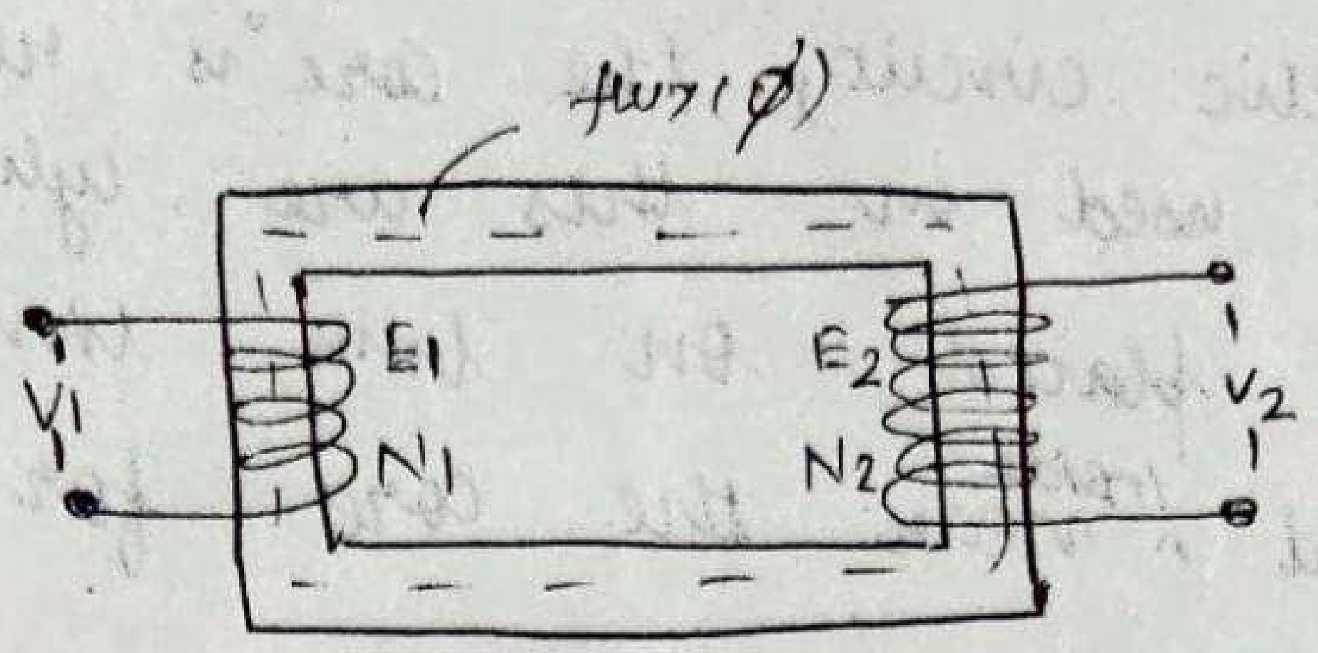
ϕ_m = max flux

* EMF EQUATION OF TRANSFORMER -



Let V_1 = AC voltage applied to primary of the T/F

ϕ = Alternating flux produced

N_1 = No. of turns in primary wdg

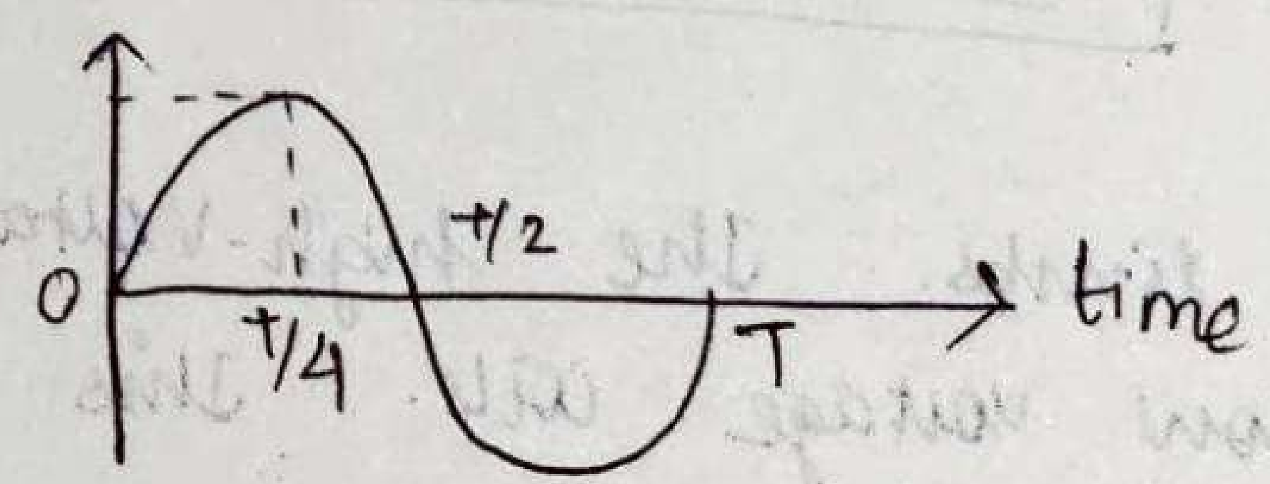
N_2 = No of turns in secondary wdg

E_1 = EMF induced in Primary due to alternating flux (ϕ)

E_2 = EMF induced in secondary due to " "

f = supply frequency

- We know from Faraday's law of electromagnetic induction
- Average emf induced per turn $= \frac{d\phi}{dt}$
- Consider 1/4th cycle of flux -



- Average emf per turn $= \frac{\text{Change in flux}}{\text{Change in time}}$

- So, average emf per turn $= \frac{\phi_m - 0}{T/4 - 0}$

$$= \frac{4\phi_m}{T}$$

- Average emf per turn $= 4f\phi_m$ $\quad\therefore$ as $T = \frac{1}{f}$

w-

Form factor = $\frac{\text{RMS value of EMF}}{\text{Average value of EMF}} = 1.11$

So, RMS value of emf per turn $= \text{Av. emf} \times 1.11$
$= 4 f \phi_m \times 1.11$
$= 4.44 f \phi_m$

Total emf induced in N_1 turns

$$\boxed{E_1 = 4.44 f \phi_m N_1} \text{ volt} \quad \text{——— (1)}$$

Total emf induced in N_2 turns of secondary

$$\boxed{E_2 = 4.44 f \phi_m N_2} \text{ volt} \quad \text{——— (2)}$$

From (1) & (2)

$$\boxed{\frac{E_1}{E_2} = \frac{N_1}{N_2}} \quad \text{——— (3)}$$

ow, $\frac{E_1}{E_2} = \frac{N_1}{N_2}$ and $\frac{E_2}{E_1} = \frac{N_2}{N_1} = K$

then, $\boxed{K = \frac{N_2}{N_1}}$ and $\boxed{K = \frac{E_2}{E_1}}$

K is Transformation ratio

Note-

(a) Step-up T/F $\Rightarrow N_2 > N_1$

(b) Step-down T/F $\Rightarrow N_2 < N_1$

(C) Isolation T/F $\Rightarrow N_2 = N_1$

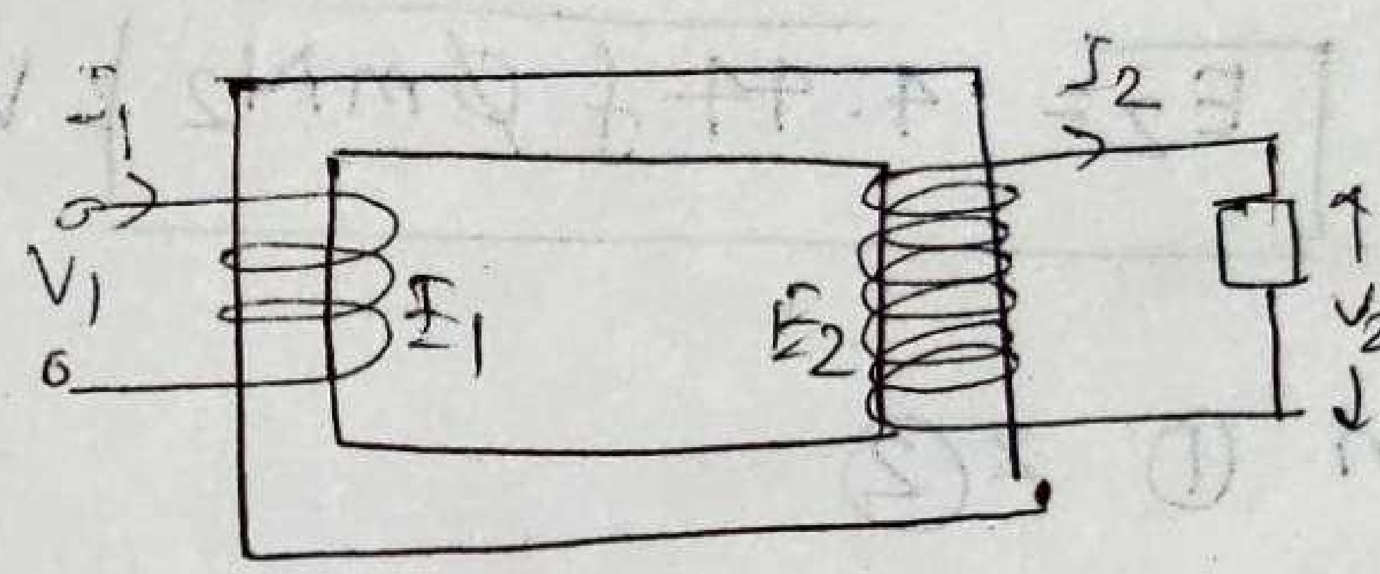
* IDEAL TRANSFORMER-

Properties-

- → It will have no loses
- → It's winding Resistance will be Zero
- → It's leakage flux will be zero
- → Very small current is required to produce flux.
- → ~~Fo~~ Their is no voltage drop in primary
- → Note:-

$V_1 = E_1$

$V_2 = E_2$



$$\boxed{\frac{E_2}{E_1} = \frac{V_2}{V_1} = k}$$

$$\boxed{V_1 I_2 = I_2 V_2}$$

⇓

$$\boxed{\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = k}$$ → Transformation ration

→ $E_2 = KE_1$
→ $V_2 = KV_1$
→ $I_2 = I_1/k$

---

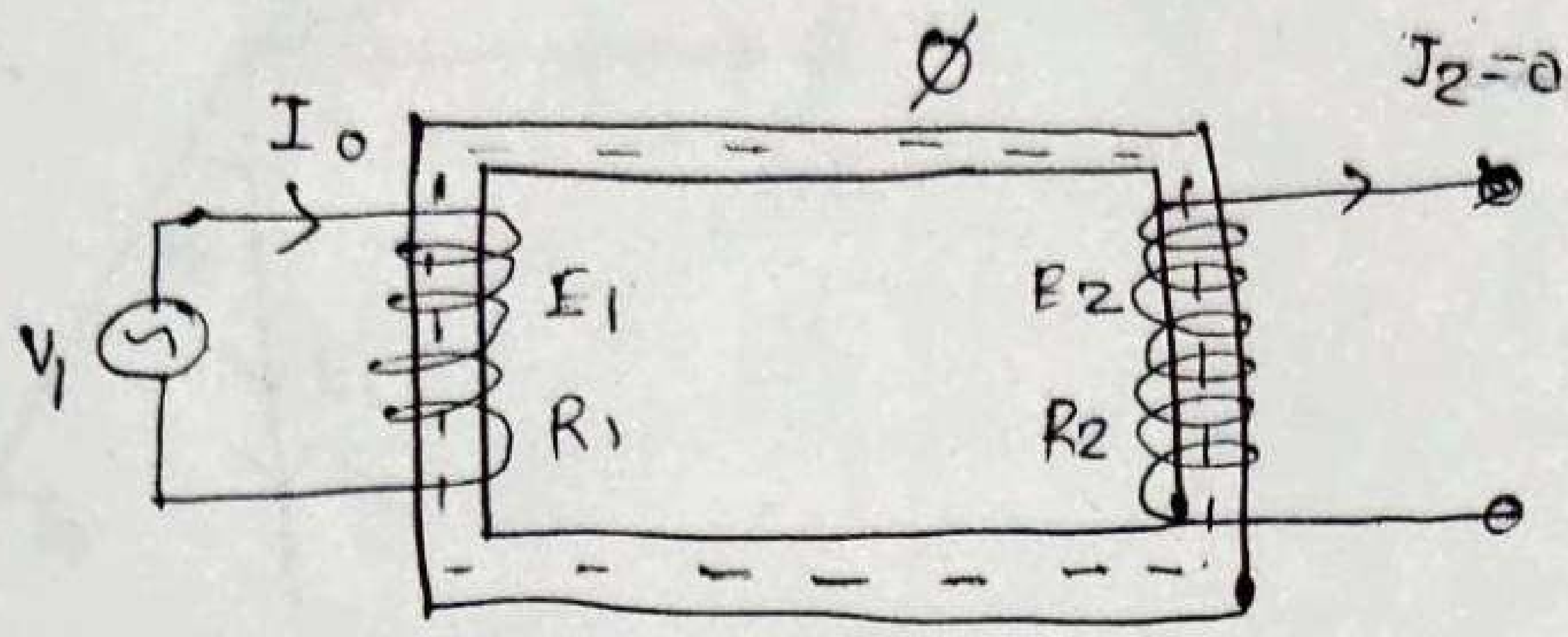
* KVA RATING OF T/F-

In transformers, ratings are given in KVA becoz power consumption in transformer is due to the following reason's.-

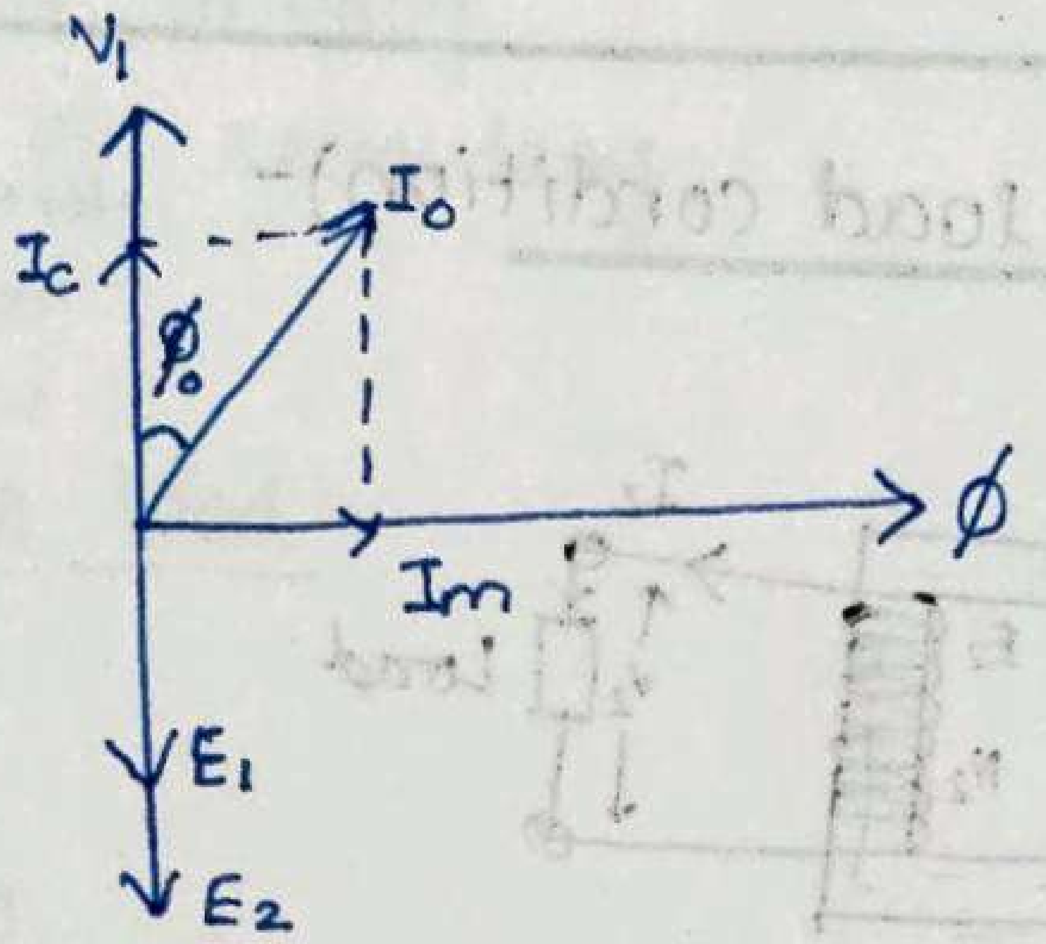
- copper loss
- Iron loss

* PRACTICAL TRANSFORMER - (on no load)-

In practical T/F primary winding has some resistance so, primary coil will have inductance as well as Resistnce.



Phasor diagram



→ ϕ_0 = no load phase angle

→ I = no load current

→ B/W V & I current is not 90°.

→ $\boxed{I_0^2 = I_m^2 + I_c^2}$

→ I_m = magnetising current (magnitised core or generation of flux)

→ I_c = core loss current

→ $\vec{I_0} = \vec{I_m} + \vec{I_c}$

→ $\boxed{I_c = W_{core} + W_{cu}}$

→ W_{cu} is very small due to small no load current.

→ $I_c \cong W_{core\ loss}$ (neglecting W_{cu})

$\therefore \boxed{I_c = W_{core\ loss}}$

→ $I_c = I_0 \cos\phi_0$

→ $I_m = I_0 \sin\phi_0$

No load power loss formula-

$$\boxed{W_0 = V I_0 \cos\phi_0}$$

- $I_0 = 3\% - 5\%$ of full load (I_{fl})
- Flux pass through core
- $\phi = \frac{MMF\ (NI)}{S}$

  $NI = \phi S$ → ϕ is constant.

