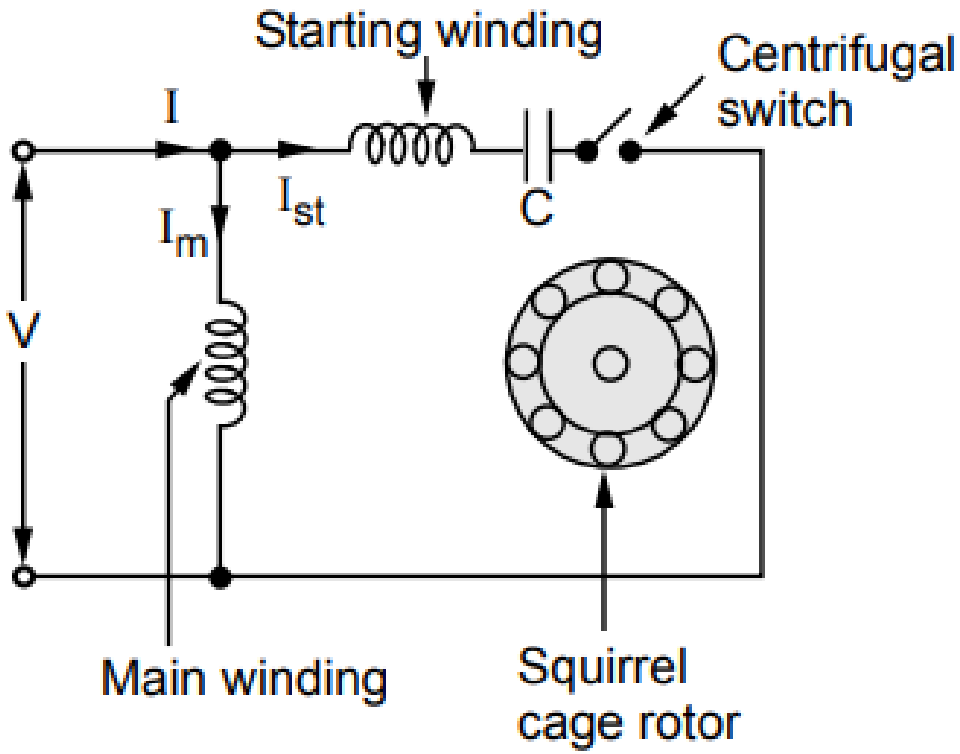
Household Appliances :-

1. Mixer / Grinder (universal motor)
2. Fans ⟶ 1ϕ IM
3. Hair dryer ⟶ 1ϕ IM
4. Hand drill ⟶ universal motor.
5. Water pumping ⟶ 1ϕ IM.





Single-phase induction motor (cont…)

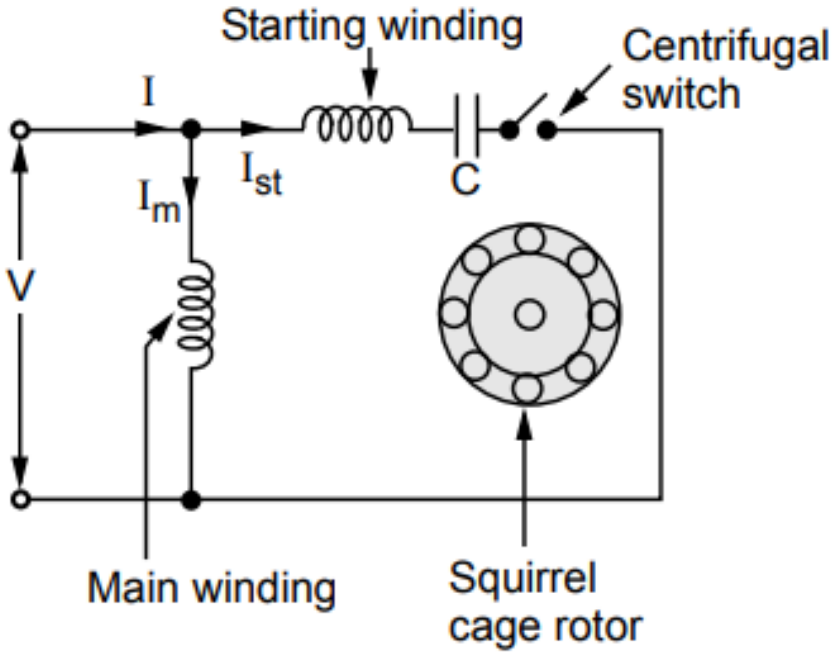


(a) Schematic representation

Single-phase induction motor (cont…)

Single Phase Induction Motor Construction

The main parts of a single -phase induction motor are the Stator, Rotor, Windings. The stator is the fixed part of the motor to which A.C. is supplied. The stator contains two types of windings. One is the main winding and the other is the Auxiliary winding. These windings are placed perpendicular to each other. A capacitor is attached to Auxiliary winding in parallel.



