SECTION-1

Q.3

Ans

Expression for reluctance torque :-

1. The complex power output per phase.

$$S_{1\phi} = VI_a^* \quad \text{—— (1)}$$

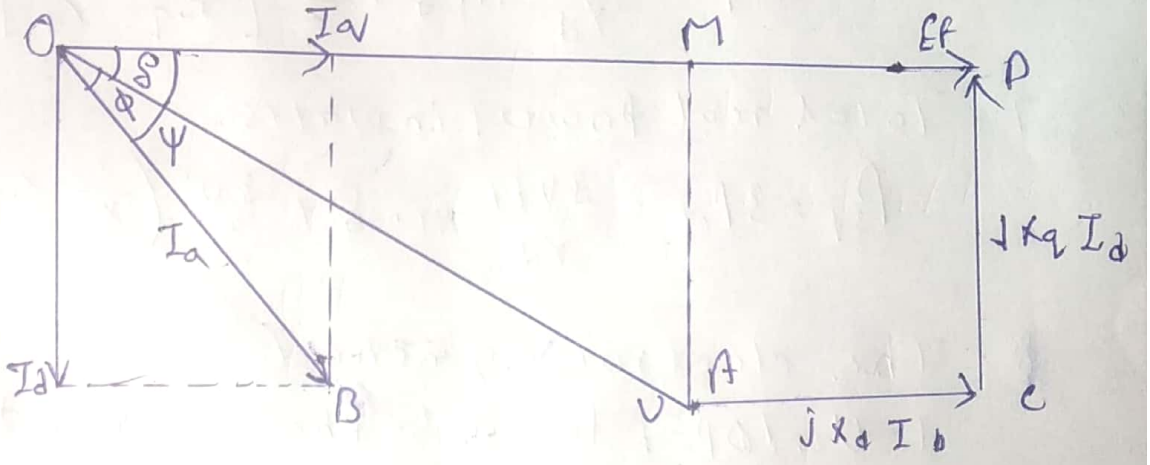
Taking Ef as the reference phasor

$$V = V\angle -\delta = V\cos\delta - jV\sin\delta$$

$$I_a = I_q - jI_d$$

$$I_a = I_a + jI_d$$

$$S_{1\phi} = VI_a^* = (V\cos\delta - jV\sin\delta)(I_q + jI_q) \quad \text{—— (2)}$$



2. From the phasor diagram

$$X_q I_q = CD = AM = V\sin\delta$$

$$I_q = \frac{V\sin\delta}{X_q} \quad \text{—— (3)}$$

$$X_d I_d = AC = MD = OD - OM = E_f - V\cos\delta$$

$$I_d = \frac{E_f - V\cos\delta}{X_d} \quad \text{—— (4)}$$

4. Substituting the values of I_q and I_d in eq (2)

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$$S_{1\phi} = V(\cos\delta - jV\sin\delta)\left(\frac{V\sin\delta}{X_q} + j\frac{E_f - V\cos\delta}{X_d}\right)$$

$$= \left[\frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left(\frac{1}{X_q} - \frac{1}{X_d}\right)\sin 2\delta\right]$$

$$+ \left[\frac{VE_f}{X_d}\cos\delta - \frac{V^2}{2X_dX_q}\left[(X_d + X_q) - (X_d - X_q)\cos 2\delta\right]\right] - (5)$$

5. Also $-S_{1\phi} = P_{1\phi} + jQ_{1\phi}$

6. Therefore the real power per phase in watts is

$$P_{1\phi} = \frac{VE_f}{X_d}\sin\delta + \frac{V^2}{2}\left[\frac{1}{X_q} - \frac{1}{X_d}\right]\sin 2\delta - (6)$$

7. Total real power in watts.

$$P_{3\phi} = 3P_{1\phi} = \frac{3VE_f}{X_d}\sin\delta + \frac{3V^2}{2}\left(\frac{1}{X_q} \times \frac{1}{X_d}\right)\sin 2\delta \quad - (7)$$

8. The electromagnetic torque or torque developed for a 3-Phase synchronous machine is given by.

$$T_{em} = \frac{3P_{1\phi}}{\omega_m} = \frac{3}{2\pi n_s}\left(\frac{VE_f}{X_d}\sin\delta + \frac{X_d - X_q}{2X_dX_q}\sin 2\delta\right) \quad - (8)$$

9. The second term in eq (8) in known as reluctance torque. T_{rel}.

$$\boxed{T_{rel} = \frac{3}{2\pi n_s}\left(\frac{X_d - X_q}{2X_dX_q}\right)\sin 2\delta}$$