Q.3

Ans :- Expression for reluctance torque :-

1. The Complex power output per phase

$$S_{1\phi} = VI_a^*$$

Taking E_f as the reference phasor

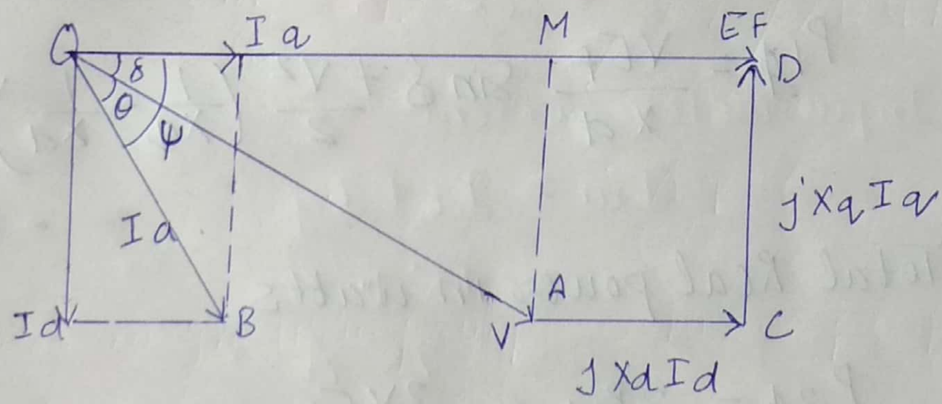
$$V = V\angle -\delta = V\cos\delta - jV\sin\delta$$

$$I_a = I_q - jI_d$$

$$I_a^* = I_q + jI_d$$

$$S_{1\phi} = VI_a^* = [V\cos\delta - jV\sin\delta)(I_q + jI_d)$$

2.



from the phasor diagram

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

$$I_q = \frac{V\sin\delta}{X_q}$$

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

$$I_d = \frac{E_f - V\cos\delta}{X_d}.$$

(4) Substituting the value of Iq and Id

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

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

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

– eqⁿ (5)

(5) $$S_{1\phi} = P_{1\phi} + jQ_{1\phi} \quad \text{— eq}^n\text{-(6)}$$

(6) the real power per phase in watts

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

– eqⁿ (7)

(7) Total Real power in watts

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

(8) The electromagnetic torque for a 3-phase synchronous machine is given by

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

– eqⁿ (8)

(9) The resulting torque has two Components. the first term in eqn (8) represents the torque τ_{exc} due to field excitation

$$\tau_{exc} = \frac{3VE_f}{2\pi n_s X_d} \sin\delta \qquad \text{eq}^n - (9)$$

(10) The second term in eq^n-(8) is known as reluctance torque, τ_{rel}.

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

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