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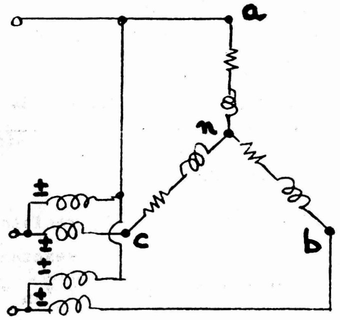
CHAPTER 2

Problem 2-1



Line Voltage = 460 V, Resistance = 8.66 ohm

Reactance = 5 ohm

Reference voltage = $\hat{V}_{an}$ = 265.6 + j0

(a) The line current

= phase current since wye connected

= (265.6 + j0) / (8.66 + j5)

= 23.0 - j13.28 = 26.56 $\underline{/-30^o}$

(b) Total power = 3 x 26.56^2 x 8.66 = 18 325.4 W

(c) The two wattmeter readings are:

Wattmeter in line B:

$\hat{V}_{ba}$ = 460 $\underline{/-150^o}$

$\hat{I}_b$ = 26.56 $\underline{/-150^o}$

P_b = 460 x 26.56 x cos (0)

= 12 217

Wattmeter in line C:

$\hat{V}_{ca}$ = 460 $\underline{/150^o}$

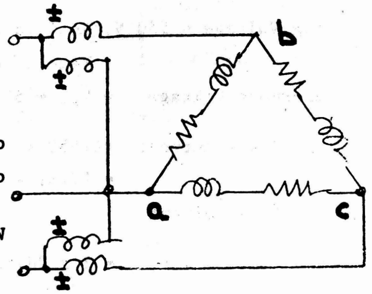
$\hat{I}_c$ = 26.56 $\underline{/90^o}$

P_c = 460 x 26.56 x cos (60)

= 6108.4

Sum of the two readings = 18 325.4 W

Problem 2-2



Line Voltage = 460 V, Resistance = 8.66 ohm

Reactance = 5.00 ohm

Reference voltage = $\hat{V}_{ab}$ = 460 + j0

(a) Phase current = (460 + j0) / (8.66 + j5)

= 39.84 - j23.00 = 46.00 $\underline{/-30^o}$

Line current = 79.68 $\underline{/-60^o}$

(b) Total power = 3 x 46.00^2 x 8.66 = 54 976.1 W

(c) The two wattmeter readings are:

Wattmeter in line B:

$\hat{V}_{ba}$ = 460 $\underline{/180^o}$

Wattmeter in line C:

$\hat{V}_{ca}$ = 460 $\underline{/120^o}$

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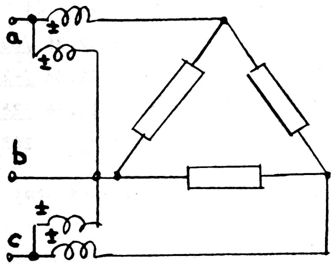
Problem 2-10



Line Voltage 208

$\hat{Z}_{ba}$ = (10 + j20) = 22.36 $\underline{/63.43^o}$

$\hat{Z}_{cb}$ = (20 - j10) = 22.36 $\underline{/-26.57^o}$

$\hat{Z}_{ac}$ = (20 + j10) = 22.36 $\underline{/26.57^o}$

Reference Voltage = $\hat{V}_{ac}$ = 208 + j0

(a) The phase voltages are:

$\hat{V}_{ac}$ = 208 + j0

$\hat{V}_{cb}$ = 208 $\underline{/-120^o}$ = -104 - j180.1

$\hat{V}_{ba}$ = 208 $\underline{/+120^o}$ = -104 + j180.1

(b) The phase currents are:

$\hat{I}_{ac}$ = (208 + j0) / (20 + j10) = 8.32 - j4.16

= 9.3 $\underline{/-26.57^o}$

$\hat{I}_{cb}$ = (-104 - j180.1) / (20 - j10) = -0.558 - j9.284

= 9.3 $\underline{/-93.44^o}$

$\hat{I}_{ba}$ = (-104 + j180.1) / (10 + j20) = 5.125 + j7.762

= 9.3 $\underline{/56.57^o}$

(c) The line currents are:

$\hat{I}_a$ = (8.32 - j4.16) - (5.125 + j7.762) = 3.195 - j11.922

= 12.343 $\underline{/-75.00^o}$

$\hat{I}_b$ = (5.125 + j7.762) - (-0.558 - j9.284) = 5.683 + j17.046

= 17.97 $\underline{/71.56^o}$

$\hat{I}_c$ = (-0.558 - j9.284) - (8.32 - j4.16) = 8.878 - j5.124

= 10.251 $\underline{/-150.00^o}$

(d) Two-wattmeter readings:

Wattmeter in line C:

