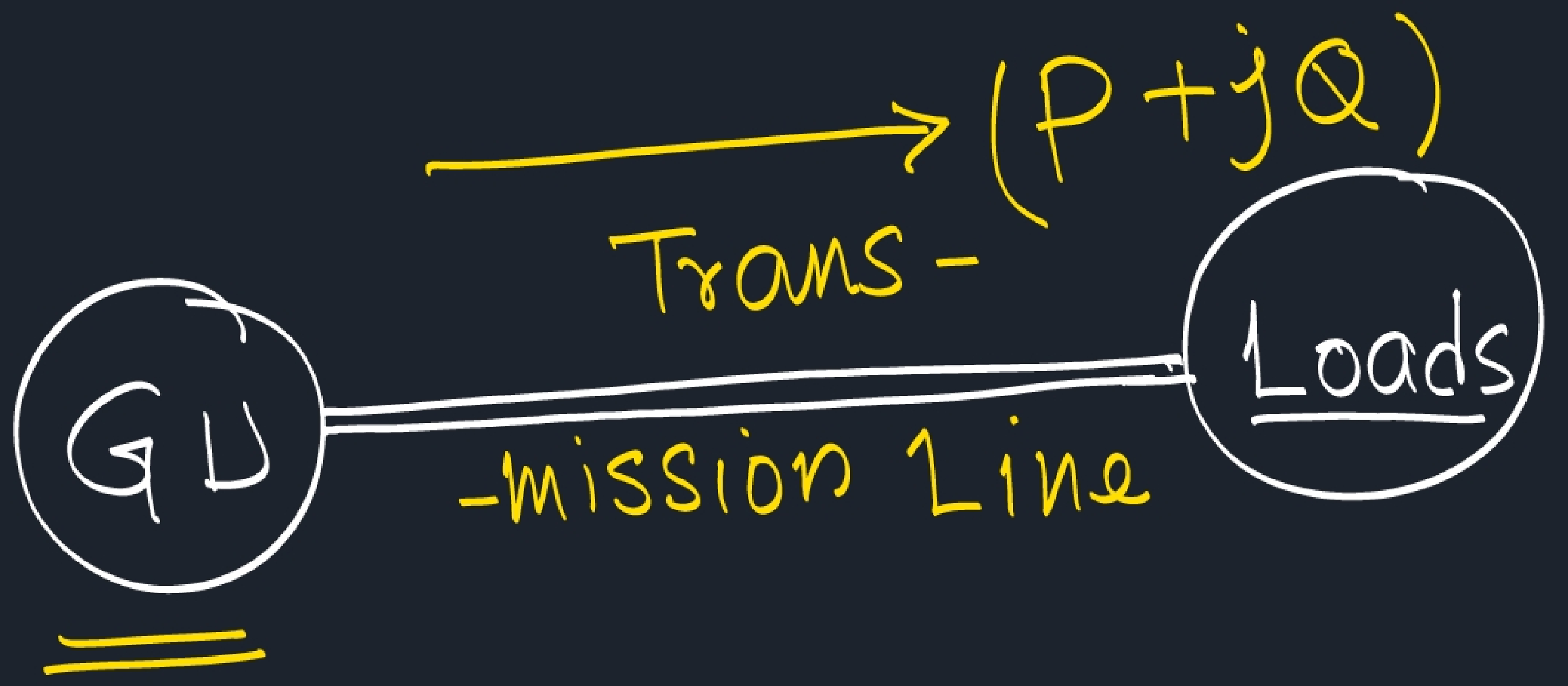
# Transformer :-



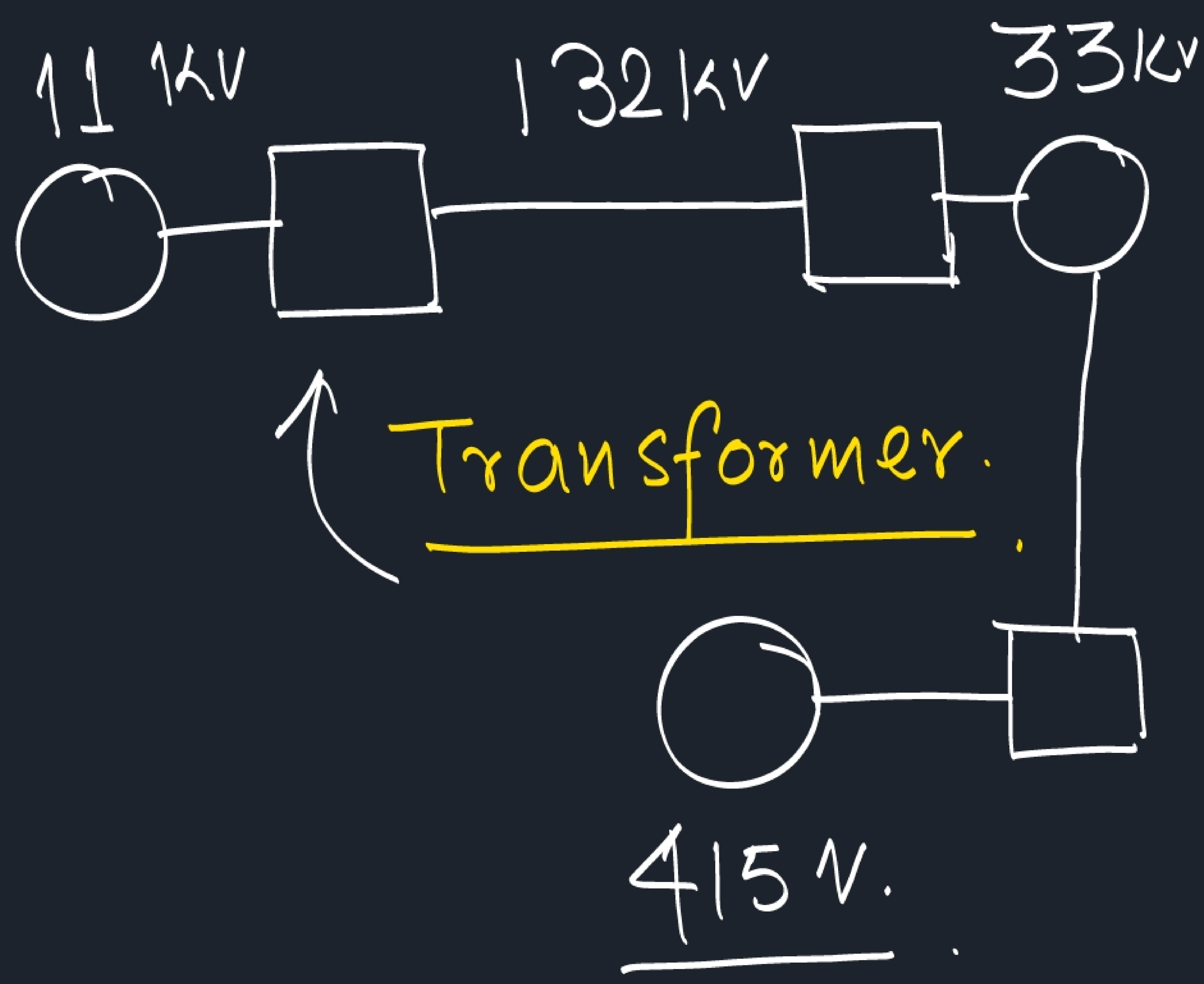

$$P_{3\phi} = 3 V_{ph} I_{ph} \cos\theta$$

$$I_{ph} = \frac{P_{3\phi}}{3 V_{ph} \cos\theta}$$

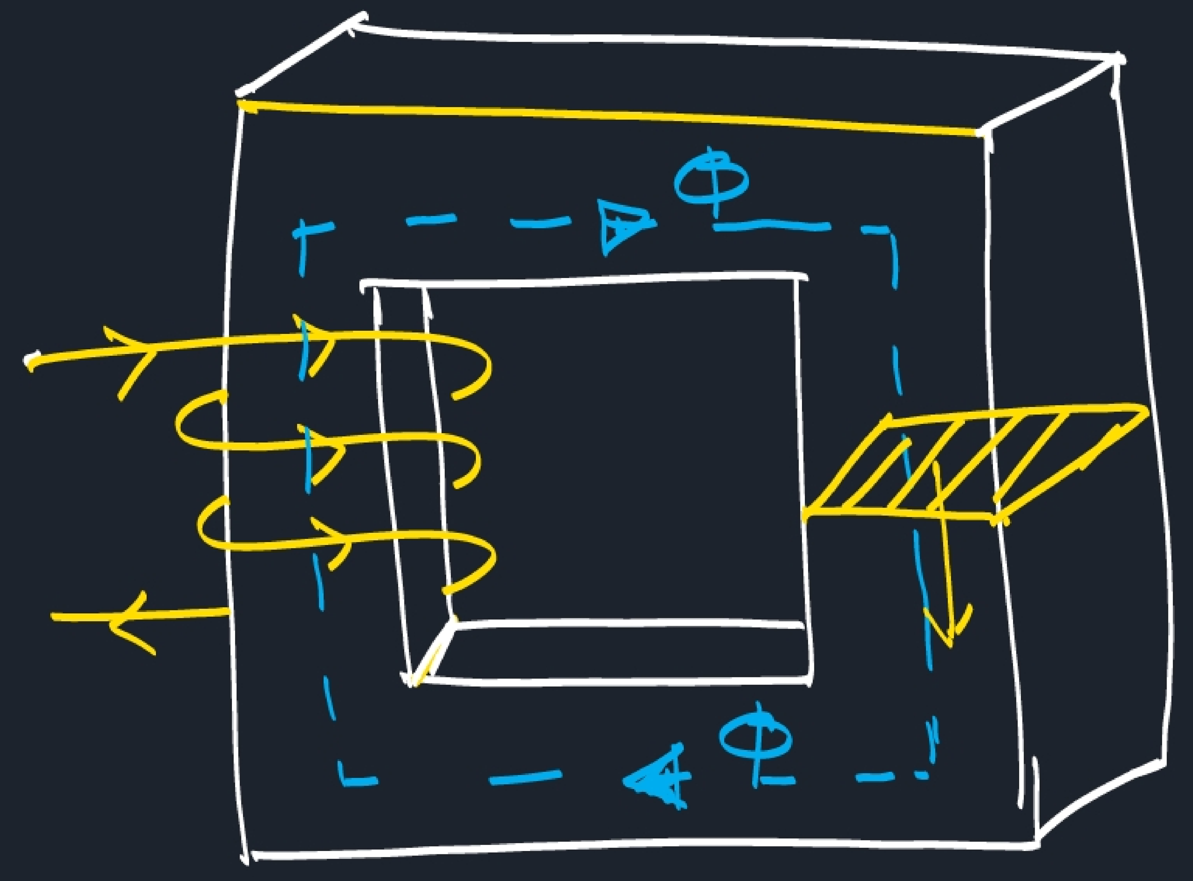
$$P_{loss} = 3 (I_{ph})^2 \cdot R_{ph}$$

$$= 3 \cdot \frac{P_{3\phi}^2}{9 V_{ph}^2 \cos^2\theta} \cdot R_{ph}$$

$$P_{loss} \propto \frac{1}{V_{ph}^2} \quad (\text{if } P_{3\phi}, \cos\theta \text{ Constant})$$




1. Step up
2. Step Down

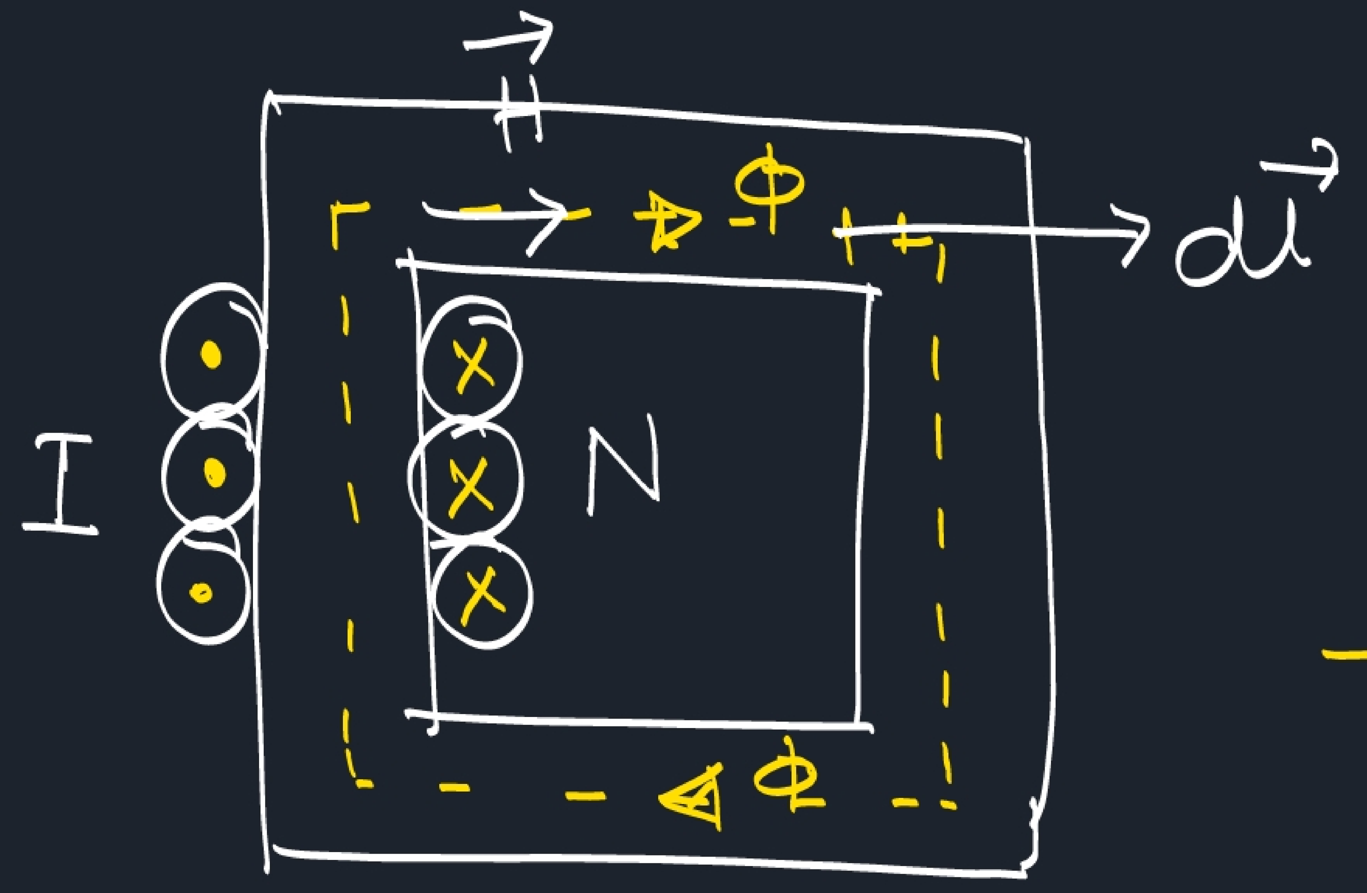



$$\Phi = \vec{B}\cdot\vec{A} = BA\cos\theta.$$

$$\boxed{\Phi = BA.}\qquad \boxed{B = \mu H.}$$

$$\boxed{\mu = \mu_0\,\mu_r}$$

$\mu_0 \rightarrow 4\pi\times10^{-7}$




Ampere's Circuital Law.

$$\oint \vec{H}\cdot\vec{dl} = NI$$

$$H\cdot l = NI$$

$$\Rightarrow H = \frac{NI}{l}$$

$$\Rightarrow B = \frac{NI}{l/\mu}$$

unit of H is
Amp-turn/m.