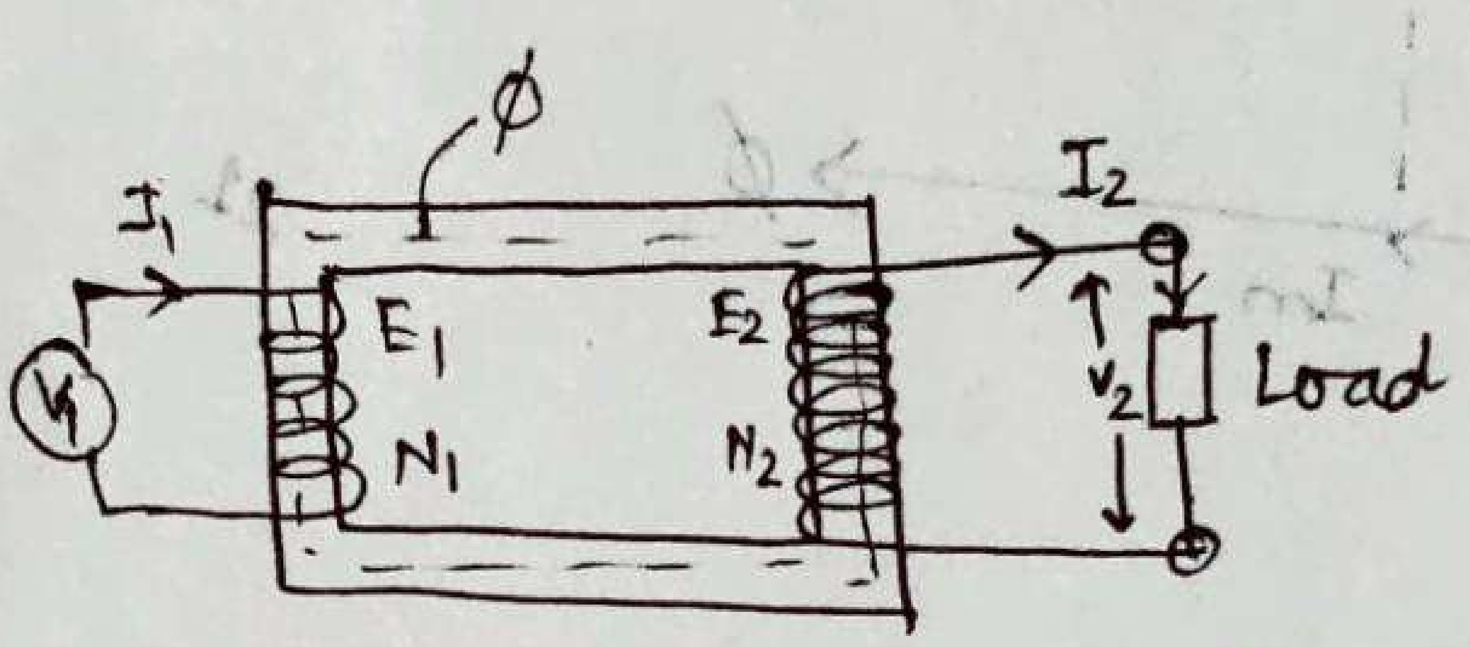
  $NI \propto S$

  $\boxed{I_0 \propto S}$

- $R = \rho \frac{l}{A}$
- $S = \frac{l}{\mu_r A}$

Ideal transformer (on-load condition)-

Here resistance is very low or negligible that's why it's a Ideal tranformer condition



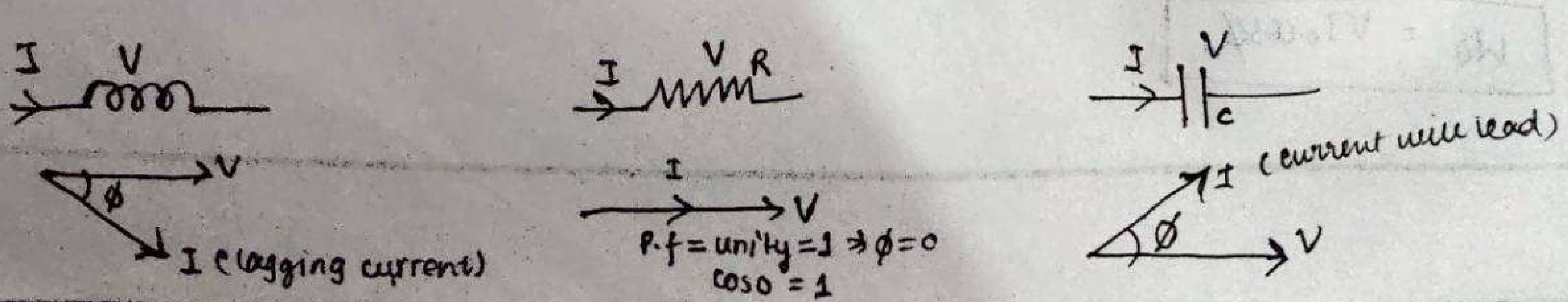
Here →

- I_1 = current drawn from primary coil under load condition
- I_2 = current in the secondary drawn by load in the secondary coil
- $\boxed{\bar{I_1} = \bar{I_0} + \bar{I_2'}}$
- $I_2' = KI_2$ and I_2' is always is antiphase of I_2

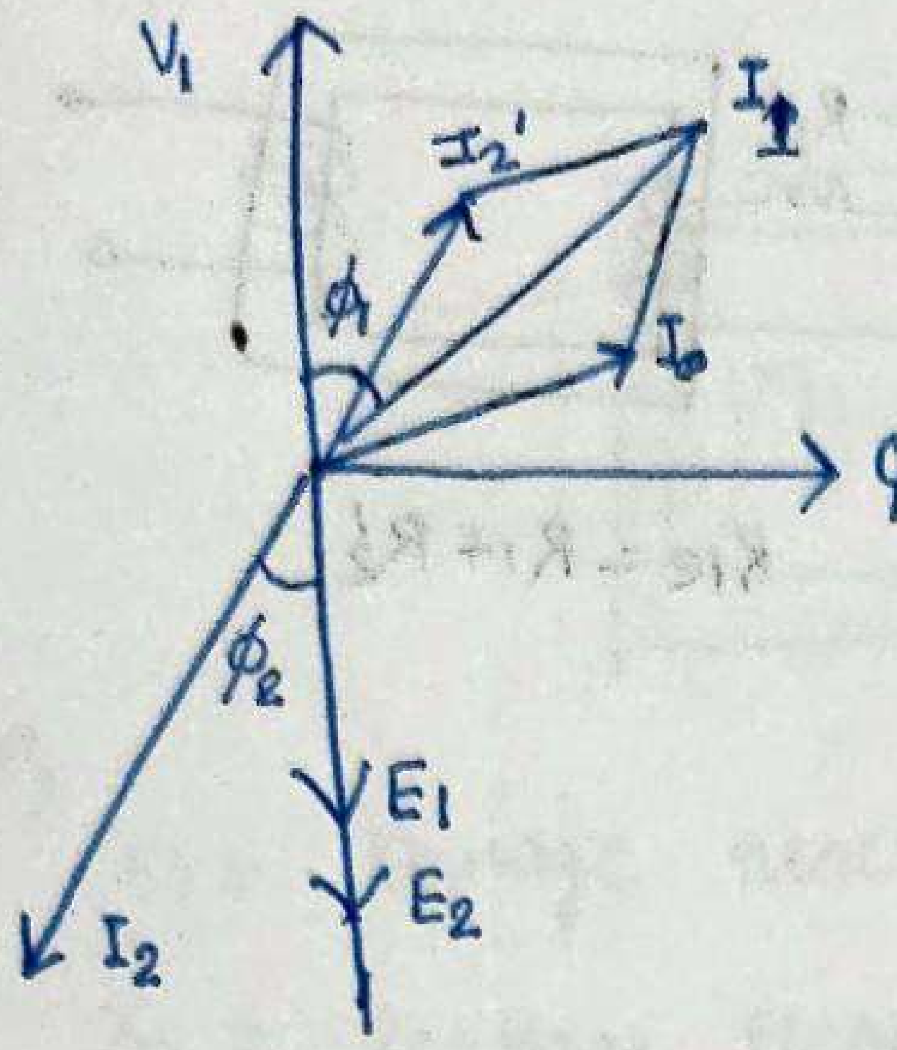
Phasor diagram-

Phasor diagram of T/F under on load condn depends up the load power factor.

- Inductive load → coil
- Resistive load → Resistance
- Conductive load → Conductance plates



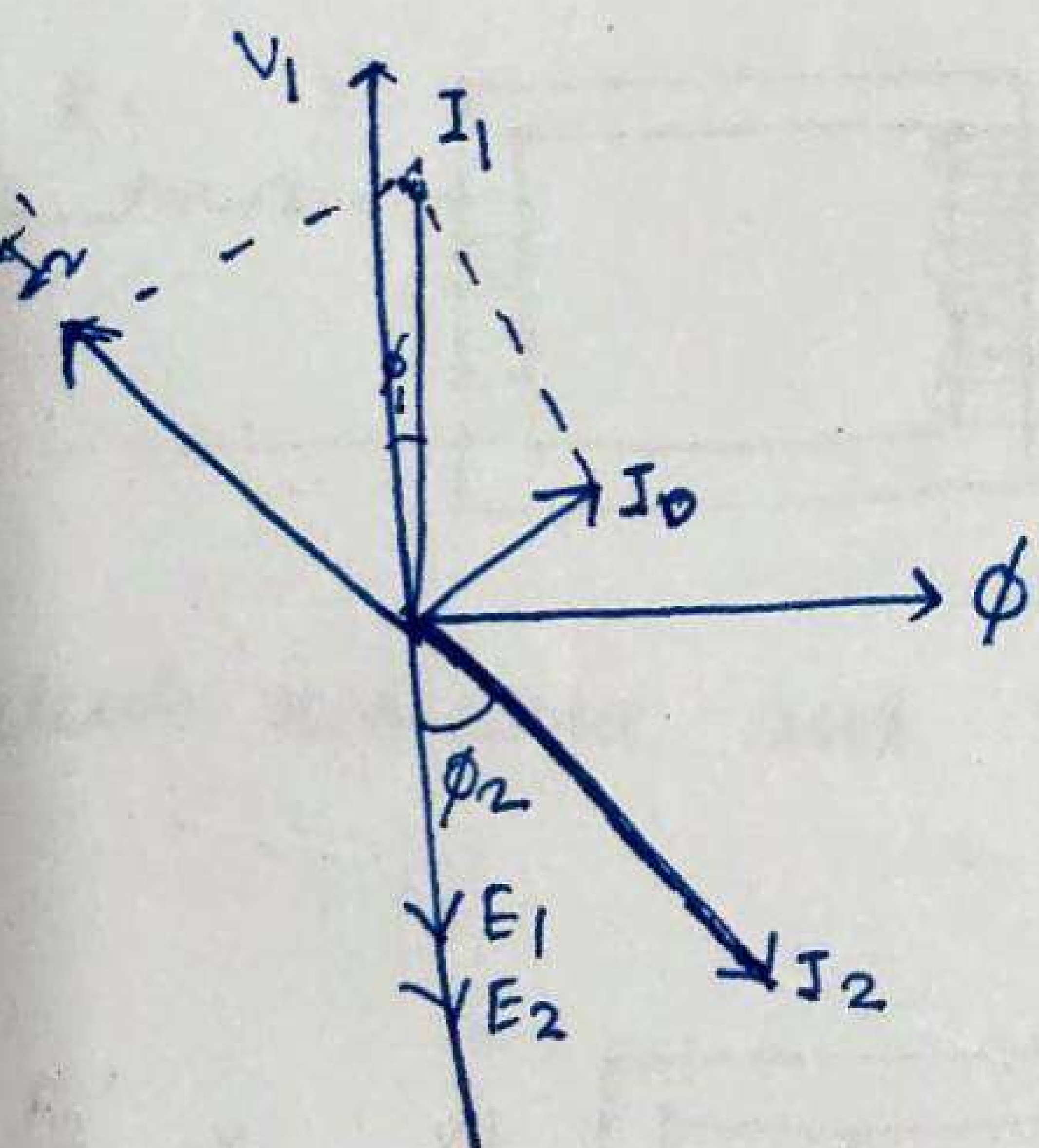
(i) For inductor load-



$\boxed{\vec{I_1} = \bar{I_0} + \bar{I_2}'}$

Note - I_2 will lag V_2 & E_2
$\phi_1 \rightarrow$ pf of primary
$\phi_2 \rightarrow$ pf of secondary

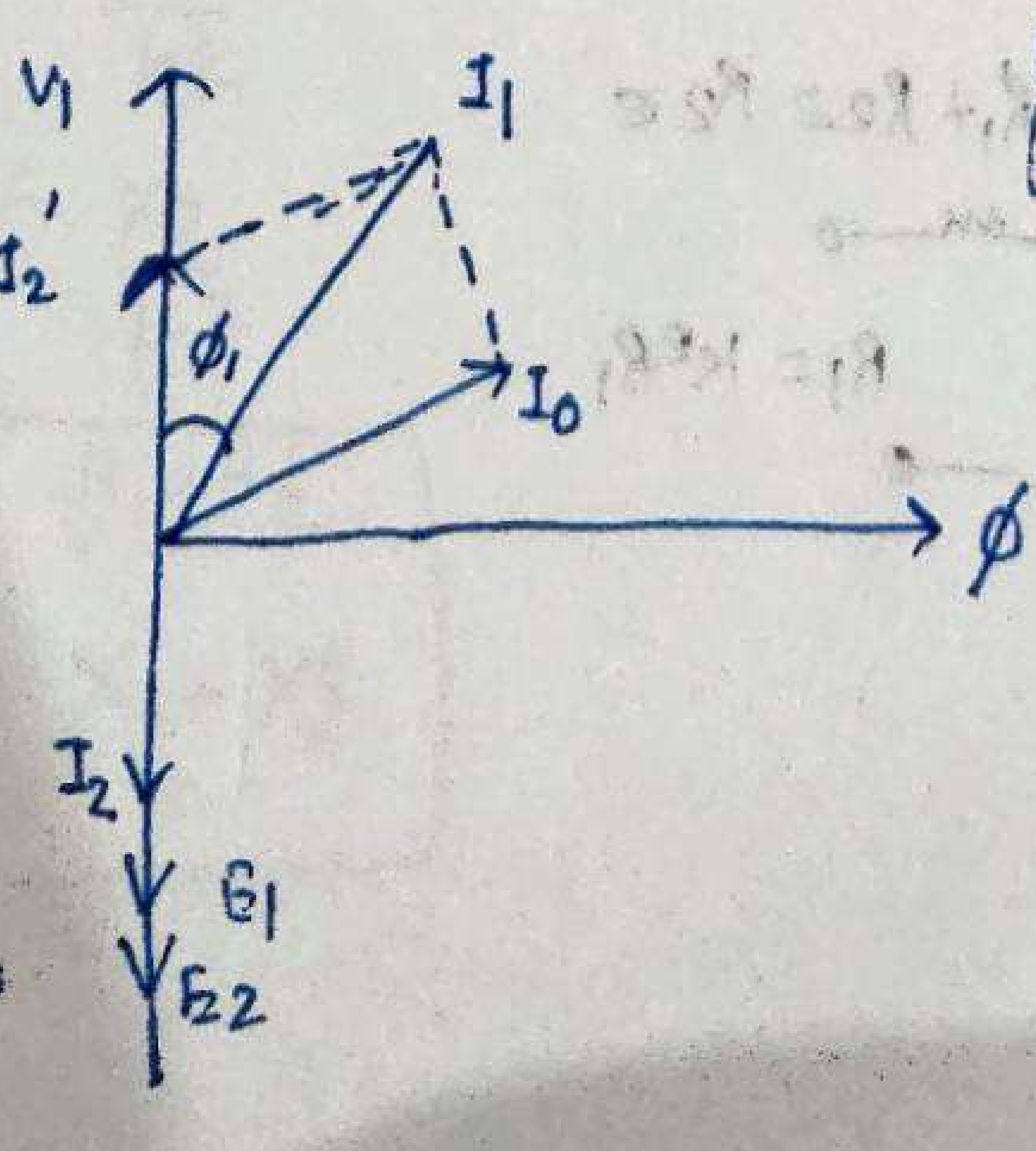
(ii) For capacitive load-



$\boxed{\bar{I_1} = \bar{I_0} + \bar{I_2}'}$

Note - I_2 leads (E_2 & V_2)

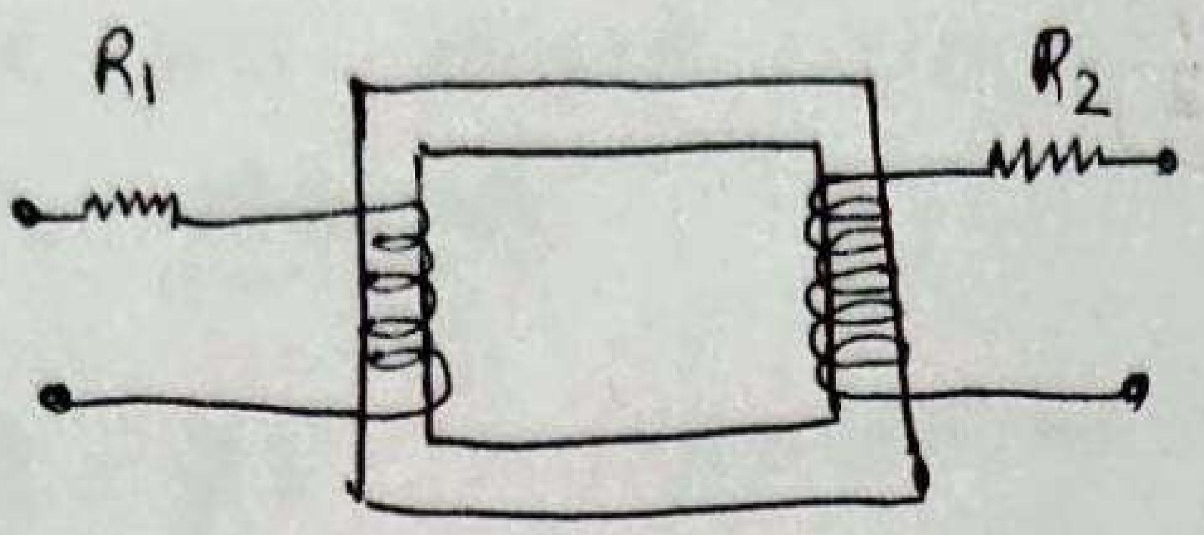
(iii) ~~Wk~~ For resistive load-

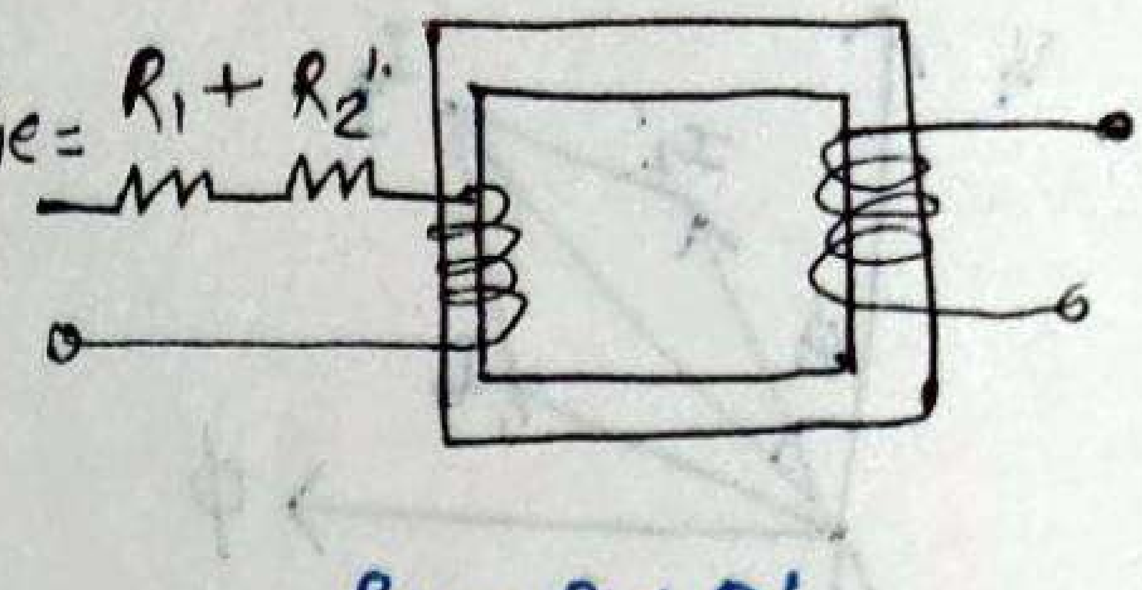


$\boxed{\bar{I_1} = \bar{I_0} + \bar{I_2}'}$

Note- I_2 will be in phase of E_2 & V_2
Here, $\phi_2 = 0$, $\cos 0 = 1 \Rightarrow$ it means secondary pf is unity.