(a) Schematic representation

Single-phase induction motor (cont…)

Working Principle of Single Phase Induction Motor

Single-phase induction motors main winding is supplied with a single -phase A.C. current. This produces fluctuating magnetic flux around the rotor. This means as the direction of the A.C. current changes, the direction of the generated magnetic field changes. This is not enough condition to cause rotation of the rotor. Here the principle of double revolving field theory is applied.

According to the double revolving field theory, a single alternating filed is due to the combination of two fields of equal magnitude but revolving in the opposite direction. The magnitude of these two fields is equal to the half the magnitude of the alternating field. This means that when A.C. is applied, two half magnitude fields are produced with equal magnitudes but revolving in opposite directions.

So, now there is a current flowing in the stator and magnetic field revolving on the rotor, thus Faraday's law of electromagnetic induction acts on the rotor. According to this law, the revolving magnetic fields produce electricity in the rotor which generates force 'F' that can rotate the rotor.

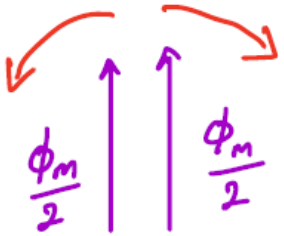
Single-phase induction motor (cont…)

❑ Double field revolving theory:

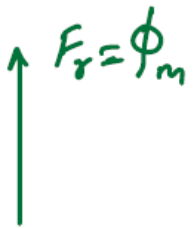
According to the double field revolving theory, we can resolve any alternating quantity into two components. Each component has a magnitude equal to half of the maximum magnitude of the alternating quantity, and both these components rotate in the opposite direction to each other.

Single-phase induction motor (cont…)

