1. A 200 kVA, 6600V/400V, 50 Hz single-phase transformer has 80 turns on the secondary. Calculate:
   (a) the approximate values of the primary and secondary currents;
   (b) the approximate number of primary turns;
   (c) the maximum value of the flux.

Ans. (a) Primary current $= \dfrac{200 \times 10^3}{6600} = 30.3\text{A}$ Secondary current $= \dfrac{200 \times 10^3}{400} = 500\text{A}$

(b) Primary turns $= 80 \times \dfrac{6600}{400} = 1320$ turns

(c) $E = 4.44 f N \Phi_{max} \Rightarrow \Phi_{max} = \dfrac{6600}{4.44 \times 50 \times 1320} = 0.0225$ Wb

2. The primary winding of a single-phase transformer is connected to a 230V 50 Hz supply. The secondary winding has 1500 turns. If the maximum value of the core flux is 0.00207Wb, determine:
   (a) the number of turns on the primary winding;
   (b) the secondary induced voltage;
   (c) the net cross-sectional core area if the flux density has a maximum value of 0.465 telsa.

Ans. (a) Primary turns $= \dfrac{230}{4.44 \times 50 \times 0.00207} = 500$ turns

(b) Secondary induced voltage $= 230 \times \dfrac{1500}{500} = 690$ Volts

(c) Cross sectional Area $= \dfrac{\text{Flux}}{\text{flux density}} = \dfrac{0.00207}{0.465} = 4452\text{mm}^2$

3. A 3200/400 single-phase transformer has winding resistance and reactance of 3Ω and 13Ω respectively in the primary and 0.02Ω and 0.065Ω in the secondary. Express these in terms of
   Also refer to detailed solution
   (a) primary alone ,
   (b) secondary alone.

Ans. (a) Turn ratio = 8, to transfer impedance from LV side to HV side, the impedance is multiplied by $8^2 = 64$, $R_2' = 0.02 \times 64 = 1.28\Omega$, $X_2' = 0.065 \times 64 = 4.16\Omega$

$R_{1eq} + j X_{1eq} = (R_1 + R_2') + j(X_1 + X_2') = (3+1.28) + j(13+4.16) = 4.28+j\ 17.16\Omega$

(b) Turn ratio = 8, to transfer impedance from HV side to LV side, the impedance is divided by $8^2 = 64$, $R_1' = 3 \div 64 = 0.0469\Omega$, $X_1' = 13 \div 64 = 0.203\Omega$

$R_{2eq} + j X_{2eq} = (R_1' + R_2) + j(X_1' + X_2)$

$= (0.0469+0.02) + j(0.203+0.065) = 0.067+j\ 0.268\Omega$

4. The primary winding of a transformer has 500 turns and is supplied at a voltage of 2000 V r.m.s. at a frequency of 50 Hz. Estimate the maximum value of the flux through the core.

Ans. $E = 4.44 f N \Phi_{max} \Rightarrow \Phi_{max} = \dfrac{2000}{4.44 \times 50 \times 500} = 0.018$ Wb

Same as PowerPoint Example.

5. A single-phase transformer has 1000 turns on the primary and 200 turns on the secondary. The no-load current is 3A at a power factor 0.2 lagging. Calculate the primary current and power factor when the secondary current is 280 A at a power factor of 0.8 lagging. Assume the voltage drop in the windings to be negligible.

$\frac{V_1}{V_2} = \frac{N_1}{N_2} = \frac{I_2}{I_1}$

Ans. Secondary current referred to the primary side $= 280 \times \frac{200}{1000} = 56A$

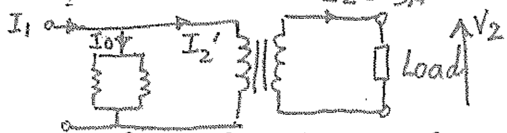
$\cos\phi = 0.8$ lagging

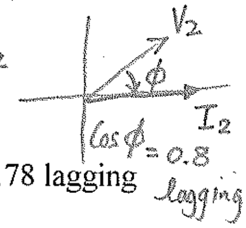
Power factor = 0.8 lagging → $\Phi = -36.9°$, i.e. $I_2' = 56\angle-36.9°$ $\quad I_2 = 3A$

$I_1 = I_o + I_2' = 3\angle-78.5° + 56\angle-36.9°$

$= 0.5981 - j2.9398 + 44.7823 - j33.6235$

$= 45.3804 - j36.5633 = 58.28\angle-38.9°$ The power factor of $I_1 = \text{Cos} - 38.9° = 0.78$ lagging





6. A single-phase transformer has a primary voltage of 2000V, a secondary voltage of 440 V and a full load-output of 20 kVA. The secondary winding has 130 turns. Calculate the number of primary turns and the primary and secondary full-load currents, neglecting losses.