* Equivalent Resistance-





$R_{1e} = R_1 + R_2'$

Let,

R_1 = Primary resistance

R_2 = secondary resistance

R_2' = secondary resistance transferred to primary

$\boxed{R_2' = \frac{R_2}{K_2}}$

Total equivalent resistance of the primary $\boxed{R_{1e} = R_1 + R_2'}$

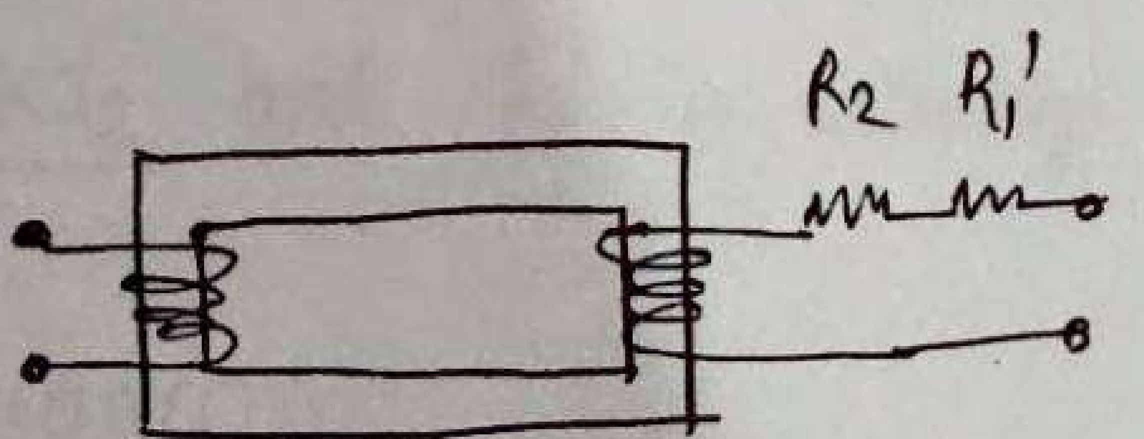
Note -

$$I_1^2 R_2' = I_2^2 R_2$$

$$\frac{I_1^2}{I_2^2} = \frac{R_2}{R_2'}$$

$$K^2 = \frac{R_2}{R_2'}$$

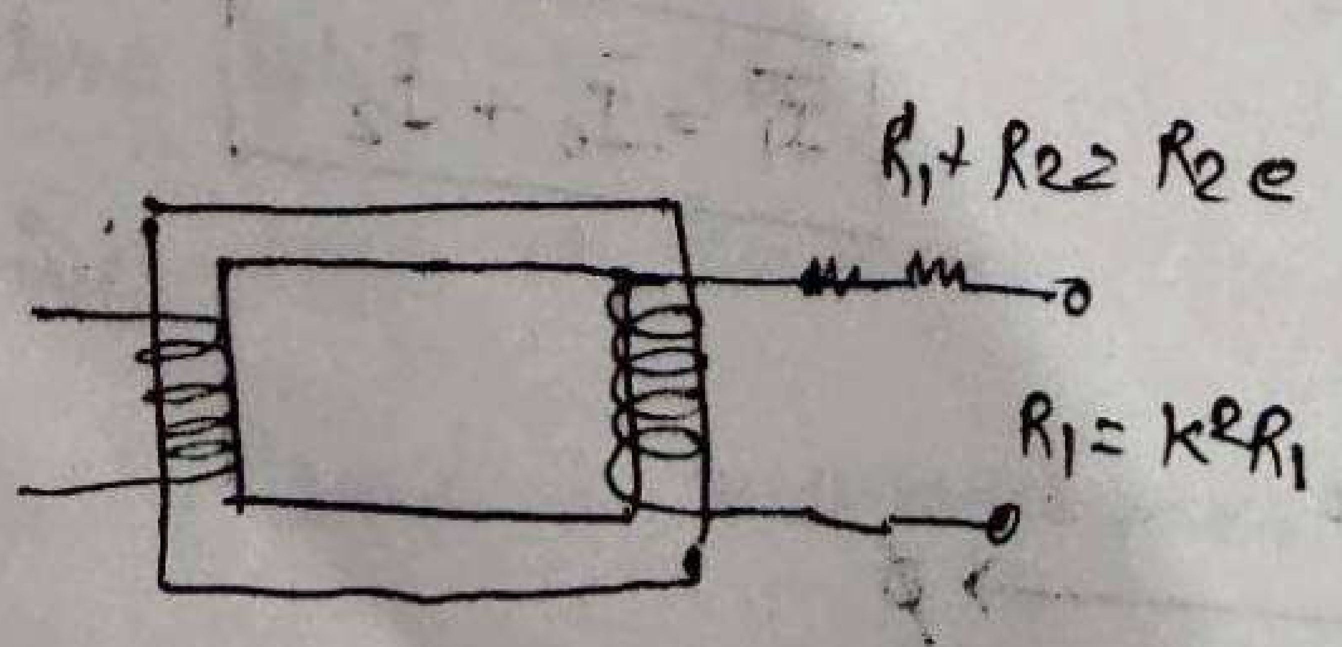
$$\boxed{R_2' = \frac{R_2}{K_2}}$$



Let,

$R_1' = R \cdot k^2$

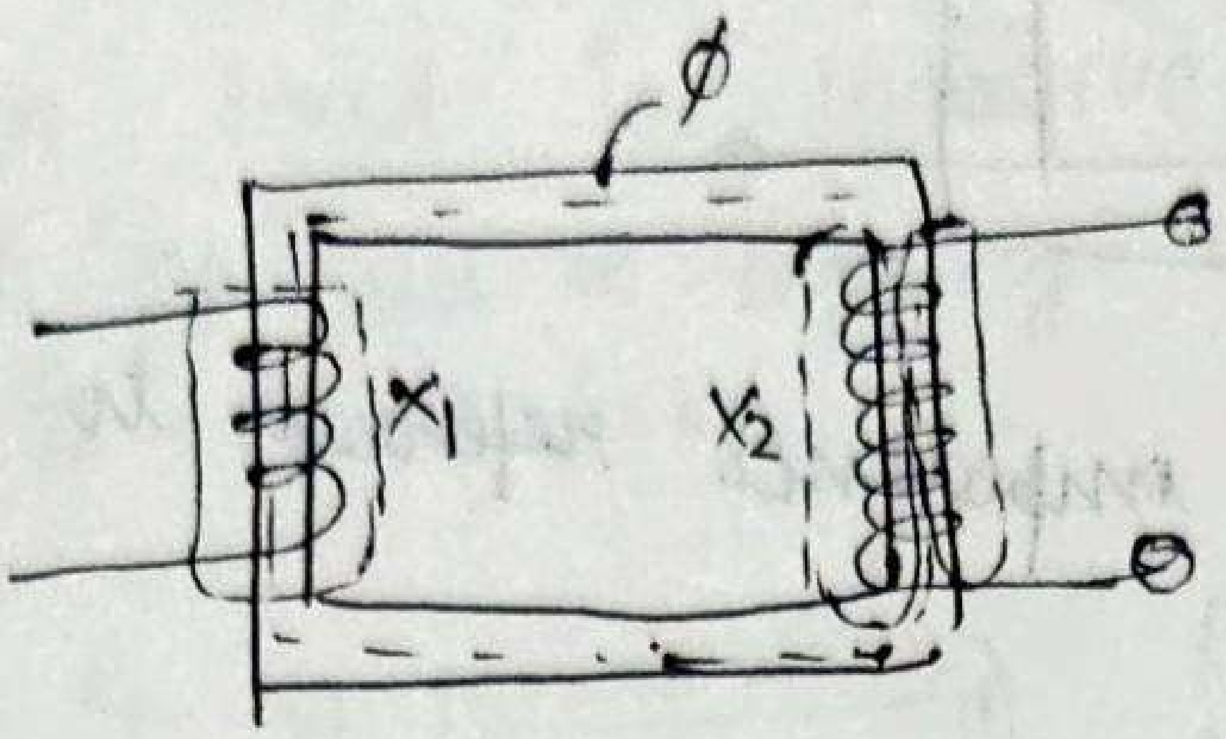
$\boxed{R_{2e} = R_2 + R_1'}$



$R_1' = R_2 = R_{2e}$

$R_1 = k^2 R_1$

* Reactance of Transformer (X) -



Where,

X_1 = leakage reactance of primary

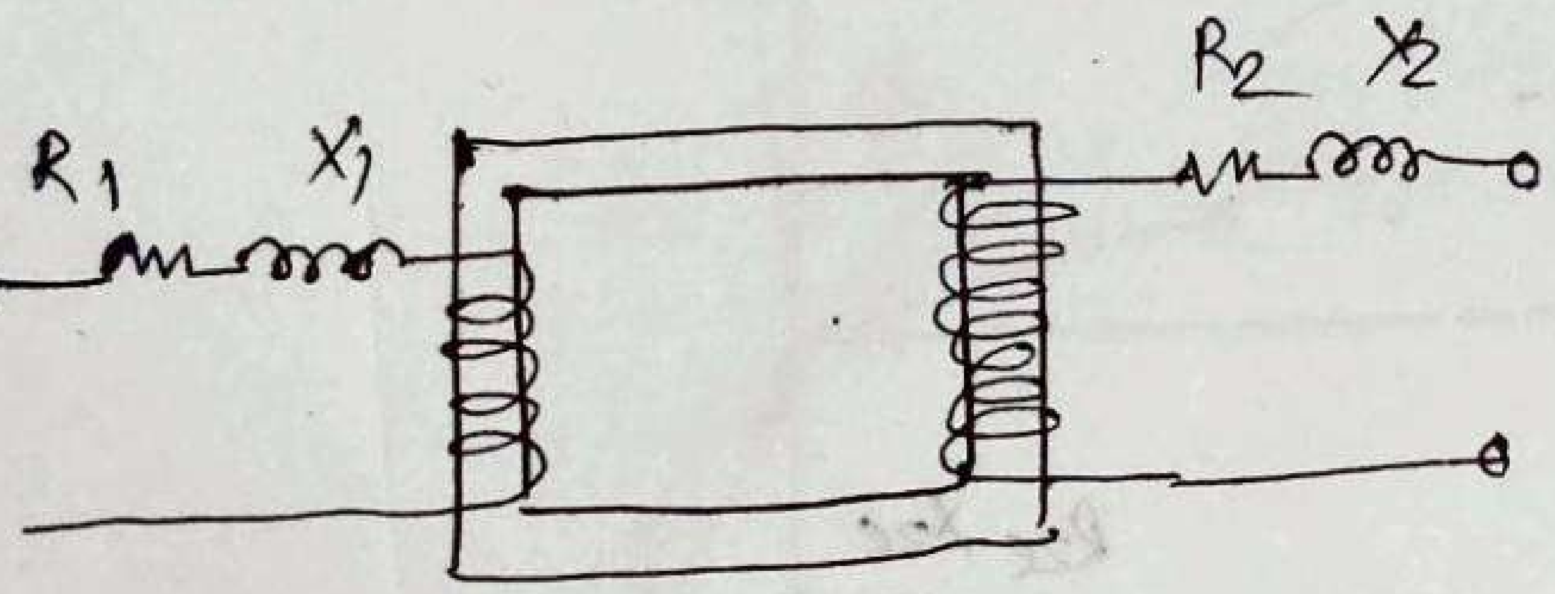
X_2 = leakage reactance of secondary

$X_1 = \omega L_1$

$X_2 = \omega L_2$

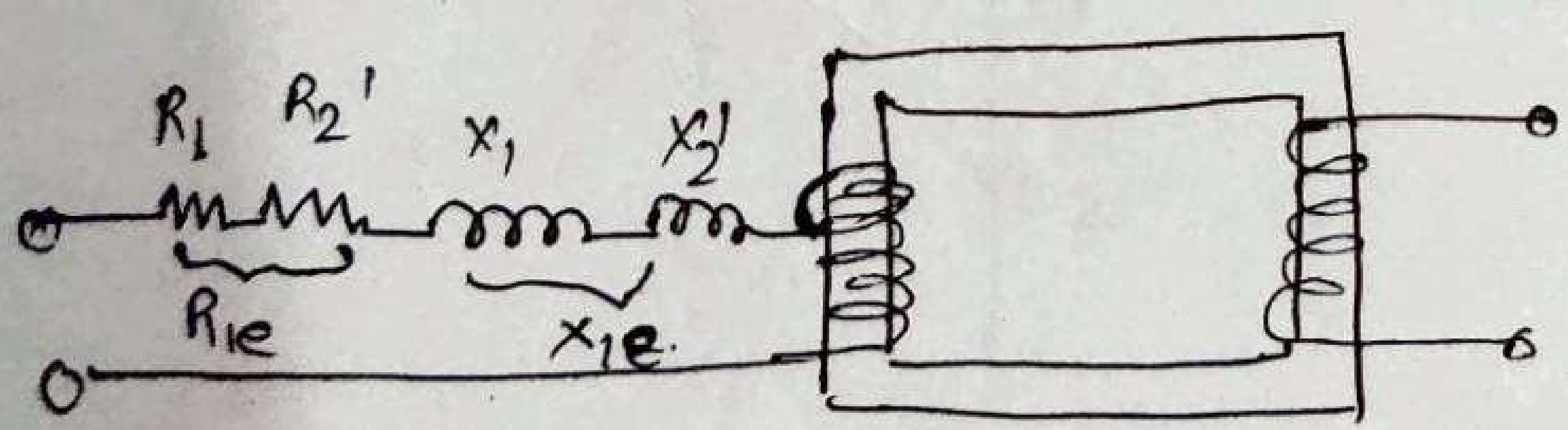
* Equivalent reactance -

(i)



Equivalent reactance and resistance on primary side

(ii)



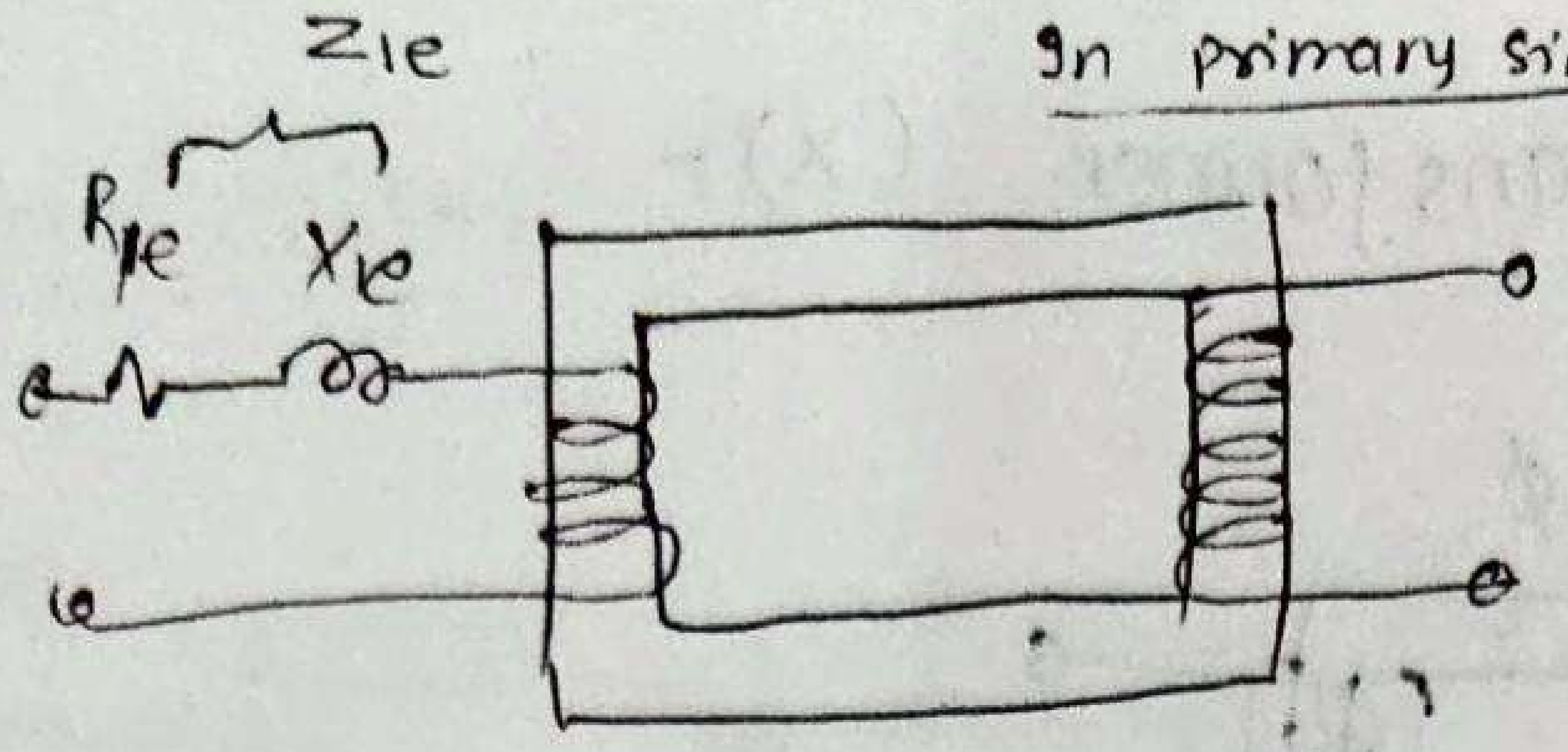
Here-

$$R_2' = \frac{R_2}{K^2}$$

$$X_2' = \frac{X_2}{K^2}$$

$$\boxed{\begin{aligned} R_{1e} &= R_1 + R_2' \\ X_{1e} &= X_1 + X_2' \end{aligned}}$$

