

### 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  $\delta$  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  $\delta$ .

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

Now  $Z_s = R_a + j X_s \Omega$

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  $|Z_s| = \sqrt{(R_a^2 + X_s^2)} \Omega$

This angle ' $\theta$ ' is called internal machine angle or an impedance angle.

The significant of ' $\theta$ ' is that it tells us that phasor  $I_{aph}$  lags behind  $E_{Rph}$  i.e.  $I_a Z_s$  by angle  $\theta$ . 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  $\theta$ . Practically  $R_a$  is very small compared to  $X_a$  and hence  $\theta$  tends to  $90^\circ$ .

and  $\cos \Phi =$  Power factor at which motor is working.

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

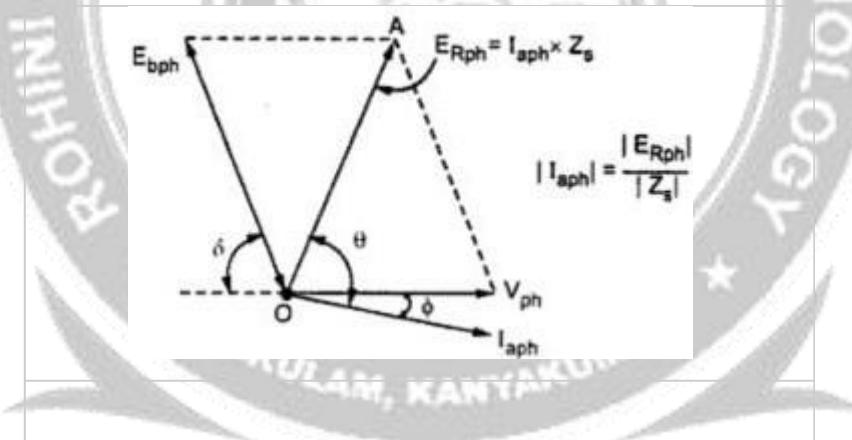


Figure 2.4 Phasor diagram under normal working condition

### Operation of synchronous motor at constant Load Variable Excitation

Consider a synchronous motor operating at a certain load. The corresponding load angle is  $\delta$ .

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.

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

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

So for critical excitation,  $\cos \Phi = 1$  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.	$E_b \approx V$
Normal excitation	Lagging	$E_b = V$

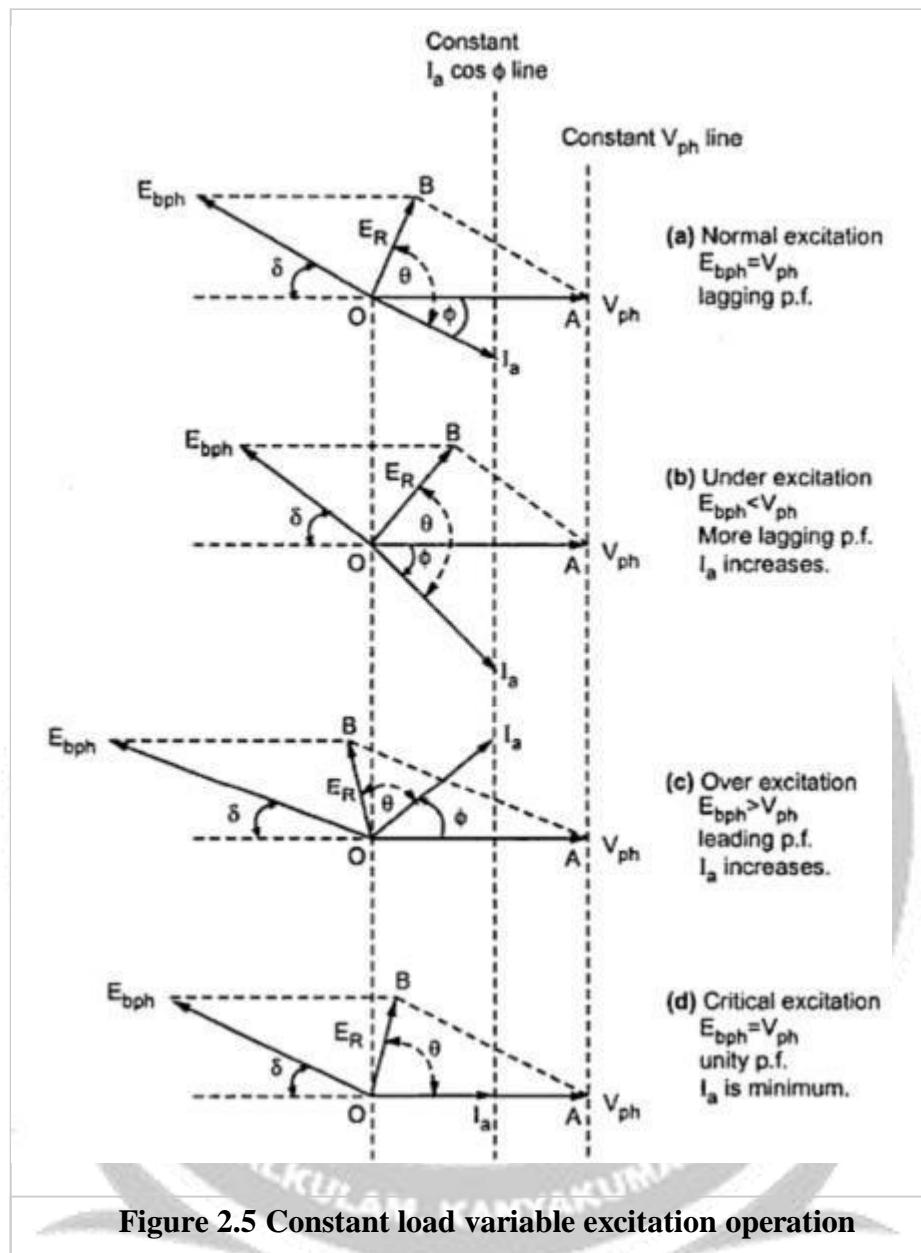


Figure 2.5 Constant load variable excitation operation