Ans. Primary turns $= 130 \times \frac{2000}{440} = 591$ turns

Primary current $= \frac{20 \times 10^3}{2000} = 10A$ Secondary current $= \frac{20 \times 10^3}{440} = 45.5A$

7. The voltage on the secondary of a single-phase transformer is 200 V when supplying a load of 8 kW at a power factor of 0.8 lagging. The secondary resistance is 0.04Ω and the secondary leakage reactance is 0.8Ω, calculate the induced e.m.f. in the secondary winding.

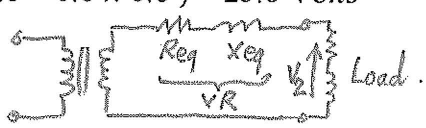
power = $VI\cos\phi$

Ans. $V_2 = 200$, $I_2 = \frac{8000}{200 \times 0.8} = 50A$, $\text{Cos}\,\Phi = 0.8$, $\text{Sin}\,\Phi = 0.6$ inductive loads, ∵ power-factor is lagging.

For secondary circuit only, voltage regulation $= I_2R_2\text{Cos}\,\Phi + I_2X_2\,\text{Sin}\,\Phi$

$VR = 50 \times (0.04 \times 0.8 + 0.8 \times 0.6) = 25.6$ Volts

Therefore, the induced e.m.f. $E_2 = 200 + 25.6 = 225.6$ Volts.



8. If the transformer of Question 7 has 500 primary turns and 50 secondary turns,

(a) find the induced e.m.f. in the primary winding.

(b) if the primary resistance is 4Ω and the primary leakage reactance is 70Ω, estimate the primary terminal voltage. The magnetizing current can be ignored.

Ans. (a) Turns ratio = 10, induced e.m.f. $E_1 = 10 \times E_2 = 2256$ Volts

(b) For Primary circuit only, voltage regulation $= I_1R_{1eq}\text{Cos}\,\Phi + I_1X_{1eq}\,\text{Sin}\,\Phi$

$I_1 = 50 / 10 = 5A$, Volt drop in primary winding $= 5\,(4 \times 0.8 + 70 \times 0.6) = 226$ Volts

Therefore primary terminal voltage = 2256 + 226 = 2482 Volts

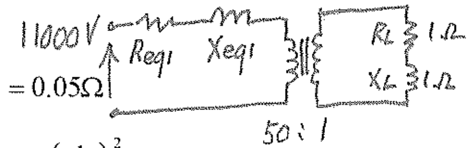
9. A farm, whose electrical load can be represented by a resistance of 1Ω in series with an inductive reactance of 1Ω, is supplied from an 11000V single-phase line through a transformer of turns ratio 50:1. The resistance and leakage reactance of the transformer are 125Ω (R_{eq1}) and 250Ω (X_{eq1}) respectively when referred to its primary and its magnetizing current may be neglected. Determine :

(a) the magnitude of the current taken from the secondary terminals of the transformer ;

(b) the potential difference between the secondary terminals,

(c) the magnitude and power-factor of the primary current. ans. (a) 145 A ; (b) 205 V, (c) 2.9 A, 0.7

Ans. (a) Primary resistance referred to the secondary side = $125\times\left(\frac{1}{50}\right)^2 = 0.05\Omega$

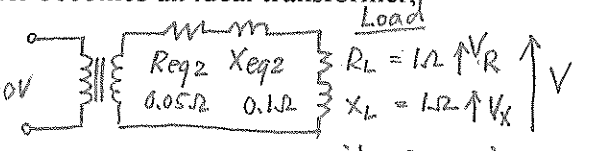


Primary leakage reactance referred to the Secondary side = $j250\times\left(\frac{1}{50}\right)^2 = j0.1\Omega$

Total impedance (including load) referred to the secondary side impedance of load = $1+j1\Omega$

$= (1+0.05) + j\,(1+0.1) = 1.05 + j\,1.1\ \Omega = 1.5207\angle 46.3°\Omega$

With all the impedance referred to the secondary, the transformer becomes an ideal transformer, therefore the e.m.f. at secondary = $11000\times\left(\frac{1}{50}\right) = 220$ Volts

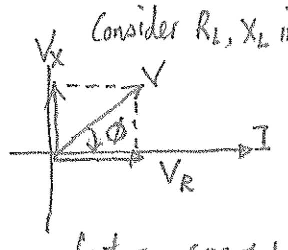


Secondary currents = $\dfrac{220}{1.5207\angle 46.3°} = 144.7$ A

Consider R_L, X_L in series.