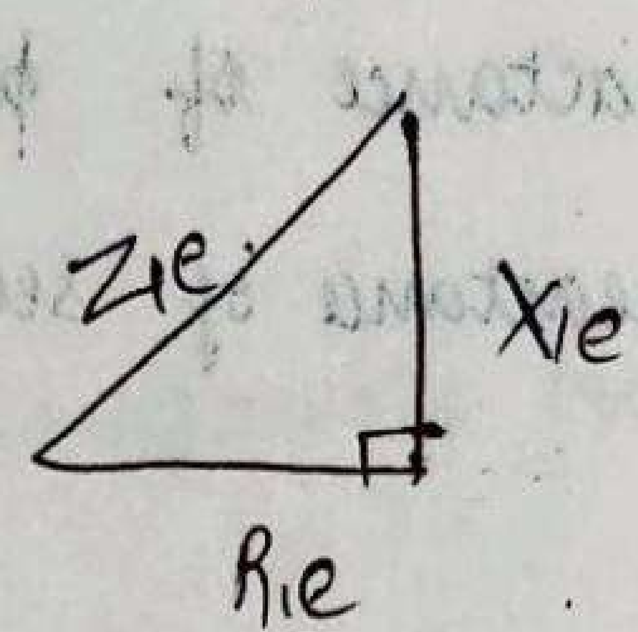
(iii) In primary side -   1 → primary



$Z_{1e} \Rightarrow$ Total equivalent impedance referred to primary

$Z_{1e}^2 = R_{1e}^2 + X_{1e}^2$

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

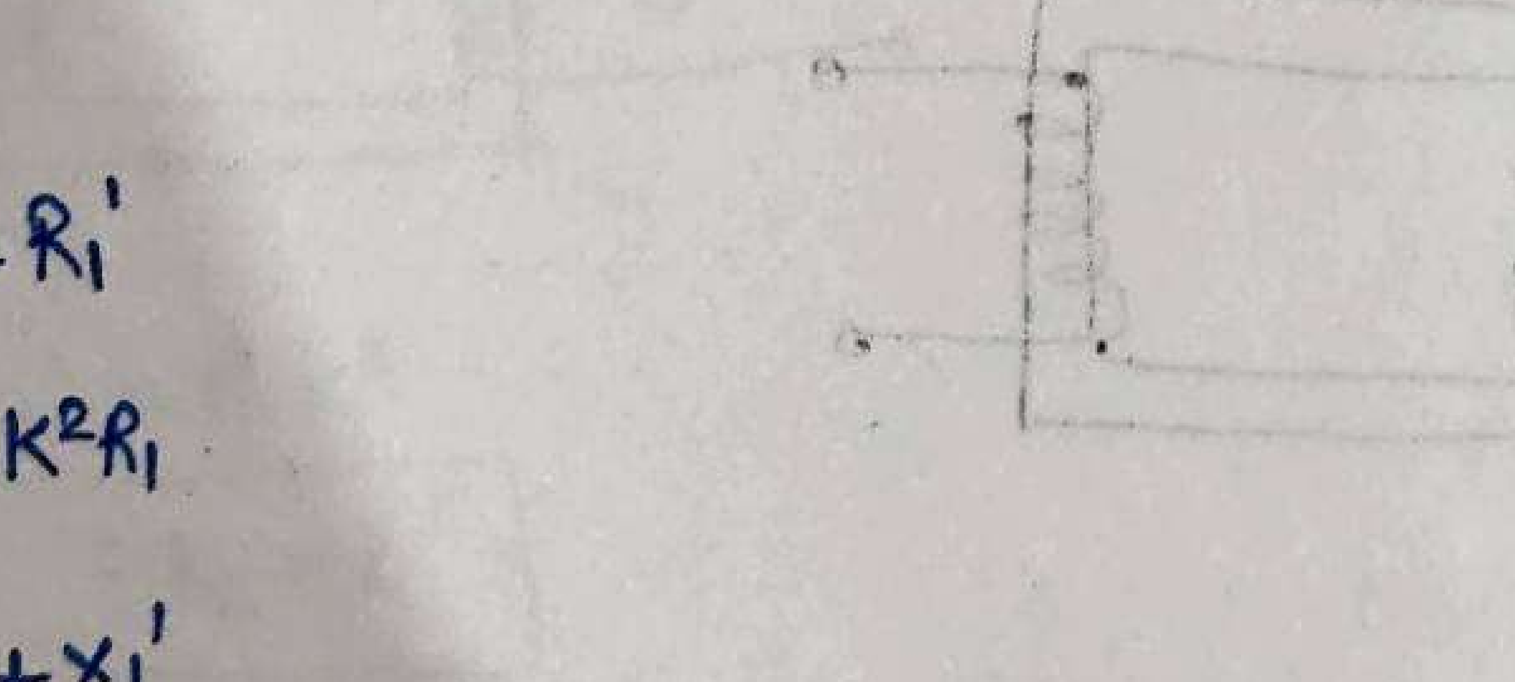


$Z_{1e} = R_{1e} + jX_{1e}$

In phasor form

$\boxed{\bar{Z}_{1e} = \bar{R}_{1e} + j\bar{X}_{1e}}$

(iv) In Secondary side -



$R_{2e} = R_2 + R_1'$

$= R_2 + K^2 R_1$

$X_{2e} = X_2 + X_1'$

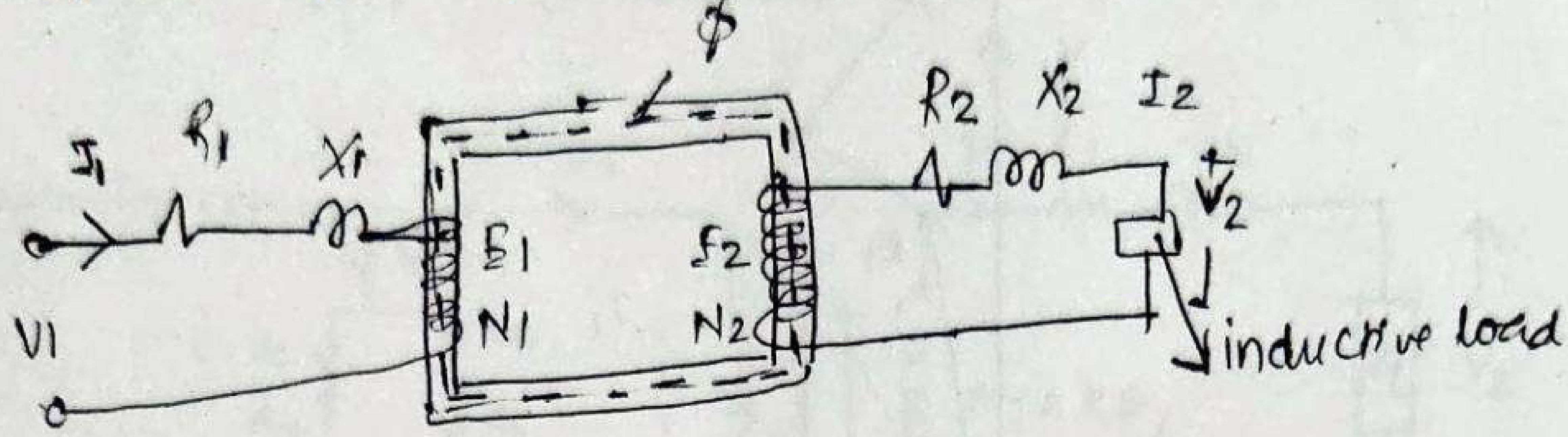
$= X_2 + K^2 X_1$

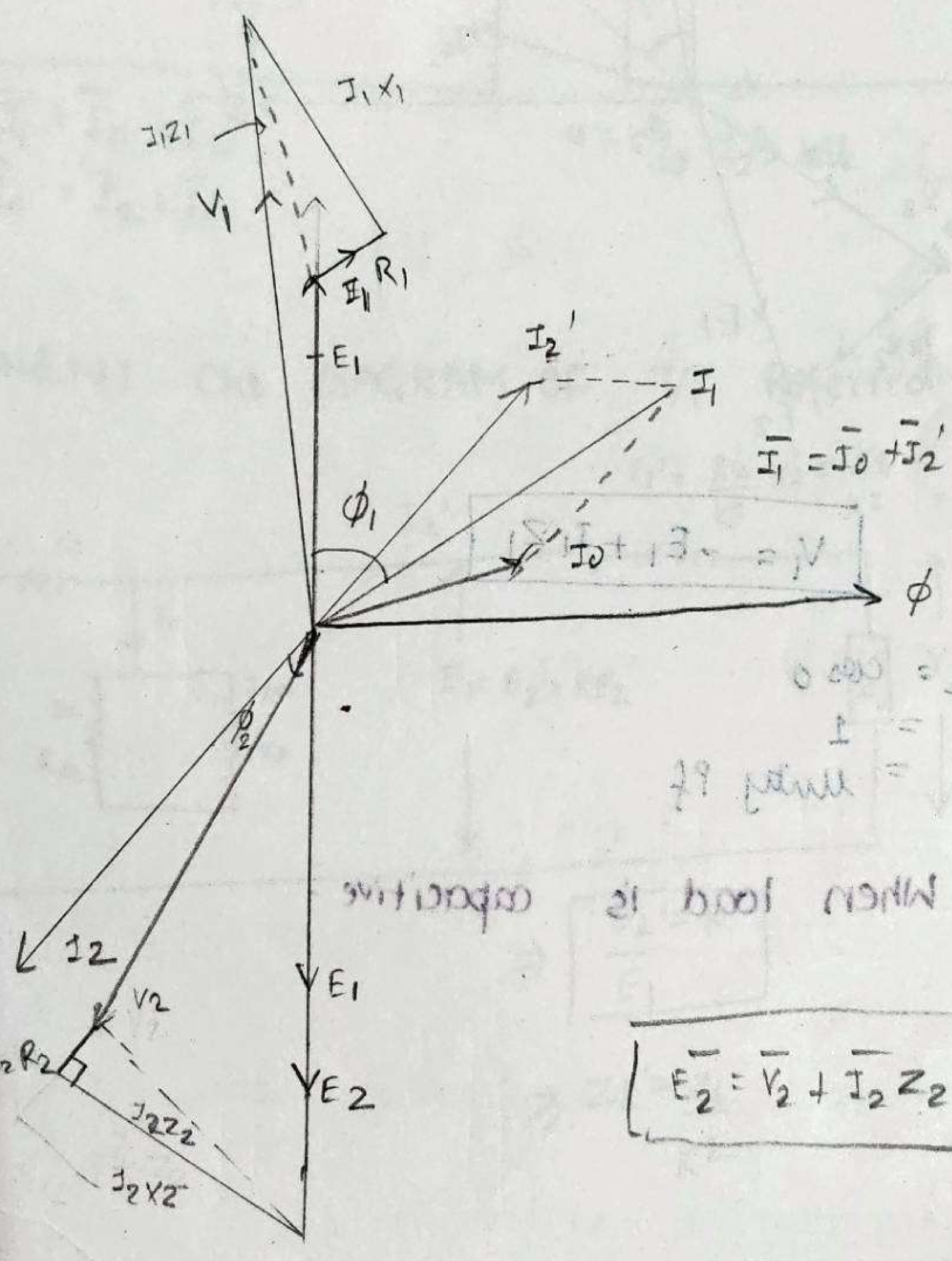
$\boxed{Z_{2e} = \sqrt{R_{2e}^2 + X_{2e}^2}}$

* Phasor diagram of T/F on load -

case(i) When load is inductive-

- Load pf will be lagging i.e. I_2 will lag V_2
- $\bar{I}_1 = \bar{I}_0 + \bar{I}_2' \Rightarrow I_2' = KI_2$





$$\boxed{\bar{E}_2 = \bar{V}_2 + \bar{I}_2 Z_2}$$

$$\bar{V}_1 = -\bar{E}_1 + \bar{I}_1\bar{R}_1 + \bar{I}_1\bar{X}_1$$

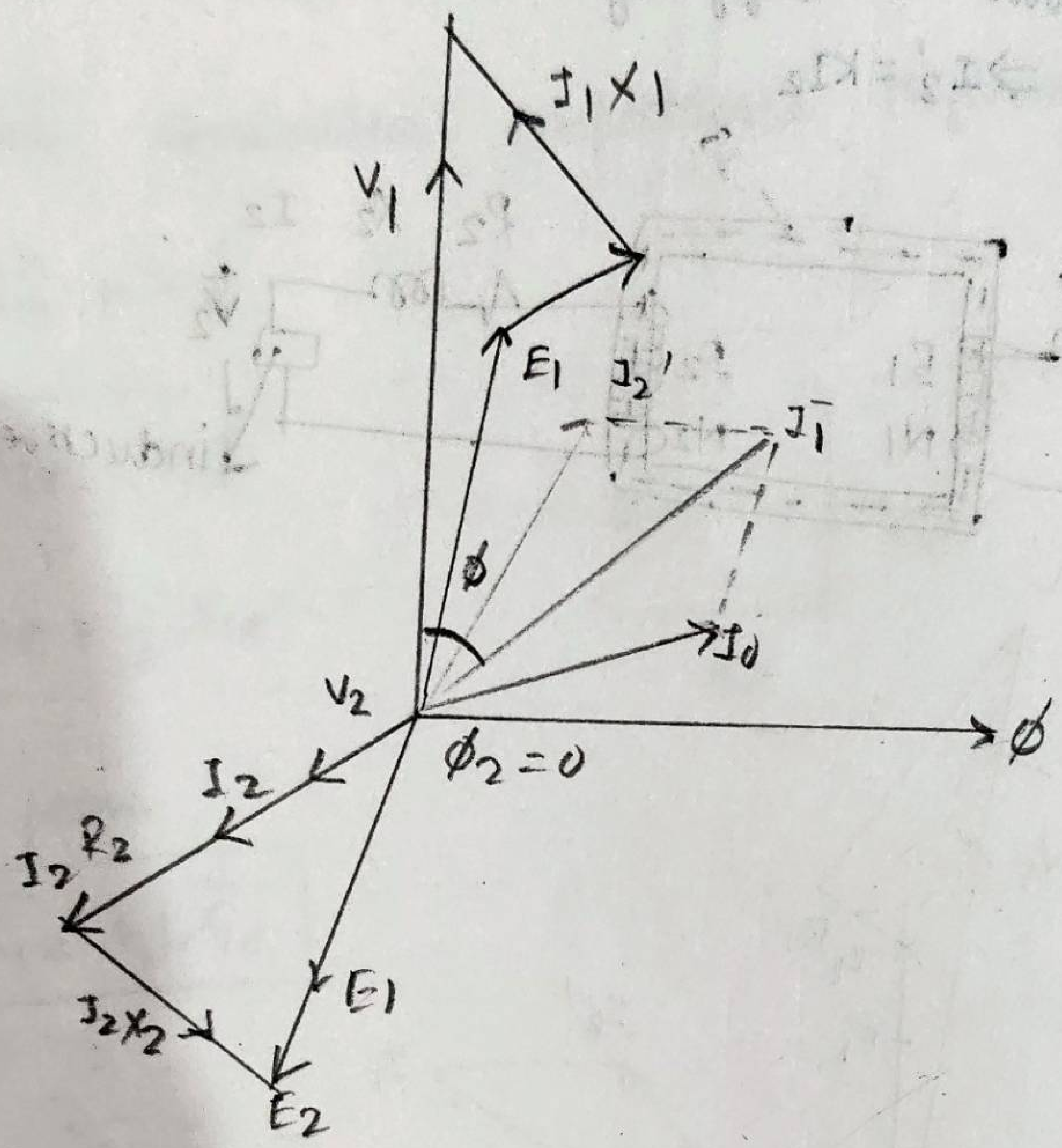
$$V_1 = -E_1 + I_1(R_1 + jX_1)$$

$$\boxed{V_1 = -E_1 + I_1 Z_1}$$

$$\boxed{V_1 - I_1 Z_1 = -E_1}$$

Case (ii) When load is resistive-

Here I_2 & V_2 will be in same phase.