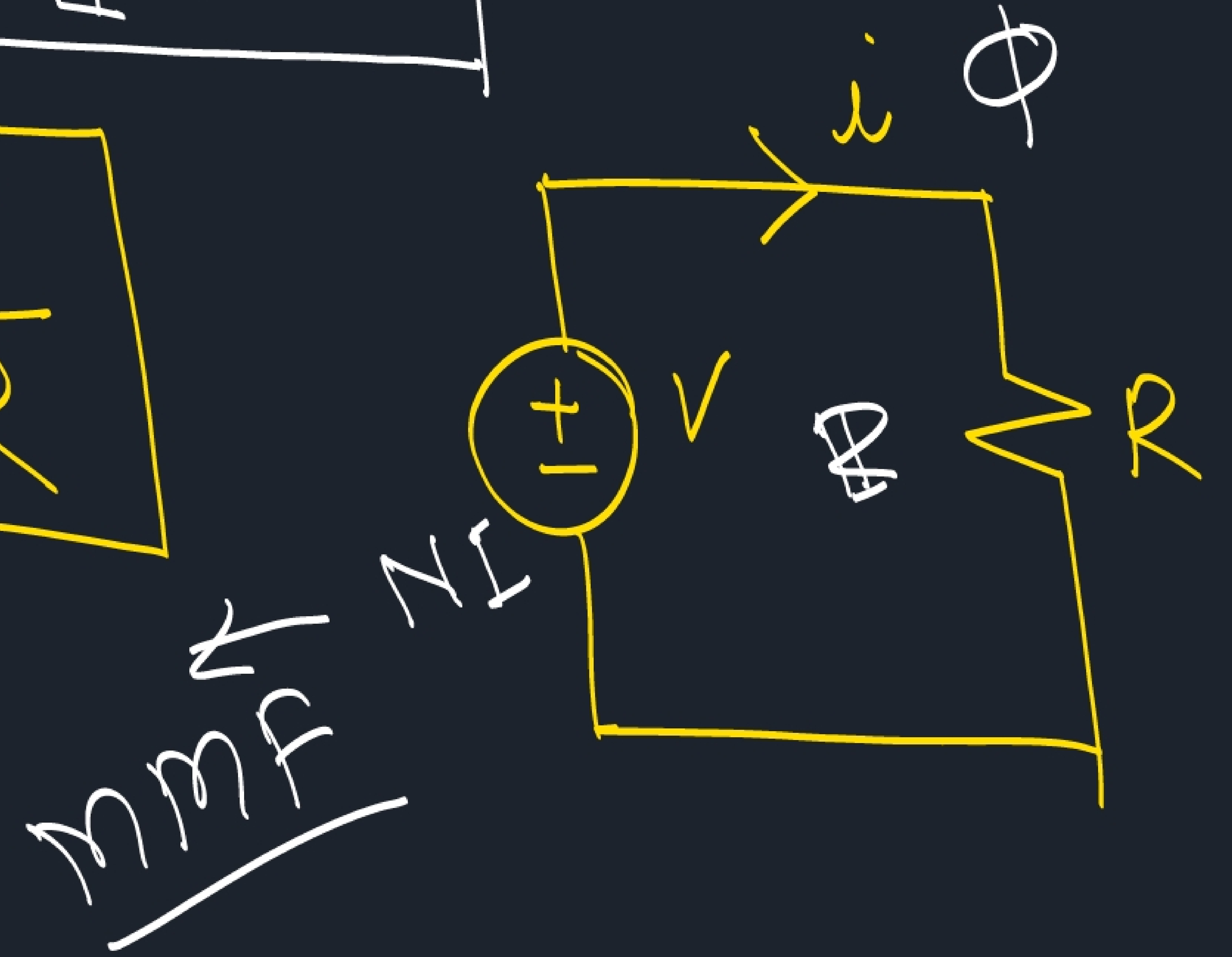
$$\boxed{\mathcal{R} = \frac{l}{A\mu_0\mu_r}}$$

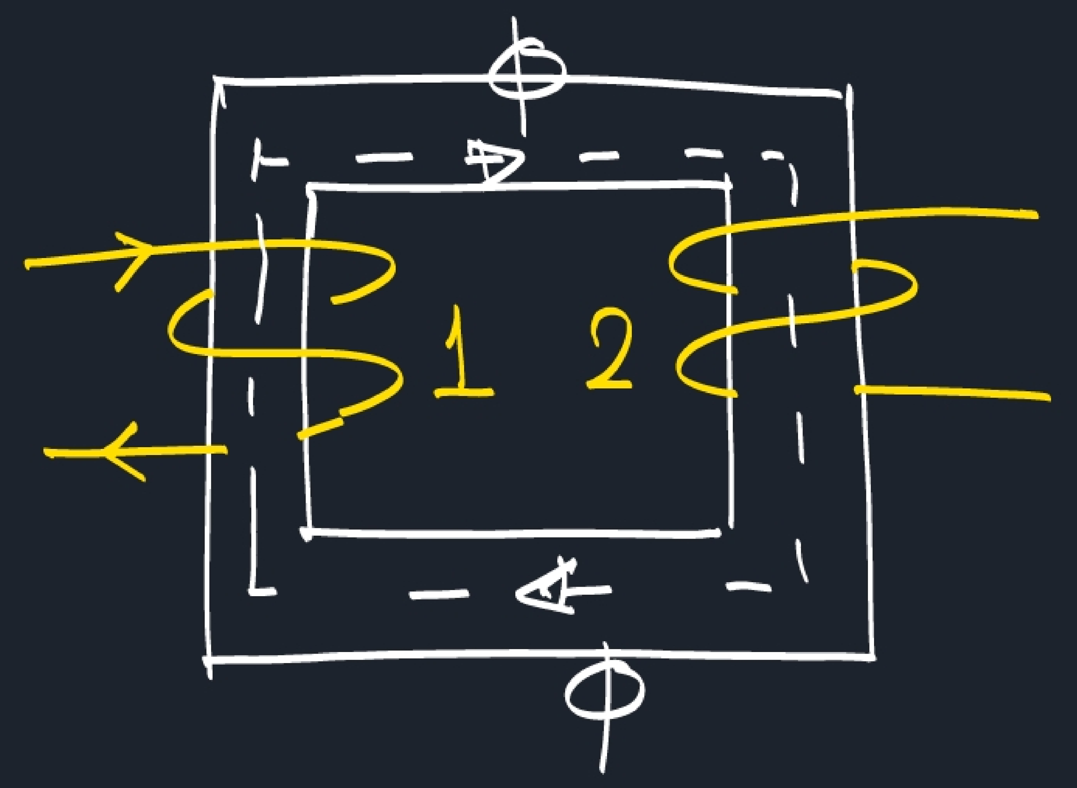
$$\Phi = BA = \frac{NI}{\frac{l}{\mu A}}$$

$\frac{l}{\mu A} \Rightarrow$ Reluctance $\mathcal{R}$

$$\boxed{\Phi = \frac{NI}{\mathcal{R}}}$$

$$\boxed{i = \frac{V}{R}}$$






$$e_1(t) = -N_1 \frac{d\phi}{dt}$$

$$e_2(t) = -N_2 \frac{d\phi}{dt}$$

$$\frac{e_1}{N_1} = -\frac{d\phi}{dt}$$

$$\frac{e_2}{N_2} = -\frac{d\phi}{dt}$$

$$\frac{e_1}{N_1} = \frac{e_2}{N_2}$$

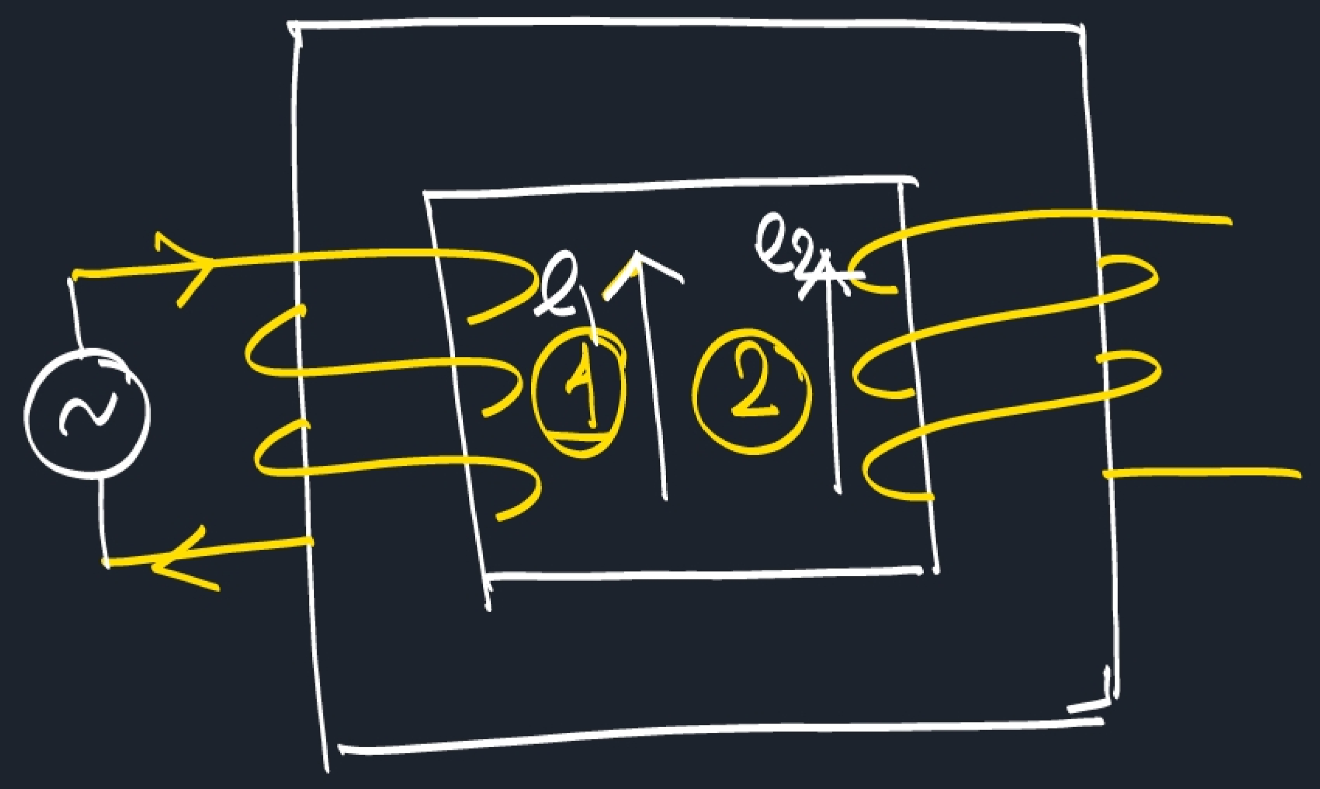
$$\boxed{\frac{e_1}{e_2} = \frac{N_1}{N_2}}$$

$N_1 < N_2$

$e_1 < e_2 \Rightarrow$ Step up T/F.

$N_1 > N_2$

$e_1 > e_2 \Rightarrow$ Step down T/F.




$e_1 = ?$  $e_2 = ?$

$$e_1(t) = -N_1 \frac{d\phi(t)}{dt}$$

$\phi = BA.$

$= B_m \sin\omega t \cdot A$

$= \phi_m \sin\omega t$

$$e_1(t) = N_1 \frac{d\phi(t)}{dt}$$

$$e_1(t) = N_1 \phi_m \omega \cos\omega t$$

$$= N_1 \phi_m \omega \sin(\omega t + \pi/2)$$

$$E_1 = \frac{N_1 \phi_m \omega}{\sqrt{2}}$$

$$= \frac{N_1 \phi_m 2\pi f}{\sqrt{2}}$$

$$= \frac{2\pi}{\sqrt{2}} \phi_m f N_1$$

1 → Primary

2 → Secondary

$$\boxed{E_1 = 4.44 f \phi_m N_1}$$

$$\boxed{E_2 = 4.44 f \phi_m N_2}$$

$f = 50\,Hz$

$\phi_m$ → Peak Flux.

$$\boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}}$$

$\phi_m \propto E_1$

T/F → constant flux m/c.