(b) Impedance of load = $1 + j\,1\ \Omega$,

power factor of the load = Cos 45° = Sin 45° = 0.7071 lagging ?????



Volt drop across transformer impedance = $I_2R_{eq2}\text{Cos}\ \Phi + I_2X_{eq2}\ \text{Sin}\ \Phi$

use + for inductive loads.

$= 144.7\ (0.05 \times 0.7071 + 0.1 \times 0.7071) = 15.35$ Volts

power factor = $\cos\phi$ lagging.

$V_2 = E_2$ – Volt drop = 220 – 15.35 = 204.65 Volts

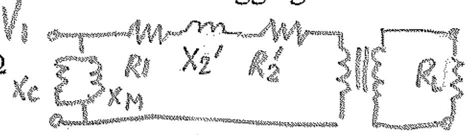
Neglecting No-load component, $I_1 = I_2' = 144.7\times\frac{1}{50} = 2.9\text{A}$ $\quad \tan^{-1}\phi = \frac{V_X}{V_R} = \frac{IX_L}{IX_R} = \frac{X_L}{X_R} = \frac{1}{1} = 45°$

Power factor of the primary current is the same as the secondary current, i.e. 0.7 lagging

10. A 4000/400V , 10 kVA transformer has primary and secondary winding resistance of 13Ω (R_1) and (R_2) 0.15Ω respectively. The leakage reactance referred to the primary (R_2') is 45Ω, the magnetizing reactance referred to the primary is 6000Ω (X_M), and the resistance corresponding to the core loss is 12000Ω (X_C). Determine

(a) total resistance referred to the primary and the values of all impedances referred to the secondary.
(b) the input current when the secondary terminals are open-circuited.
(c) the input current when the secondary load current is 25 A at a power factor of 0.8 lagging.

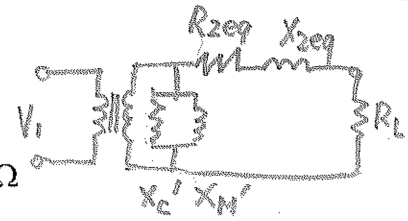
Ans. (a) Secondary resistance referred to primary (R_2') $= 0.15\times\left(\frac{4000}{400}\right)^2 = 15\Omega$



$(R_1 + R_2')$ = Total resistance referred to the primary = R_{1eq} = 13 + 15 = 28 Ω

$$R_{2eq} = 28\times\left(\frac{400}{4000}\right)^2 = 0.28\Omega \qquad X_{2eq} = 45\times\left(\frac{400}{4000}\right)^2 = 0.45\Omega$$

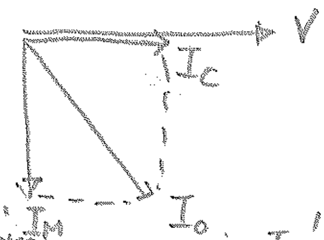
$$R_C' = 12000\left(\frac{400}{4000}\right)^2 = 120\Omega \qquad X_M' = 6000\left(\frac{400}{4000}\right)^2 = j60\Omega$$



(b) During open circuit, only the no load current flow, $I_O{}^2 = I_C{}^2 + I_M{}^2$

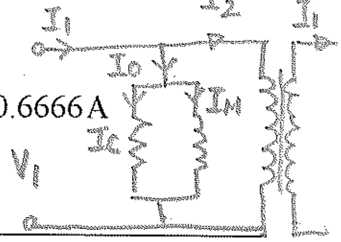
$$I_C = \frac{V_1}{R_C} = \left(\frac{4000}{12000}\right) = 0.3333\text{A} \quad I_M = \frac{V_1}{X_M} = \left(\frac{4000}{6000}\right) = -j0.6666\text{A}$$

$$I_O = \sqrt{0.3333^2 + 0.6666^2}\angle -\tan^{-1}\left(\frac{0.6666}{0.3333}\right) = 0.745\angle -63.4°\text{A}$$