Let us consider :-



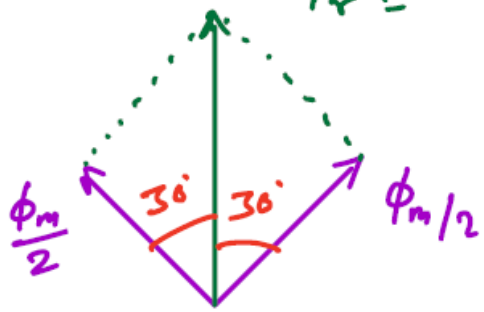
① $\omega t = 0$



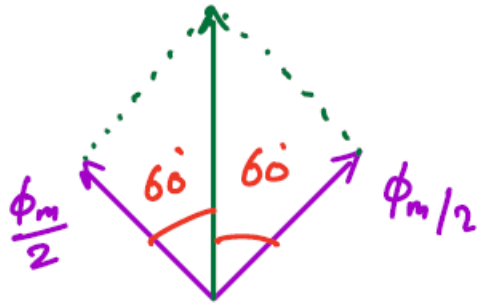
② $\omega t = 30^\circ$

$$F_r = \frac{2\phi_m}{2}\cos 30^\circ$$

$$= 0.866\,\phi_m$$



③ $\omega t = 60^\circ$



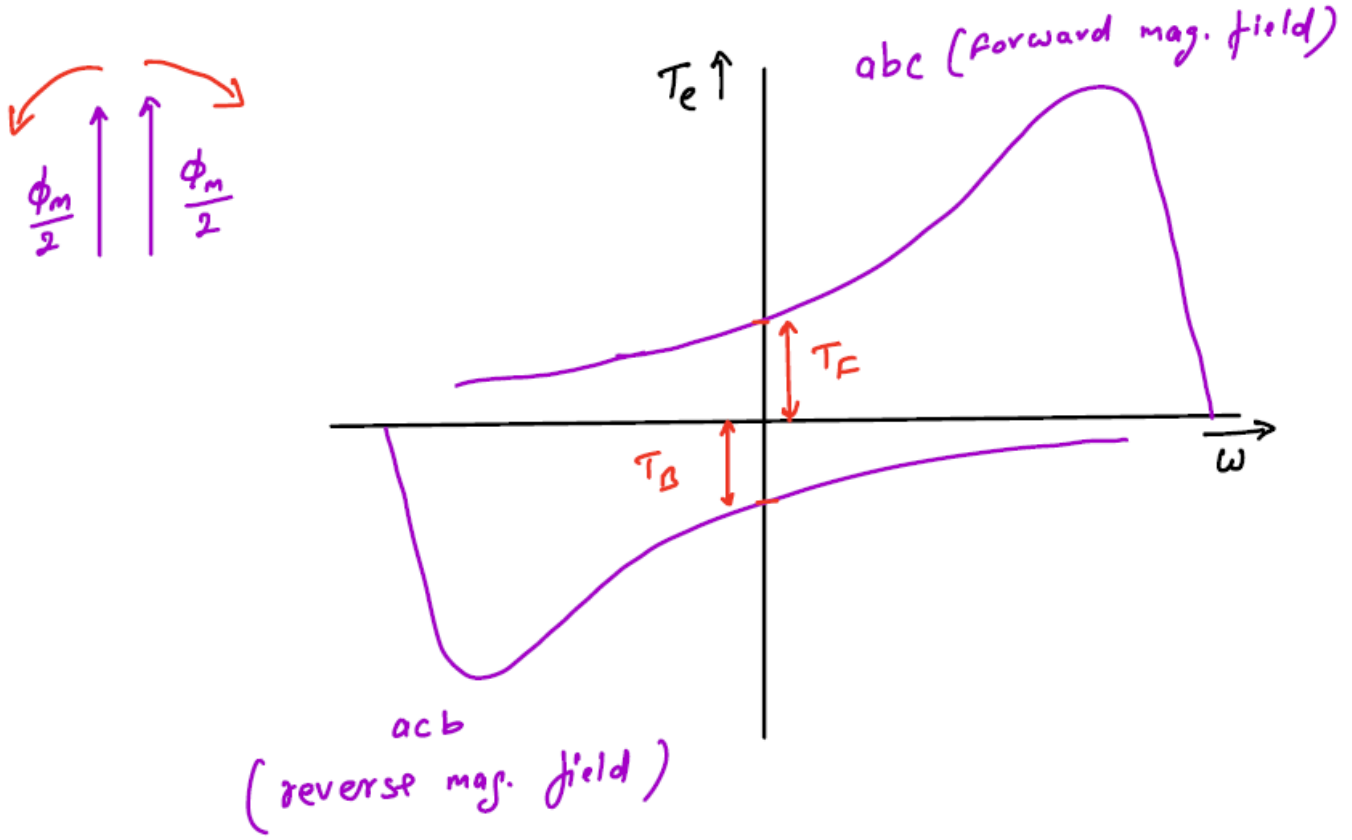
$$F_r = \frac{2\phi_m}{2}\cdot\cos 60^\circ$$