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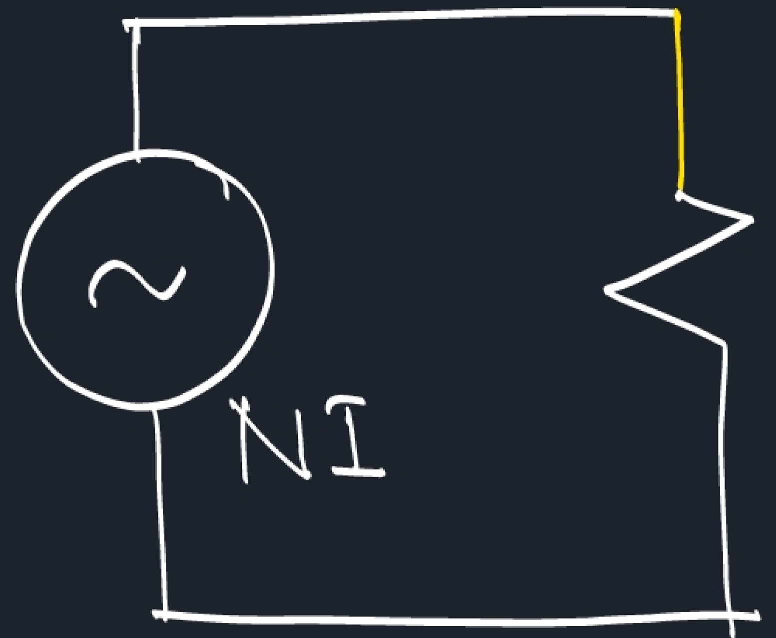
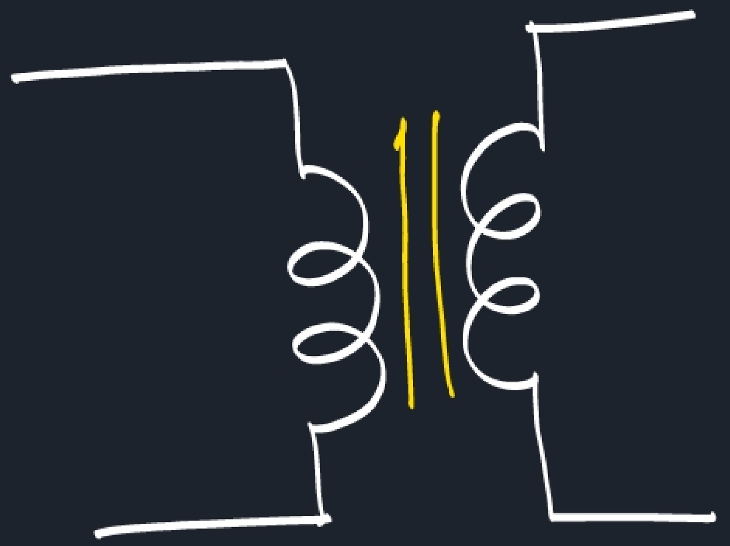
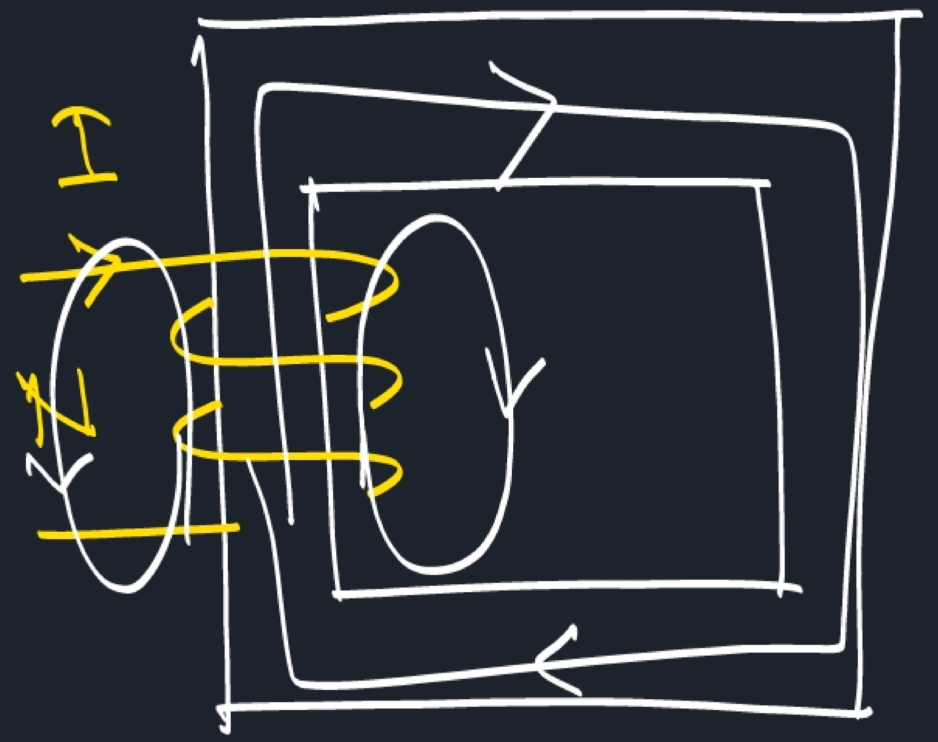
$$\Phi = \frac{NI}{\mathcal{R}}$$






