

158) 2079 Baisakh

given, $\epsilon_r = 5$, $pf = 0.05$

Volume of plywood to be heated (V),

$$\begin{aligned} &= 30 \times 10 \times 25 \times 10^{-6} \text{ m}^3 \\ &= 12000 \times 10^{-6} \text{ m}^3 \\ &= 0.012 \text{ m}^3 \end{aligned}$$

Density of plywood (ρ) = 0.55 gm/cc

$$= \frac{0.55 \text{ kg}}{1000 \times \frac{\text{m}^3}{10^6}}$$

$$= 550 \text{ kg/m}^3$$

Specific heat of wood (s) = $0.35 \text{ cal/gm}^\circ\text{C}$

$$= 0.35 \times 4200 \text{ J/kg}^\circ\text{C}$$

$$= 1470 \text{ J/kg}^\circ\text{C}$$

Then,

Heat required to raise the temp. of plywood from 20°C to 170°C

$$= ms\Delta\theta$$

$$= \rho V s \Delta\theta$$

$$= 550 \times 0.012 \times 1470 \times (170 - 20)$$

$$= 1.455 \times 10^6 \text{ J}$$

$$\text{Time (t)} = 10 \text{ min}$$

$$\text{Average o/p power} = \frac{1.455 \times 10^6}{10 \times 60}$$

$$= 2425 \text{ W}$$

$$\text{Average i/p power} = \frac{\text{o/p}}{\text{Efficiency}}$$

$$= \frac{2425}{0.85}$$

$$\left[\because \text{since } 15\% \text{ energy is lost,} \right. \\ \left. \eta = 100 - 15 = 85\% \right]$$

$$\therefore \text{I/P Power} = 2852.941 \text{ W}$$

This power should be supplied from source.

Now,

Capacitance of capacitor formed,

$$C = \frac{\epsilon_0 G A}{t}$$

$$= \frac{8.85 \times 10^{-12} \times 5 \times 30 \times 10^{-2} \times 16 \times 10^{-2}}{25 \times 10^{-2}}$$

$$= 8.496 \times 10^{-12} \text{ F}$$

Then,

$$2\pi f C V^2 \times \cos \phi = 2852.941$$

$$\text{or, } 2\pi \times 30 \times 8.496 \times 10^{-12} \times V^2 \times 0.05 = 2852.941$$

$$\therefore V = 5969.027 \text{ V}$$

Now,

Current Flowing through the material,

$$I = \frac{P}{V \cos \phi} = \frac{2852.941}{5969.027 \times 0.05}$$

$$= 9.469 \text{ A}$$

2021 Chaitra

159) given,

For a 3- ϕ electric arc furnace,

Quantity of steel to be melted in one hour = 4.3 tonnes

$$= 4.3 \times 10^3 \text{ kg}$$

Specific heat of steel = $0.5 \text{ kJ/kg}^\circ\text{C}$

$$= 0.5 \times 10^3 \text{ J/kg}^\circ\text{C}$$

Latent heat of steel = 37.2 kJ/kg

$$= 37.2 \times 10^3 \text{ J/kg}$$

Melting point = 1370°C

Initial temp. = 19.1°C

Overall efficiency of steel

furnace = 50%

Input current (I) = 5700 A

Referred to secondary,

$$\rightarrow \text{Resistance} = 0.008 \Omega$$

$$\rightarrow \text{Reactance} = 0.014 \Omega$$

Now,
Energy required to melt steel,

$$= ms(t_2 - t_1) + mL$$

$$= \frac{4.3 \times 10^3}{0.5 \times 10^3} \times (1370 - 19.1) + \frac{4.3 \times 10^3}{37.2 \times 10^3}$$

$$= 3064395 \times 10^3 \text{ J}$$

Since, this much energy is required in one hour,

$$\text{Useful power o/p} = \frac{3064395 \times 10^3}{60 \times 60}$$

$$= 851.22 \text{ kW}$$

Now,

$$P_{g/p} = \frac{\text{Power o/p}}{\text{Overall efficiency}}$$

$$= \frac{851.22}{0.5}$$

$$= 1702.44 \text{ kW}$$

We have,

Input current (I) = 5700 A

So,

Voltage drop due to resistance of furnace leads (including transformer)