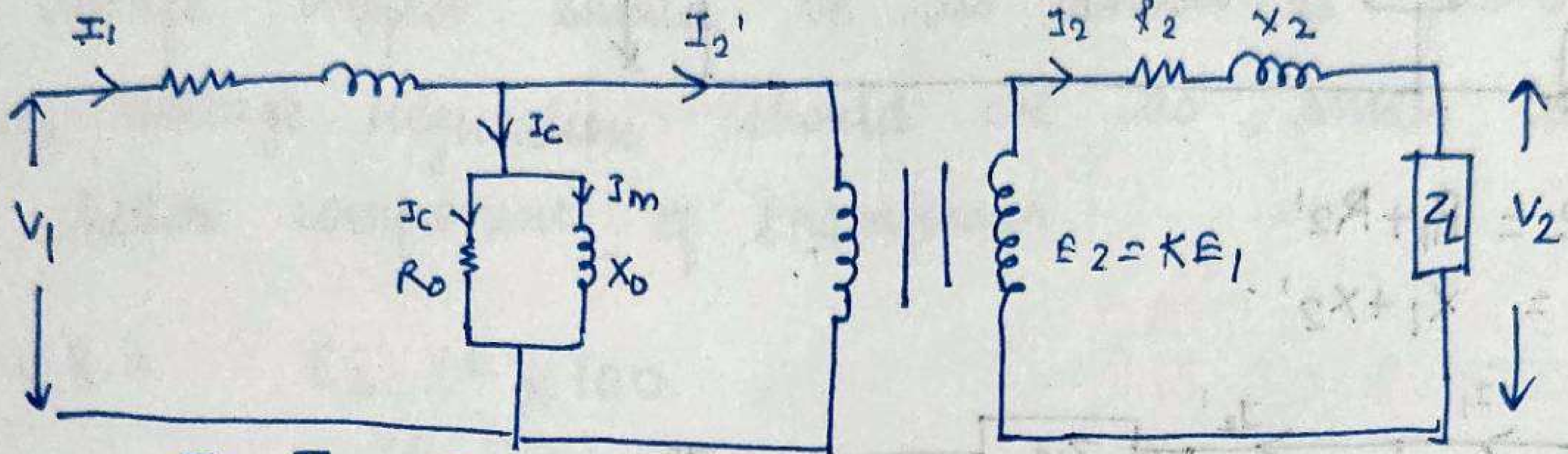
$$\boxed{V_1 = -E_1 + I_1 Z_1}$$

$\cos\phi_2 = \cos 0$

$= 1$

$=$ unity pf

* EQUIVALENT CKT DIAGRAM OF T/F -

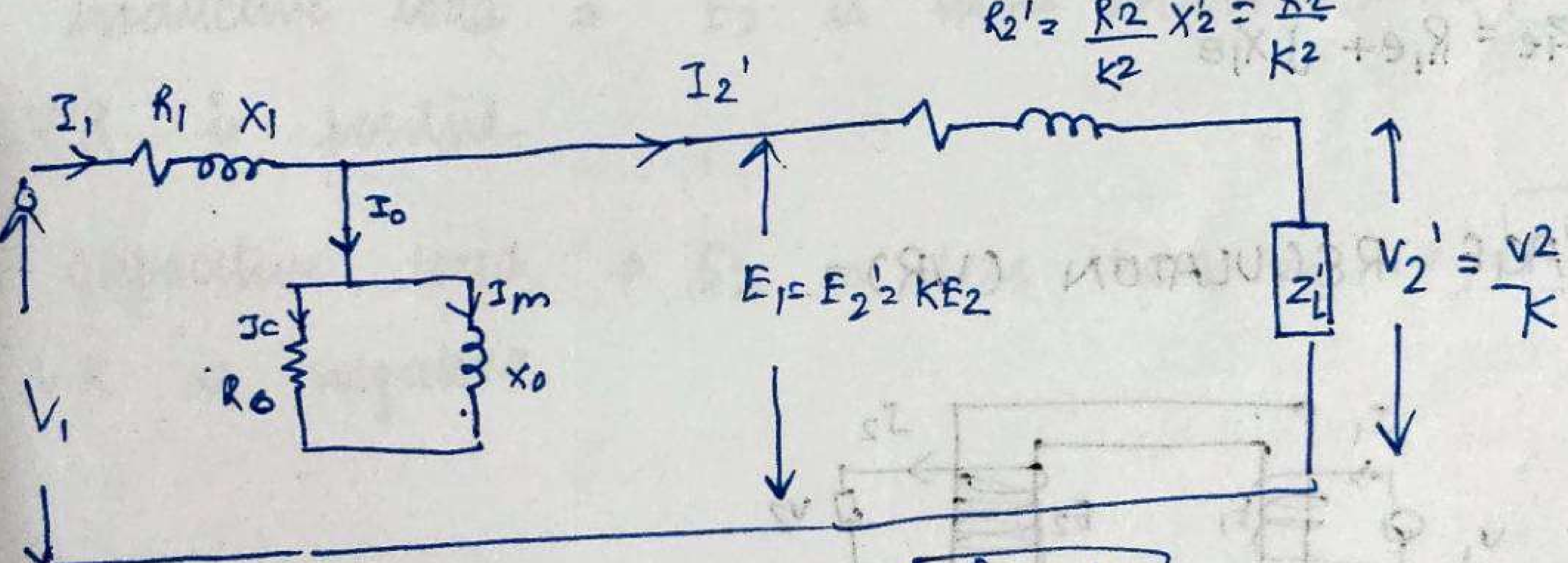


$\Rightarrow \overline{I}_1 = \overline{I}_0 + \overline{I}_2'$

$\vec{I}_0 = \vec{I}_c + \vec{I}_m$

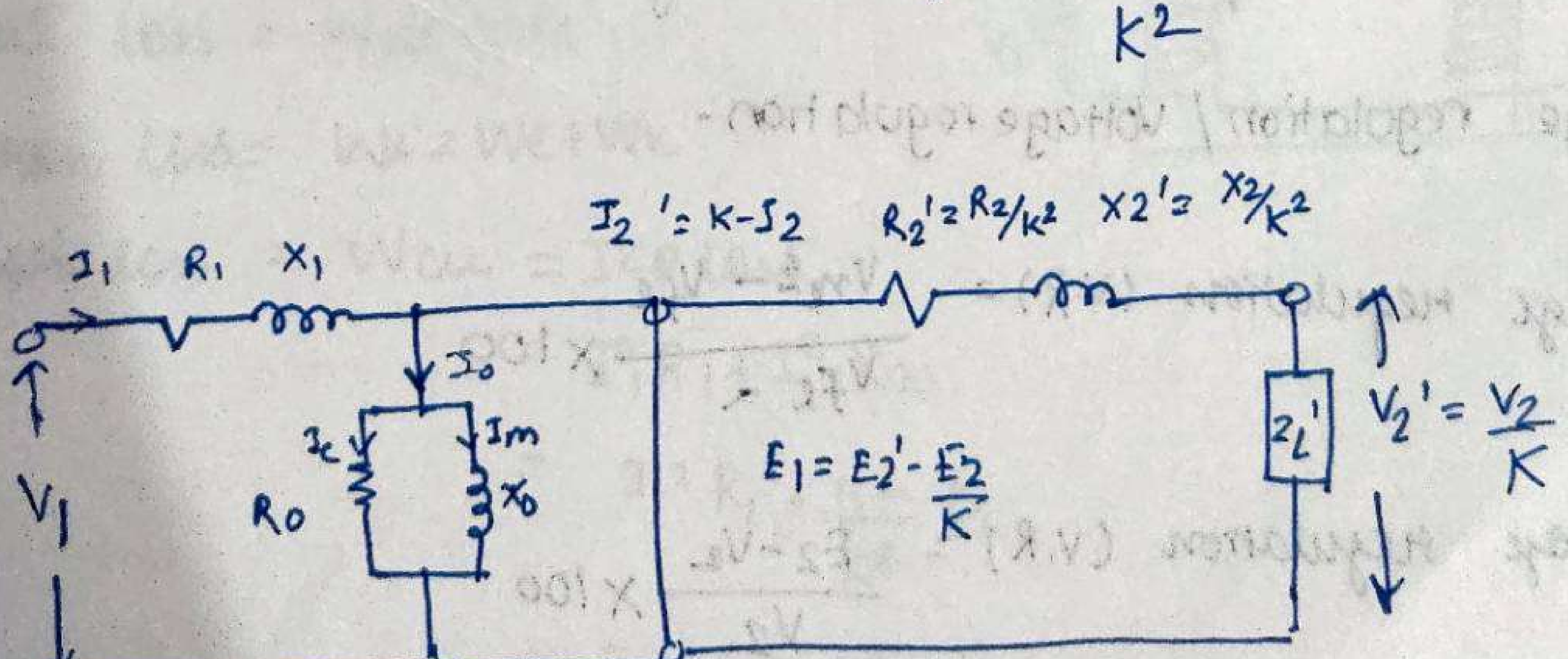
$\Rightarrow I_2' = kI_2$

* EQUIVALENT Ckt DIAGRAM OF T/F Referred Primary side

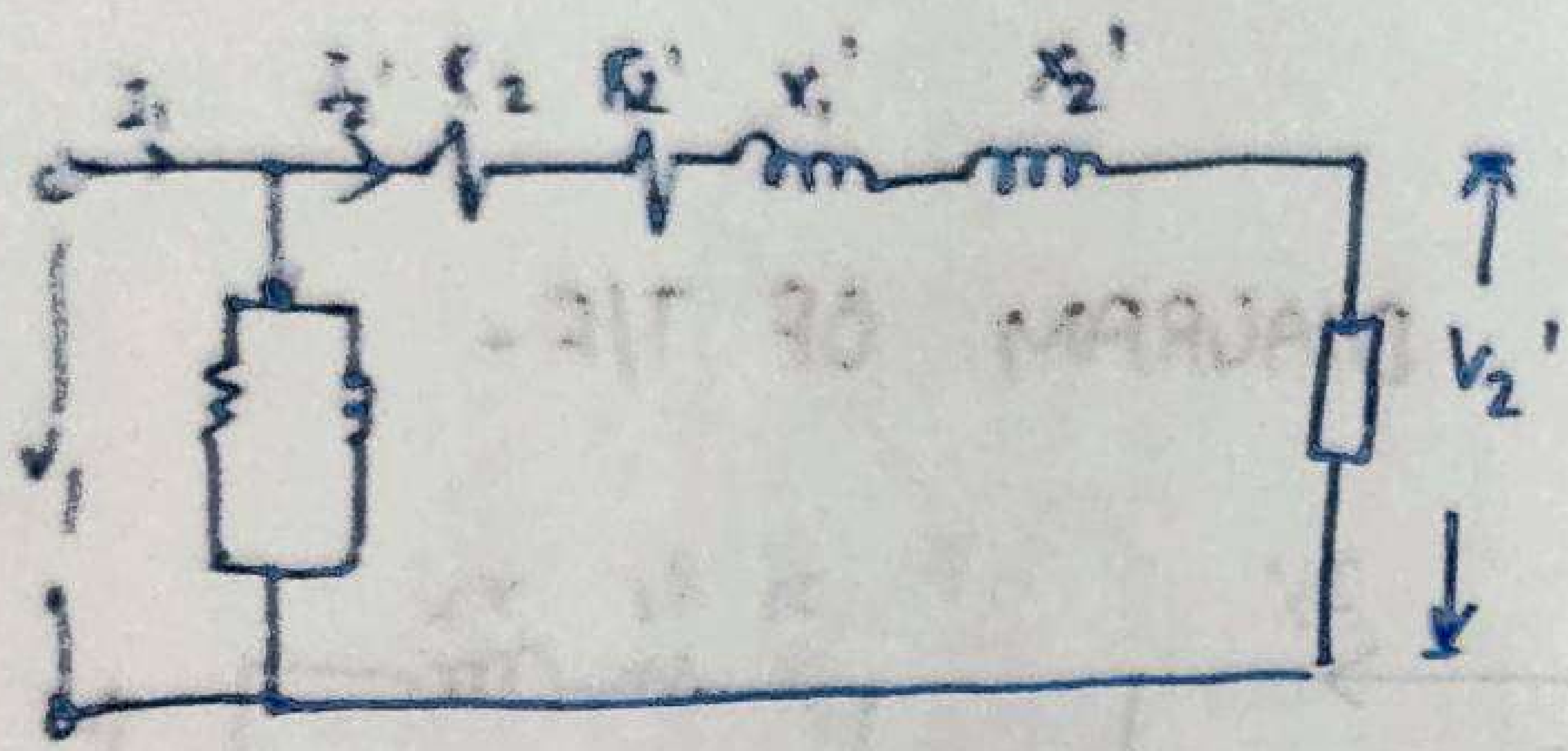


$\Rightarrow \boxed{\frac{E_2}{E_1} = K}$

$\Rightarrow Z_L' = \frac{Z_L}{K^2}$

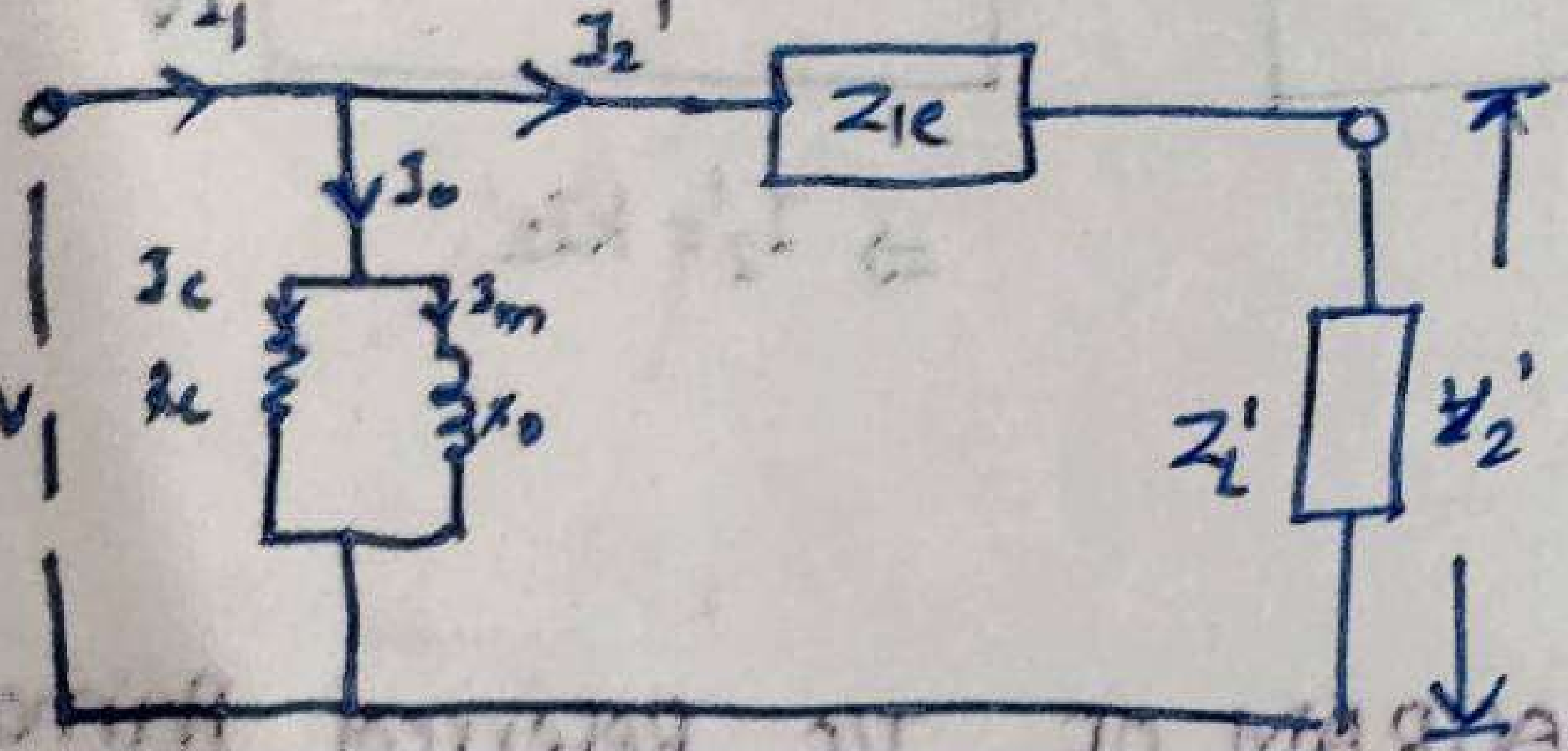


* APPROXIMATE EQUIVALENT CIRCUIT OF T/F -



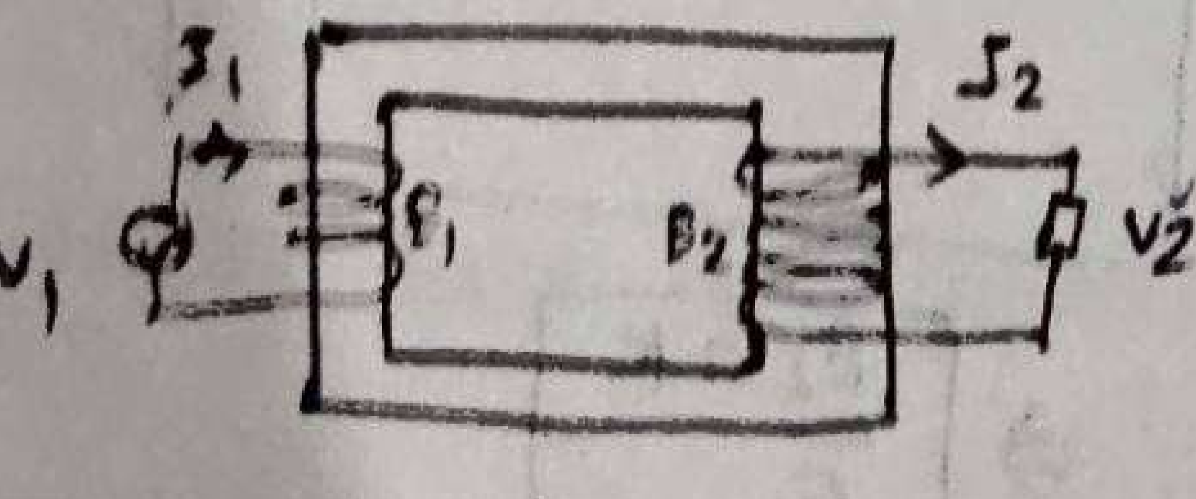
$\Rightarrow R_{1}e = R_1 + R_2'$

$\Rightarrow X_{1}e = X_1 + X_2'$



$\Rightarrow Z_{1e} = R_{1}e + j X_{1}e$

* VOLTAGE REGULATON (VR) -



$\Rightarrow V_2 \neq E_2$

$\Rightarrow V_2 =$ It is full load secondary voltage or rated voltage

→ Percentage regulation / Voltage regulation.

% voltage regulation (V.R) = $\frac{V_{NL} - V_{FL}}{V_{FL}} \times 100$

% voltage regulation (V.R) = $\frac{E_2 - V_2}{V_2} \times 100$

Definition-

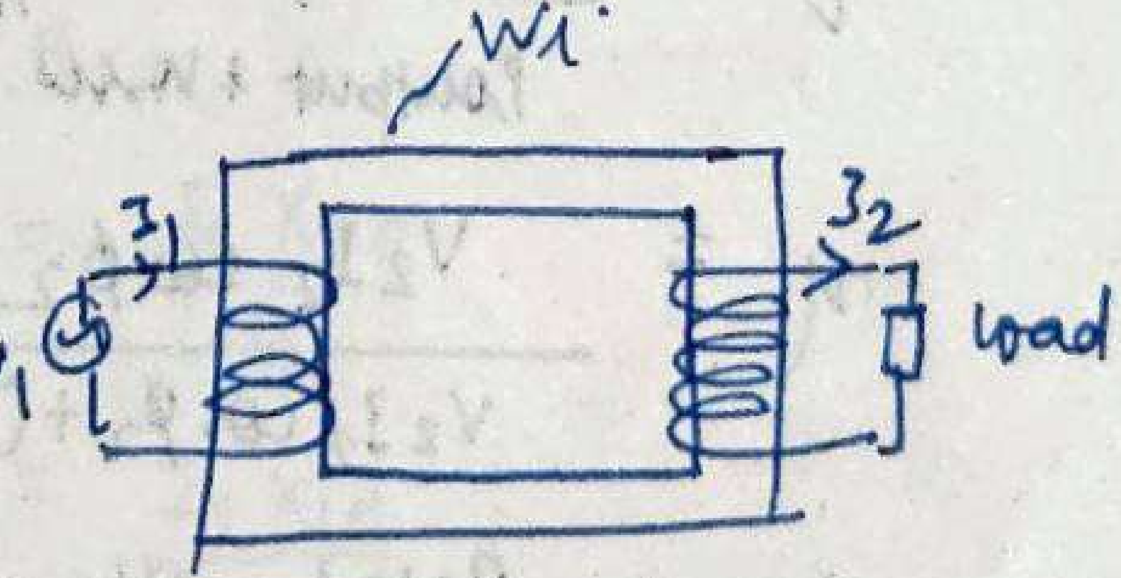
The regulation is the change of when the full load is reduced to no-load.

Note-

- The voltage droped should be as small as possible
- Hence, voltage regulation should be as small as possible for better component of transformer.
- $\% V.R = \frac{E_2 - V_2}{V_2} \times 100$
- $\% V.R = \frac{\text{Voltage drop}}{V_2} \times 100$
- VR also depends upon the pf of load.
- For inductive load ⇒ E_2 is more than V_2 i.e, $\boxed{E_2 > V_2}$
- $\% V.R$ is positive
- For capacitive load → E_2 is less than V_2 i.e, $\boxed{E_2 < V_2}$
  $\% VR$ is negative

Pg no-22 works continue here-

*LOSSES IN T/F



Total loss = $W_{cu} + W_i$

Iron loss = $W_i = W_e + W_h$

copper loss = $W_{cu} = I^2R$ loss

$= I_1^2 R_1 + I_2^2 R_2$

$= I_1^2 R_1 + \frac{I_1^2}{K^2} R_2$

$\frac{E_2}{E_1} = \frac{I_1}{I_2} = K$

$I_1 = K I_2$

$I_2 = \frac{I_1}{K}$

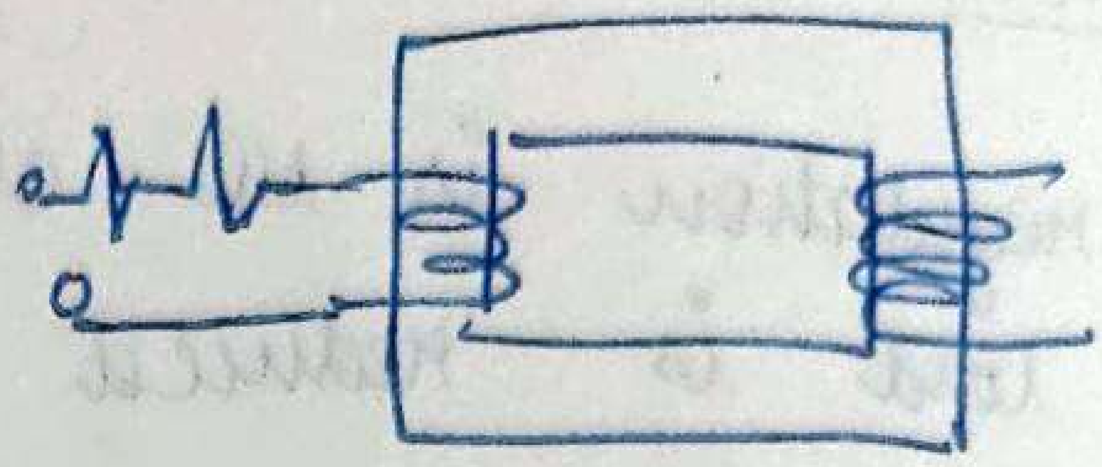
$W_{cu} = I_1^2 \left(R_1 + \frac{R_2}{K^2}\right)$

$= I_1^2 \cdot (R_1 + R_2')$

$\therefore R_2' = \frac{R_2}{K^2}$

similarly we can write

$$\boxed{W_{cu} = I_1^2 \cdot R_{1e}}$$

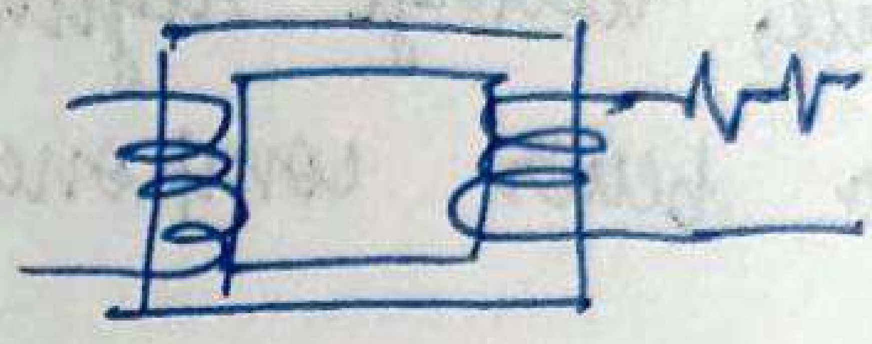


$$\therefore R_{1e} = R_1 + R_2'$$

$$W_{cu} = I_2^2 R_{2e}$$

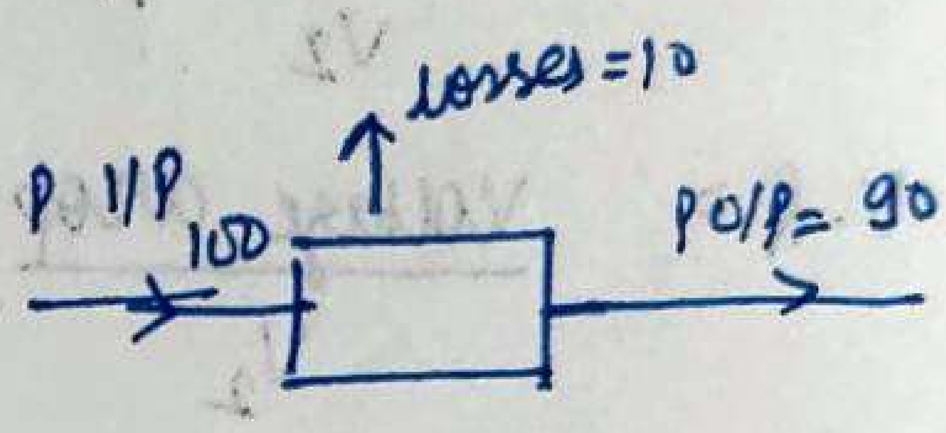
$$\boxed{R_{2e} = R_2 + R_1'}$$

$$\boxed{R_1' = k^2 R_1}$$



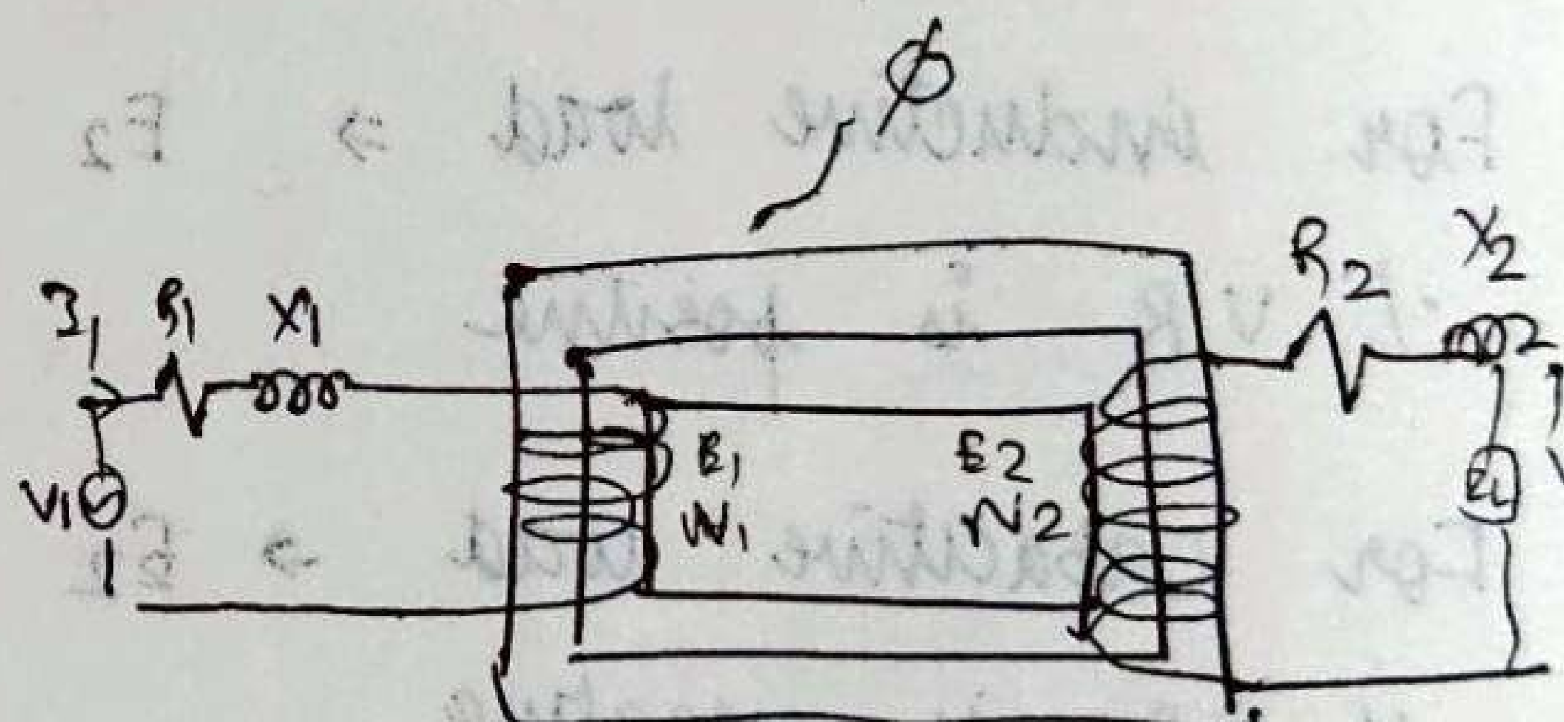
* EFFICIEENCY OF T/F -

$$\eta = \frac{\text{O/P Power}}{\text{I/P Power}} \times 100$$



$$= \frac{P_{O/P}}{P_{I/P}} \times 100$$

$$= \frac{P_{O/P}}{P_{O/P} + \text{losses}} \times 100$$



$\Rightarrow P_{O/P} = V_2 I_2 \cos\phi_2$

$W_{cu} = I_2^2 R_{2e}$

$W_i = W_e + W_h$

Total loss $= W_{cu} + W_i$

$$\eta = \frac{P_{output}}{P_{output} + \text{losses}} \times 100 =$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + (W_i + W_{cu})} \times 100$$

V_2 = Rated voltage = V

I_2 = Rated current = I

$\cos\phi_2$ = load P.f = $\cos\phi_2$

$$\eta = \frac{VI\cos\phi}{VI\cos\phi + W_i + W_{cu}} \times 100$$

We know that load $\propto I^2$, so, efficiency of diff load (or fractional load) will be diff

Let, $x = \frac{\text{actual load}}{\text{full load}}$, $\Rightarrow \boxed{\eta_x = \frac{x(VI\cos\phi)}{x(VI\cos\phi) + W_i + x^2 W_{cu}}}$ $\therefore W_{cu} \propto I^2$

x is fractiong load

efficiency of fraction of load -

Formula-

Voltage drop = $I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi$

$R_{2e} = k^2 R_1' + R_2$

$R_{2e} = k^2 R_1 + R_2$

$X_{2e} = X_1' + X_2$

$= k^2 X_1 + X_2$

- Take (+) sign of load lagging
- Take -ve sign if load is leading

$\% VR = \frac{\text{Voltage drop}}{V_2} \times 100$

$= \frac{I_2 R_{2e} \cos\phi \pm I_2 X_{2e} \sin\phi}{V_2} \times 100$

$\% VR = \frac{I_1 R_{1e} \cos\phi \pm I_1 X_{1e} \sin\phi}{V_1} \times 100$

* Constants of transformers-

(1) Per unit resistance drop $= V_R \Rightarrow \frac{I_2 R_{2e}}{E_2}$

$\Rightarrow \frac{I_1 R_{1e}}{E_1}$

(2) Per unit reactance drop $= V_X = \frac{I_2 X_{2e}}{E_2}$

$= \frac{I_1 X_{1e}}{E_1}$

* LOSSES IN T/F-

(1) Iron loss – core loss – W_i $\Rightarrow$ $\boxed{W_i = W_e + W_h}$

W_e → eddy current loss.