$$\boxed{\mathcal{R} = \frac{l}{A\mu_0\mu_r}}$$

$$\boxed{B = \mu_0\mu_r H.}$$

$$\boxed{H = \frac{NI}{l}}$$

$$\frac{V_1}{N_1} = \frac{V_2}{N_2} \quad \cdots (i)$$

$$I_1N_1 = I_2N_2 \quad -- (ii)$$

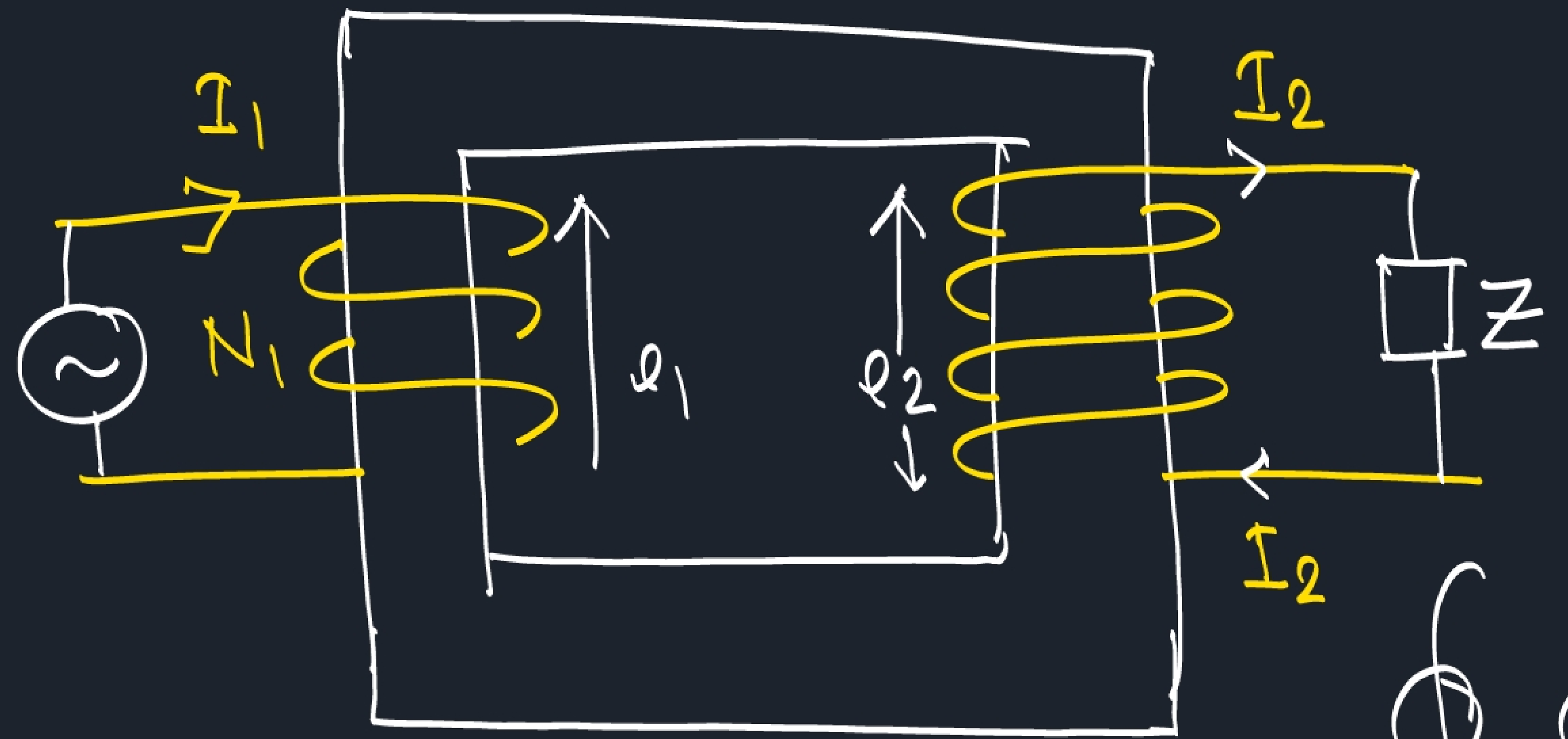
Ideal Case

$\mathcal{R} \to 0$

$\mu_r \to \infty$

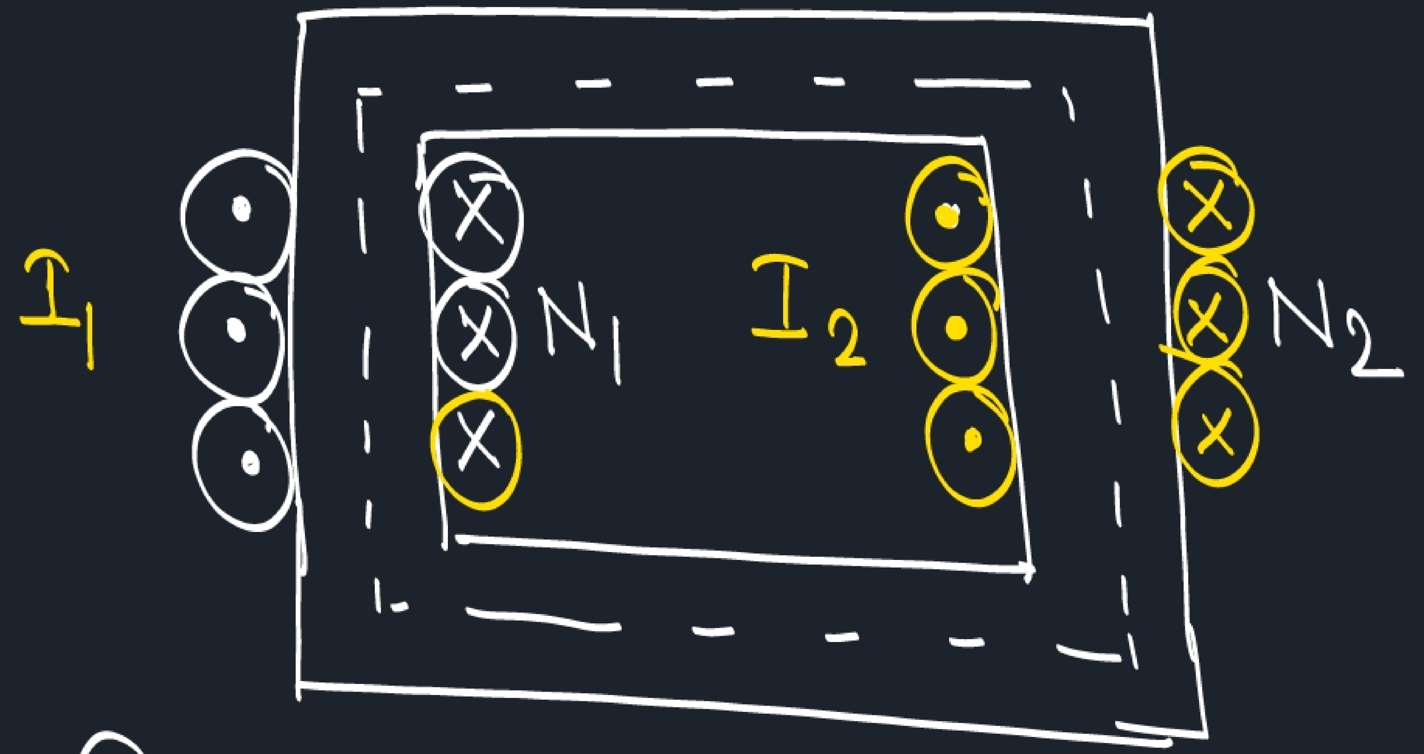
$\eta_{T/F} \to 100\%$

$\boxed{V_1I_1 = V_2I_2} \Rightarrow$ VA Rating



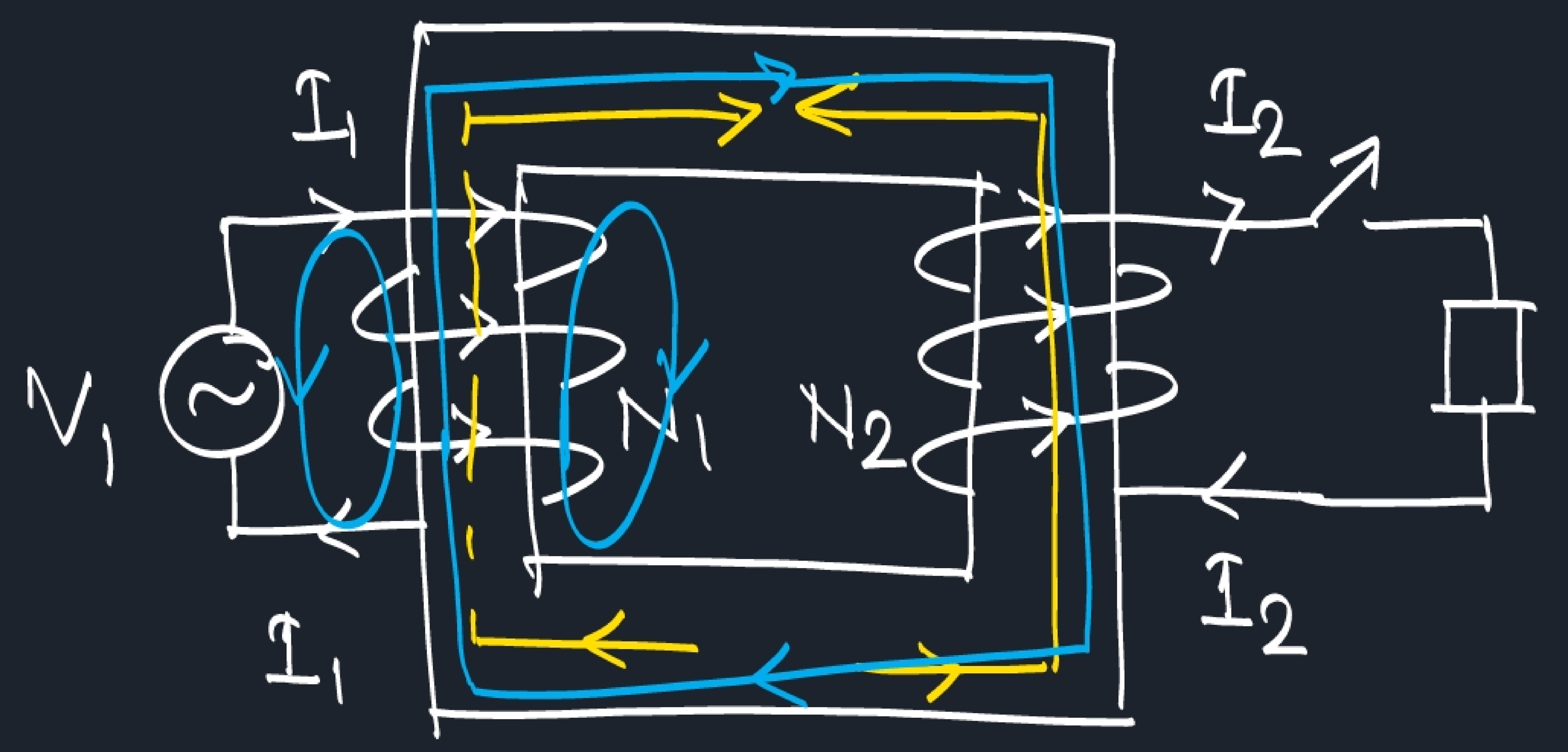

$$\boxed{I_2 = \frac{E_2}{Z.}}$$

$\oint \quad \oiint \quad \oiiint$




$$\oint \vec{H}\cdot d\vec{l} = N_1I_1 - N_2I_2 = 0$$

$\boxed{N_1I_1 = N_2I_2}$ MMF Balance.




$$\Phi_{total} = \Phi_m + \Phi_{l1}$$

$$E_1^{total} = 4.44 f \Phi_{total} N_1$$

$$= 4.44 f (\Phi_m + \Phi_{l1}) N_1$$

$$E_1^{total} = \underbrace{4.44 f \Phi_m N_1} + \underbrace{4.44 f \Phi_{l1} N_1}$$

$$\Phi_m = \frac{N_1 I_m - N_2 I_2 + N_1 I_1'}{\mathcal{R}}$$

$$\Phi_m = \frac{N_1 I_m}{\mathcal{R}}$$

$$\Phi_m' = \frac{N_1 I_m - I_2 N_2}{\mathcal{R}}$$

$$\boxed{N_1 I_1' = N_2 I_2}$$

$$\boxed{I_1 = I_m + I_1'}$$

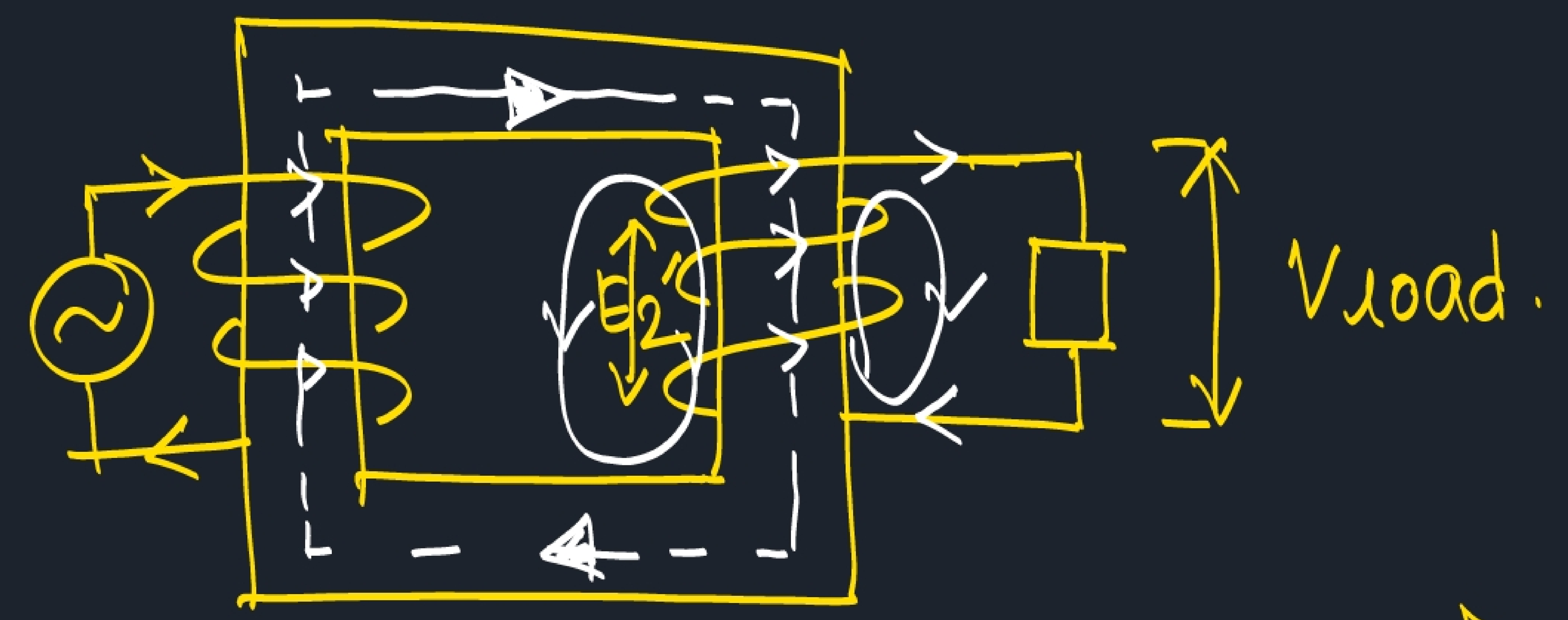
$$\boxed{V_1 = E_1 + I_1 R_1 + j I_1 X_{l1}}$$

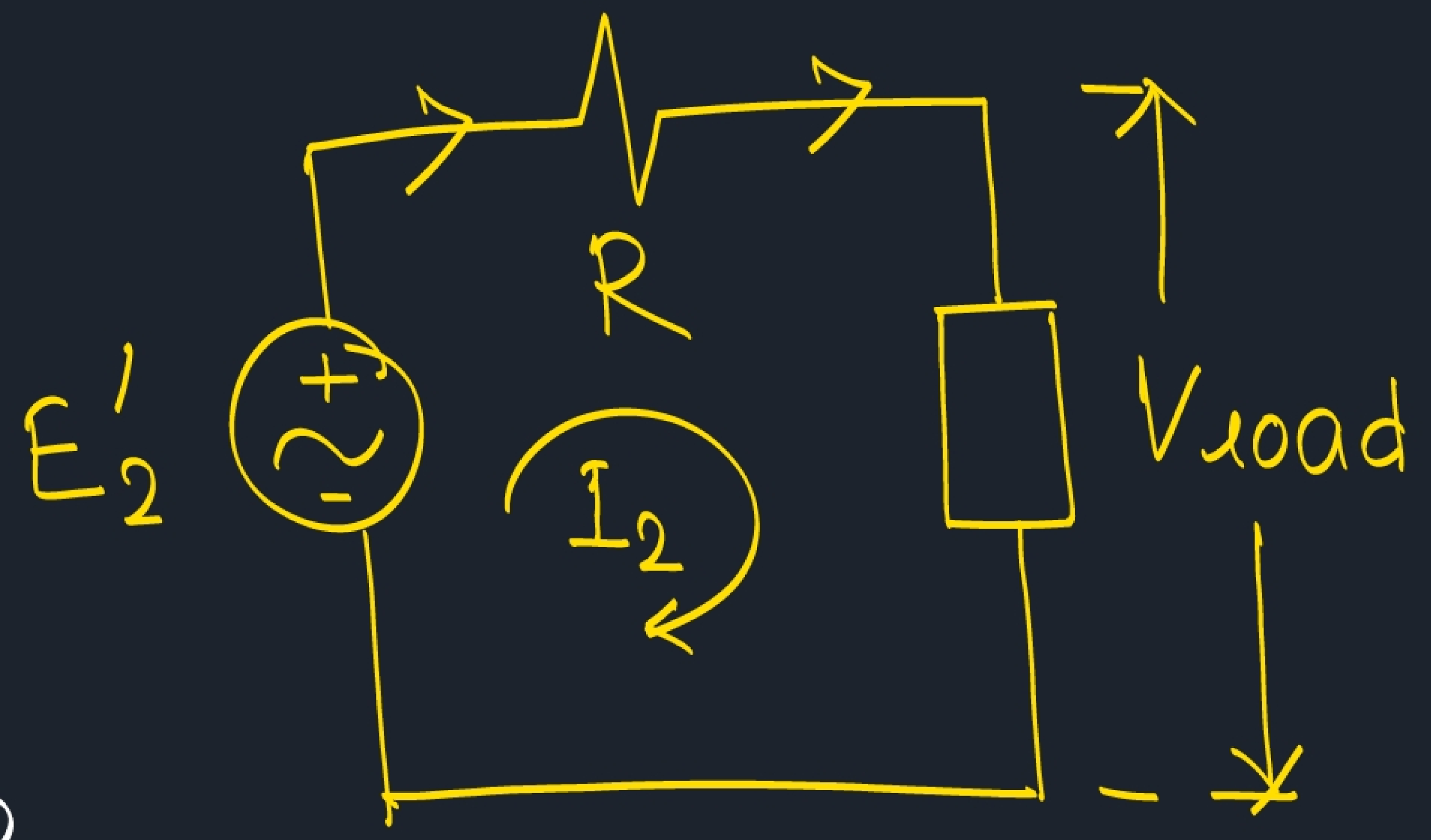
$$V_1 - I_1 R_1 = E_1^{total} = \underbrace{4.44 f \Phi_m N_1} + E_{l1}$$

