PRINCE OF SONGKLA UNIVERSITY

FACULTY OF ENGINEERING

Final Examination: Semester 1 Academic Year: 2549

Date: 8 October 2549 Time: 9.00 - 12.00

Subject: 211-221 Fundamentals of Electrical Machines Room: A 400

คำสั่ง - ข้อสอบมีทั้งหมด 5 ข้อ ข้อละ 20 คะแนน

- อนุญาตให้ใช้เครื่องคิดเลขได้

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1. A 60 Hz single-phase transformer has 200 turns on its primary winding and 500 turns on its secondary winding. The corresponding resistances are 0.242 Ω and 0.076 Ω respectively. The primary is connected to a 220 V sinusoidal supply and the secondary supplies 10 kVA to a load.
   a. Determine the load voltage, secondary current and primary current
   b. Determine the maximum flux ϕ_m in the core
   c. Determine the equivalent resistance in primary terms.
2. A standard 5 kVA 2300/230 V distribution transformer is connected as an autotransformer to step down the voltage from 2530 V to 2300 V. The transformer conection is as shown in figure 1, the 230 V winding is section ab, the 2300 V winding is section bc. Calculate
   a. The load power P_L
   b. The conducted power P_c
   c. The tranformed power P_{tr}

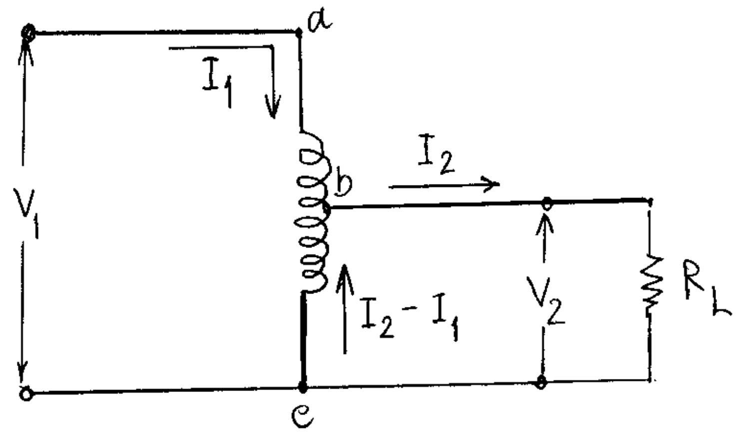

Figure 1

3. A 2300/208 V 500 kVA 60 Hz single-phase transformer was tested by means of the open-circuit test (on the low-voltage winding) and short-circuit test (on the high-voltage winding).

The test data obtained are :

Open-circuit test : $V_{oc} = 208$ V , $I_{oc} = 52.5$ A , $P_{oc} = 3800$ W

Short-circuit test : $V_{sc} = 95$ V , $I_{sc} = 217.4$ A , $P_{sc} = 6200$ W

Calculate

a. The equivalent transformer parameters referred to the low-votage side (R_{eL}, X_{eL}, Z_{eL})

b. The efficiency of the transformer at rated kVA, when the power factor is 0.866 lagging

c. The voltage regulation when supplying full load at a power factor 0.866 lagging

4. A three-phase 125 hp 440 V 60 Hz eight-pole Y-connected induction motor has the following electric circuit parameters on a per phase basis referred to stator

$$R_s = 0.068\ \Omega \qquad X_s = X_R' = 0.224\ \Omega$$
$$R_R' = 0.052\ \Omega \qquad X_m = 7.68\ \Omega$$

The rotational losses are 2400 W. For a slip of 3% determine

a. The line current and the power factor

b. The shaft torque

c. The efficiency

Y-connected

5. A 5 hp 220 V 60 Hz four-pole three-phase induction motor was tested and the following data were obtained

No-load test : $V_{NL} = 220$ V, $P_{NL} = 340$ W, $I_{NL} = 6.2$ A

Blocked-rotor test : $V_{BR} = 49.4$ V, $P_{BR} = 360$ W , $I_{BR} = 13.9$ A

The dc resistance measurement on the stator winding gives a 4.0 V drop between terminals, when dc current flows 13.9 A. Calculate

a. The equivalent parameters(R_e , Z_e , X_e) in stator terms

b. The rotational loss

c. The efficiency of the motor when operating at a slip of 0.04

(Hint: The effective ac resistance is 1.25 times of the dc value)

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Transformer

no load current $I_0 = I_m + I_e$

$$E_P = 4.44 f N_P \phi_m$$
$$E_S = 4.44 f N_S \phi_m$$

turn ratio $a = \frac{E_P}{E_S} = \frac{N_P}{N_S}$, $\frac{I_S}{I_P} = a$

Equivalent Circuit

$$R_{eP} = R_P + a^2 R_S$$
$$X_{eP} = X_P + a^2 X_S$$
} in primary term.

$$R_{eS} = R_S + \frac{R_P}{a^2}$$
$$X_{eS} = X_S + \frac{X_P}{a^2}$$
} in secondary term.

