Analysis of Phasor Diagram

Consider a phasor diagram with normal excitation i.e. such a current through field winding which will produce flux that will adjust magnitude of E_{bph} same as V_{ph}.

Let δ be the load angle corresponding to the load on the motor. So from the exact opposing position of E_{bph} with respect to V_{ph}. E_{bph} gets displaced by angle δ.

Vector difference of E_{bph} and V_{ph}, gives the phasor which represents I_a Z_s, called E_{Rph}.

Now $Z_s = R_a + j X_s$ Ω

where R_a = Resistance of stator per phase

X_s = Synchronous reactance of stator per phase

i.e. $\theta = \tan^{-1} (X_s/R_a)$

and $| Z_s | = \sqrt{(R_a^2 + R_s^2)}$ Ω

This angle 'θ' is called internal machine angle or an impedance angle.

The significant of 'θ' is that it tells us that phasor I_{aph} lags behind E_{Rph} i.e. I_a $Z_s$by angle θ. Current always lags in case of inductive impedance with respect to voltage drop across that impedance. So phasor I_{aph} can be shown lagging with respect to E_{Rph} by angle θ. Practically R_a is very small compared to X_a and hence θ tends to 90°.

and cos Φ = Power factor at which motor is working.

The nature of this p.f. is lagging if Iaph lags V_{ph} by angle Φ. While it is leading if Iaph leads V_{ph} by angle Φ. Phasor diagram indicating all the details is shown in the Fig

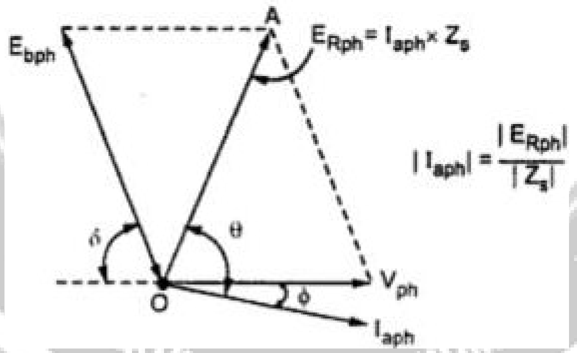

Figure 2.4 Phasor diagram under normal working condition

Operation of synchronous motor at constant Load Variable Excitation

Consider a synchronous motor operating at a certain load. The corresponding load angle is δ.

At start, consider normal behaviour of the synchronous motor, where excitation is adjusted to get $E_b = V$ i.e. induced e.m.f. is equal to applied voltage. Such an excitation is called Normal Excitation of the motor. Motor is drawing certain current from the supply and power input to the motor is say P_{in}. The power factor of the motor is lagging in nature as shown in the Fig. 1(a).

Now when excitation is changed, changes but there is hardly any change in the losses of the motor. So the power input also remains same for constant load demanding same power output.

Now $P_{in} = \sqrt{3}\, V_L I_L \cos\Phi = 3\,(V_{ph} I_{ph} \cos\Phi)$

Most of the times, the voltage applied to the motor is constant. Hence for constant power input as V_{ph} is constant, '$I_{ph} \cos\Phi$' remains constant.

Note : So far this entire operation of variable excitation it is necessary to remember that the cosine component of armature current, $I_a \cos\Phi$ remains constant.

So motor adjusts its cos Φ i.e. p.f. nature and value so that $I_a \cos\Phi$ remains constant when excitation of the motor is changed keeping load constant. This is the reason why synchronous motor reacts by changing its power factor to variable excitation conditions.

Under Excitation

When the excitation is adjusted in such a way that the magnitude of induced e.m.f. is less than the applied voltage ($E_b < V$) the excitation is called Under Excitation.

Due to this, E_R increases in magnitude. This means for constant Z_s, current drawn by the motor increases. But E_R phase shifts in such a way that, phasor I_a also shifts (as $E_R \wedge I_a = \theta$) to keep $I_a \cos\Phi$ component constant. This is shown in the Fig. 1(b). So in under excited condition, current drawn by the motor increases. The p.f. cos Φ decreases and becomes more and more lagging in nature.

Over Excitation

The excitation to the field winding for which the induced e.m.f. becomes greater than applied voltage ($E_b < V$), is called over excitation.