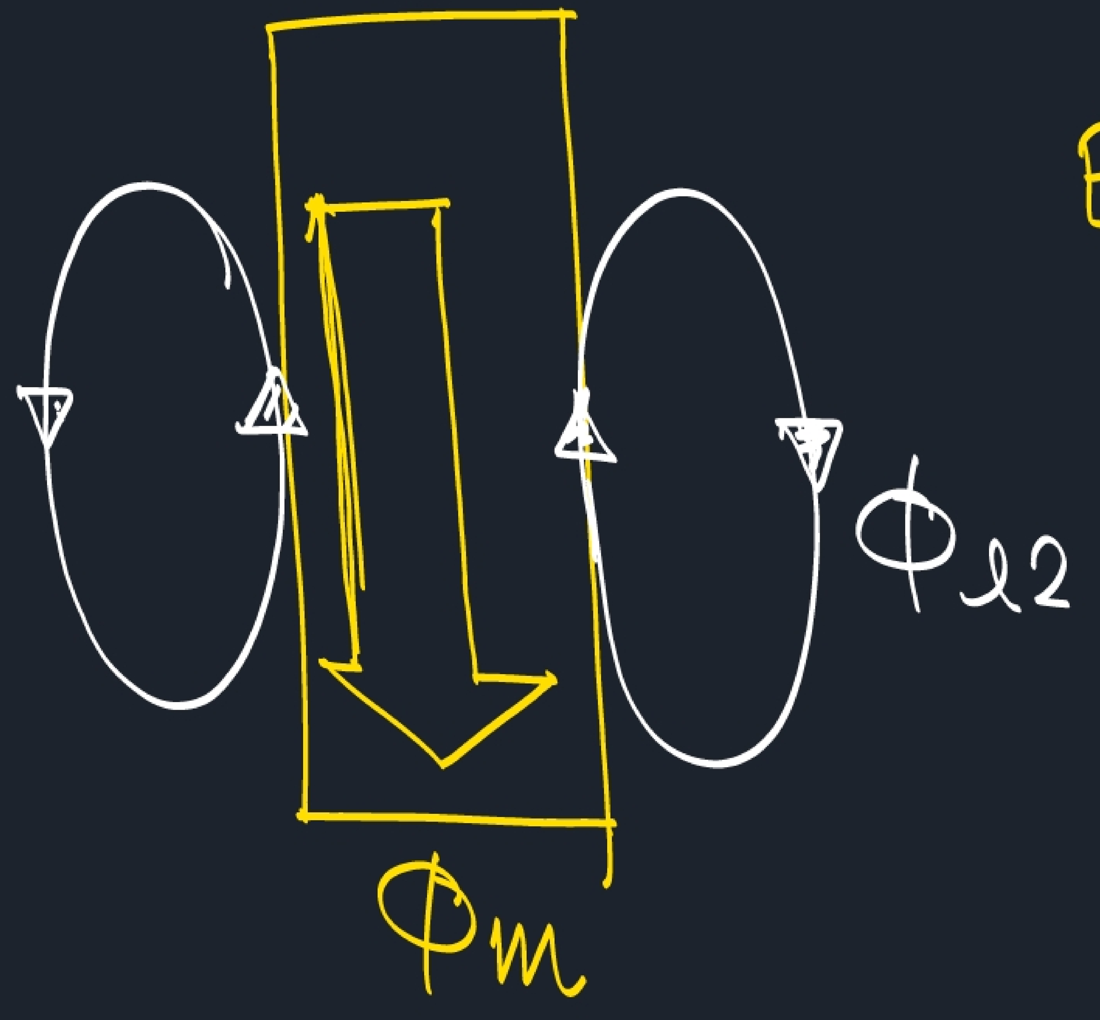
$$= E_1 + E_{l1}$$

$$\boxed{V_1 - E_1 = I_1 R_1 + E_{l1}}$$

$$= I_1 R_1 + j I_1 X_{l1}$$




$$\Phi_m \gg \Phi_{l2}$$

$$E_2' = V_{load} + I_2 R_2 \Rightarrow E_2 - E_{l2} = V_{load} + I_2 R_2$$

$$E_2 = V_{load} + I_2 R_2 + E_{l2}$$

$$= V_{load} + I_2 R_2 + (I_2 \times j\omega L_2)$$

$$E_2' = 4.44 f \Phi N_2$$

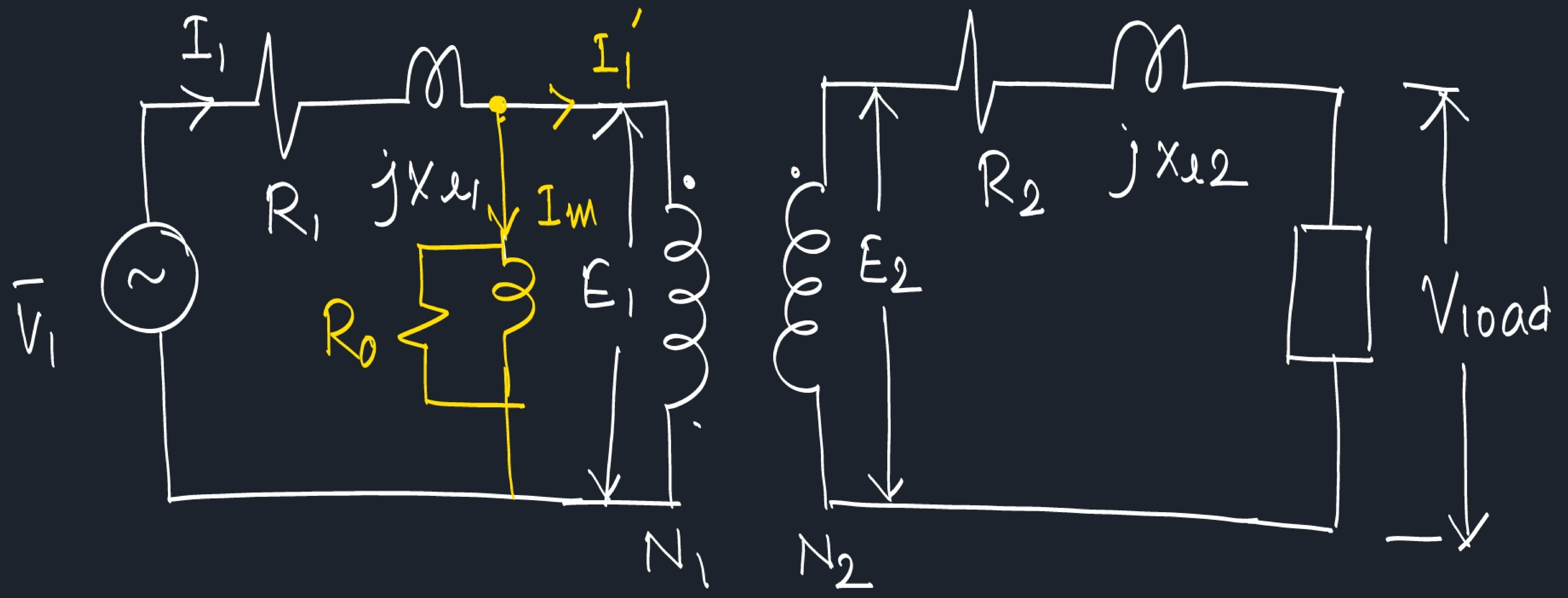
$$= 4.44 f (\Phi_m - \Phi_{l2}) N_2$$

$$= \underbrace{4.44 f \Phi_m N_2} - \underbrace{4.44 f \Phi_{l2} N_2}$$

$$= E_2 - E_{l2}$$

$$\boxed{E_2 = V_{load} + I_2 R_2 + j I_2 X_{l2}}$$

$$\begin{cases} V_1 = E_1 + I_1 R_1 + jI_1 X_{l1} & \text{- - - - (i)} \\ E_2 = V_{load} + I_2 R_2 + jI_2 X_{l2} & \text{- - - (ii)} \\ \hat{I}_1 = \hat{I}_m + \hat{I}_1' & \text{- - - - - - - (iii)} \\ I_1' N_1 = I_2 N_2 & \text{- - - - - - - (iv)} \end{cases}$$




$I_m$ Creates $\Phi_m$.

i.e. an inductor should be associated to $\Phi_m$.

$R_0 \Rightarrow$ represents inter loss of T/F.

↳ Hysteresis + Eddy Current.

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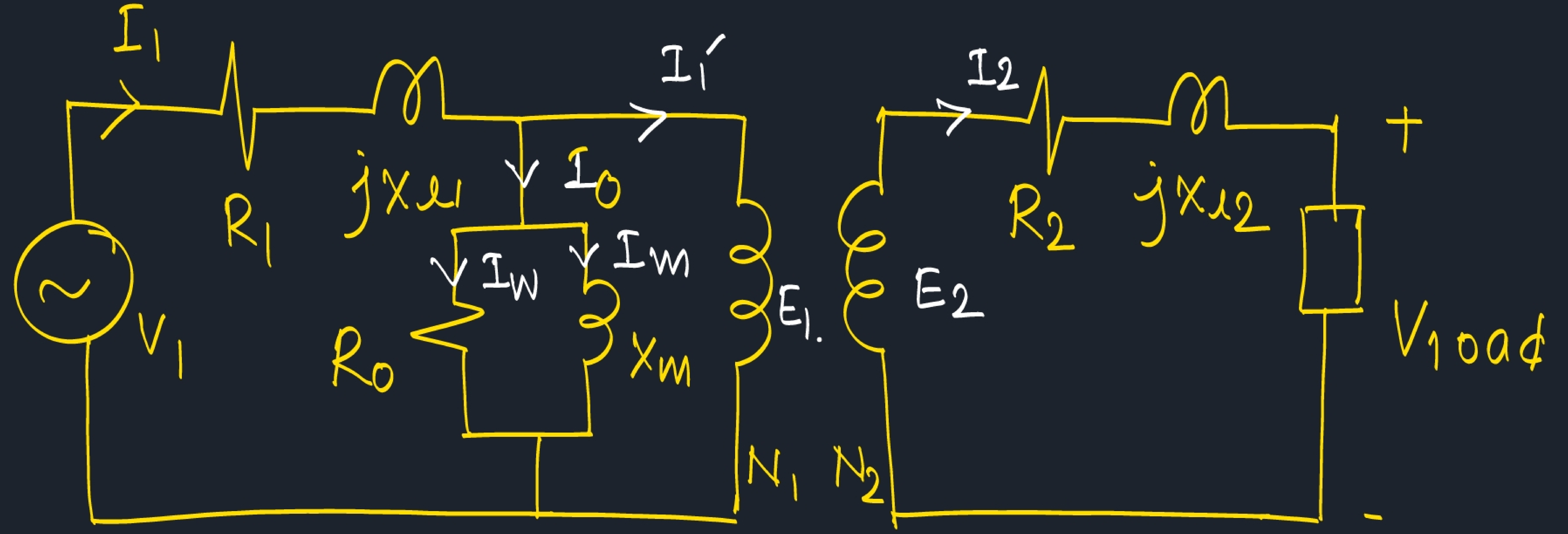
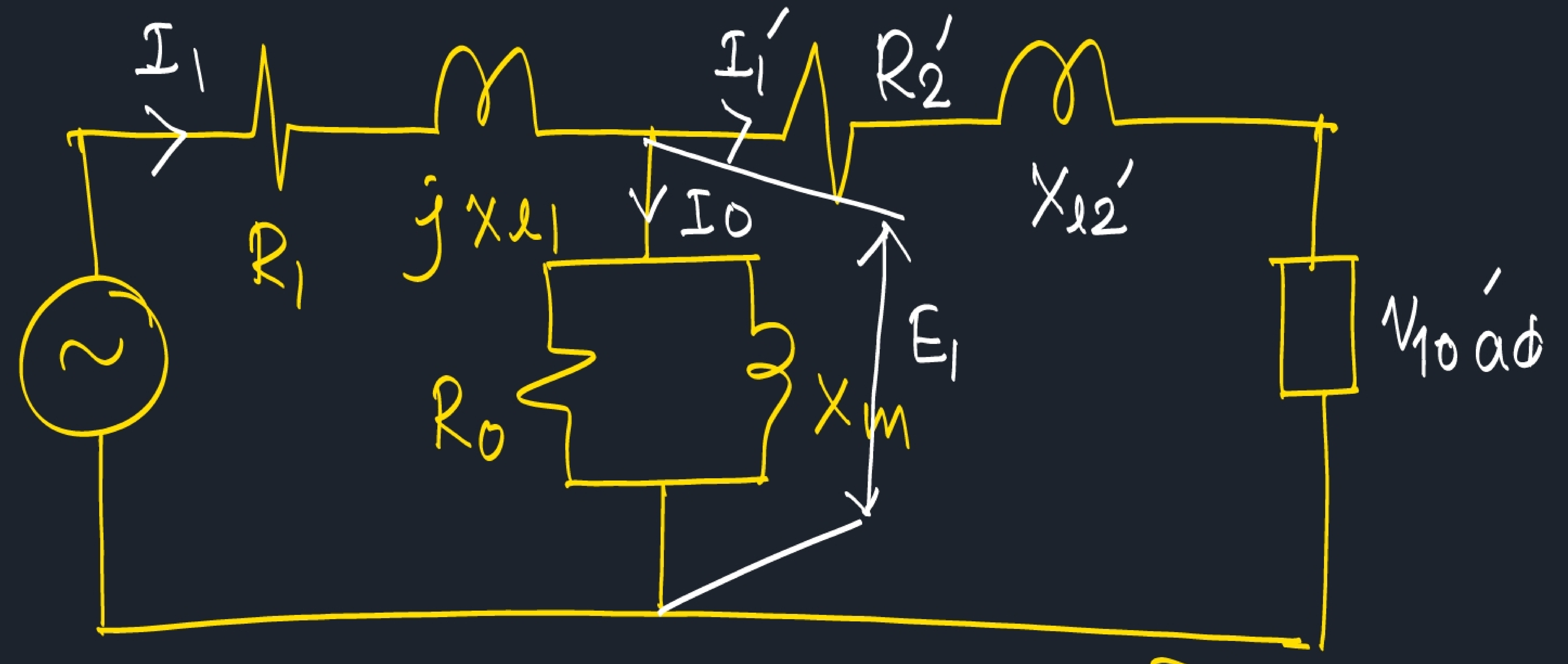



$\Rightarrow$




$$E_2 = V_{load} + I_2\left(R_2 + jX_{l2}\right)$$

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \qquad I_1' N_1 = I_2 N_2 \qquad I_2 = I_1'\left(\frac{N_1}{N_2}\right)$$

$$\Rightarrow E_1 \cdot \frac{N_2}{N_1} = V_{load} + I_2\left(R_2 + jX_{l2}\right)$$

$$\Rightarrow E_1 = \left(\frac{N_1}{N_2}\right) \cdot V_{load} + \left(\frac{N_1}{N_2}\right) I_2\left(R_2 + jX_{12}\right)$$