$\cos\theta = 0.8$ lagging
$\theta = -36.9°$

(c) When the secondary current is 25A at p.f. 0.8 lagging,



$$I_2 = 25\angle -\underbrace{36.9}_{\theta}\text{A}°,\quad I_2' = I_2\frac{1}{a} = 2.5\angle -36.9\text{A}° = 2 - j1.5\text{A},\quad I_O = 0.3333 - j0.6666\,\text{A}$$

$$I_1 = I_O + I_2' = (2 + 0.3333) - j(1.5 + 0.6666) = 3.18\angle -43°\text{A}$$

11. The primary and secondary windings of a 40kVA 6600/250V single-phase transformer have resistances of 10Ω and 0.02Ω respectively. The leakage reactance of the transformer referred to the primary is 35Ω. Neglect the no-load current, calculate: ans. (a) 257 V, (b) 2.2 %, 3.7 %

(a) the primary voltage required to circulate full load current when the secondary is short-circuited,
(b) the full load regulation at (i) unity (ii) 0.8 lagging power factor.

Ans. (a) $R_2' = 0.02\left(\frac{6600}{250}\right)^2 = 13.94\Omega$,

$Z_{1eq} = R_{1eq} + X_{1eq} = (10+13.94)+j35 = 23.94 + j35\Omega = 42.4\angle 55.6°$

Full load primary current = 40000/6600 = 6.06A

Primary voltage required to circulate full load current = 6.06 x 42.4 = 257 Volts

(b) At full load unity power factor, V.R. = 6.06 x (23.94 x 1 + 35 x 0) = 145Volts

Percentage voltage regulation = 145/6600 x 100% = 2.2%

At full load 0.8 p.f. lagging, V.R. = 6.06 x (23.94 x 0.8 + 35 x 0.6) = 243.3 Volts

Percentage voltage regulation = 243.3/6600 x 100% = 3.7%

12. A 40kVA 6000V/240V power transformer has the following parameters: Also Refer to detailed solution.

Resistance of primary winding = 10Ω ; Resistance of secondary winding = 0.017Ω
Reactance referred to primary side = 35Ω. Calculate:
(a) the primary voltage and power required to circulate full-load current when the secondary is short-circuited ,
(b) the percentage voltage regulation and secondary terminal voltage for load of 33kVA at 0.65 leading power factor.

Ans. (a) The problem ask for primary voltage therefore we have to transfer all the impedance to the primary:

Secondary resistance referred to the primary = $0.017\times\left(\frac{6000}{240}\right)^2 = 10.625\Omega$

Total equivalent impedance referred to the primary = (10 + 10.625) + j 35 Ω

$= 20.625 + j35\Omega = 40.625\angle 59.5°$

Primary full load current $= \frac{40000}{6000} = 6.6667A$

Primary voltage required to circulate full load current = 6.6667 x 40.625 = 270.83 V

Power required = $I^2R_{1eq} = 6.6667^2 \times 20.625 = 916.66W$

(b) With a load of 33kVA, primary current $= \frac{33000}{6000} = 5.5A$

p.f. = 0.65 → $\cos\Phi = 0.65$, $\sin\Phi = 0.76$
Voltage regulation = $I_1R_{eq1}\cos\Phi + I_1X_{eq1}\sin\Phi$,

% Voltage regulation $= \frac{5.5\times(20.625\times0.65-35\times0.76)}{6000}\times100\% = -1.209\%$

$E_1 = V_1 - V.R. = 6000 - (-72.54) = 6072.54$ Volt

$E_2 = E_1\times\left(\frac{N_2}{N_1}\right) = 6072\times\left(\frac{240}{6000}\right) = 242.9$ Volts

13. A 50 kVA transformer, which steps down from 6600V to 220V, has a primary resistance of 10Ω and a secondary resistance of 0.01Ω, with the leakage reactance neglected, calculate:

(a) the total resistance referred to the secondary;
(b) the total resistance referred to the primary;
(c) the full-load copper loss.