W_h → hysterisis loss

$\rightarrow W_e \propto B_m^2 f^2$

$\boxed{B_m \propto \phi_m}$

$\rightarrow \boxed{W_e \propto \phi_m^2 f^2}$

$W_e = \eta B_m^2 f^2$ (volume)

$\Rightarrow \eta$ const.

$B_m \Rightarrow$ max flux density.

$B_m = \frac{\phi_m}{A}$ Wb/m²

high load → low resistance
$\therefore P \propto \frac{1}{R}$ (22)
Less load → more resistance.
$R \propto \frac{1}{I}$ & $P \propto I$
More watt → more load → low R.

→ $V \propto \phi m f$

→ $W_h = \eta B_m^{1.6} f$ (volume)

$\boxed{\rightarrow W_h = B_m^{1.6} f}$

→ So eddy current loss depends upon → $\boxed{W_e \propto B_m^2 f^2}$
→ & hysteresis loss depend upon → $\boxed{W_h \propto B_m^{1.6} f}$

For practical purpose -

* $W_e \propto B_m^2 f^2$
* $W_h \propto B_m^2 f$ } (approx)

(2) Copper loss - variable loss

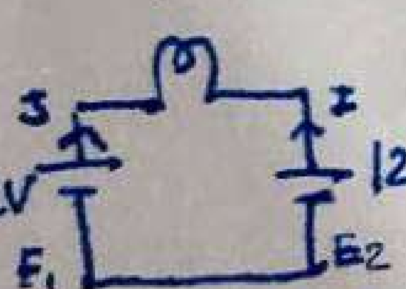
$W_{cu} = I^2 R$

$W_{cu} \propto I^2$

$W_{cu} \propto (\text{current})^2$ ($\because I \propto$ load)

Note-
⟹

1 unit = 1 KWh = 1 unit of electricity



here bulb doesn't glow
$I = \frac{E_1 - E_2}{R} = \frac{0}{R} = 0.$

KVA sinϕ = KVAR
Q

KW = KVA cosϕ
= P

Iron loss doesn't depend upon load
that why it's also called fix load
or constant loss.
cu loss is variable loss.
earth voltage=0
high to low V flow

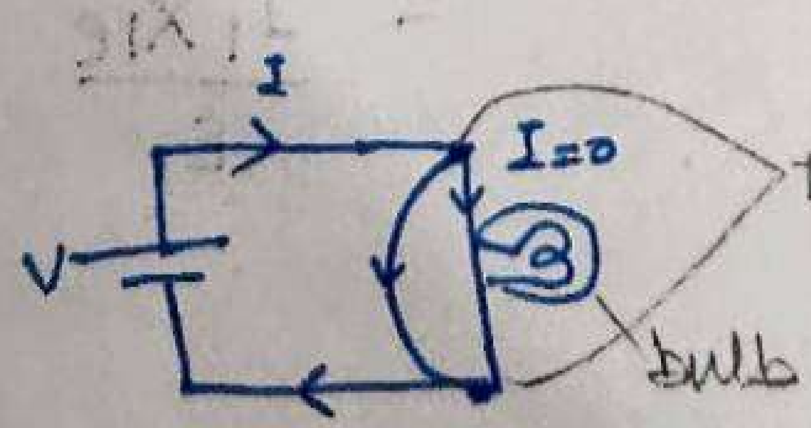
$\boxed{S^2 = P^2 + Q^2.}$

$P = \frac{W}{t} \Rightarrow W = P \times t$
work is energy
So, $E = P \times t$
$= kW \times h$

disadvantage → SC & OC.

Short ckt -

Suppose -



These 2 terminal attached to itself

Current - high to low

No resistance $\therefore I \propto \frac{1}{R} = I \propto \frac{1}{0} = I = \infty$

ie, when no resistance is present, current is more & heat is more
that's why SC is happen & sometimes fire is also occured

Open ckt - When ckt is open then no current will flow
$R \propto \frac{1}{I}$ $\therefore R \propto \frac{1}{0} = R = \infty$

in air ∞ Resistance.

* Maximum efficiency of T/F -

$$\eta_x = \frac{x(VA\cos\phi)}{x(VA\cos\phi) + W_i + x^2 W_{cu}}$$

divide above eqn by x, then we get -

$$\eta_x = \frac{VA\cos\phi}{VA\cos\phi + \frac{W_i}{x} + x.W_{cu}}$$

→ For η_x to be max, the denominator must be minimum.

→ For min and max value $\frac{d}{dx}\left(VA\cos\phi + \frac{W_i}{x} + x W_{cu}\right) = 0$.

$$\Rightarrow \frac{d}{dx}\left\{(VA\cos\phi) + \frac{W_i}{x} + x W_{cu}\right) = 0$$

$$\Rightarrow \frac{d}{dx}(VA\cos\phi) + \frac{d}{dx}\left(\frac{W_i}{x}\right) + \frac{d}{dx}(x W_{cu}) = 0$$

$$\Rightarrow 0 + (-x^{-2}.W_i) + 1.W_{cu} = 0$$

$$\Rightarrow -\frac{1}{x^2} W_i = -W_{cu}$$

$\boxed{W_i = x^2 . W_{cu}}$ → variable or Cu loss.

↓ Iron loss or constant loss

for fractional load -

$\therefore$ $\boxed{\text{constant loss} = x^2 \text{ (variable loss)}}$

→ for full load, $x = 1$ then $\boxed{W_i = W_{cu}}$

* ALL DAY EFFICIENCY OF T/F -

- The ratio of the total energy O/P to the total energy I/P is called all day efficiency of transformer.

$$\% \text{ All day } \eta = \frac{\text{O/P energy in KWh per day}}{\text{I/P energy in kWh per day}} \times 100$$

$\boxed{1 \text{ unit} = 1 \text{ KWh.}}$

- Distribution T/F are used for distributive & commercial loads The loads on T/F varies considerably during a day.

- For most period of day the load of T/F is 30-40% of full load or even less than this.
- But primary wdg remains energised at it's rated time for 24 hrs to provide continous supply to consumer.
- The core loss depends upon voltage takes place continously for all loads but cu loss depend upon loads.
- Henced, power efficiency can't give its true measure for a distribution T/F.
- Therefore, energy O/P is calculated in KWh. and various losses are calculated in KWh.

* TESTING OF TRANSFORMER-

(i) direct test on T/F
(ii) indirect test on T/F
  - No load test (open ckt test) → For iron loss (Wi) Calculation
  - Short ckt test → for copper loss (Wcu) calculations.

(iii) polarity test
(iv) Back to back test → sumpner's test

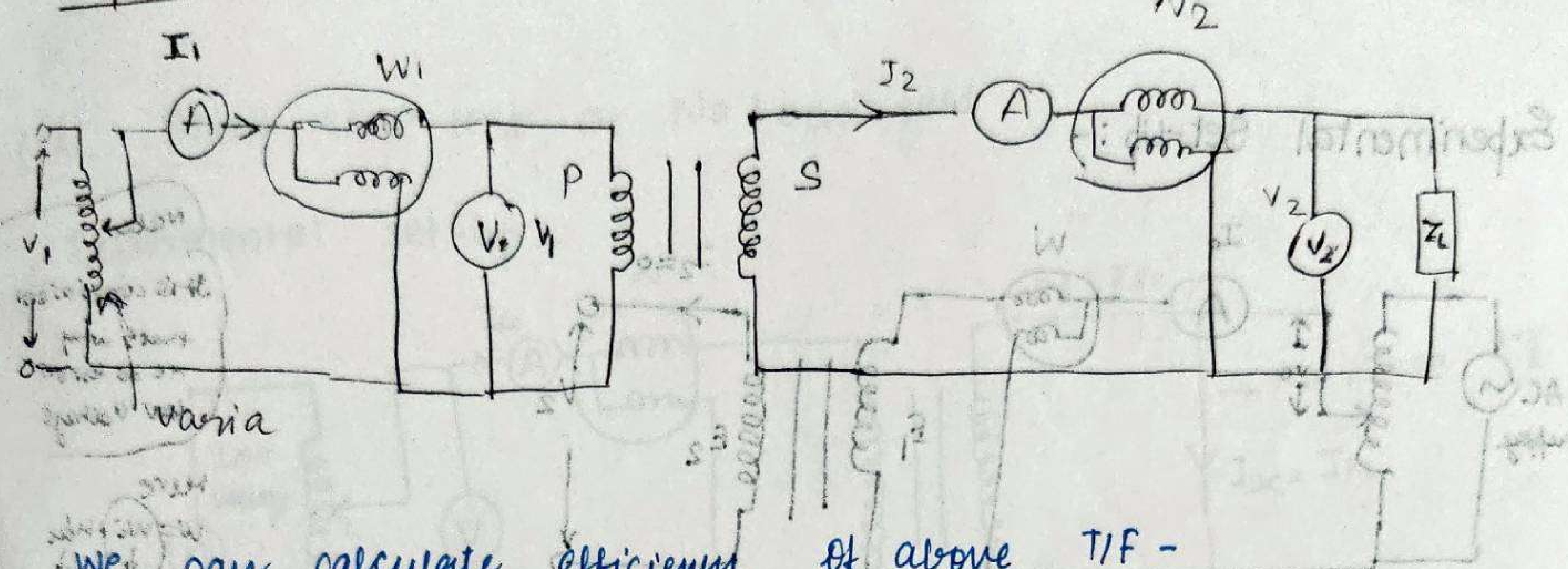
- DIRECT TEST ON T/F / LOAD TEST-

→ In this method load is directly connected to the T/F. A load is varying from no load to full load

→ This test is suitable for small transformers becoz large loads can't be

→ In this test, there is large no. of power loss

Experimental Set-up -



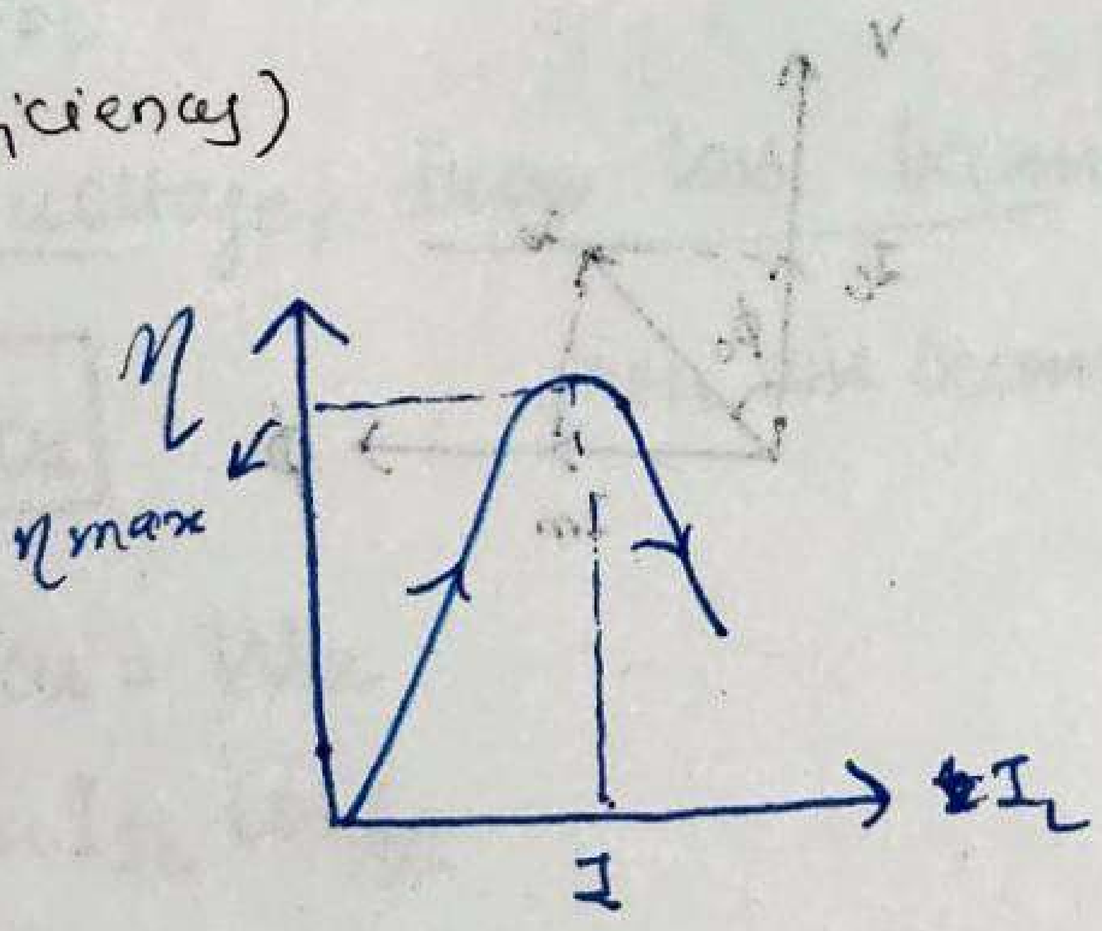
We can calculate efficiency of above T/F -

$$\% \eta = \frac{O/P \text{ Power}}{I/P \text{ Power}} \times 100$$

$$= \frac{W2}{W_1} \times 100 \quad \text{(From fig).}$$

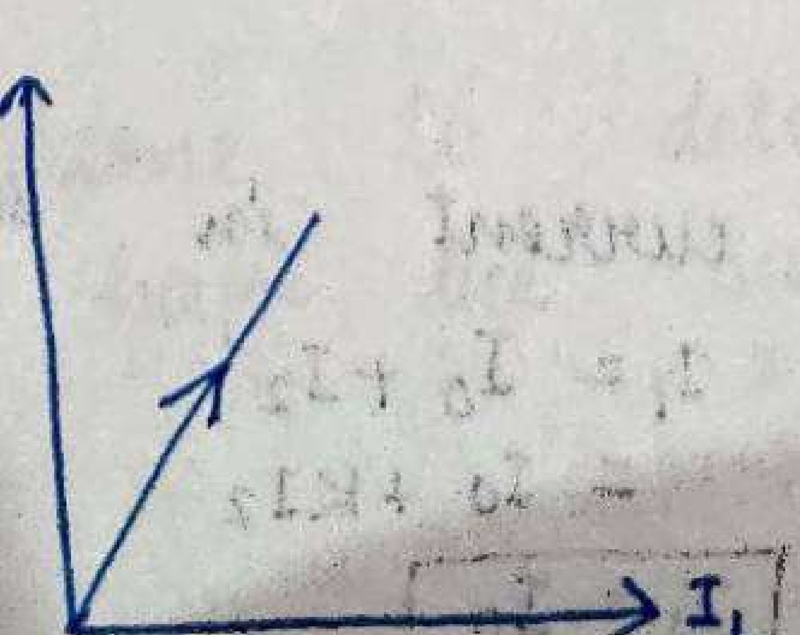
Voltage regulation $= \% VR \Rightarrow \frac{E_2 - V_2}{V2} \times 100$

Graph - (efficiency)



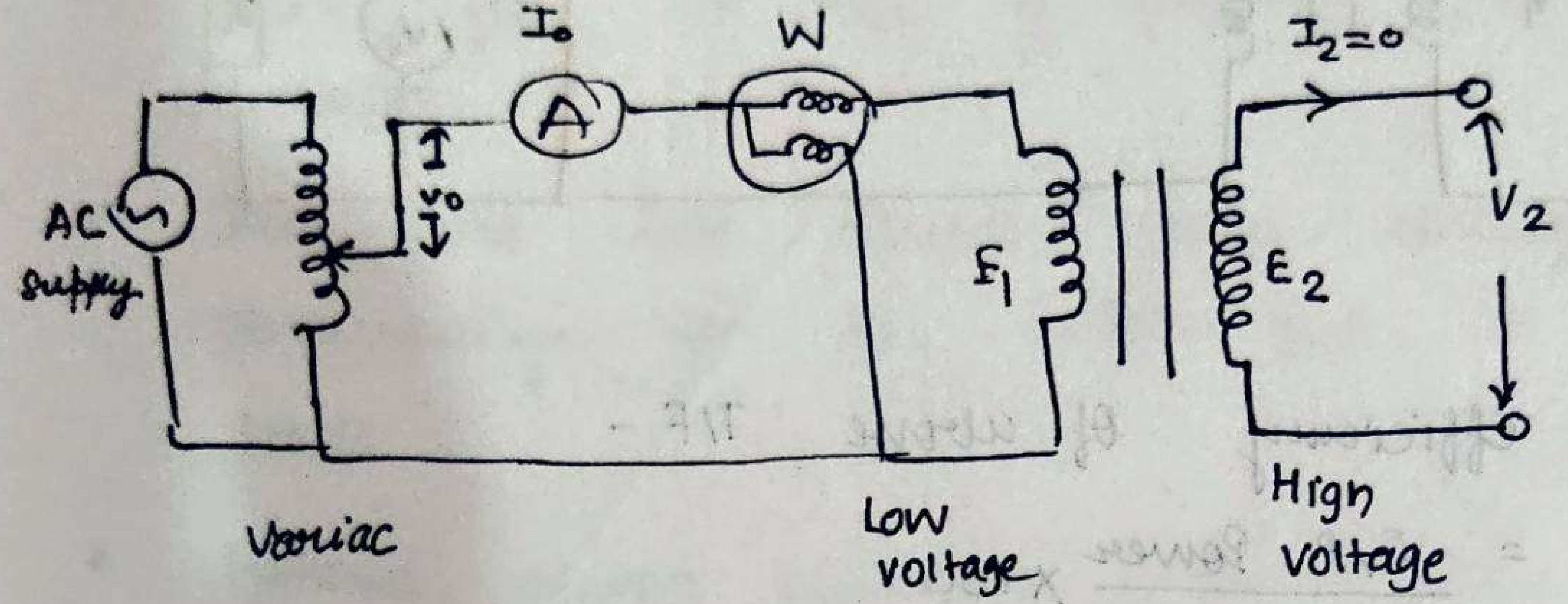
- With ↑ in load efficiency also ↑. At a certain load when, $W_{cu} = W_i$ efficiency becomes maximum & thereafter again it's starts decreasing
- Regulation or V.R also increases as load ↑.