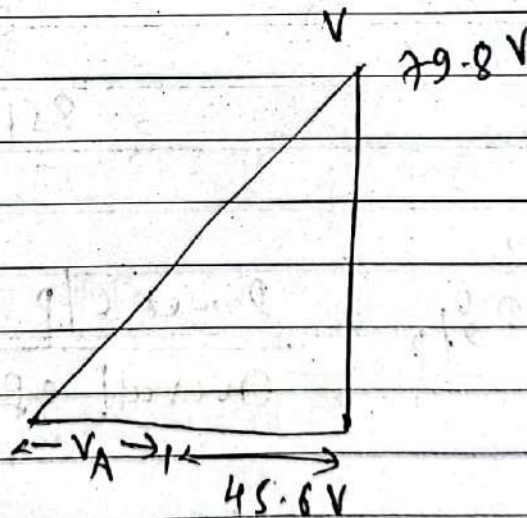
$$= 5700 \times 0.008$$

$$= 45.6 \text{ V}$$

Voltage drop due to the reactance of furnace leads (including transformer)

$$= 5700 \times 0.014$$

$$= 79.8 \text{ V}$$



Let, the arc voltage drop be V_A volts resistive in nature.

then,

Open-circuit voltage of transformer secondary,

$$= \sqrt{(V_A + 45.6)^2 + 79.8^2}$$

then,

$$\cos \phi = \frac{P}{S} = \frac{V_A + 45.6}{\sqrt{(V_A + 45.6)^2 + 79.8^2}}$$

then,

$$\text{Total Power } W/P = 3 \times \text{Voltage} \times \text{Current} \times \cos \phi$$

$$\text{or, } 1702.44 \times 10^3 = 3 \times 5700$$

$$\times \sqrt{(V_A + 45.6)^2 + 79.8^2}$$

$$\times \frac{V_A + 45.6}{\sqrt{(V_A + 45.6)^2 + 79.8^2}}$$

$$\sqrt{(V_A + 45.6)^2 + 79.8^2}$$

$$\text{or, } 1702.44 \times 10^3 = 3 \times 5700 \times (V_A + 45.6)$$

$$\text{or, } V_A + 45.6 = 99.558$$

$$\text{or, } V_A = 53.958 \text{ V}$$

$$\therefore \text{Arc Voltage, } V_A = 53.958 \text{ V}$$

then,

$$\text{Arc Resistance, } R_A = \frac{\text{Arc voltage}}{\text{Arc current}}$$

$$= \frac{53.958}{5700}$$

$$= 0.00947 \Omega$$

then,

Secondary phase voltage,

$$V = \sqrt{(V_A + 45.6)^2 + (79.8)^2}$$

$$= \sqrt{(53.958 + 45.6)^2 + (79.8)^2}$$

$$= 127.59 \text{ V}$$

again, for,

Average kVA input to the furnace,

$$\text{kVA} = 3 \times I \times V_{\text{phase}} \times 10^{-3}$$

$$= 3 \times 5700 \times 127.59 \times 10^{-3}$$

$$= 2181.789 \text{ kVA}$$

Again, for, pf,

$$\cos \phi = \frac{V_A + 45.6}{\sqrt{(V_A + 45.6)^2 + (79.8)^2}}$$

$$= \frac{53.958 + 45.6}{\sqrt{(53.958 + 45.6)^2 + (79.8)^2}}$$

$$= 0.780 \text{ lagging}$$

2079 Bhadra

160) given,

25 kW, 240 V, 50 Hz

To be wire temp = 1400°C
change temp = 500°C

Resistivity of nicrome = $42.5 \mu\Omega\text{-m}$

We have,

power supplied, $P = 25 \text{ kW} = 25 \times 10^3 \text{ W}$

$$\text{Supply voltage (V)} = 240\text{V}$$

$$\text{Radiating efficiency (\%)} = \cancel{1.0} = 0.9$$

$$\text{Emissivity (e)} = 0.85$$

$$\begin{aligned} \rho &= 42.5 \mu\Omega\text{-m} \\ &= 42.5 \times 10^{-6} \Omega\text{m} \end{aligned}$$