Due to increased magnitude of E_b, E_R also increases in magnitude. But the phase of E_R also changes. Now = $E_R \wedge I_a = \theta$ is constant, hence I_a also changes its phase. So Φ changes. The I_a increases to keep $I_a \cos\Phi$ constant as shown in Fig.1(c). The phase of E_R changes so that I_a becomes leading with respect to V_{ph} in over excited condition. So power factor of the motor becomes leading in nature. So overexcited synchronous motor works on leading power factor. So power factor decreases as over excitation increases but it becomes more and more leading in nature.

Critical Excitation

When the excitation is changed, the power factor changes. The excitation for which the power factor of the motor is unity (cos Φ = 1) is called critical excitation. Then I_{aph} is in phase with V_{ph}. Now $I_a \cos\Phi$ must be constant, cos Φ = 1 is at its maximum hence motor has to draw minimum current from supply for unity power factor condition.

So for critical excitation, cos Φ = 1 and current drawn by the motor is minimum compared to current drawn by the motor for various excitation conditions. This is shown in the Fig. 1(d).

Under excitation	Lagging p.f.	$E_b < V$
Over excitation	Leading p.f.	$E_b > V$
Critical excitation	Unity p.f.	$E_b \cong V$
Normal excitation	Lagging	$E_b = V$

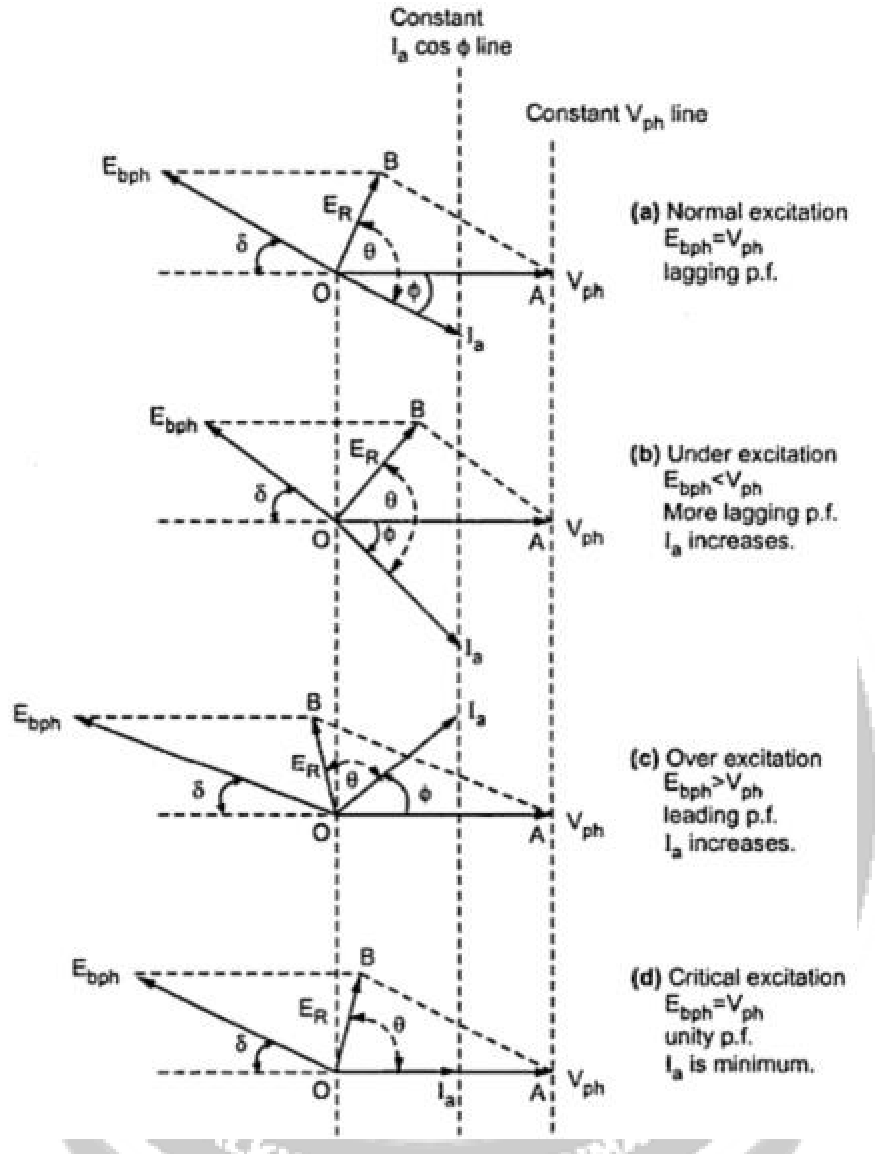

Figure 2.5 Constant load variable excitation operation