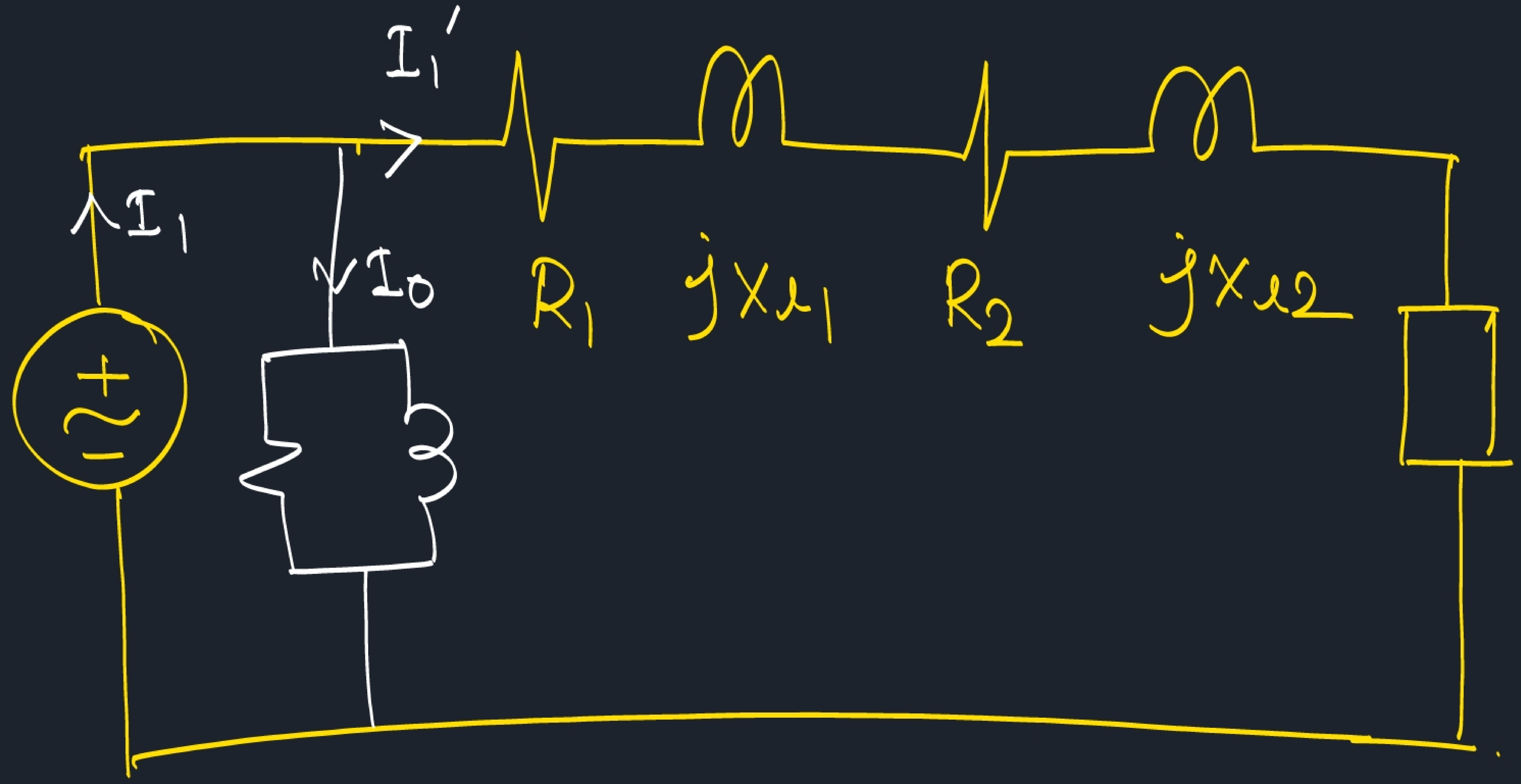
$$E_1 = \underbrace{\left(\frac{N_1}{N_2}\right) V_{load}} + \left(\frac{N_1}{N_2}\right)^2 \cdot I_1'\left(R_2 + jX_{l2}\right)$$

$$= V_{load}' + I_1'\left(R_2' + jX_{l2}'\right)$$

$$R_2' = \left(\frac{N_1}{N_2}\right)^2 R_2 \Rightarrow \text{Secondary Referred to the Primary}$$

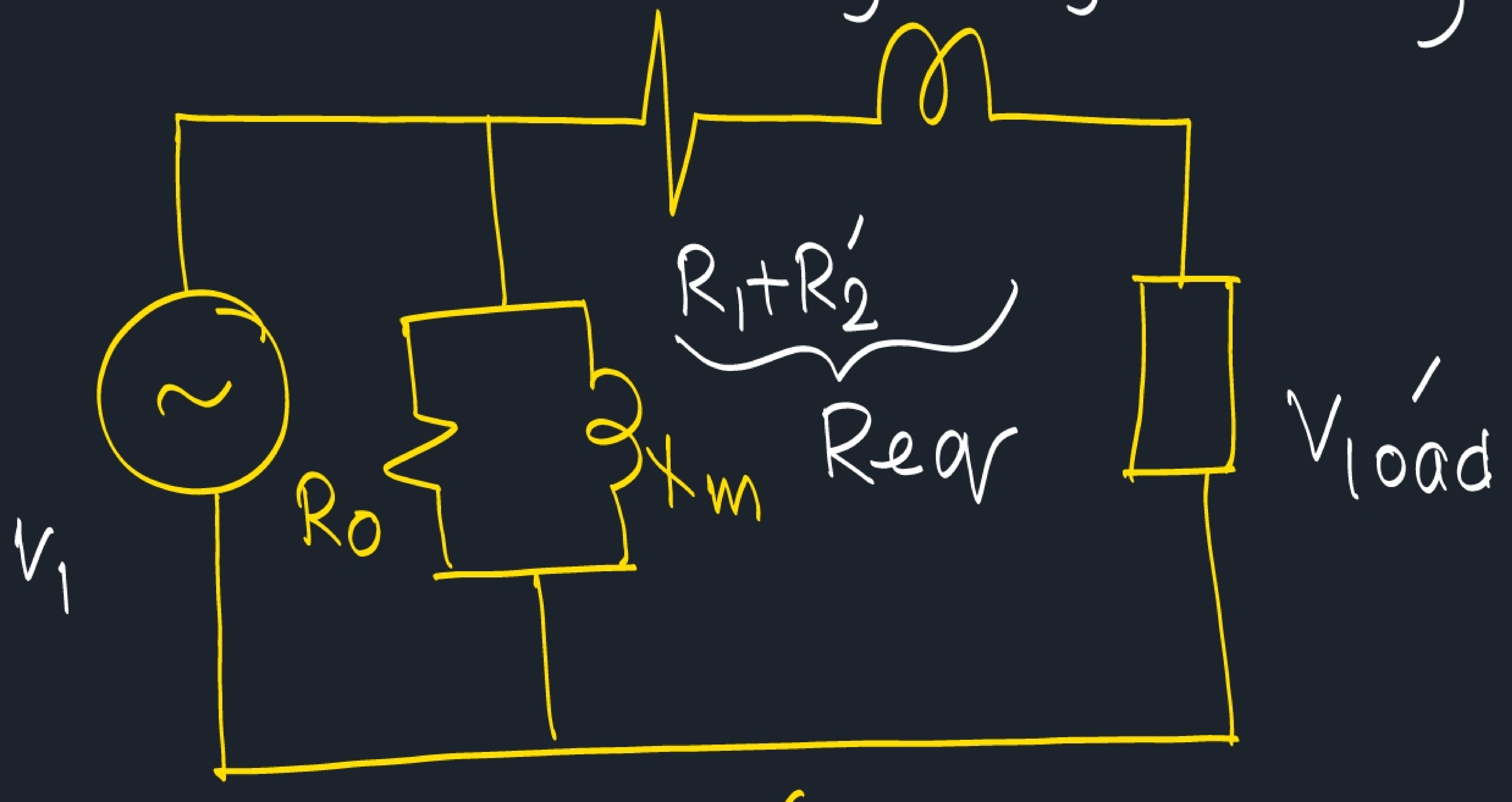
$$X_{l2}' = \left(\frac{N_1}{N_2}\right)^2 X_{l2}$$

EXACT Equivalent ckt of the T/F.




$\Rightarrow$

$jx_{l1}+jx_{l2}' = jx_{eq}$




$\hat{I}_0 <<<< \hat{I}_1 \;\&\; \hat{I}_1'$

approx. (2-5%)

$R_0, X_m \Rightarrow$ Shunt Branch parameters

↳ Approximated Equivalent ckt of the T/F.

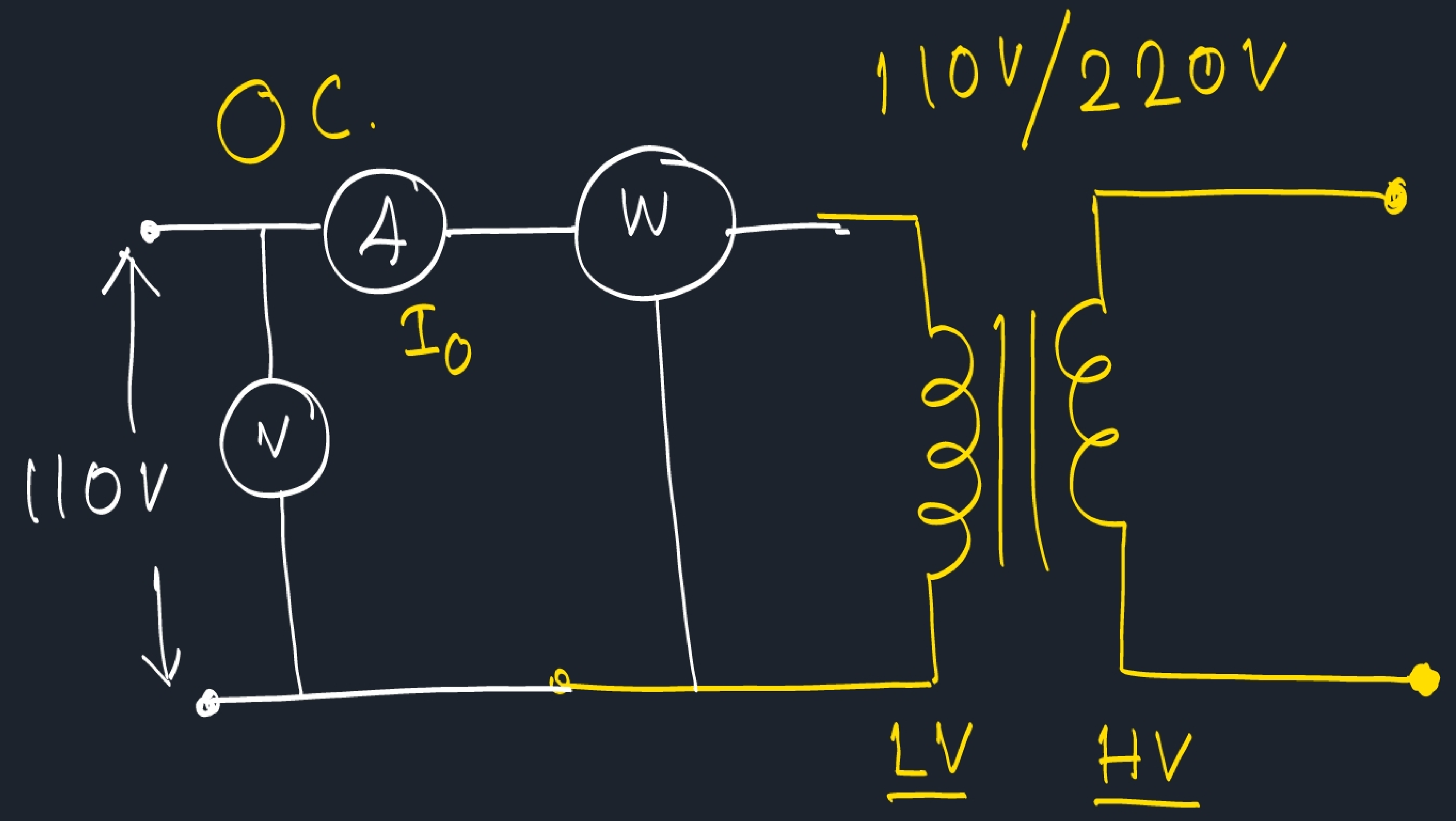
$R_{eq}, X_{eq} \Rightarrow$ Series Branch Parameters.

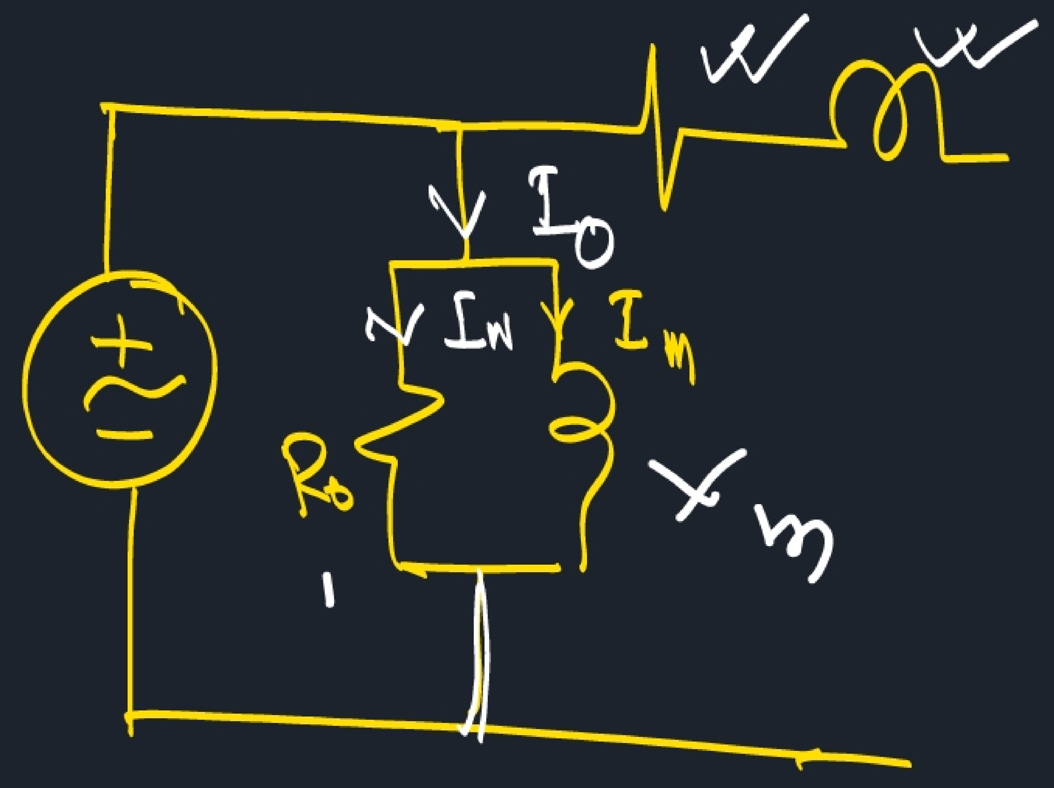
## Two tests.