We have,

$$\begin{aligned} R &= \rho \frac{l}{a} \\ &= \frac{\rho l}{\left(\frac{\pi d^2}{4}\right)} \\ &= \frac{4\rho l}{\pi d^2} \end{aligned}$$

then,

$$P = \frac{V^2}{R} = \frac{V^2}{\frac{4\rho l}{\pi d^2}} = \frac{\pi d^2 V^2}{4\rho l}$$

$$\text{or, } P = \frac{\pi d^2 V^2}{4\rho l}$$

$$\text{or, } \frac{J}{d^2} = \frac{\pi V^2}{4\rho l} \quad 2 \text{ (*)}$$

$$\text{or, } \frac{d}{d^2} = \frac{\pi \times 240^2}{4 \times 42.5 \times 10^{-6} \times 25 \times 10^3}$$

$$\text{or, } \frac{d}{d^2} = 42577.820 \quad 2 \text{ (1)}$$

Also,

at steady temp, power i/p = heat dissipated

$$\text{or, } P = \pi d l H$$

$$\text{or, } \frac{\pi d^2 \sqrt{2}}{4 \pi d} = \pi d l H$$

$$\text{or, } \frac{d}{d^2} = \frac{4 \pi d l H}{\sqrt{2}} \quad 2 \text{ (**) (**)}$$

also, from Stefan's law,

Dissipated heat,

$$H = 5.72 e^4 \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \text{ W/m}^2$$

$$= 5.72 \times 0.85 \times 0.9 \left[\left(\frac{1400+273}{100} \right)^4 - \left(\frac{500+273}{100} \right)^4 \right]$$

$$= 327176.93 \text{ W/m}^2$$

i.e.

$$U = 327.18 \text{ kW/m}^2$$

Now,

From (i) (ii)

$$\frac{d}{L^2} = \frac{4\mu H}{V^2}$$

Now,

From (i) (ii),

$$\frac{d}{L^2} = \frac{4\mu H}{V^2}$$

$$\text{or, } \frac{L^2}{d} = \frac{V^2}{4\mu H}$$

We have,

$$P = \pi d L H$$

$$\text{or, } 25 \times 10^3 = 327176.93 \pi d L$$

$$\text{or, } d L = 0.02432$$

i.e.

$$d^2 L^2 = 0.00059146 \quad (iv)$$

Multiplying (i) and (ii),

$$\frac{l}{d^2} \times d^2 l^2 = 0.00059146 \times 42577.820$$

$$\text{or, } l^3 = 25.1832$$

$$\text{i.e. } l = 2.931 \text{ m}$$

Again,

$$\frac{l}{d^2} = 42577.820$$

$$\text{or, } d^2 = \frac{2.931}{42577.820} = 0.00006884$$

$$\therefore d = 0.00829 \text{ m} = 8.297 \text{ mm}$$

2022 Chaitra
(161)

Mero Engineering

Date _____
Page _____

Here,

$$\text{Volume (V)} = 0.3 \times 0.15 \times 0.025 \\ = 0.001125 \text{ m}^3$$

given,

$$\rho = 575 \text{ kg/m}^3$$

$$\epsilon_r = 5$$

$$\rho_f = 0.05$$

$$S = 1465 \text{ J/kg}^\circ\text{C}$$

$$t = 10 \text{ mins}$$

$$\text{Then, } f = 30 \text{ MHz} = 30 \times 10^6 \text{ Hz}$$

Mass of wooden board,

$$m = \rho V$$

$$= 575 \times 0.001125 \\ = 0.646875 \text{ Kg}$$

Now, Assuming the initial temp. as,
 20°C

Then,

$$Q = ms d\theta \\ = 0.646875 \times 1465 \times (160 - 20) \\ = 132.674 \text{ KJ}$$

then,

$$\begin{aligned}
 P_{o/p} &= \frac{Q}{t} \\
 &= \frac{132.674 \times 10^3}{10 \times 60} \\
 &= 221.123 \text{ W}
 \end{aligned}$$

Since, efficiency is between 85% and 90%,

$$\begin{aligned}
 \eta &= \frac{0.85 + 0.90}{2} \\
 &= 0.875 \\
 &= 87.5\%
 \end{aligned}$$

then,

$$\begin{aligned}
 P_{i/p} &= \frac{P_{o/p}}{\eta} = \frac{221.123}{0.875} \\
 &= 252.712 \text{ W}
 \end{aligned}$$

