ECE 385

HOMEWORK 5

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(1) A 3ϕ, 10HP, 208V, 6 pole, 60Hz wound-rotor induction machine has a stator to rotor turns ratio of 1:0.5, where both stator and rotor phases are wye-connected. The stator is connected to a 3ϕ, 208V, $\underbrace{60Hz}_{f_s}$ source. The motor runs @ $\underbrace{1140 rpm}_{n_m}$.

$V_{in} \rightarrow$

A) OPERATING SLIP.

$$n_s = \frac{120 f_s}{P} = \frac{120(60)}{6} = 1200 \text{ rpm}$$

$$\Rightarrow s = 1 - \frac{n_m}{n_s} = 1 - \frac{1140}{1200} = \boxed{0.05 \text{ operating slip}}$$

B) PER PHASE ROTOR VOLTAGE (MAG. & FREQ)

$E_{r,s}$: induced rotor voltage @ slip

E_r: induced rotor voltage

$\rightarrow E_{r,s} = sE_r = s\, E_s/a = s\, \frac{V_{in}}{a\sqrt{3}}$

(From WYE) $\rightarrow \frac{V_{in}}{\sqrt{3}} = E_s$: "induced" stator voltage.

$$E_{r,s} = \frac{(0.05)(208)}{2\sqrt{3}} = \boxed{3.0V}$$

$a = 1/0.5 = 2$

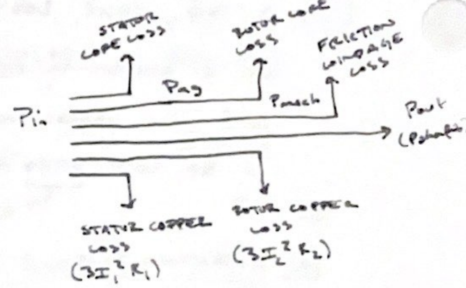
FREQ $\Rightarrow f_r = s f_s = (0.05)(60Hz) = \boxed{3Hz}$

C) RPM OF ROTOR FIELD w.r.t ROTOR & w.r.t STATOR.

ROTOR FIELD wrt ROTOR is SLIP RPM $= s n_s = 0.05(1200 \text{rpm}) = \boxed{60 \text{ rpm}}$

ROTOR FIELD wrt STATOR is $\underbrace{(1-s)n_s}_{n_m} + \underbrace{s n_s}_{\text{SLIP RPM}} = n_s = \boxed{1200 \text{rpm}}$

② A 3φ, 460V, 60Hz, 20kW induction machine draws 25A at a power factor of 0.9 lagging when connected to a 3φ, 460V, 60Hz supply. The core loss is 900W, stator copper loss is 1100W, rotor copper loss is 550W, and friction and windage loss is 300W. Calculate:



A AIR GAP POWER

From the diagram, $P_{ag} = P_{in} - P_{core} - P_{s,cu}$

$$P_{3\phi} = \sqrt{3}\, V_L I_L \cdot pf = 3\cdot\underbrace{\left(\tfrac{V_L}{\sqrt{3}}\right)}_{V_{phase}} I_{phase}\cdot pf$$

$$\hookrightarrow P_{in} = \sqrt{3}(460)(25)(0.9) = 17926.7W$$

$$\Rightarrow P_{ag} = 17926.7 - 900 - 1100 = \boxed{15926.7W}$$ AIR GAP POWER

* the airgap power is what is left from the input stage for the rotor to convert to mechanical power.

B MECHANICAL POWER

The mechanical power we get will be the airgap power the rotor recieves minus the copper loss in the rotor. No core losses given in rotor.

$$P_{mech} = P_{ag} - P_{r,cu} = 15926.7 - 550 = \boxed{15376.7W}$$

C OUTPUT HORSEPOWER

$P_{f,w}$: friction & windage loss

$$P_{out} = P_{mech} - P_{f,w} = 15376.7 - 300 = 15076.7W$$

$$\Rightarrow \frac{15076.7W}{1}\left(\frac{1\,HP}{746\,W}\right) = \boxed{20.2HP}$$

D EFFICIENCY

The efficiency can be calculated between P_{out} & P_{in}.

$$\eta = \frac{P_{out}}{P_{in}}\times 100\% = \frac{15076.7}{17926.7}\times 100\% = \boxed{84.1\%\ \text{efficient}}$$

(3) A 3ϕ, 10HP, 460V, 60Hz, 4-pole induction motor runs at 1730 rpm at full-load. The stator copper loss is 200W and the windage & friction loss is 320W. Determine:

$n_m = 1730$ rpm

$$n_s = \frac{120 f_e}{P} = \frac{120(60\,Hz)}{4} = 1800 \text{ rpm}$$

A MECHANICAL POWER

First we need to find slip s.

$$\Rightarrow s = 1 - n_m/n_s = 1 - \frac{1730}{1800} = 0.0389$$

Next, $P_{out} = 10Hp = 10Hp\left(\frac{746W}{1Hp}\right) = 7460W$

$$\Rightarrow P_{out} = P_{mech} - P_{f,w} \Rightarrow P_{mech} = P_{out} + P_{f,w} = 7460 + 320 = \boxed{7780W}$$