To find out the parameters of T/F.

i) Open Circuit Test (OC Test)

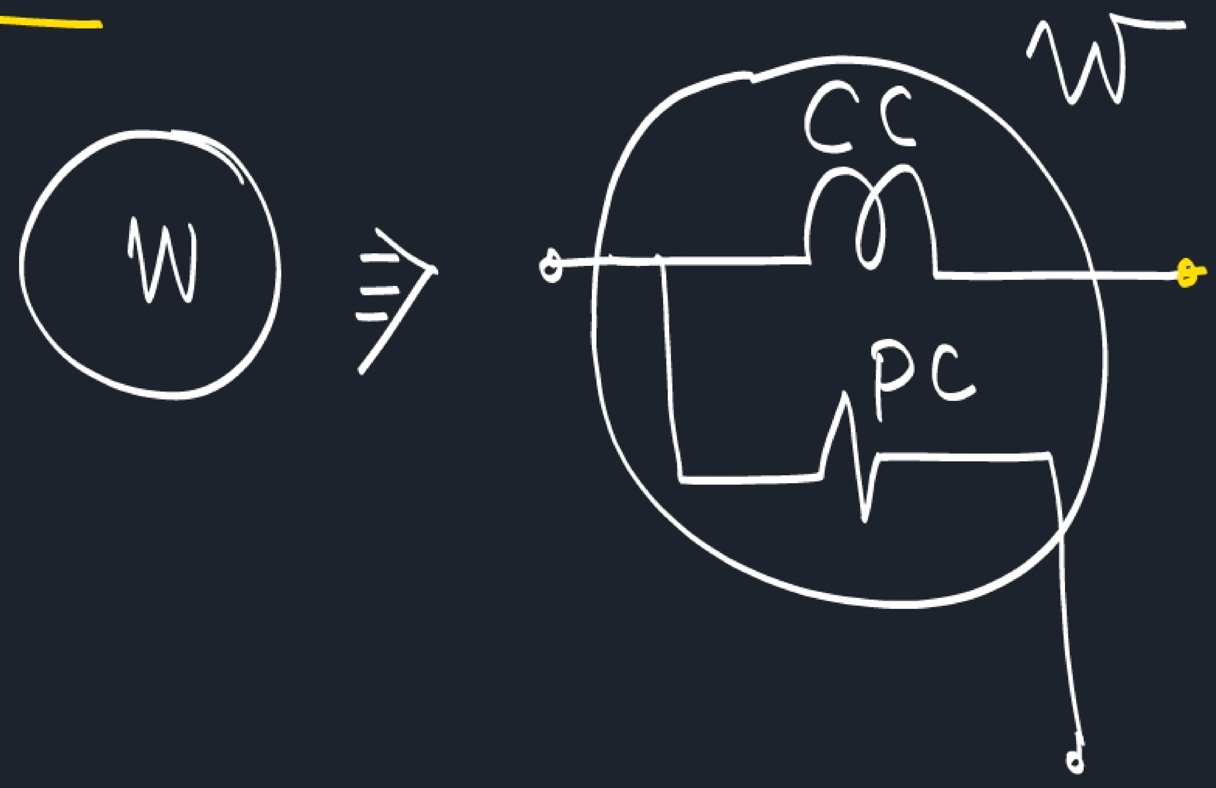
ii) Short Circuit Test (SC Test)



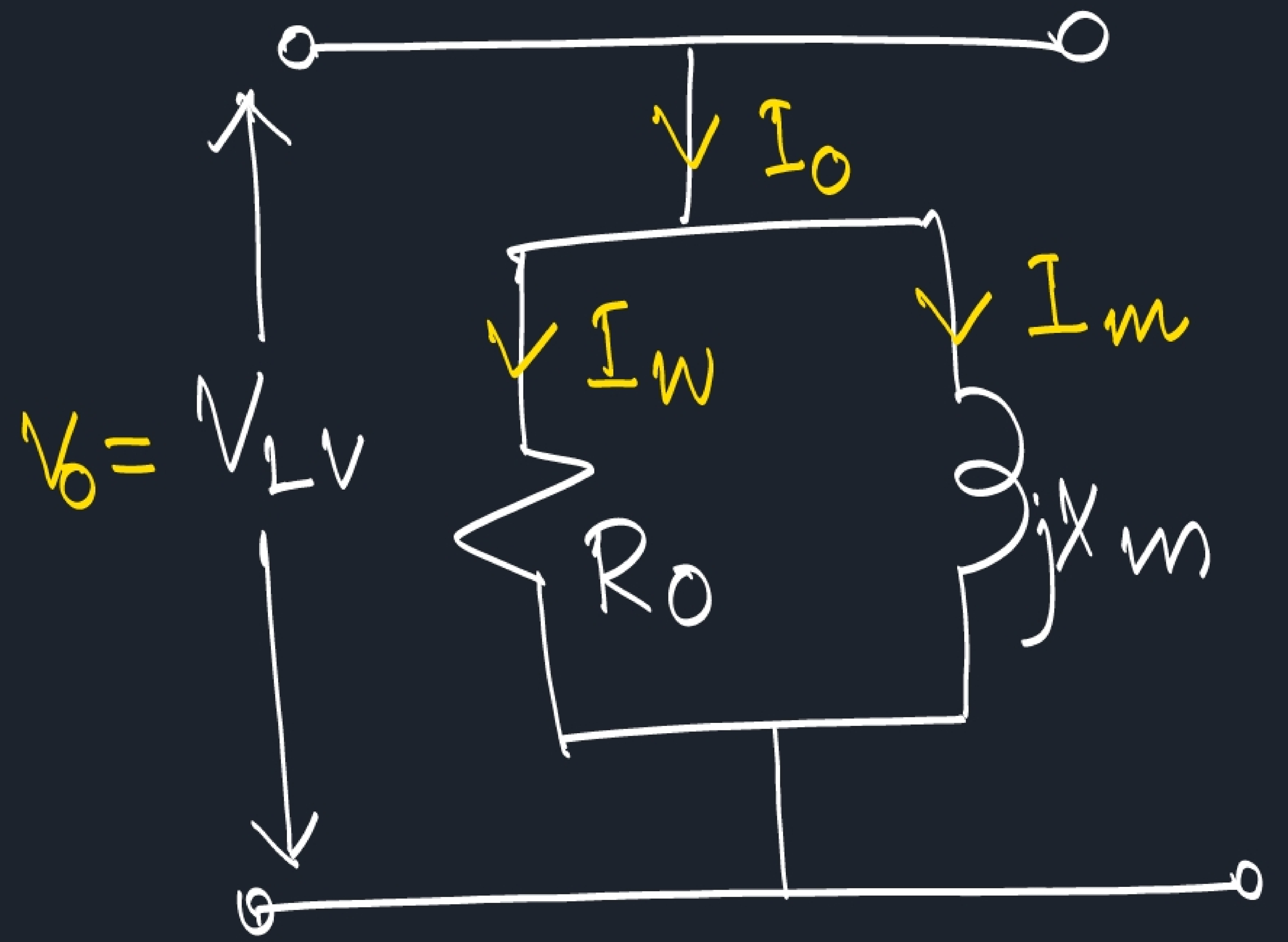

$V_0, I_0, W_0$

i) Voltmeter
ii) Ammeter
iii) Wattmeter.




$W = (I_W^2 \times R_0)$

V = Rated Voltage.




$$R_o = \frac{V_o}{I_w}$$

$$jX_m = \frac{V_o}{I_m}$$

$$W_o = I_w^2 R_o$$

$$W_o = V I_w = V_o I_o \cos\theta_o$$

$$\theta_o = \cos^{-1}\left(\frac{W_o}{V_o I_o}\right)$$

$$I_w = |I_o| \cos\theta_o$$

$$I_m = |I_o| \sin\theta_o$$

$V_o$, $W_o$, $I_o$

$$\tilde{I}_o = \underbrace{|I_o|}_{\text{Measured By Ammeter.}} \angle \theta_o$$

$$R_o = \frac{V_o}{|I_o| \cos\theta_o} \qquad X_m = \frac{V_o}{|I_o| \sin\theta_o}$$

# SC Test :-

$1\phi$ T/F

$$\underbrace{220\,V}_{HV} \Big/ \underbrace{110\,V}_{LV}$$

1 KVA Rating

$$V_1 I_1 = V_2 I_2 = 1000$$

$$\left.\begin{aligned} V_{LV} I_{LV} &= 1000 \\ V_{HV} I_{HV} &= 1000 \end{aligned}\right\}$$

$$\left.\begin{aligned} |I_{LV}| &= \frac{1000}{110} \text{ Amp} \\ |I_{HV}| &= \frac{1000}{220} \text{ Amp.} \end{aligned}\right\}$$

Q.

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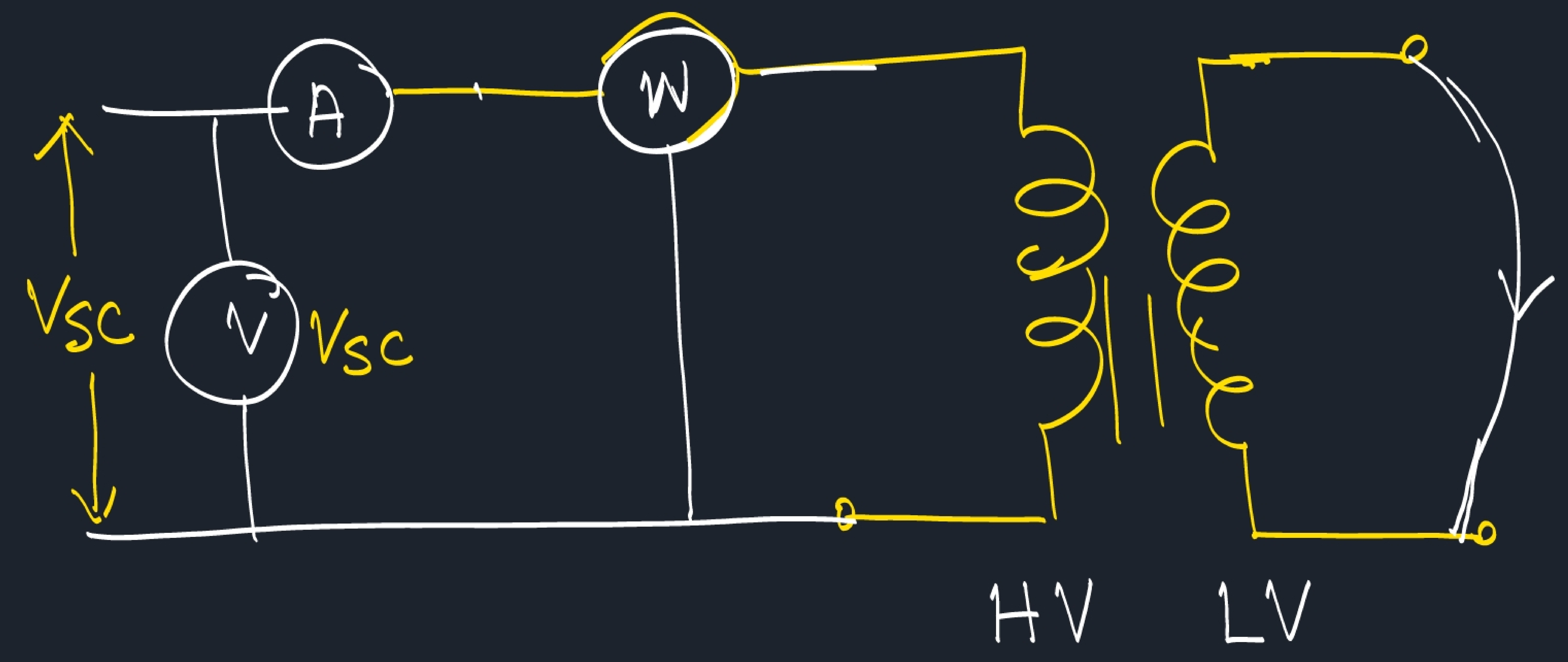
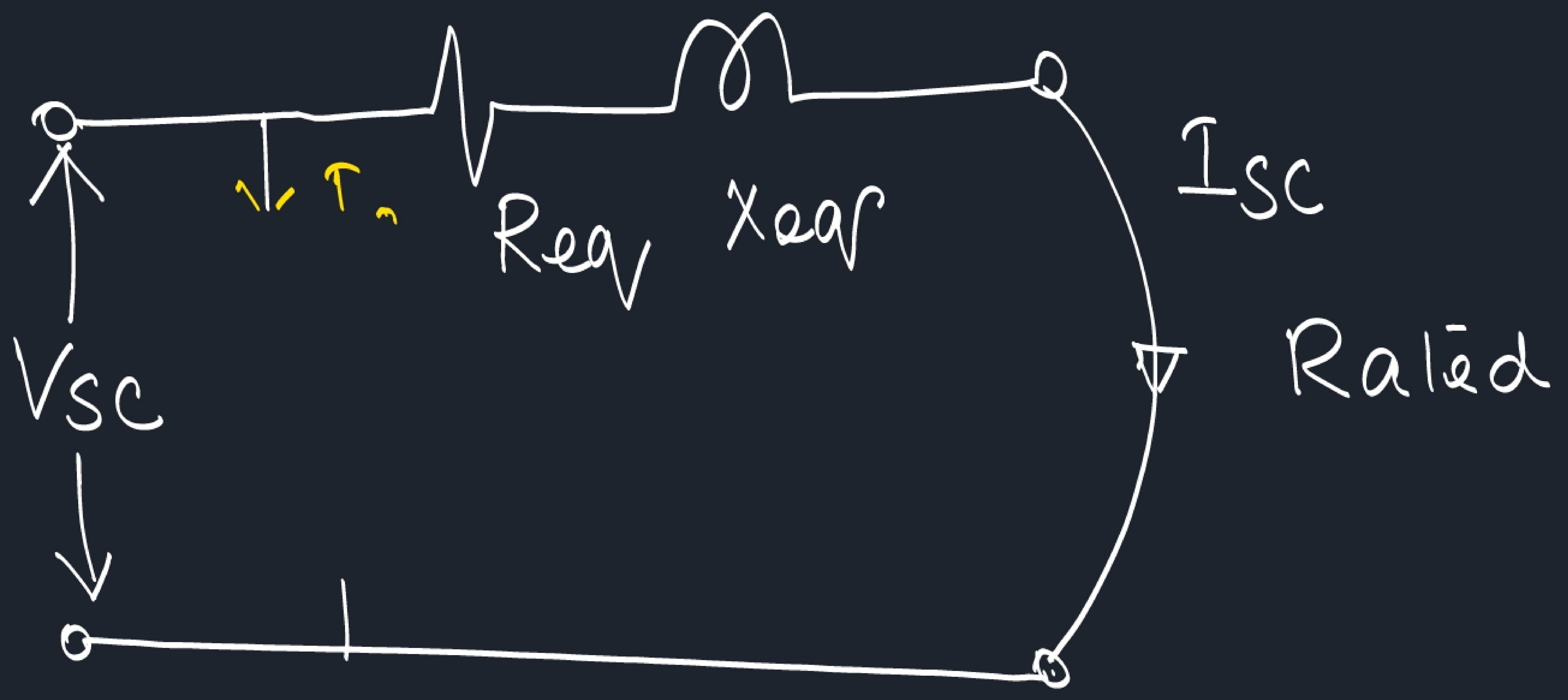