Now, for dielectric heating,

$$P = 2\pi f C V^2 \cos \phi$$

where,

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

$$\begin{aligned}
 &= \frac{8.854 \times 10^{-12} \times 5 \times 0.3 \times 0.15}{0.025}
 \end{aligned}$$

$$\therefore C = 7.9686 \times 10^{-11} \text{ F}$$

Then,

$$V = \sqrt{\frac{P}{2\pi f C \omega \phi}}$$

$$= \sqrt{\frac{252.712}{2\pi \times 30 \times 7.9686 \times 10^{-11} \times 0.05 \times 10^6}}$$

$$= \cancel{18343.675 \text{ V}} \quad 580.078 \text{ V}$$

then,

Capacitive current through the dielectric is,

$$I = 2\pi f C V$$

$$= 2\pi \times 30 \times 10^6 \times 7.9686 \times 10^{-11} \times 580.078$$

$$= 8.713 \text{ A}$$

162) Here,

$$\text{Current drawn } (I) = 4500 \text{ A}$$

$$\text{Arc Voltage } (V_A) = 50 \text{ V}$$

$$\text{Resistance of transformer referred to secondary} = 0.002 \Omega$$

$$\text{Reactance of transformer referred to secondary} = 0.004 \Omega$$

Now,

$$\text{Voltage drop due to resistance} = 4500 \times 0.002 = 9 \text{ V}$$

$$\text{Voltage drop due to reactance} = 4500 \times 0.004 = 18 \text{ V}$$

Since, arc voltage drop is resistive in nature, it is vectorially added to transformer resistance drop.

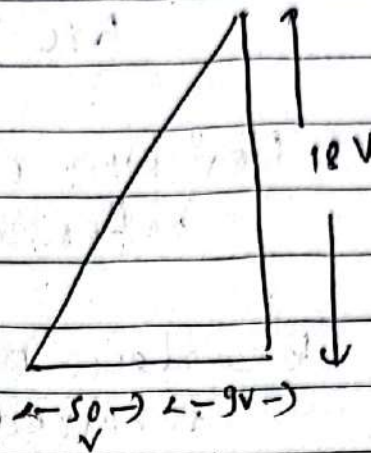
then,

Open circuit transformer secondary voltage/phase

$$= \sqrt{(50 + 9)^2 + 18^2}$$

$$= 61.685 \text{ V}$$

Then,



Then,

$$\cos \phi = \frac{50 + 9}{61.685}$$

$$= 0.9565 \text{ lagging}$$

Then,

Power drawn by secondary/phase

$$= 3 V I \cos \phi$$

$$= 3 \times 61.685 \times 4500 \times 0.9565$$

$$= 796.522 \text{ KW}$$

Or,

$$\text{Arc Power (P}_a) = 3 V_a I$$

$$= 3 \times 50 \times 4500$$

$$= 675 \text{ KW}$$

Transformer copper loss (P_r) = $3I^2R$

$$= 3 \times 4500^2 \times 0.002$$

$$= 121.5 \text{ KW}$$

Then,

$$P_{g/p} = P_a + P_r$$

$$= 675 + 121.5$$

$$= 796.5 \text{ KW}$$

Then, for

$$\text{Electrical efficiency } (\eta) = \frac{P_{a/c}}{P_{g/p}}$$

$$\text{or, } \eta = \frac{675}{796.5}$$

$$\eta = 0.84746$$

$$= 84.75 \%$$

164) given, tank is cubical

$$\text{Total surface area, } A = 6\text{m}^2$$

Filled to 90% capacity

Number of fillings per day,

$$n = 6$$

We have,

$$T_1 = 20^\circ\text{C}$$

$$T_2 = 65^\circ\text{C}$$

Then,

$$\Delta T = 65 - 20 = 45^\circ\text{C}$$

also,

$$\text{Heat loss per square metre} = 6.3 \text{ W/m}^2/^\circ\text{C}$$

$$\text{Specific heat (J)} = 4200 \text{ J/kg/}^\circ\text{C}$$

$$1\text{m}^3 = 1000 \text{ kg}$$

$$1\text{ kWh} = 3.6 \text{ MJ}$$

Now,

$$\text{For a cube, Surface area} = 6a^2$$

So,

$$6a^2 = 6$$

$$\text{or, } a^2 = 1$$

$$\therefore a = 1\text{m}$$

Hence,

$$\begin{aligned}\text{Volume of tank (V)} &= a^3 \\ &= 1^3 \\ &= 1 \text{ m}^3\end{aligned}$$