Graph - (VR)



• INDIRECT TEST ON T/F - (i) OPEN CKT or No load Test-

Experimental Set-Up :-



Note
This is convinient that's why we do test on low voltage
Here
$W = W_i + W_{cu}$
Test
I^2R
0

V_0 = rated voltage at no load

W_0 = I/P power

I_0 = I/P current at no load (3% to 5% of rated current)

$\bar{I_0} = \bar{I_c} + \bar{I_m}$

$I_0 = \sqrt{I_c^2 + I_m^2}$

$I_c = I_0 \cos\phi_0$

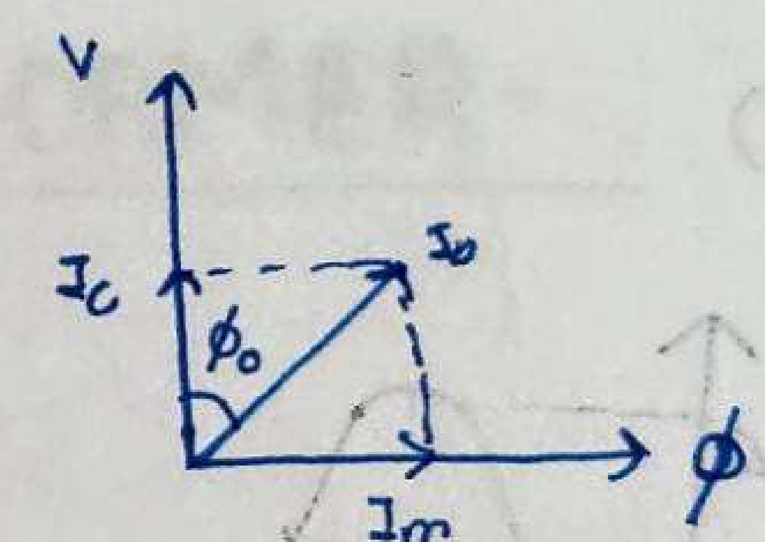
$I_m = I_0 \sin\phi_0$

$\cos\phi_0$ = no-load p.f

$W_0 = V_0 I_0 \cos\phi_0$

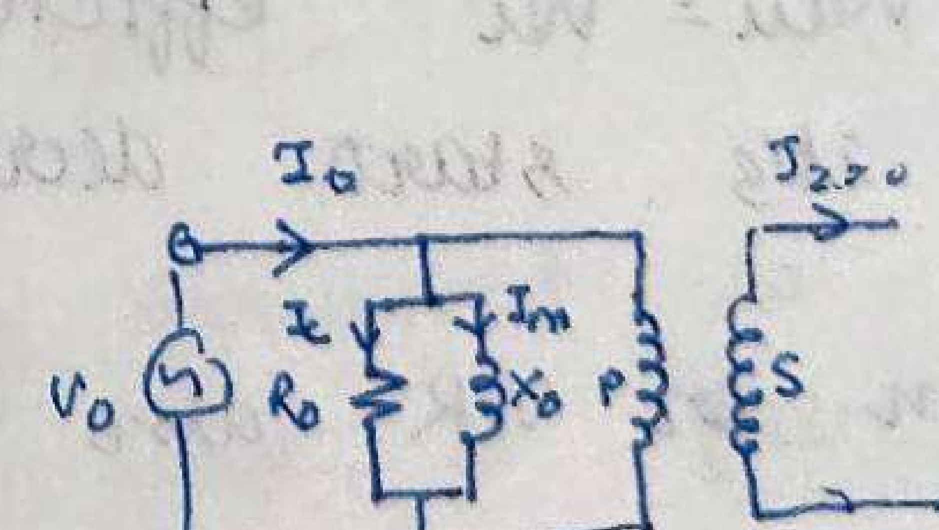
$\cos\phi_0 = \dfrac{W_0}{V_0 I_0}$

$\sin\phi_0 = \sqrt{1 - \cos^2\phi_0}$



$R_0 = \dfrac{V_0}{I_c}$

$X_0 = \dfrac{V_0}{I_m}$
Reactance



→ In Open ckt test there is no current in secondary side so I_2 is 0 and total current is $I_1 = I_0 + I_2'$

$= I_0 + KI_2$ $\quad \therefore I_2 = 0$

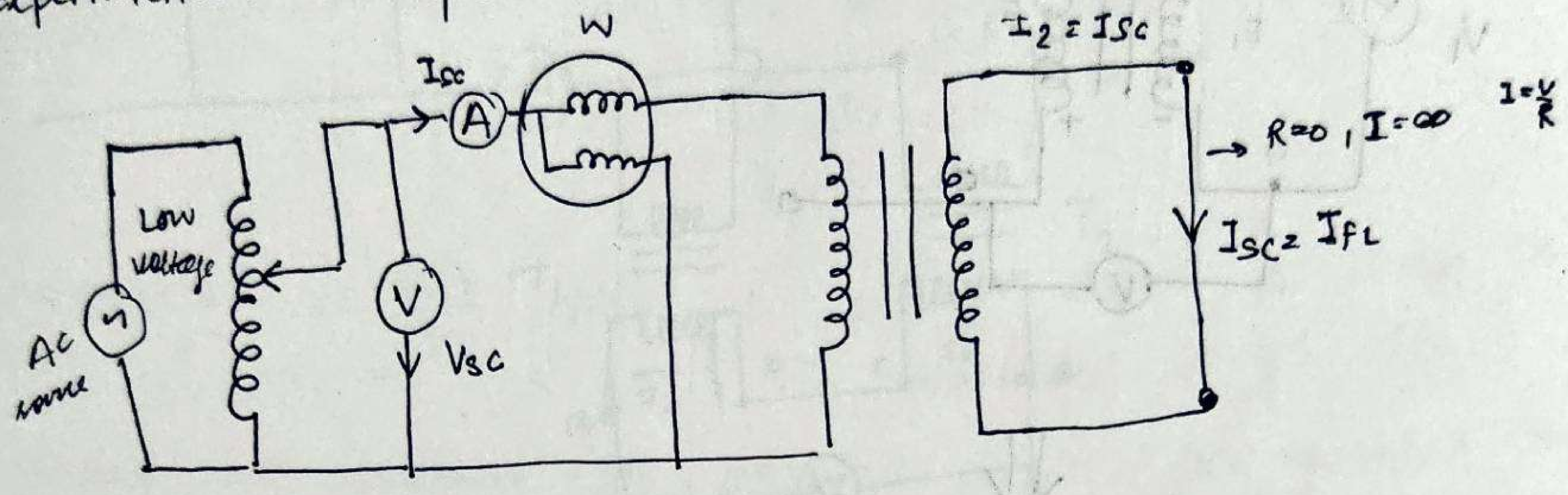
$\boxed{I_1 = I_0}$

→ so current drawn by primary $I_1 = I_0$ which is only 3 to 5% of the rated current, therefore Cu loss in case of no load will be negligible.

→ Therefore the only loss which is occuring in T/F is iron loss.

(ii) Short ckt-test or No load test

Experimental set-up:-



VARIAC
↓
variable AC

$W = W_i + W_{cu}$

$W_i \propto V^2$

$W_{cu} \propto I_{FL}^2$

At low voltage, iron loss becomes negligible as compared to Cu loss.

Here, $\boxed{W = W_{cu}}$ ∴ iron loss becomes negligible i.e. 0.

$W = W_{cu} = W_{sc}$

$W_{sc} = V_{sc} I_{sc} \cos\phi_{sc}$

$W_{sc} = I_{sc}^2 R_{1e}$ ∴ $R_{1e} = R_1 + R_2'$ & $R_2' = R_2/K^2$

$$\boxed{R_{1e} = \frac{W_{sc}}{I_{sc}^2}}$$

R_{1e} :- 1 → primary
e → equivalent.

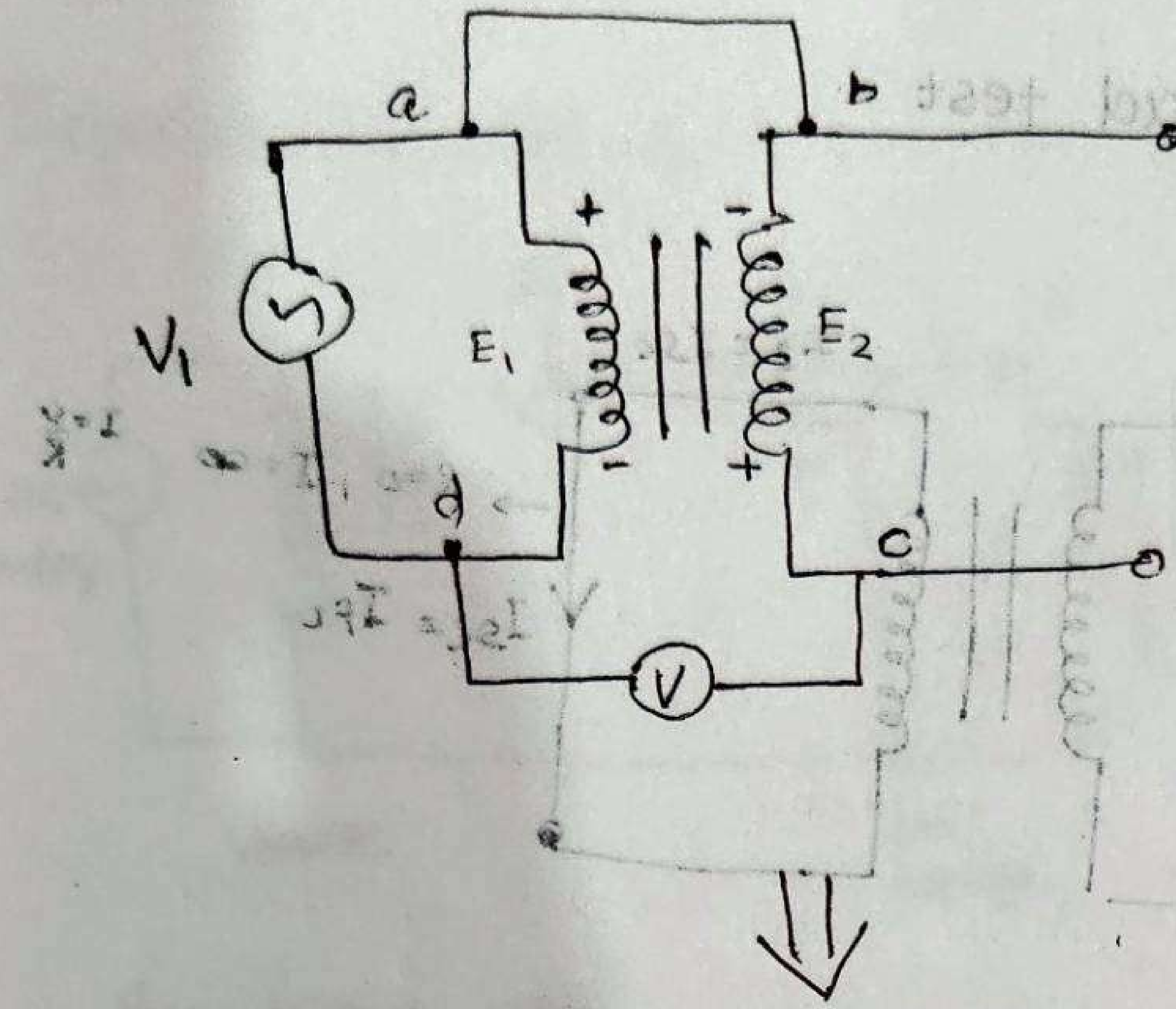
$Z_{1e} = \frac{V_{sc}}{I_{sc}}$

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

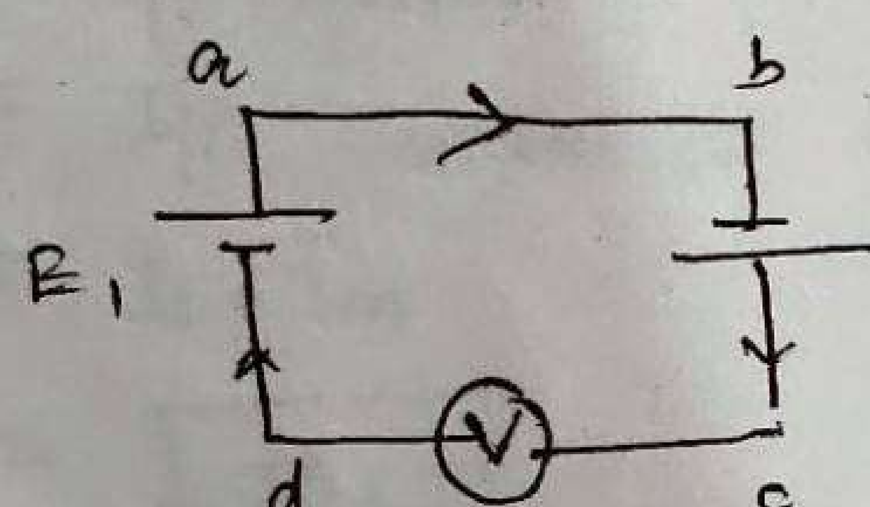
⊙ POLARITY TEST-

→ This test is done to determine which ends of two winding of T/F have the same polarity at same time.

→ **Ckt diagram** -

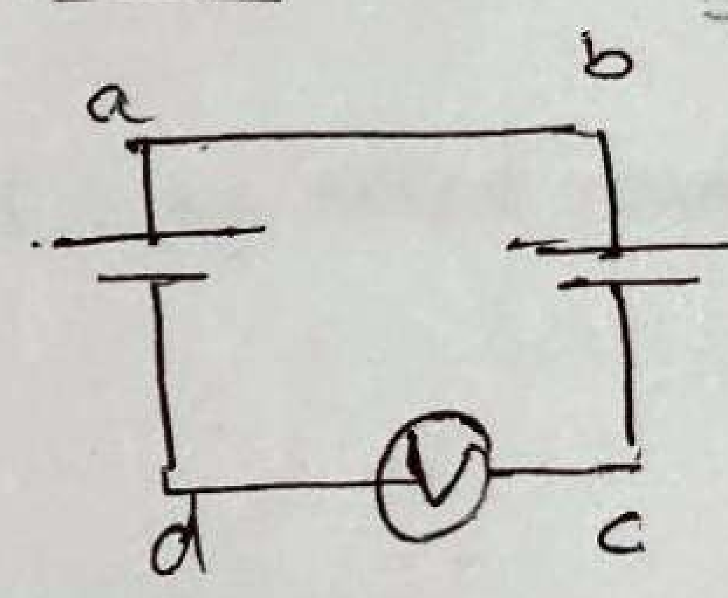


Case (i) - When have different polarity on both side.



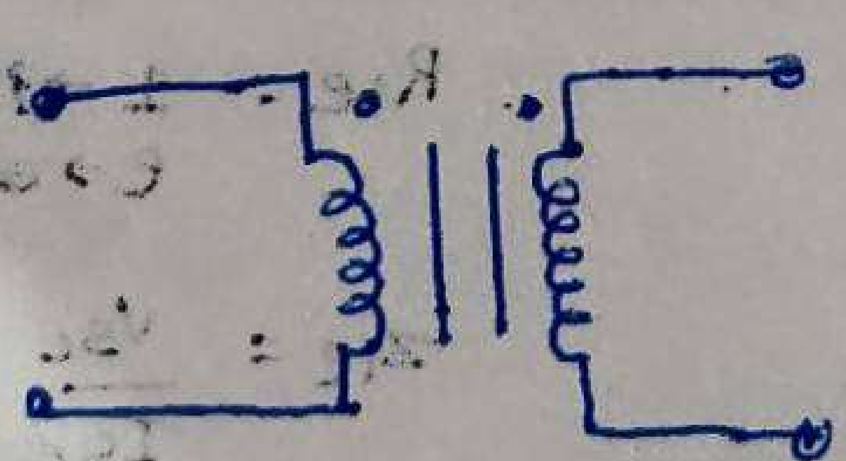
Net voltage = Sum of the two voltages
$= (E_1 + E_2)$

Case (ii) - when have same polarity on both side.



Net voltage $= E_1 \sim E_2$

→ **Symbol for same polarity** -

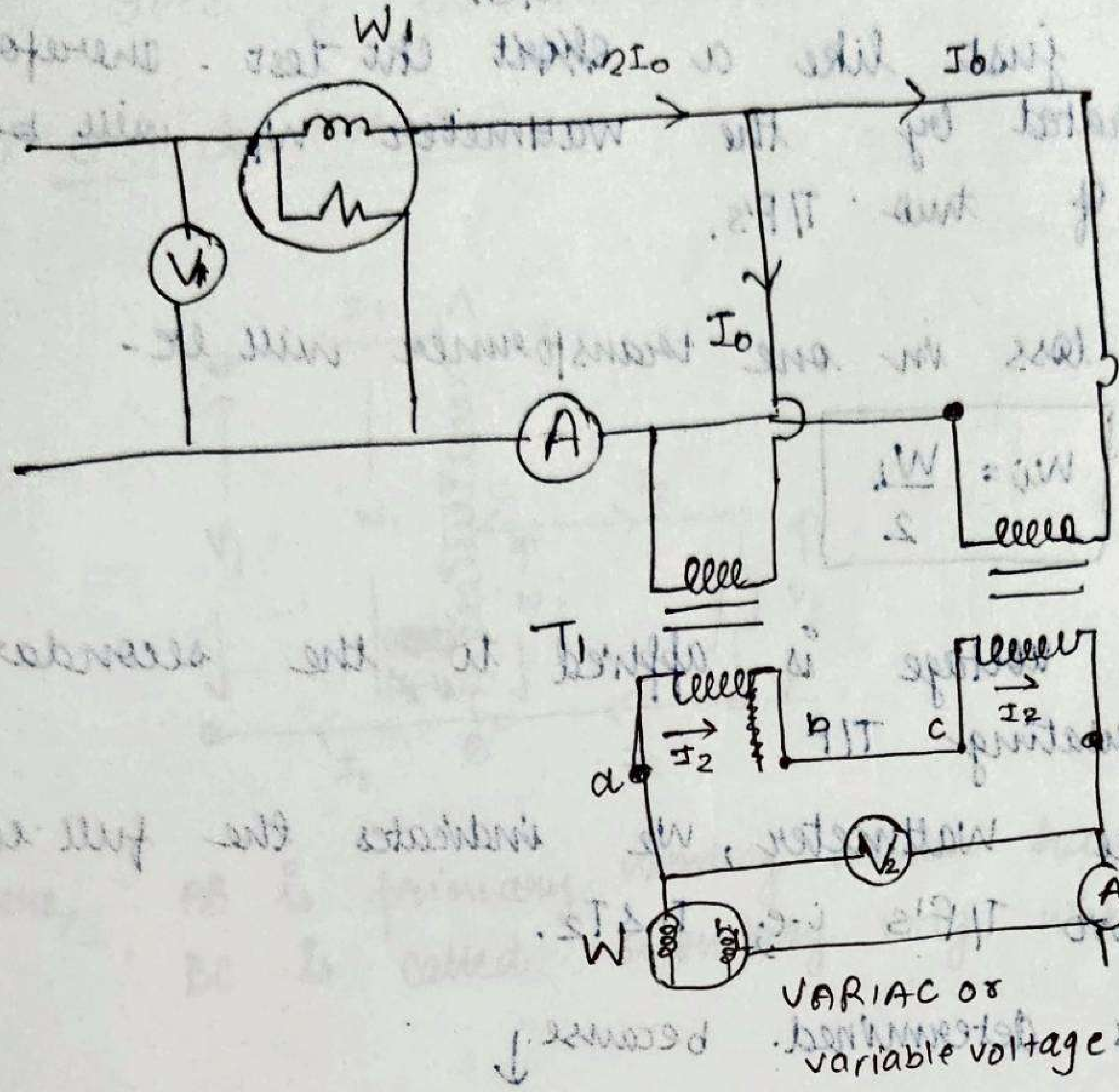


⑥. SUMPNE'S TEST (Back to back test):-

→ This is another for determining efficiency, regulation & heating of the T/F of under load.

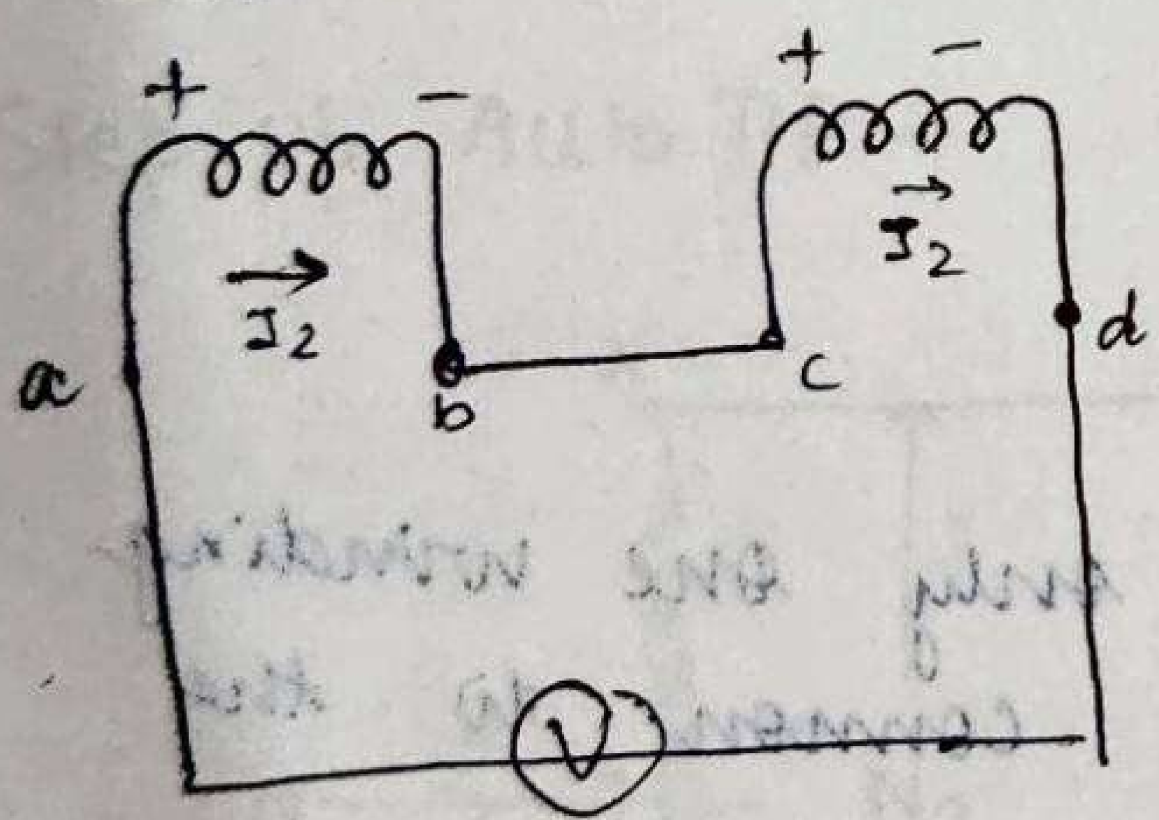
→ In order to determine max temp rise it is necessary to conduct a full load test on a T/F. For this we need two identical T/F

→ The primary wdg of two T/F are connected in ||r & rated voltage is applied in the primary side.