220/110 V.

1000 VA.

$\frac{1000}{220}$ Amps.

$V_{sc}, I_{sc}, W_{sc}$.

$I_0 <<< I_{sc}$.

$$W_{sc} = I_{sc}^2 R_{eq}$$

$$\boxed{R_{eq} = \frac{W_{sc}}{I_{sc}^2}}$$

$$|Z_{eq}| = \frac{V_{sc}}{I_{sc}}$$

$$\boxed{X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}}$$

Problem:-

$1\Phi$ T/F

$N_1 = 250$ (pri)

$N_2 = 500$ (Sec)

$A_{core} = 60 cm^2$

$f = 50 Hz$

$V = 230 V$ (Primary)

Peak flux density $B_m$

$V_1 = E_1 = 4.44 f \Phi_m N_1$

$$\Phi_m = \frac{230}{4.44 \times 50 \times 250} \text{ Wb.} = ?$$

$$B_m = \frac{\Phi_m}{A} = \frac{\Phi_m}{60 \times 10^{-4}} \text{ Wb/m}^2 = ?$$

## Problem:-

T/F : 5 kVA
200/1000 V --- (i)

OC. Test : 200 V, 1.2 A, 90 W --- (ii)

SC Test : 50 V, 5 A, 110 W --- (iii)

Estimate the transformer parameters.

(i) $\left.\begin{array}{l} V_{LV} = 200\text{ V} \\ V_{HV} = 1000\text{ V} \end{array}\right\}$ $V_{HV} I_{HV} = V_{LV} I_{LV} = 5000$

$I_{HV} = 5$ Amps. $I_{LV} = \frac{5000}{200} = 25$ Amps

(ii) LV Side is Choosen for OC Test

$V_0 = 200\text{ V}, \quad I_0 = 1.2\text{ A}, W_0 = 90\text{ W}$

(iii) HV Side is Choosen for SC Test

$V_{SC} = 50\text{ V}, \quad I_{SC} = 5\text{A}, \quad W_{SC} = 110\text{ W}$

## OC Test:-

### Step-1

$$\cos\theta_0 = \frac{W_0}{V_0 I_0}$$

$$= \frac{90}{200 \times 1.2}$$

$\theta_0 = ?$ $67.9756^\circ$

### Step-2

$$R_0^{LV} = \frac{V_0}{I_0 \cos\theta_0} = 444.44\,\Omega$$

### Step-3

$$X_m^{LV} = \frac{V_0}{I_0 \sin\theta_0}$$

$$= 179.7866\,\Omega$$

## SC Test:-

### Step-1

$$R_{eq}^{HV} = \frac{W_{sc}}{I_{sc}^2}$$

$$= \frac{110}{(5)^2} = 4.4\,\Omega$$

### Step-2

$$|Z_{eq}|^{HV} = \frac{V_{sc}}{I_{sc}}$$

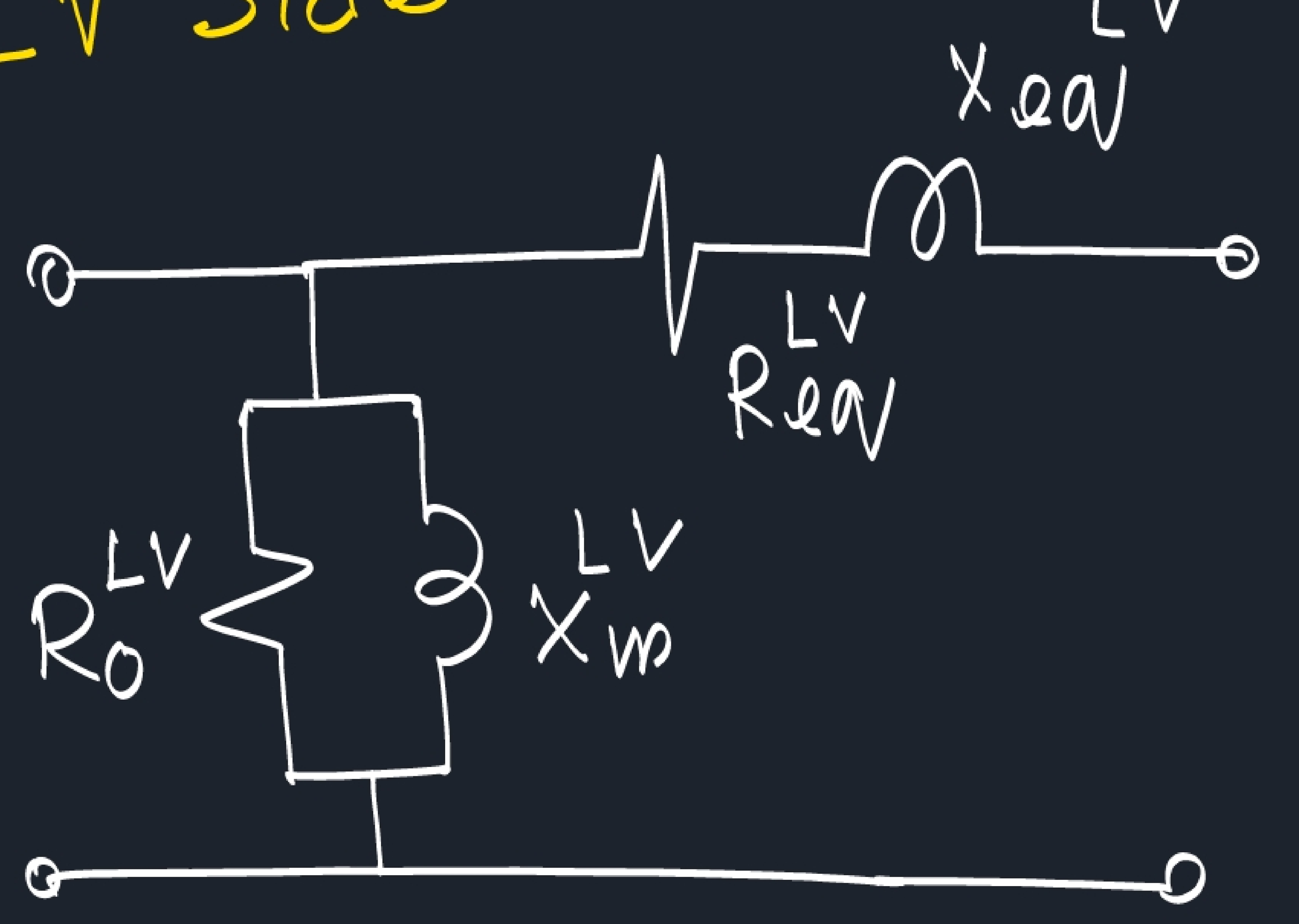
$$= \frac{50}{5} = 10\,\Omega$$

### Step-3

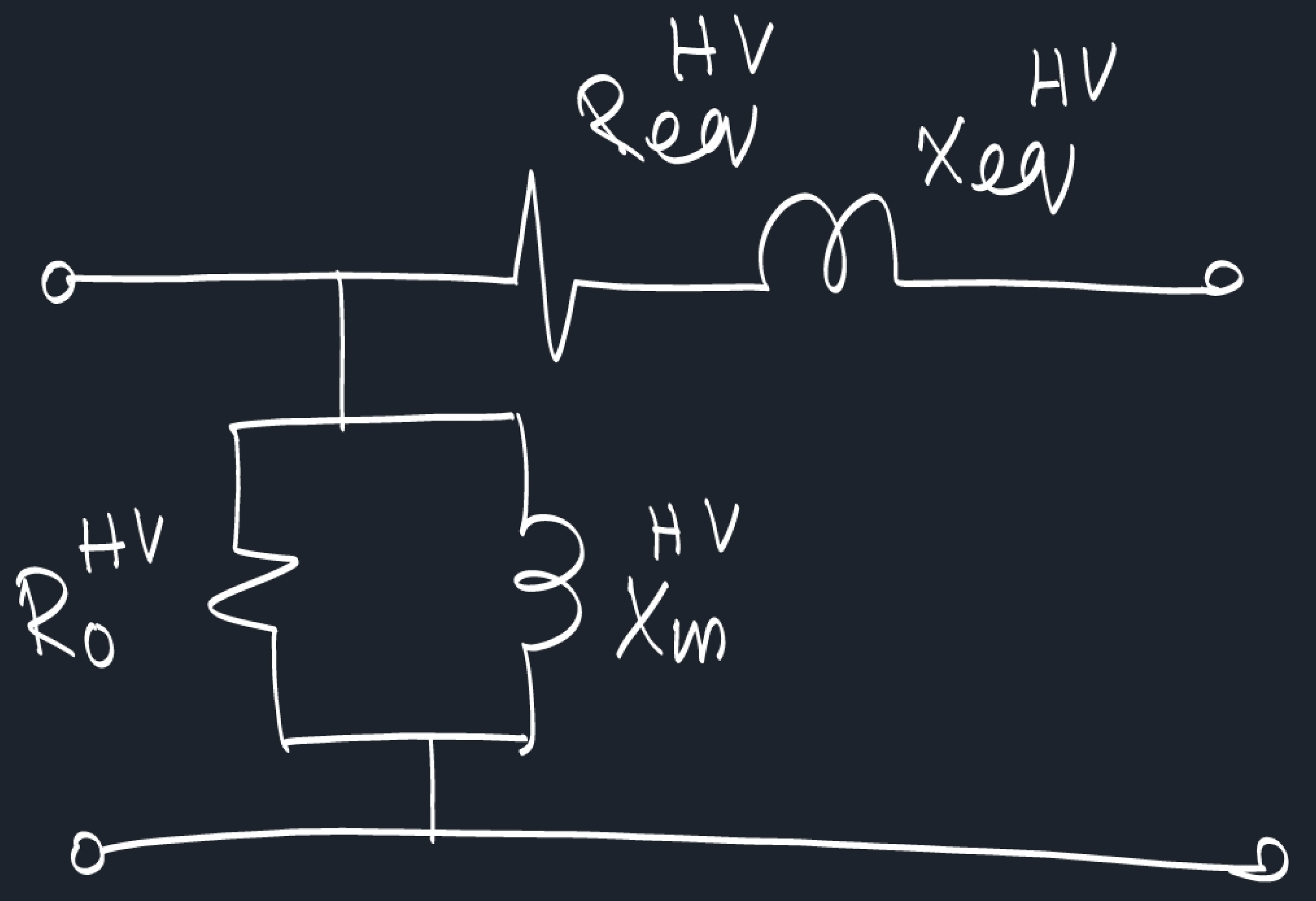
$$X_{eq}^{HV} = \sqrt{|Z_{eq}|^2 - R_{eq}^2}$$

$$= \sqrt{10^2 - (4.4)^2} = 8.97\,\Omega$$

LV Side




HV




$$\frac{R_{eq}^{LV}}{R_{eq}^{HV}} = \left(\frac{N_{LV}}{N_{HV}}\right)^2 = \left(\frac{V_{LV}}{V_{HV}}\right)^2 = \left(\frac{200}{1000}\right)^2$$

$$\frac{X_{eq}^{LV}}{X_{eq}^{HV}} = \left(\frac{V_{LV}}{V_{HV}}\right)^2$$