4.6 PHASOR DIAGRAM OF A BRUSHLESS PM SNW OR BLPB SYNCHRONOUS MOTOR:

Consider a BLPM SNW motor, the stator carries a balanced 3υ winding .this winding is connected to a dc supply through an electronic commutator whose switching action is influenced by the signal obtained from the rotor position sensor.

Under steady state operating condition, the voltage available at the input terminals of the armature winding is assumed to be sinusoidally varying three phase balanced voltage. The electronic commutator acts as an ideal inverter whose frequency is influenced by the rotor speed. Under this condition a revolving magnetic field is set up in the air gap which is sinusoidally distributed in space, having a number of poles is equal to the rotor. It rotates in air gap in the same direction as that of rotor and a speed eq1ual to the aped of the rotor

Rotor carries a permanent magnet. Its flux density is sine distributed. It also revolved in the air gap with as particular speed

It is assumed that the motor acts as a balanced 3υsystem. Ther4efore it is sufficient to draw the phasor diagram for only one phase. The armature winding circuit is influenced by the following emfs.

1. V - Supply voltage per phase across each winding of the armature.

   The magnitude of this voltage depends upon dc voltage and switching techniques adopted.
2. E_f - Emf induced in the armature winding per phase due to sinusoidally varying permanent magnetic field flux.

   Magnitude of $E_f = 4.44 υ_m f K_{w1} T_{ph} = I\ E_f I$

   As per Faradays law of electromagnetic induct5ion, this emf lags behind $υ_{mf}$- permanent magnet flux enclosed by armature phase winding by 90°.
3. E_a - emf induced in the armature phase winding due to the flux $υ_a$ set up by resultant armature mmf $υ \infty I_a$

   $I\ E_a I = 4.44 f υ_a K_{w1} T_{ph}$

   $= 4.44 f (K_{Ia}) K_{w1} T_{ph}$

   $I\ E_a I = I\ I_a X_a I$ where $X_a = 4.44 f K K_{w1} T_{ph}$

   This lags behind $υ_a$ by 90° or in other words E_a lags behind I_a by 90°.

   Therefore $E_a = -jX_a I_a$

4. E_{al} - emf induced in the same armature winding due to armature leakage flux.

$|E_{al}| = 4.44\ f \emptyset_{al} K_{w1} T_{ph}$

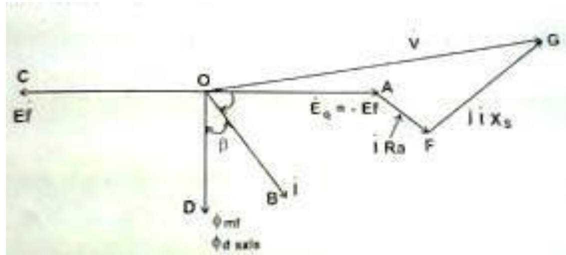

Figure 4.6.1 phasor diagram of BLPM sine wave motor

[Source: "special electric machines" by R.Srinivasan page:5.3]

ϕ_{mf} be the mutual flux set up by the permanent magnet, but linked by the armature winding.

Ef lags behind $\phi_{mf} = \phi_d$

AF represents IaRa

FG represents Ia Xs; FG is perpendicular to I phasor

OG represents V

Angle between the I and is β the torque or power angle.

Power input = 3VI

= 3 (Eq +Ia Ra + j I Xs).I

= 3 Eq.Ia+3 I^2 Ra+O

3Eq I – electromagnetic power transferred as mechanical power.

3I^2Ra – copper losss.

Mechanical power developed = 3 Eq.I

= 3 Eq I cos(90-β)

= 3 Eq I sin β

= 3 Ef I sin β

The motor operates at Ns rpm or 120f/2p rpm

Therefore electromagnetic torque developed =60/2 Ns × 3Eq I sin β

The same phasor diagram can be redrawn as shown in fig with Φ_d or $_{fm}$ as the reference phasor.

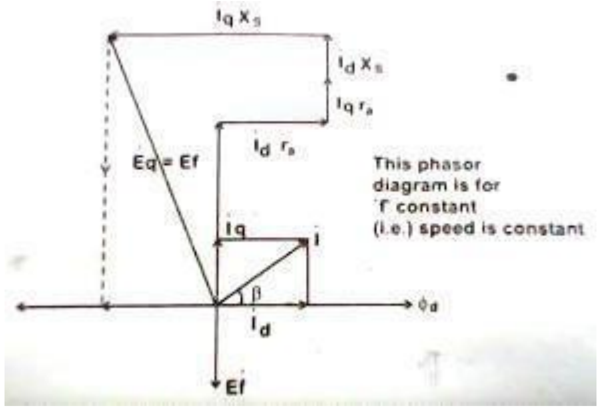

Figure 4.6.2 Phasor Diagram of BLPM sine wave motor with ϕ d or ϕ mf as reference axis