Therefore, mass of water when tank is completely filled is,

$$m = 1000 \text{ kg}$$

Since, the tank is filled to 90% capacity,

$$\begin{aligned}m_w &= 0.9 \times 1000 \\ &= 900 \text{ kg}\end{aligned}$$

Now

Heat required to heat water for one filling,

$$\begin{aligned}Q &= m_w s \Delta T \\ &= 900 \times 4200 \times (65 - 20) \\ &= 170.1 \text{ MJ}\end{aligned}$$

Then,

$$Q = \frac{170.1 \text{ MJ}}{9.6 \text{ MJ}}$$

$$= 17.725 \text{ kWh}$$

Since, the tank is filled and heated six times / day,

$$Q_4 = 6 \times 47.25 \\ = 283.5 \text{ kWh/day}$$

then,

the average useful power required is,

$$P_4 = \frac{283.5}{24}$$

$$= 11.8125 \text{ kW}$$

Now,

heat loss from the tank,

$$P_L = 6.3 \times A \times \Delta T$$

$$= 6.3 \times 6 \times 45$$

$$= 1701 \text{ W}$$

$$= 1.701 \text{ kW}$$

then, Required loading of the tank,

$$P = P_4 + P_L$$

$$= 11.8125 + 1.701$$

$$= 13.5135 \text{ kW}$$

* Note, $P_{loss} = (\text{loss per m}^2/^{\circ}\text{C}) \times A \times \Delta T$

Now,

Efficiency of the tank is given by,

$$\eta = \frac{P_u}{P_u + P_L} \times 100\%$$

$$= \frac{11.8125}{11.8125 + 1701} \times 100\%$$

$$= 0.87.413\%$$

2082 Balsakh

167) given,

Secondary Voltage, $V = 20 \text{ Volts}$

Power drawn, $P = 500 \text{ kW}$

then,

$$\text{Secondary current, } I = \frac{P}{V \cos \phi}$$

$$= \frac{500 \times 10^3}{20 \times 0.5}$$

$$= 50 \text{ A } 50,000 \text{ A}$$

Impedance of the secondary circuit when hearth
is full,

$$Z = \frac{V}{I} = \frac{20}{50,000} \\ = 0.0004 \Omega$$

Resistance of secondary circuit when hearth
is full,

$$R = Z \cos \phi \\ = 0.0004 \times 0.5 \\ = 0.0002 \Omega$$

Reactance of secondary circuit when hearth
is full,

$$X = Z \sin \phi \\ = 0.0004 \times \sin \left[\cos^{-1} 0.5 \right] \\ = 0.0003464 \Omega$$

→ When hearth is half full,

$$\text{Resistance of sec. circuit, } R' = 2R \\ = 2 \times 0.0002 \\ = 0.0004 \Omega$$

Reactance of sec. circuit,

$$X' = X = 0.0003464 \Omega$$

then,

Impedance of sec. circuit,

$$Z' = \sqrt{(R')^2 + (X')^2}$$

$$= \sqrt{0.0004^2 + 0.0003464^2}$$

$$= 0.00052914 \Omega$$

then,

$$\text{New pf} = \frac{R'}{Z'}$$

$$= \frac{0.0004}{0.00052914}$$

$$= 0.756 \text{ lagging}$$

then,

$$\text{Secondary current, } I' = \frac{V}{Z'}$$

$$= \frac{20}{0.00052914}$$

$$= 37,797.18 \text{ A}$$

then,
power drawn,

$$P = VI' \cos \phi'$$

$$= 20 \times 37,797.18 \times 0.756$$

$$= 5,71,493.362 \text{ W}$$

$$= 571.49 \text{ kW}$$

or,

$$\checkmark \text{ Power Drawn } (P) = (I')^2 R'$$

$$= 37,797.18^2 \times 0.0004$$

$$= 5,71,450.73 \text{ W}$$

$$= 571.450 \text{ kW}$$

2079 Asadh

169) given,

30 kW, 3 ϕ , 400V (Not connected)

$$t = 0.025 \text{ cm}$$

$$T_1 = 1100^\circ\text{C} = 1100 + 273 = 1373 \text{ K}$$

$$T_2 = 700^\circ\text{C} = 700 + 273 = 973 \text{ K}$$

$$w = 0$$

$$k = 0.6$$

$$e = 0.9$$

$$\rho = 10.3 \times 10^{-6} \Omega m$$

Now,

$$\text{Power per phase} = \frac{30 \times 10^3}{3} = 10,000 \text{ W}$$

$$\text{Phase voltage, } V_p = \frac{400}{\sqrt{3}} = 230.94 \text{ V}$$

$$\text{Resistance of strip, } R = \frac{V_p^2}{P} = \frac{230.94^2}{10,000} = 5.33 \Omega$$

