Where I_1 = Primary current

I_2 = Secondary current

Transformation ratio $a = \dfrac{V_1}{V_2} = \dfrac{E_1}{E_2} = \dfrac{N_1}{N_2} = \dfrac{I_2}{I_1}$

The phasor diagram of ideal transformer is as below:

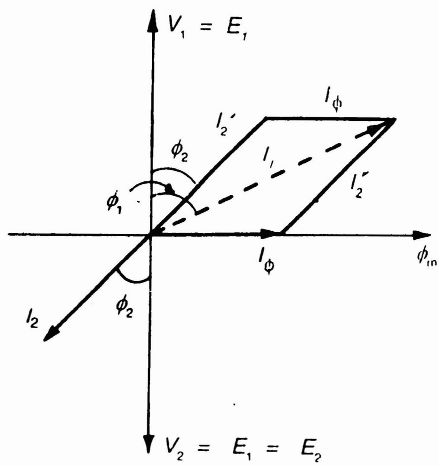

Fig. 1.3

CURRENT, VOLTAGE AND IMPEDANCE REFERRED TO PRIMARY SIDE

Secondary voltage referred to primary side.

$$V_2' = \left(\frac{N_1}{N_2}\right) V_1$$

Secondary load current referred to primary side.

$$I_2' = \left(\frac{N_2}{N_1}\right) I_1$$

Secondary impedance referred to primary side.

$$Z_2' = \left(\frac{N_1}{N_2}\right)^2 Z_2$$

$$\bar{I}_a r_a = 0.02 \ (0.8 - j\ 0.6)$$

$$\bar{I}_a r_a = 0.016 - j\ 0.012$$

Applying the relation. $E'_f = \bar{V}_t + j\bar{I}_a X_q - \bar{I}_a r_a$

$$= 1 + 0.48 + j\ 0.64 + 0.016 - j\ 0.012$$

$$= 1.496 + j\ 0.532 = 1.588 \angle 19.58$$

$\therefore$ Load angle $= 19.58°$

$\therefore$ $\delta + \theta = 19.58° + 36.9° = 56.48°$

We have $I_d = I_a \sin(\delta + \theta) = 1.00 \sin 56.48° = 0.834$ pu

$$I_q = I_a \cos(\delta + \theta) = 1.00 \cos 56.48 = 0.552 \text{ pu}$$

To calculate excitation $E_f = E'_f + I_d (x_d - x_q)$

$= 1.588 + 0.834 \times 0.2 = 1.755$ **Ans.**

$\bar{E}_f = 1.755 \angle 19.58°$ pu **Ans.**

Problem 5.39 : A 25 MVA, 3-phase star-connected alternator, with an impedance of 6 Ω and a resistance of 0.4 Ω is operating in parallel with constant voltage 10 kV bus bars. If its field is adjusted to give an excitation voltage of 11 kV. Calculate

(a) The maximum power output from the alternator

(b) The armature current and power factor under maximum power condition.

Solution :

Given, $E_f = 11$ kV, $V_t = 10$ kV, $Z_s = 6\,\Omega$, $r_a = 0.4\,\Omega$

Alternator excitation/phase $= \dfrac{11000}{\sqrt{3}} = 6351$ V

Alternator terminal voltage/phase $= \dfrac{10000}{\sqrt{3}} = 5774$ V

(a) To calculate maximum power, Applying the relation

$$P_{o\max} = \frac{E_f V_t}{Z_s} - \frac{V_t^2}{Z_s^2} \times r_a = \frac{5774 \times 6351}{6} - \frac{(5774)^2}{36} \times 0.4$$

$= 5741344.8 = 5.7$ MW/phase

$= 17.1$ MW for line **Ans.**

$$\text{Now, Slip } (s) = \frac{\text{Rotor copper loss}}{\text{Power across air gap}} = \frac{3}{86.5} = 0.0347 \quad \textbf{Ans.}$$

Problem 6.9 : The power supplied to a 3-phase induction motor is 40 kW and the corresponding stator losses are 1.5 kW. Calculate the net mechanical power developed and the rotor I^2R loss when the slip is 0.04 per unit. What will be the net power developed if the speed of the above motor is reduced to 40 % of the synchronous speed by means of external rotor resistors, assuming the torque and stator losses to remain unaltered? Friction and windage losses may be assumed to be 0.8 kW. (*I.A.S.*, 1980)

Solution :

Let un choose 40 kW as base power and speed 1500 rpm as base synchronous speed

$$\therefore \quad \text{Power input, } p_i = \frac{40}{40} = 1.00 \text{ p.u.}$$

$$\text{Synchronous speed } (n_s) = \frac{1500}{1500} = 1 \text{ p.u., slip} = 0.04$$

$$\text{Stator losses in p.u.} = \frac{\text{Stator losses}}{\text{base power}} = \frac{1.5}{40} = 0.0375 \text{ p.u.}$$

$$\text{Friction and windage losses} = \frac{0.8}{40} = 0.02 \text{ p.u.}$$

$$\text{Now, Power across air gap, } p_G = p_{in} - \text{Stator losses}$$
$$= 1 - 0.0375 = 0.9625 \text{ p.u.}$$

$$\text{Rotor copper loss} = s \times p_G = (0.04 \times 0.9625) \text{ p.u.} = 0.0385$$

$$\text{Net power output } P_{net} = p_G - \text{rotor loss} - \text{windage and friction loss}$$
$$= 0.9625 - 0.0385 - 0.02 = 0.904 \text{ p.u.}$$

$$\text{Actual power developed} = \text{Power in p.u.} \times P_{base}$$
$$= 40 \times 0.904 = 36.16 \text{ kW} \quad \textbf{Ans.}$$

$$\text{Rotor speed } (n_r) = (1 - s)\, n_s = (1 - 0.04) \times 1 = 0.96 \text{ p.u.}$$

$$\text{Actual speed of the rotor} = 0.96 \times \text{base speed}$$
$$= 0.96 \times 1500 = 1440 \text{ rpm}$$

When the speed is reduced to 40 % of synchronous speed

Problem 6.13 : The maximum torque of a 3-phase squirrel-cage induction motor is 4 times the full-load torque and the starting torque is 1.6 times the full-load torque. Neglect stator resistance. Calculate

(i) The slip at the maximum torque

(ii) Full-load slip and

(iii) The rotor current at starting in terms of full-load rotor current.

Solution :

Given, $T_{max} = 4 \times T_{fl}$

and $T_{st} = 1.6 \times T_{fl}$

(i) Applying the relation,

$$\frac{T_{st}}{T_{max}} = \frac{2}{\frac{s_{max,T}}{1} + \frac{1}{s_{max,T}}}$$

or $$\frac{1.6\,T_{fl}}{4\,T_{fl}} = \frac{2\,s_{max,T}}{s_{max,T}^2 + 1}$$

or $$0.4 = \frac{2\,s_{max,T}}{s_{max,T}^2 + 1}$$

or $$s_{max,T}^2 - \frac{2}{0.4}\,s_{max,T} + 1 = 0$$

or $$s_{max,T}^2 - 5\,s_{max,T} + 1 = 0$$

This yields $$s_{max,T} = \frac{5 \pm \sqrt{25-4}}{2}$$

$$= \frac{5 \pm 4.5826}{2}$$

Neglective higher value, $s_{max,T} = 0.21$ **Ans.**

(ii) To calculate full load slip, Applying the relation,

$$\frac{T_{fl}}{T_{max}} = \frac{2}{\frac{s_{fl}}{s_{max,T}} + \frac{s_{max,T}}{s_{fl}}}$$