[Source: "special electric machines" by R.Srinivasan page:5.3]

Further the current I phasor is resolved into two components Id and Iq Id

set up mmf along the direct axis (or axis of the permanent magnet)

Iq sets up mmf along quadrature axis (i,e) axis perpendicular to the axis of permanent magnet.

$$V = Eq + I\,Ra + j\,I\,Xs$$

$$I = Iq + Id$$

Therefore $V = Eq + Id\,r_a + Iq\,r_a + j\,Id\,Xs + j\,Iq\,Xs$

V can be represented as a complex quantity.

$$V = (V_r + j\,V_{IP})$$

From the above drawn phasor.

$$V = (Id\,r_a - Iq\,Xs) + j\,(Eq + Iq\,r_a + Id\,Xs)$$

I can also be represented as a complex quantity

$$I = Id + j\,Iq$$

Power input = Re $(3VI^*)$ I^* - conjugate

$$= Re(3((Id\,r_a - Iq\,Xs) + j\,(Eq + Iq\,r_a + Id\,Xs))\,((Id - j\,IQ)))$$

(i,e) power input = Re(3(I_d ra – Id Iq Xs) + (-j Id Iq ra + j Xs) + j (Eq Id + Iq Id ra+ Xs) + (Eq Iq +I_q ra + Id Iq Xs))

= 3(I_d^2 ra – Id Iq Xs) + 3 (Eq Iq + I_q^2 ra + Id Iq Xs)

= 3 Eq Iq + 3(I_d^2 + I_q^2) r_a

= 3 Eq Iq + 3$I^2 r_a$

Electromagnetic power transferred = 3 Eq Iq

= 3 EI sin β

Torque developed = 60/2πNs . 3 EI sin β

Note:

In case of salient pole rotors the electromagnetic torque developed from the electrical power.

From eqn. (5.43)

$$\frac{p}{\omega m} = 3[I_d^2 r_a \; I_d I_q X_s] + 3[E_q I_q \; + \; + I_d I_q X_s]$$

$$=3[I_d^2 r_a \; I_d I_q (X_d + X_q)] + 3[E_q I_q + I_q^2 r_a + I_d I_q (X_d + X_q)]$$

Power input = $R_e\, 3[(I_d r_a - I_q X_s) + j(E_q + I_d X_s + I_q r_a)(I_d - jI_q)]$

$$= R_e\, 3[((I_d r_a - I_q (X_d + X_q)) + j(E_q + I_d (X_d + X_q) + I_q r_a)(I_d - jI_q)]$$

$$= R_e\, 3[I_d^2 r_a - I_q (X_d + X_q) I_d + E_q I_q + I_d I_q \; + \; + I_q^2 r_a]$$

$$=3\; E_q I_q + 3I^2 R_a$$

Torque developed for a salient pole machine is given by

$$T=\frac{3p}{\omega_m}[E_q I_q + (X_d - X_q) I_d I_q] N - m$$

$\frac{3p}{\omega_m} E_q I_q$= magnet alignment torque.

$\frac{3p}{\omega_m}(X_d - X_q) I_d I_q$= reluctance torque.

In case of surface – magnet motors, the reluctance torque becomes zero.

Therefore, torque developed = $\frac{3E_q I_q}{\omega_m}$ N-m

Or = $\frac{3P}{\omega} E_q I_q$ N-m

At a given speed, E_q is fixed as it is proportional to speed. Then torque is proportional to q-axis current I_q.

The linear relationship between torque and current simplifies the controller design and makes the dynamic performance more regular and predictable. The same property is shared by the square wave motor and the permanent commutator motor.

In the phasor diagram shown in fig. 5.10.

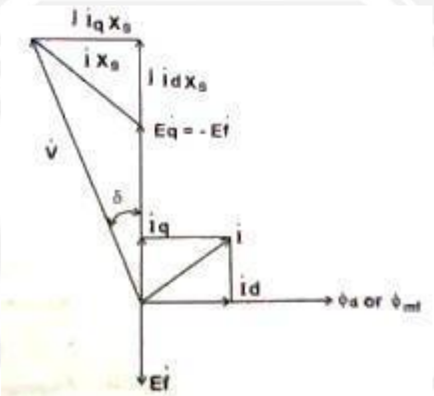

Figure 4.6.2 Phasor Diagram neglecting the effect of resistance Neglecting the effect of resistance, the basic voltage equation *[Source: "special electric machines" by R.Srinivasan page:5.3]*

As the effect of resistance is neglected

$$\frac{\dot{V}}{jX_s} = \frac{\dot{E_q}}{jX_s} + \dot{I}$$

$$\dot{I} = \frac{\dot{V} - \dot{E_q}}{jX_s}$$