$\hat{V}_{cb}$ = 208 $\underline{/-120^o}$

$\hat{I}_c$ = 10.251 $\underline{/-150^o}$

P_c = 208 x 10.251 x cos (30)

= 1846.55

Wattmeter in line A:

$\hat{V}_{ab}$ = 208 at $\underline{/-60^o}$

$\hat{I}_a$ = 12.343 $\underline{/-75.00^o}$

P_a = 208 x 12.343 x cos (15)

= 2479.86

Sum of the 2 readings = 4326.4 W

(e) The phase powers:

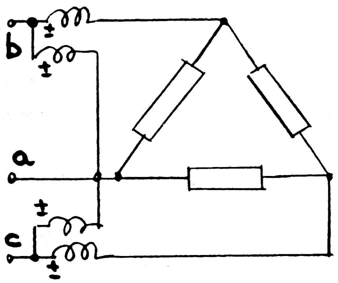
P_{ac} = 9.3^2 x 20 = 1730.56 W

P_{cb} = 9.3^2 x 20 = 1730.56 W

P_{ba} = 9.3^2 x 10 = 865.28 W

Sum = 4326.40 W

Problem 2-11



Line Voltage = 460 V

$\hat{Z}_{ab}$ = (25 + j15) = 29.15 $\underline{/30.96^o}$

$\hat{Z}_{bc}$ = (15 - j25) = 29.15 $\underline{/-59.04^o}$

$\hat{Z}_{ca}$ = (20 + j20) = 28.28 $\underline{/45^o}$

Reference voltage = $\hat{V}_{ab}$ = 460 $\underline{/0^o}$

(a) The phase voltages are:

$\hat{V}_{ab}$ = 460 $\underline{/0^o}$ = 460 + j0

$\hat{V}_{bc}$ = 460 $\underline{/-120^o}$ = -230 - j398.37

$\hat{V}_{ca}$ = 460 $\underline{/+120^o}$ = -230 + j398.37

(b) The phase currents are:

$\hat{I}_{ab}$ = (460 + j0) / (25 + j15) = 13.529 - j8.118

= 15.78 $\underline{/-30.96^o}$

$\hat{I}_{bc}$ = (-230 - j398.37) / (15 - j25) = 7.658 - j13.795

= 15.78 $\underline{/-60.96^o}$

$\hat{I}_{ca}$ = (-230 + j398.37 / (20 + j20) = 4.209 + j15.709

= 16.26 $\underline{/75^o}$

(c) The line currents are:

$\hat{I}_a$ = (13.529 - j8.118) - (4.209 + j15.709) = 9.32 - j23.827

= 25.585 $\underline{/-68.64^o}$

$\hat{I}_b$ = (7.658 - j13.795) - (13.529 - j8.118) = -5.871 - j5.667

= 8.167 $\underline{/-135.96^o}$

$\hat{I}_c$ = (4.209 + j15.709) - (7.658 - j13.795) = -3.448 + j29.504

= 29.705 $\underline{/96.67^o}$

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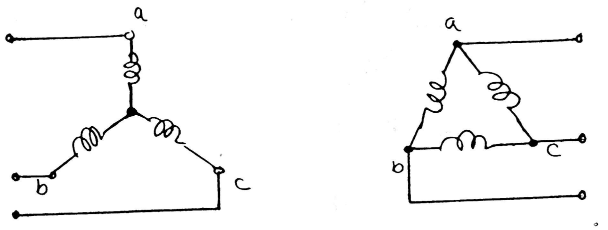
Problem 5-19

R_{eq} = 1.2, X_1 = 4.5 ohm

Turns ratio = 2300/460 = 5.0

(a) A Wye / Delta connection is required



(b) Specified load: Voltage 460 V

Apparent power 300 000 VA

Reactive power 120 000 var (inductive)

Secondary phase current = 300 000 / (3 x 460) = 217.3913 A

Primary current = 217.3913 x 460 / 2300 = 43.4783 A

(c) The following values are referred to the primary of each transformer.

Equivalent impedance = (1.2 + j4.5) ohm

Secondary phase voltage = 2300.0 V

Secondary current = 39.8485 - j17.3913 = 43.4783 $\underline{/-23.58^\circ}$ A

Primary voltage = (2300.0 + j0) + (39.8485 - j17.3913) (1.2 + j4.5)

= 2426.0791 + j158.4487 = 2431.2478 $\underline{/3.74^\circ}$ V

Primary line voltage = 4211.0447 V

Voltage regulation = (2431.2478 - 2300) / 2300 = 0.0571 pu = 5.71%

Losses: Copper = 3 x 43.4783^2 x 1.2 = 6805.3 W

Core = 0 (neglected, since unknown)