$$= \frac{\phi_m}{2}$$

④ $\omega t = 90^\circ$

$F_r = 0$

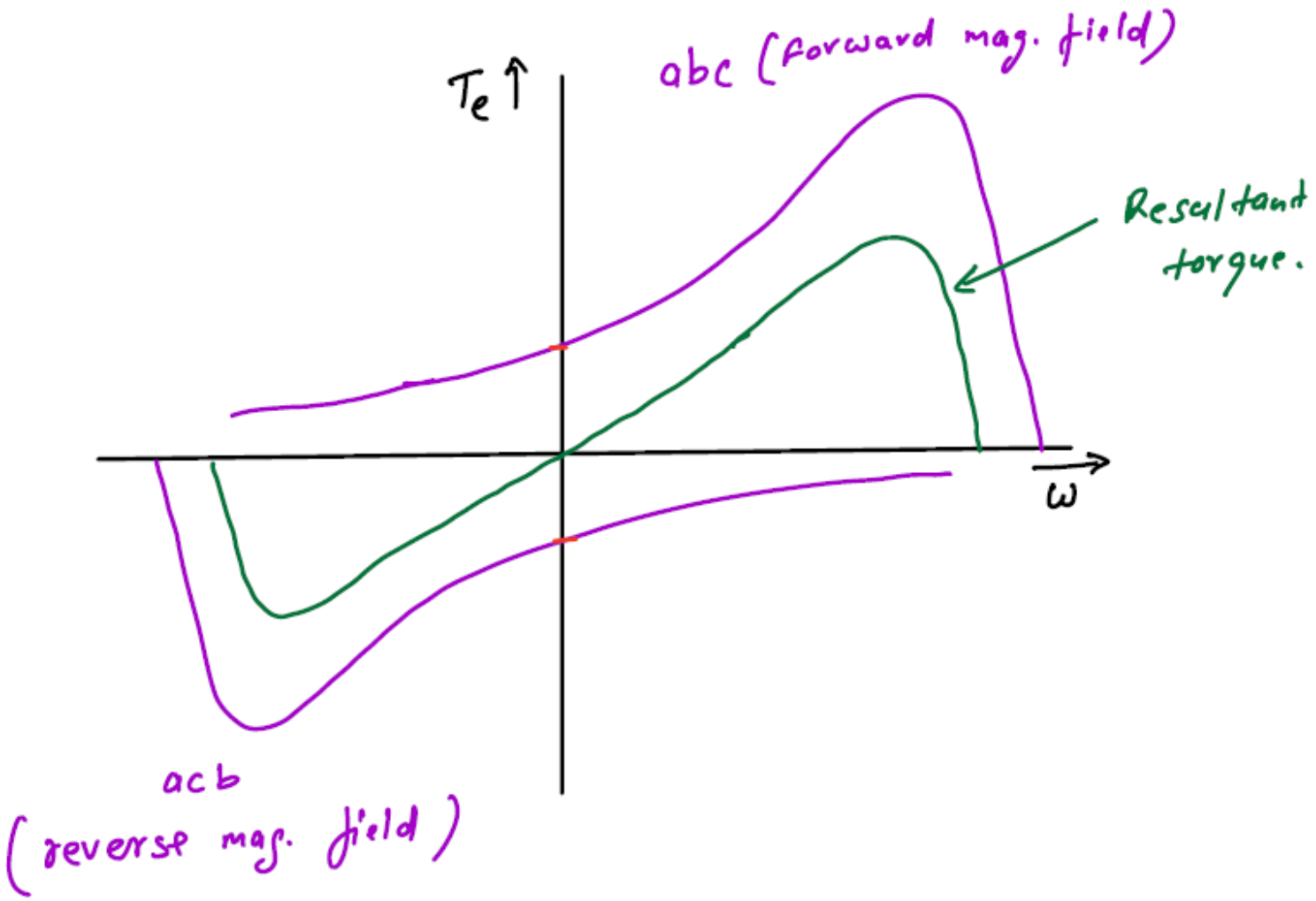
Single-phase induction motor (cont…)



→ $T_F = T_B$ at $\omega = 0$ (No net starting torque).

→ Single phase IM is inherently not self-starting.

Single-phase induction motor (cont…)



Single-phase induction motor (cont…)

Why Single Phase Induction Motor is Not Self Starting?

When faradays electromagnetic induction law is applied to the rotor, electricity is induced and force is generated on the rotor bars. But according to Double Revolving Field theory, there are two magnetic fields with the same magnitude but revolving in the opposite direction. Thus, two force vectors are produced with equal magnitude but opposite in direction.

Thus, these force vectors, as they are of the same magnitude but opposite in direction, doesn't cause the rotor to rotate. So, single-phase induction motors are not self-starting. The motor simply buzzes in this condition. To prevent this situation and rotate the rotor, the starting force has to be applied for a single -phase motor. As the force in one direction, becomes greater than the force the other direction, the rotor starts rotating. In single -phase induction motors, Auxiliary windings are used for this purpose.

Single-phase induction motor (cont…)

Starting Methods of Single Phase Induction Motor

Single -phase induction motor doesn't have starting torque, so external circuitry is needed to provide this starting torque. The stator of these motors contains Auxiliary winding for this purpose. The Auxiliary winding is connected in parallel to a capacitor. When the capacitor is turned on, similar to main winding, revolving two magnetic fields of the same magnitude but opposite direction are observed on Auxiliary winding.