If 'l' is the length of strip and 'w' is the width of strip then,

$$\text{Resistance, } R = \frac{\rho l}{w \times t}$$

$$\text{or, } \frac{l}{w} = \frac{R \times t}{\rho}$$

$$= \frac{5.33 \times 0.025 \times 10^{-2}}{10.3 \times 10^{-6}}$$

$$10.03 \times 10^{-6}$$

$$129.369$$

$$\text{or, } \frac{d}{w} = 1293.689 \quad (1)$$

Then,

Heat dissipated from the surface,

$$H = 5.72 e K \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \text{ W/m}^2$$

$$= 5.72 \times 0.9 \times 0.6 \left[\left(\frac{1373}{100} \right)^4 - \left(\frac{973}{100} \right)^4 \right]$$

$$= 82082.251 \text{ W/m}^2$$

Now, We have,

Surface area available for heat radiation = $2wl \text{ m}^2$

Since,

Heat dissipated = Electrical I/p power

$$\text{or, } 82,082.251 \times 2wl = 10,000$$

$$\text{or, } wl = \frac{10,000}{2 \times 82,082.251} = 0.06091$$

(11)

then, (i) $\times$ (ii),

$$\frac{l}{w} \times w l = 129.369 \times 0.060914$$

$$\text{or, } l^2 = \frac{7.8804}{78.8038}$$

$$\therefore l = \frac{2.807}{8.8771} \approx 2.81 \text{ m (per phase)}$$

then, from (i),

$$\begin{aligned} \text{width } (w) &= \frac{l}{1293.689} \\ &= \frac{8.8771}{1293.689} \\ &= 0.006862 \text{ m} \\ &= 6.862 \text{ mm} \end{aligned}$$

$$\text{or, } w = \frac{l}{129.369} = \frac{2.81}{129.369}$$

$$\therefore w = 0.02172 \text{ m} = 21.72 \text{ mm}$$

no

given, when the hearth is full

$$\text{Secondary voltage (V)} = 10 \text{ V}$$

$$\text{Power drawn (P)} = 500 \text{ kW}$$

$$\text{PF} = 0.5$$

then,

$$\text{Secondary current (I)} = \frac{P}{V \cos \phi}$$

$$= \frac{500 \times 10^3}{10 \times 0.5}$$

$$= 1,00,000 \text{ A}$$

Impedance of sec. ckt. when the hearth is full,

$$Z = \frac{V}{I} = \frac{10}{1,00,000}$$

$$= 0.0001 \Omega$$

then,

$$\sin \phi = \sin [\cos^{-1} 0.5]$$

$$= 0.866$$

→ Resistance of secondary ckt. when hearth is full,

$$R = Z \cos \phi$$

$$= 0.0001 \times 0.5$$

$$= 0.00005 \Omega$$

→ Reactance of sec. ckt. when hearth is full,

$$X = Z \sin \phi$$

$$= 0.0001 \times 0.866$$

$$= 0.0000866 \Omega$$

⇒ When the hearth is half full,

$$R' = \frac{R}{2} = \frac{0.00005}{2} = 0.000025 \Omega$$

$$X' = X = 0.0000866 \Omega$$

then, New pf,

$$\begin{aligned} \text{pf}' &= \frac{R'}{Z'} = \frac{0.000025}{\sqrt{0.000025^2 + 0.0000866^2}} \\ &= 0.2774 \text{ lagging} \end{aligned}$$

Then,

$$\text{Secondary current, } I' = \frac{V}{Z'}$$

$$= \frac{10}{\sqrt{0.000025^2 + 0.0000866^2}}$$

$$= 1,10,943.043 \text{ A}$$

Then,

$$\text{Power Drawn (P)} = (I')^2 \times R'$$

$$= 1,10,943.043^2 \times 0.000025$$

$$= 3,07,708.97 \text{ W}$$

$$= 307.71 \text{ kW}$$