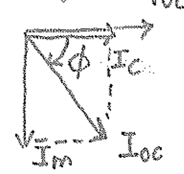
$P_{oc} = V_{oc} I_{oc} \cos\phi$

$I_c = I_{oc} \cos\phi$

$I_m = I_o \sin\phi$

Ans. (a) Primary resistance referred to the secondary $= 10 \times \left(\dfrac{220}{6600}\right)^2 = 0.0111\Omega$

Total equivalent resistance referred to the secondary = 0.01 + 0.01111 = 0.02111Ω

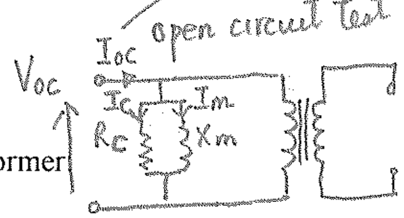


(b) Total equivalent resistance referred to the primary $= 0.021111 \times \left(\dfrac{6600}{220}\right)^2 = 19\Omega$

(c) Full load primary current $= \left(\dfrac{50000}{6600}\right) = 7.58\text{A}$

Full load copper loss $= I^2R_{1eq} = 7.58^2 \times 19 = 1091.7$ W

open circuit test



14. The following results were obtained on a 50 kVA single-phase transformer

Open circuit test -	Short circuit test -
$V_1 = V_{oc}$ = Primary voltage, 3300 V	Primary voltage, 124 V = V_{sc}
V_2 = Secondary voltage, 400 V	Primary current, 15.3 A, = I_{sc}
Primary power, 430 W = iron loss	At Secondary current, full load value, Primary power, 525 W = Copper Loss

$R_c = \dfrac{V_{oc}}{I_c}$ $X_m = \dfrac{V_{oc}}{I_m}$

Calculate: (a) the efficiencies at full load and at half load for 0.7 power factor;
(b) the voltage regulations for power factor 0.7 lag, 0.7 leading,
(c) the secondary terminal voltages corresponding to (a) & (b).

Short Circuit Test:
$P_{sc} = V_{sc} I_{sc} \cos\phi_{eq}$

Ans. (a) The transformer on open circuit test is at full voltage and on short circuit test is at full current, therefore full load iron loss = 430W, full load copper loss = 525 W $P_{sc} = I_{sc}^2 R_{1eq}$

$$\text{Full load efficiency} = \left(\frac{\text{Output power}}{\text{Output power} + \text{Iron Loss} + \text{Copper Loss}}\right) \times 100\%$$

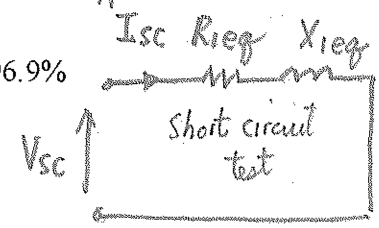
$Z_{1eq} = \sqrt{R_{1eq}^2 + X_{1eq}^2}$

$$= \left(\frac{50000 \times 0.7}{50000 \times 0.7 + 430 + 525}\right) \times 100\% = 97.34\%$$

$Z_{1eq} = \dfrac{V_{sc}}{I_{sc}}$

At half load, the iron loss remains at 430W but the copper loss is only 1/4 of the copper loss at full load, since copper loss is proportional to the square of the current. P_{sc} = Copper loss = 525W

$$\text{Half load efficiency} = \left(\frac{0.5 \times 50000 \times 0.7}{0.5 \times 50000 \times 0.7 + 430 + 525 \times (0.5)^2}\right) \times 100\% = 96.9\%$$



(b) From short circuit test, $I_1^2R_{1eq} = 525\text{W} \rightarrow R_{1eq} = \dfrac{525}{(15.3)^2} = 2.2427\Omega$

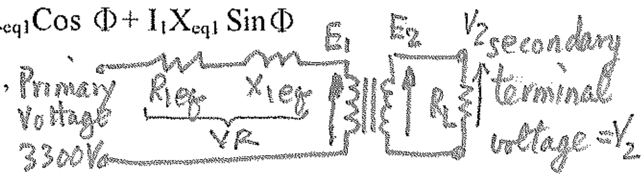
$$Z_{1eq} = \frac{124}{(15.3)} = 8.1046\Omega \quad => \quad X_{1eq} = \sqrt{Z_{1eq}^2 - R_{1eq}^2} = \sqrt{8.1046^2 - 2.2427^2} = 7.7881\Omega$$

Voltage regulation at full load 0.7 p.f. lagging $= I_1R_{eq1}\cos\Phi + I_1X_{eq1}\sin\Phi$

Power factor = 0.7 → $\cos\Phi = 0.7$, $\sin\Phi = 0.7141$,

Full load primary current $= \dfrac{50000}{3300} = 15.1515$ A

50 kVA



V.R. = 15.1515 x (2.2427 x 0.7 + 7.7881 x 0.7141) = 108.05 V ; % V.R. $= \dfrac{108.05}{3300} \times 100\% = 3.3\%$