Open-Circuit test

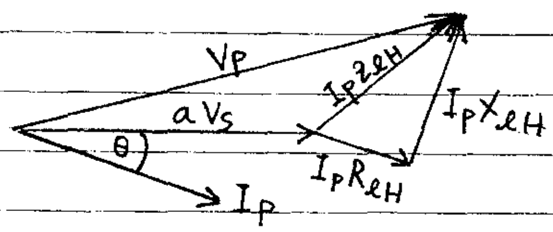
ค่าที่อ่านได้จาก Watt-meter คือค่า core losses

Short-Circuit Test

$R_{eH} = \frac{P_{se}}{I_{se}^2}$, $Z_{eH} = \frac{V_{se}}{I_{se}}$, $X_{eH} = \sqrt{Z_{eH}^2 - R_{eH}^2}$

Voltage Regulation

$$\text{voltage regulation} = \frac{V_{no\text{-}load} - V_{full\text{-}load}}{V_{full\text{-}load}} \times 100\%$$



Efficiency

$$\eta = \frac{\text{output power}}{\text{input Power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

rotor speed $n_r = (1 - S) \times N_S$ r/min

rotor power input (RPI) = rotor copper loss (RCL) + rotor power developed (RPD)

เมื่อ RPI (per phase) $= I_R^2 \frac{R_R}{S}$

$$RCL = I_R^2 R_R$$
$$RPD = I_R^2 R_R \frac{1-S}{S} = RPI(1-S)$$

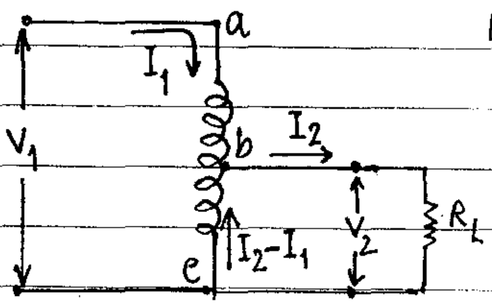
$$\eta = \frac{kVA_{out} \times PF}{kVA_{out} \times PF + \text{copper losses} + \text{core loss}}$$

The efficiency is maximum when the copper losses equal the eore losses

All-day Energy Efficiency

$$\eta_e = \frac{\text{energy output over 24 hours}}{\text{energy input over 24 hours}}$$

Autotransformer



$P_c = V_2 I_1$ = conducted power to load through ab

$P_{tr} = V_2(I_2 - I_1)$ = transformed power to load through be

Induction Motor

synchronous speed $n_s = \frac{120f}{P}$ r/min

Slip $S = \frac{n_s - n_r}{n_s} \times 100\%$

rotor speed $n_r = (1 - S) \times N_s$ r/min

rotor power input (RPI) = rotor copper loss (RCL) + rotor power developed (RPD)

เมื่อ RPI (per phase) $= I_R^2 \frac{R_R}{S}$

$RCL = I_R^2 R_R$

$RPD = I_R^2 R_R \frac{1-S}{S} = RPI(1-S)$

developed torque $T_d = \frac{RPD}{\omega_r}$ N-m.

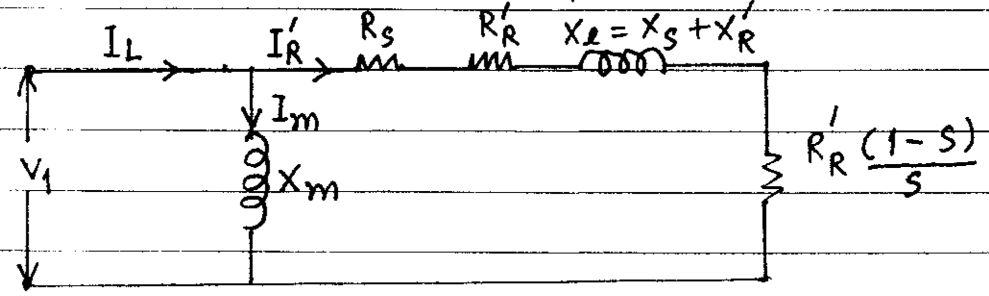
เมื่อ $\omega_r = \frac{2\pi n_r}{60}$ rad/s

~~shaft torque $T = \frac{RPD - P_{rot}}{\omega_r}$~~

$$P_{out} = RPD - P_{rot}$$

P_{rot} = rotational loss = friction, windage and core losses

Equivalent circuit per phase of Induction motor

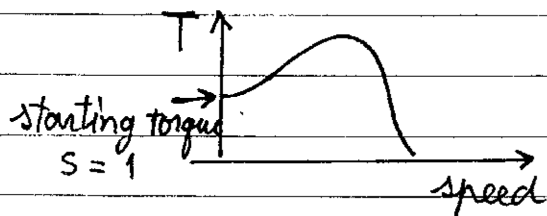


เมื่อ stator winding ถูกต่อแบบ Y และเมื่อสมมติว่าพิกัด voltage ของมอเตอร์ คือ 220 V. , V_1 คือ phase voltage $= \frac{220}{\sqrt{3}}$ V.

$$I'_R = \frac{V_1}{\left(R_S + \frac{R'_R}{S}\right) + j(X_S + X'_R)}$$

$$I_m = \frac{V_1}{jX_m} \quad , \quad I_L = I_m + I'_R$$

Starting Torque



$$T_{st} = \frac{RPI_{st}}{\omega_S}$$

เมื่อ $\omega_S = \frac{2\pi n_s}{60}$

Maximum Torque

$$S_{mt} = \frac{R'_R}{\sqrt{R_S^2 + (X_S + X'_R)^2}}$$

$$T_{mt} = \frac{RPD_{mt} - P_{rot}}{\omega_{r\,mt}}$$

No-load test

$$P_{NL} = P_C + P_{fr+w} + 3I_{NL}^2 R_S$$

$$P_{rot} = P_{NL} - 3I_{NL}^2 R_S$$

เมื่อ $P_{rot} = P_C + P_{fr+w}$ = friction + windage + core losses

$$X_m = \frac{V_{NL}}{\sqrt{3}\, I_{NL}}$$

Blocked Rotor Test

$$Z_e = \frac{V_{BR}}{\sqrt{3}\, I_{BR}} = \sqrt{(R_S + R_R') + j(X_S + X_R')}$$

$$R_e = \frac{P_{BR}}{3I_{BR}^2} = R_S + R_R'$$

$$X_e = \sqrt{Z_e^2 - R_e^2} = X_S + X_R'$$

$$X_S = X_R' = 0.5X_e$$