Total losses = 6 805.3 W

Output power = 274 954.5 W

Input power = 281 759.8 W

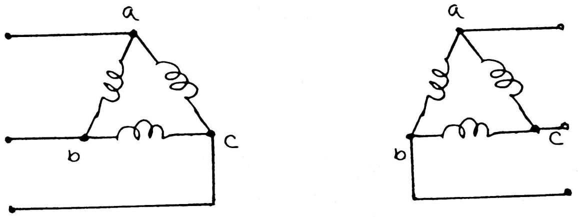
Efficiency = 274 954.5 / 281 759.8 = 0.9758 pu = 97.58%

Problem 5-20

R_1 = 0.4, X_1 = 0.9 ohm

Turns ratio = 460/208 = 2.2115

(a) A Delta / Delta connection is required.



(b) Specified load: Voltage 208 V

Power 50 000 W

Apparent power 60 000 VA (inductive)

Secondary phase current = 60 000 / (3 x 208) = 96.1538 A

Primary current = 96.1538 x 208 / 460 = 43.4783 A

(c) The following values are referred to the primary of each transformer.

Equivalent impedance = (0.4 + j0.9) ohm

Secondary phase voltage = 460 V

Secondary current = 36.2319 - j24.0335 = 43.4783 $\underline{/-33.56^\circ}$ A

Primary voltage = (460 + j0) + (36.2319 - j24.0335) (0.4 + j0.9)

= 496.1229 + j22.9953 = 496.6555 $\underline{/2.65^\circ}$ V

Voltage regulation = (496.6555 - 460) / 460 = 0.0797 pu = 7.97%

Losses: Copper = 3 x 43.4783^2 x 0.4 = 2268.4

Core = 0 (neglected)

Total losses = 2 268.4 W

Output power = 50 000 W

Input power = 52 268.4 W

Efficiency = 50 000 / 52 268.4 = 0.9566 pu = 95.66%

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Problem 7-19

V_t = 440 V, f = 60 Hz, Poles = 6, Delta connection

R_1 = 1.5 ohm, R_2' = 0.8 ohm

Stator leakage inductance = 0.008 H, Rotor leakage inductance = 0.008 H

Magnetizing inductance = 0.3 H, Turns ratio = 1

Approximate equivalent

X_1 = 3.016, X_2' = 3.016, X_m = 113.1 ohm at 60 Hz

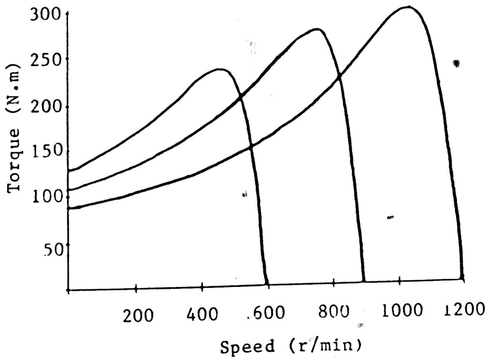
(a) This is a repeat of Prob. 7-18

(b) Repeat Prob 7-18 with X_1 = 2.262, X_2' = 2.262, X_m = 84.8 ohm at 45 Hz

V_{ph} = 0.75 x 440 = 330 V

(c) Repeat Prob 7-18 with X_1 = 1.508, X_2' = 1.508, X_m = 56.55 ohm at 30 Hz

V_{ph} = 0.5 x 440 = 220 V



(d) The maximum torques are

f (Hz)	T_m (N.m)	Speed (r/min)	Slip
60	300	1045	0.19
45	275	750	0.17
30	235	460	0.24

Note: T_m is reduced as the frequency is reduced since R_1 is not neglected.

Problem 7-20

V_t = 440 V, f = 60 Hz, Poles = 6, Delta connection

R_1 = 1.5 ohm, R_2' = 0.8 ohm

Stator leakage inductance = 0.008 H, Rotor leakage inductance = 0.008 H

Magnetizing inductance = 0.3 H, Turns ratio = 1

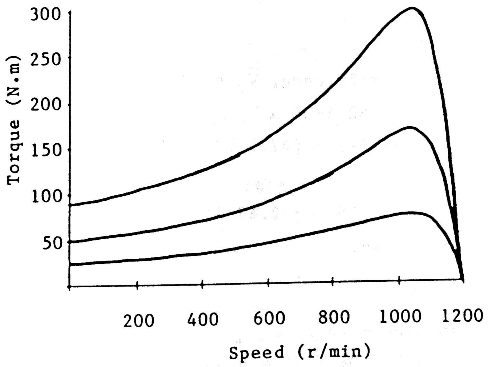
Approximate equivalent

X_1 = 3.016, X_2' = 3.016, X_m = 113.1 ohm at 60 Hz

(a) This is a repeat of Prob. 7-18

(b) Repeat 7-18 with V_{ph} = 330 V

(c) Repeat 7-18 with V_{ph} = 220 V



(d) The maximum torques are:

Voltage (V)	T_m (N.m)	Speed (r/min)	Slip
440	300	1045	0.19
330	170	1045	0.19
220	75	1045	0.19

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Problem 8-10

V_t = 550 V, f = 60 Hz, Poles = 10, Wye connection

X_s = 2.9 ohm/ph, R_a = 0

Power = 75 kW, Power factor = 1.0, Increase in I_f = 20%

(a) Taking $\hat{V}_t$ (phase) as reference, $\hat{V}_t$ = 317.54 + j0

$$I_a = \frac{75 \times 1000}{1.7321 \times 550 \times 1} = 78.73$$

$\hat{I}_a$ = 78.73 + j0

$\hat{E}_f$ = (317.54 + j0) - (78.73 + j0) (j2.9) = 317.5426 - j228.316

= 391.10 $\underline{/-35.72^o}$ V (phase)

E_f = 677.41 V (line)

(b) I_r = component of $\hat{I}_a$ in phase with $\hat{V}_t$

= 78.73 A (constant)

E_f = 391.10 x 1.2 = 469.328

Im[$\hat{E}_f$] = -228.316 (constant)

Re[$\hat{E}_f$] = √(469.328^2 - 228.316^2) = 410.04

That is, $\hat{E}_f$ = 410.04 - j228.32 = 469.328 $\underline{/-29.11^o}$ V

But $\hat{V}_t$ = 317.54 + j0

j$\hat{I}_a X_s$ = (317.54 + j0) - (410.04 - j228.32) = -92.50 + j228.32

= 246.34 $\underline{/112.06^o}$ V

$\hat{I}_a$ = 84.95 $\underline{/22.06^o}$ A

Increase in I_a = (84.95 - 78.73) / 78.73 = 7.90%

Problem 8-11

V_t = 460 V, f = 60 Hz, Poles = 10, Wye connection

X_s = 2.5 ohm/ph, R_a = 0

Power = 60 kW, Power factor = 1.0, Increase in I_f = 25%

(a) Taking $\hat{V}_t$ (phase) as reference, $\hat{V}_t$ = 265.58 + j0

$$I_a = \frac{60 \times 1000}{1.732 \times 460 \times 1} = 75.31 \text{ A}$$

$\hat{I}_a$ = 75.31 + j0

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$\hat{E}_f$ = (265.58 + j0) - (75.31 + j0) (j2.5) = 265.5811 -188.266

= 325.54 $\underline{/-35.33^o}$ V (phase)

E_f = 563.86 V (line)

(b) I_r = component of $\hat{I}_a$ in phase with $\hat{V}_t$

= 75.31

E_f = 325.54 x 1.25 = 406.93 V

Im[$\hat{E}_f$] = -188.27

Re[$\hat{E}_f$] = √(406.93^2 - 188.27^2) = 360.76

$\hat{E}_f$ = 360.76 - j188.27 = 406.93 $\underline{/-27.56^o}$

$\hat{V}_t$ = 265.58 + j0

j$\hat{I}_a X_s$ = (265.58 + j0) - (360.76 - j188.27)

= -95.18 + j188.27 = 210.96 $\underline{/116.82^o}$ V

$\hat{I}_a$ = 84.38 $\underline{/26.82^o}$ A

Increase in I_a = (84.38 - 75.31) / 75.31 = 12.05%

Problem 8-12

V_t = 460 V, f = 60 Hz, Poles = 10, Wye connection

X_s = 0.8 ohm/ph, R_a = 0

Power = 200 kW, Power factor = 0.8 (leading), Increase in torque = 100%

(a) Taking $\hat{V}_t$ (phase) as reference, $\hat{V}_t$ = 265.58 + j0

$$I_a = \frac{200 \times 1000}{1.7321 \times 460 \times 0.8} = 313.78 \text{ A}$$

$\hat{I}_a$ = 313.78 (0.8 + j0.6) = 251.0264 + j188.2664

$\hat{E}_f$ = (265.58 + j0) - (251.0264 + j188.2664) (j0.8) = 416.1942 - j200.817

= 462.11 $\underline{/-25.76^o}$ V (phase)

E_f = 800.40 V (line)

(b) I_r = component of $\hat{I}_a$ in phase with $\hat{V}_t$

= 251.0264 x 2 = 502.0528 A

E_f = 462.11 V (constant)

Im[$\hat{E}_f$] = -502.0528 x 0.8 = -401.63 V

Re[$\hat{E}_f$] = √(462.11^2 - 401.63^2) = 228.55 V

$\hat{E}_f$ = 228.55 - j401.63

$\hat{V}_t$ = (265.58 + j0)