P_{mech}

B AIRGAP POWER

$$P_{ag} = \frac{P_{mech}}{1-s} = \frac{7780}{1-0.0389} = \boxed{8094.9\,W}$$

C ROTOR COPPER LOSS

$$P_{r,cu} = sP_{ag} = 0.0389(8094.9) = \boxed{314.9\,W}$$

* also could do $P_{r,cu} = P_{ag} - P_{mech}$

D INPUT POWER

No stator copper loss given $\therefore P_{in} = P_{ag} + P_{s,cu}$

$$P_{in} = 8094.9 + 200 = \boxed{8294.9W}$$

E EFFICIENCY

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{7460}{8294.9} \times 100\% = \boxed{89.9\% \text{ efficient}}$$

(4) Test results for 3ϕ, 230V, 60Hz, 6.5A, 500W induction machine

BLOCKED ROTOR: 44V, 60Hz, 25A, 1250W

NO-LOAD: 208V, 60Hz, 6.5A, 500W

The average resistance measured by a DC Bridge btwn two stator terminals is 0.54Ω → since 2 stator phases $\quad \underline{R_1} = \frac{0.54\Omega}{2} = \underline{0.27\Omega}$

$\boxed{A}$ NO-LOAD ROTATIONAL LOSS

$$P_{rot} = P_{NL} - 3I_1^2 R_1 = 500 - 3(6.5)^2(0.27\Omega) = \boxed{465.8\,W}$$

$\boxed{B}$ IEEE EQ. CKT.

We already know $R_1 = \frac{0.54\Omega}{2} = 0.27\Omega$

$\boxed{Z_{NL}}$ $\quad R_{NL} = \frac{P_{NL}}{3I_1^2} = \frac{500}{3(6.5)^2} = 3.94\Omega \quad , \quad Z_{NL} = \frac{V_1}{I_1} = \frac{208}{\sqrt{3}\,6.5} = 18.5\Omega$ (phase voltage)

$$X_{NL} = \sqrt{Z_{NL}^2 - R_{NL}^2} = \sqrt{18.5^2 - 3.94^2} = j18.1\,\Omega$$

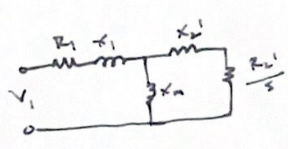
$\uparrow = X_1 + X_m$

$\boxed{Z_{BL}}$ $\quad s=1, \quad R_{BL} = \frac{P_{BL}}{3I_{BL}^2} = \frac{1250}{3(25)^2} = 0.667\Omega \quad$ where $R_2' = R_{BL} - R_1 = 0.667 - 0.27 = 0.397\Omega$

$$Z_{BL} = \frac{V_1}{I_1} = \frac{44}{\sqrt{3}\cdot 25} = 1.016\Omega \rightarrow X_{BL} = \sqrt{1.016^2 - 0.667^2} = j0.766\,\Omega$$

$$X_{BL} = X_1 + X_2' \quad \therefore \quad X_1 = X_2' = \frac{X_{BL}}{2} = \frac{0.766}{2} = j0.383\Omega$$

$$\Rightarrow X_m = X_{NL} - X_1 = 18.1 - 0.383 = j17.7\Omega$$



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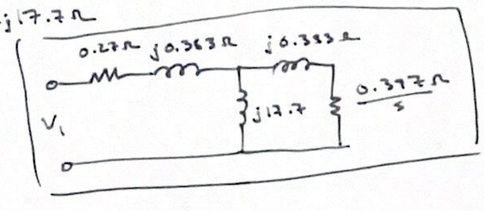

$\boxed{C}$ OUTPUT HP @ s=0.1

$$\frac{R_2'}{s} = \frac{0.383}{0.1} = 3.83\Omega \quad \Rightarrow Z_1 = R_1 + jX_1 + X_m \,||\left(\frac{R_2'}{s} + jX_2'\right) = 0.27 + j0.383 + \frac{j17.7(3.83 + j0.383)}{j17.7 + 3.83 + j.383}$$

$$= 4.07\angle 21.7^\circ\,\Omega$$

$$\Rightarrow I_1 = \frac{V_1}{\sqrt{3}Z_1} = \frac{208}{\sqrt{3}(4.07\angle 21.7^\circ)} = 29.5\angle{-21.7^\circ}\,A$$

$$\Rightarrow P_{in} = \sqrt{3}(208)(29.7)\cos(-21.7^\circ)$$
$$= 9874.69$$

$$P_{ag} = P_{in} - 3I_1^2R_1 = 9874.7 - 3(29.5)^2(0.27)$$
$$= 9169.8\,W$$

$$P_{mech} = (1-s)P_{ag} = (0.9)(9169.8) = 8252.8\,W$$

$$P_{out} = P_{mech} - P_{rot,loss}$$
$$= 8252.8 - 465.8$$
$$= \boxed{7787\,W = 10.4\,HP}$$