V.R. at 0.7 p.f. leading = 15.1515 x (2.2427 x 0.7 – 7.7881 x 0.7141)= – 60.48 Volts

$$\% \text{ V.R.} = \frac{-60.48}{3300} \times 100\% = -1.83\%$$

(c) At full load 0.7 p.f. lagging, $E_1 = V_1$ – Volt drop = 3300 – 108.05 = 3192 Volts
Now all the impedance has been transferred to the primary, therefore the transformer becomes an ideal transformer, $V_2 = E_2 = E_1\left(\frac{N_2}{N_1}\right) = 3192 \times \frac{400 \; (=V_2)}{3300 \; (=V_1)} = 386.9\text{Volts}$

Similarly, at full load 0.7 power factor leading,
$E_1 = V_1$ – Volt drop = 3300 – (−60.48) = 3360.48 Volts

$$V_2 = E_1\left(\frac{N_2}{N_1}\right) = 3360.48 \times \frac{400}{3300} = 407.3 \text{ Volts}$$

15. A 250kVA, 4160 / 480V, 60Hz single-phase transformer has the following parameters :
$R_1 = 0.09\Omega$, $R_2 = 0.0012\Omega$, $R_m = 31.6k\Omega$, $X_1 = 1.7\Omega$, $X_2 = 0.0226\Omega$, $X_m = 3.24k\Omega$
The transformer is step-down. Also refer to detailed solution .

(a) Calculate the values of the transformer parameters referred to the primary side.
(b) Hence sketch the equivalent circuit with all values referred to the primary.
(c) Calculate the primary voltage for rated load at 0.76 ~~lagging~~ **leading** power factor.
(d) Calculate the transformer efficiency for (c) if core loss obtained from the no-load test is 547W.
(e) Find the voltage regulation of this transformer operating at 0.76 leading power factor.

Ans. (a) $R_1 = 0.09\Omega$, $R_2 = 0.0012\Omega$, $R_m = 31.6k\Omega$, $X_1 = 1.7\Omega$, $X_2 = 0.0226\Omega$, $X_m = 3.24k\Omega$

$$R_2' = R_2\left(\frac{N_1}{N_2}\right)^2 = 0.0012\left(\frac{4160}{480}\right)^2 = 0.09\Omega \quad => \quad R_{1eq} = R_1 + R_2' = 0.09 + 0.09 = 0.18\Omega$$

$$X_2' = X_2\left(\frac{N_1}{N_2}\right)^2 = 0.0226 \times \left(\frac{4160}{480}\right)^2 = j1.7\Omega \quad => \quad X_{1eq} = X_1 + X_2' = 1.7 + 1.7 = j\,3.4\ \Omega$$

(c) Full load secondary current $= \frac{250000}{480} = 520.8\text{A}$,

$$R_{2eq} = R_{1eq}\left(\frac{N_2}{N_1}\right)^2 = 0.18 \times \left(\frac{480}{4160}\right)^2 = 0.0024\Omega \ ; \quad X_{2eq} = X_{1eq}\left(\frac{N_2}{N_1}\right)^2 = 3.4 \times \left(\frac{480}{4160}\right)^2 = j0.0453\Omega$$

p.f. = 0.76 → Cos Φ = 0.76, Sin Φ = 0.65

At 0.76 p.f. leading, V.R. = $I_2 R_{eq2} \cos \Phi - I_2 X_{eq2} \sin \Phi$

520.8 x (0.0024 x 0.76 − 0.0453 x 0.65) = −14.39 V

$E_2 = V_2$ + Volt drop across in Z_{2eq} = 480 + (– 14.39) = 465.61 Volts

Since all the impedance is transferred to the secondary, the transformer becomes an ideal transformer:

$$V_1 = E_1 = E_2\left(\frac{N_1}{N_2}\right) = 465.61 \times \frac{4160}{480} = 4035\text{ Volts}$$

(d) Given core loss = 547 W, full load copper loss = 520.8^2 x 0.0024 = 651 W
Total transformer loss at full load = iron loss + copper loss = 1198 W

$$\text{Efficiency} = \frac{\text{output power}}{\text{output power + losses}} = \frac{250000 \times 0.76}{250000 \times 0.76 + 1198} \times 100\% = 99.37\%$$

(e) Voltage regulation at p.f. = 0.76 leading = – 14.35 Volts ; $\% \text{ V.R.} = \frac{-14.35}{480} \times 100\% = -3\%$