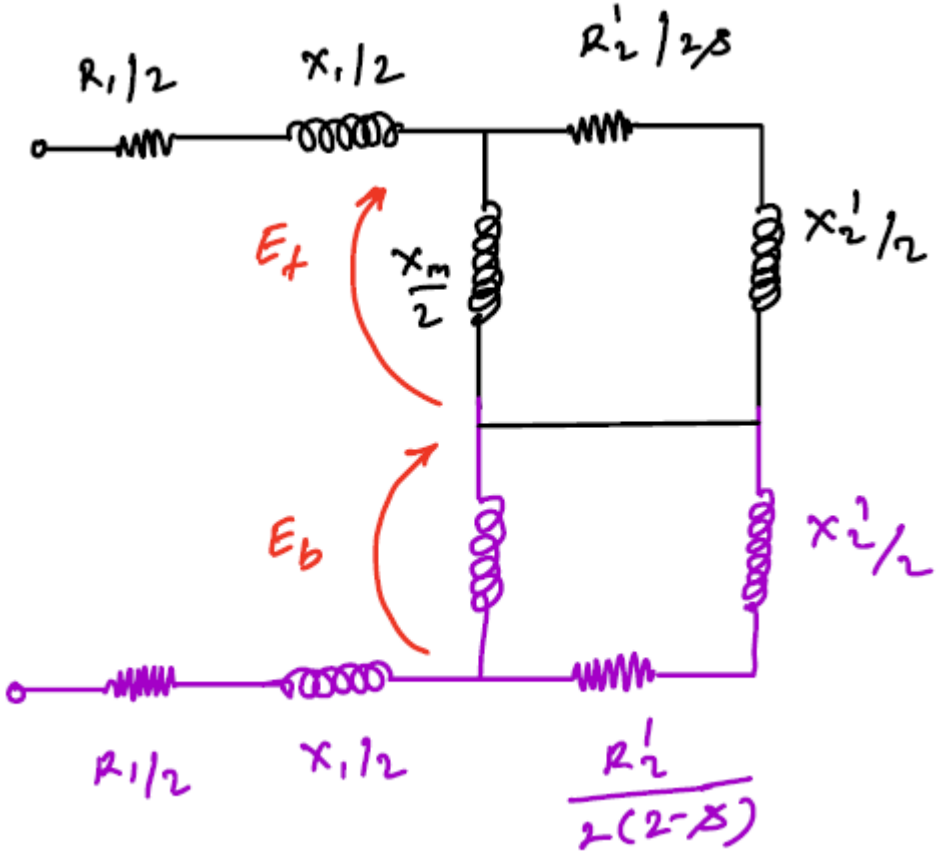
From these two magnetic fields of Auxiliary winding, one cancel outs one of the magnetic fields of main winding whereas the other adds up with another magnetic field of main winding. Thus, resulting in a single revolving magnetic field with high magnitude. This produces force in one direction, hence rotating the rotor. Once the rotor starts rotating it rotates even if the capacitor is turned off.

Single-phase induction motor (cont…)

There are different stating methods of single-phase induction motors. Usually, these motors are chosen based on their starting methods. These methods can be classified as

- Split-phase starting.
- Shaded-pole starting.
- Repulsion motor starting
- Reluctance starting.

Single-phase induction motor (cont…)



Forward $S_f = \dfrac{\omega_s - \omega_r}{\omega_s} = s$

Reverse $S_b = \dfrac{-\omega_s - \omega_r}{-\omega_s} = (2 - s)$

Stepper motor

- The stepper motor working principle is Electro-Magnetism. It includes a rotor which is made with a permanent magnet whereas a stator is with electromagnets. Once the supply is provided to the winding of the stator then the magnetic field will be developed within the stator. Now rotor in the motor will start to move with the rotating magnetic field of the stator. So, this is the fundamental working principle of this motor.

Stepper Motor Construction

Stepper motor (cont…)

- In this motor, there is a soft iron that is enclosed through the electromagnetic stators. The poles of the stator as well as the rotor don't depend on the kind of stepper. Once the stators of this motor are energized then the rotor will rotate to line up itself with the stator otherwise turns to have the least gap through the stator. In this way, the stators are activated in a series to revolve the stepper motor.

Stepper Motor Construction

All the best for End Sem Exam