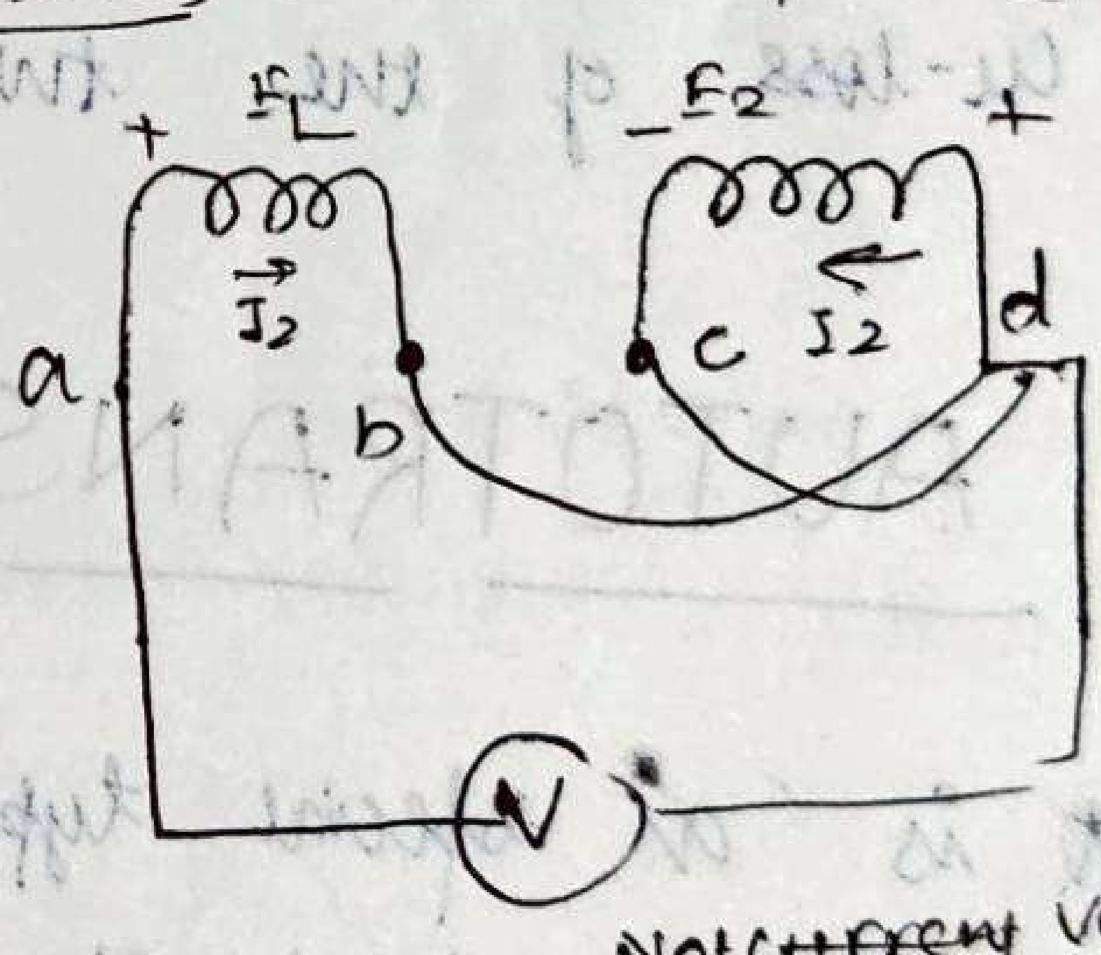


Case (ii) - Reverse polarity

Case (i) - Same polarity



Net current = $J_0 = J_1 + J_2$



Net current Voltage
$V = E_1 + E_2$

→ The secondaries wdg are connected in series with their polarities in phase opposition which is checked by voltmeter V_2. When the seconday are in phase opposition voltmeter will read zero. and therefore there will be no current in secondaries of the two T/F's.

→ As there is no current in the secondaries, there will be no copper loss in the two transformers. Wattmeter W_2 reading will be zero.

→ This situation is just like a ~~short~~ open ckt test. Therefore, the losses integrated by the wattmeter W_1 will be the iron loss of two T/F's.

→ Therefore, iron loss in one transformer will be-

$$\boxed{W_i = \frac{W_1}{2}}$$

→ Now a small voltage is applied to the secondary ckt by a regulating T/F.

→ Reading of the wattmeter, W_2 indicates the full load Cu-loss of two T/F's i.e; T_1 & T_2.

→ Only Cu-loss is determined. because ↓

→ At low voltage iron losses are almost negligible. Therefore, the reading of wattmeter W_2 indicates only Cu-loss of the two T/F's.

* AUTOTRANSFORMER-

7

→ It is a special type of T/F having only one winding such that part of the winding is common to the primary & secondary.

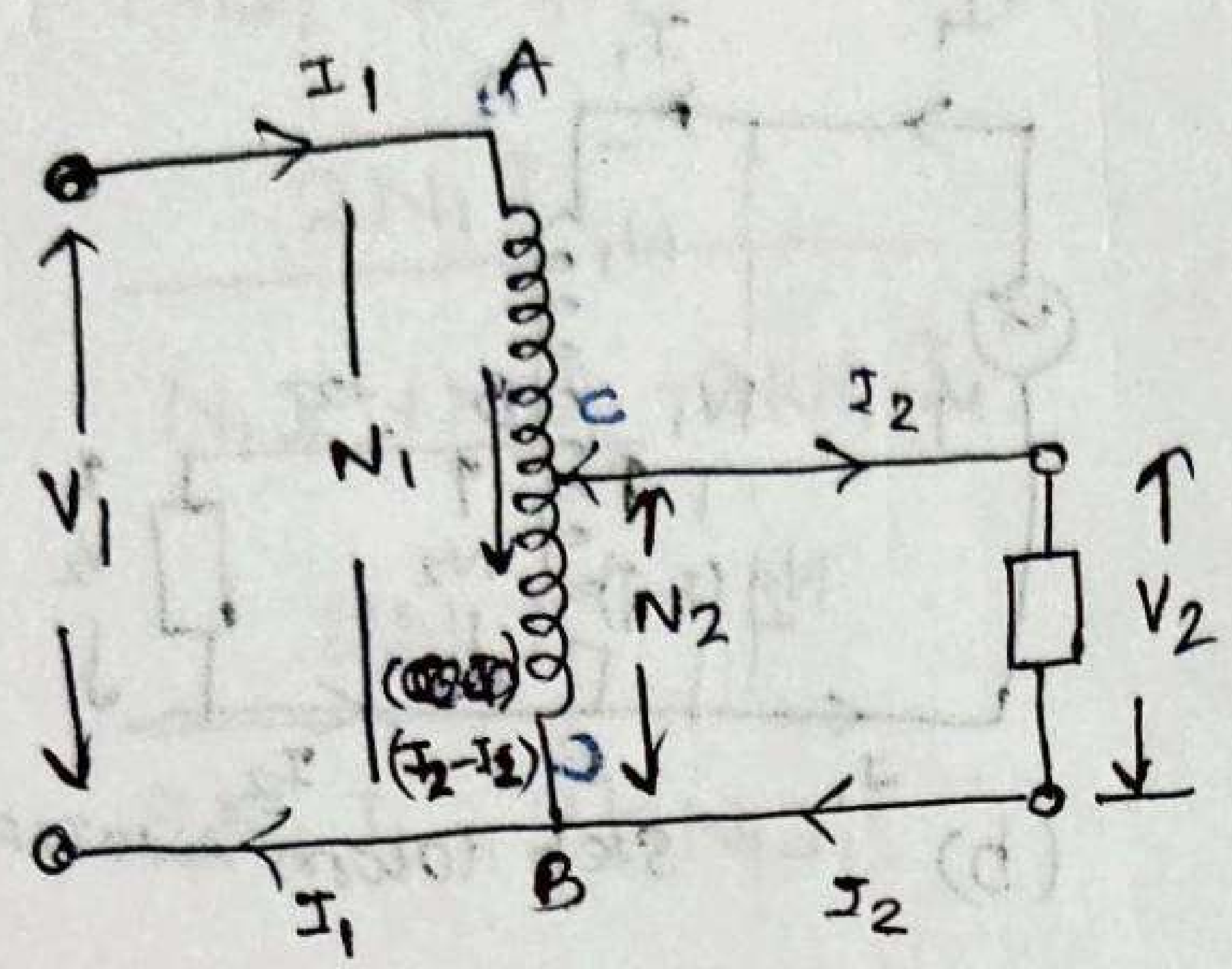
→ The two wdgs are electrically connected. This T/F works on the principle of both conduction & induction.

→ In this T/F, the part of power is transfered conductively and inductively as well. Therefore, it's KVA rating is higher than two winding t/F.

→ It's efficiency is high and voltage regulation is low. as compared to two wdg T/F

* Types of Autotransformer.

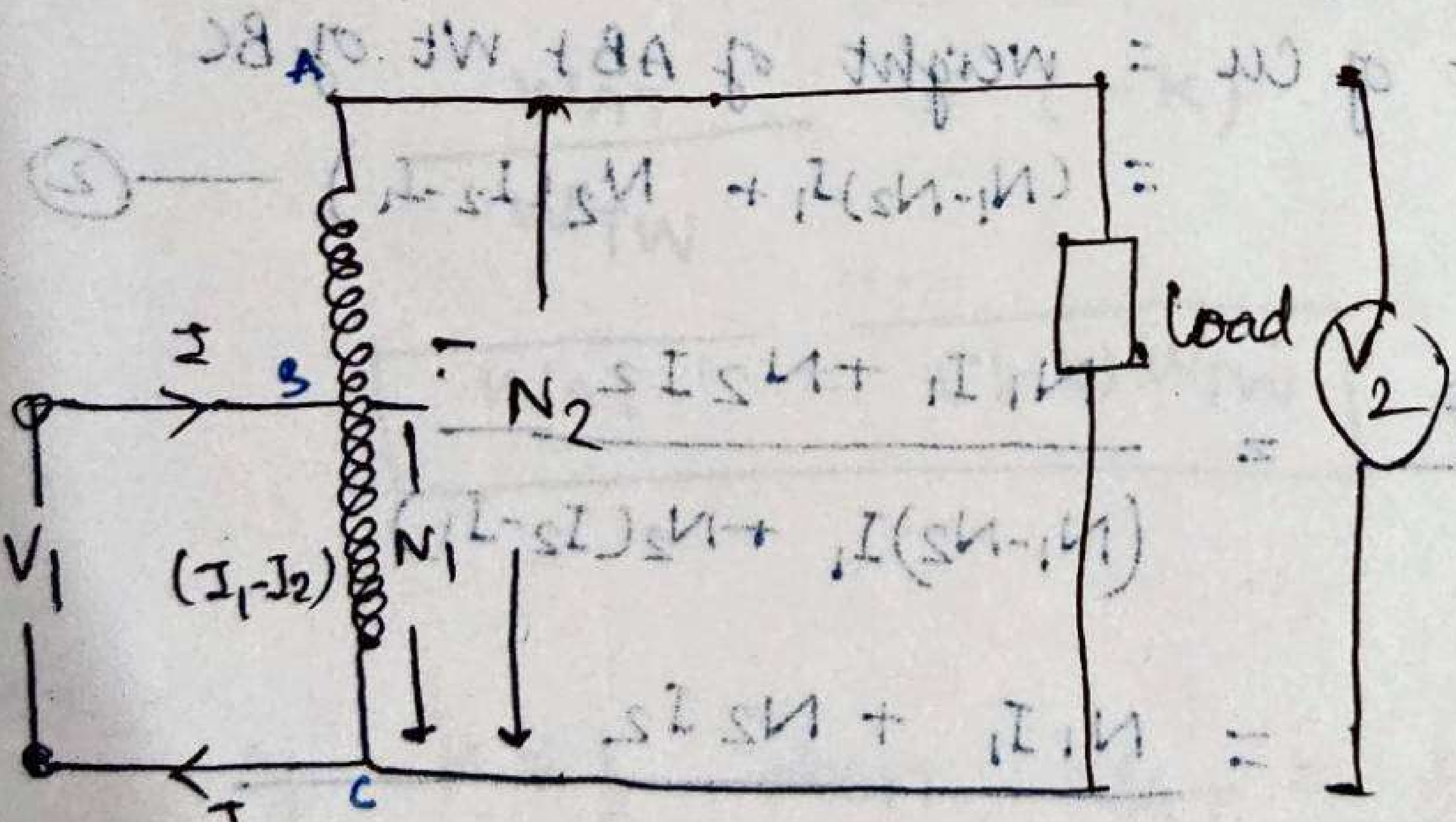
(a) Step-down Auto T/F -



Here, AB is primary winding which has N_1 turns.
BC is called secondary wdg which has N_2 turns.

~~(b) Steps-up Tran~~

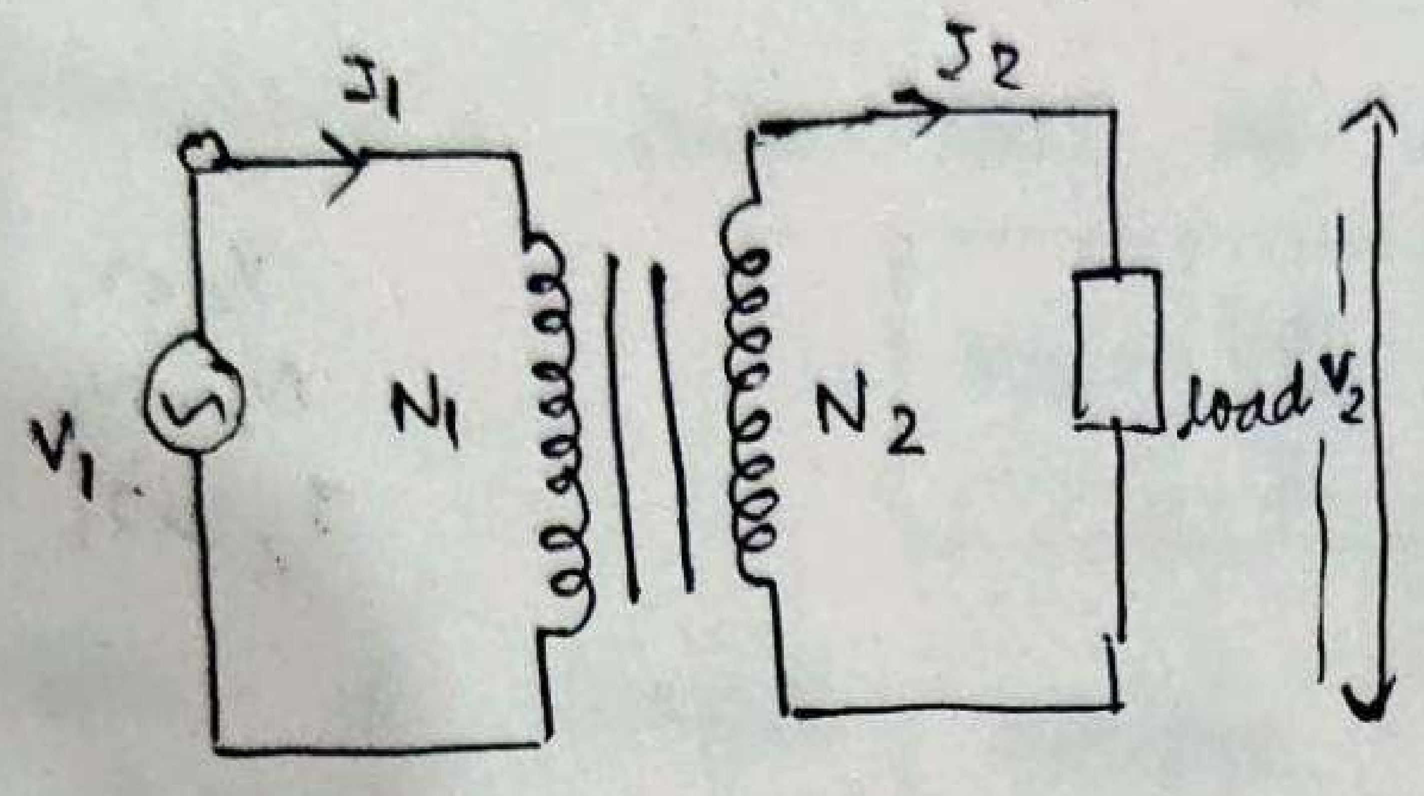
(b) Step up Auto T/F —



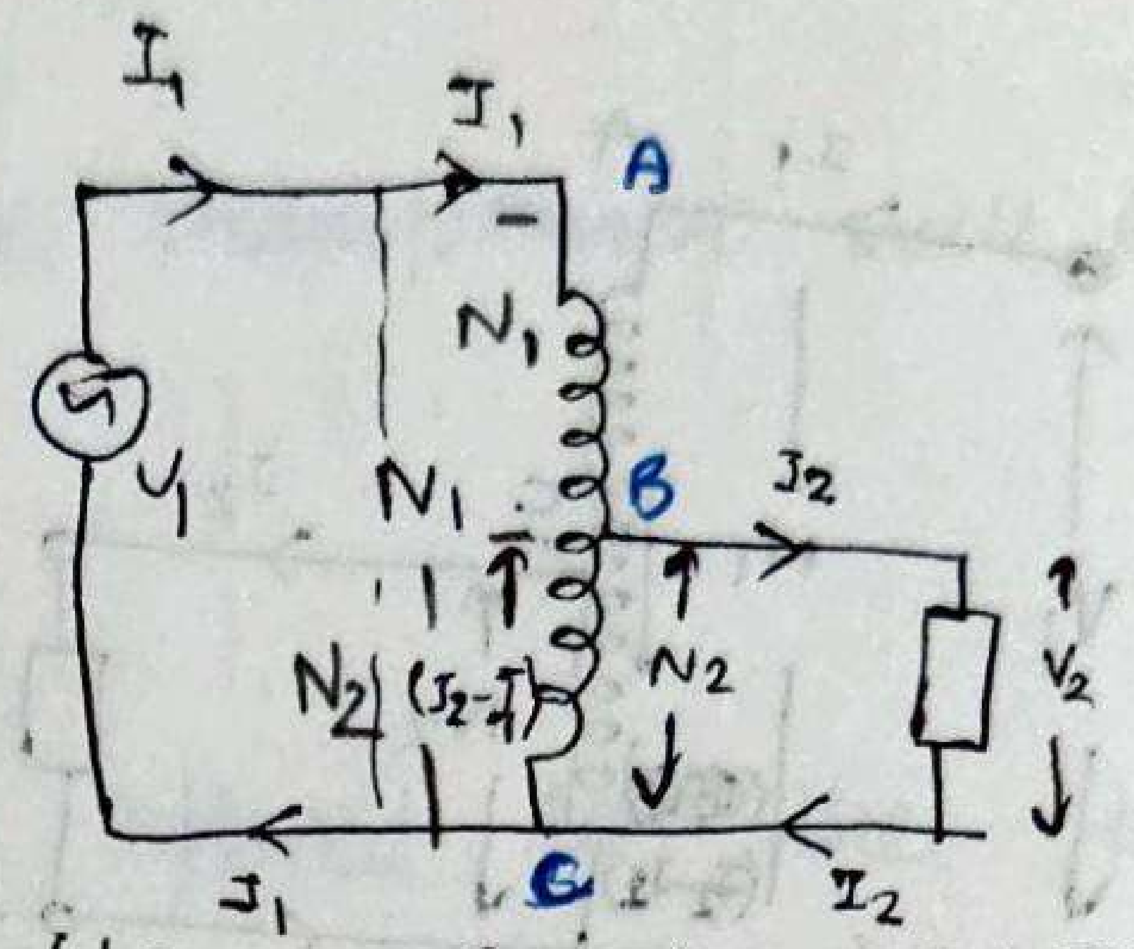
Here, $N_2 > N$
$V_2 > V_1$
$I_2 < I_1$

* SAVING OF COPPER IN AUTOTRANSFORMER-

Consider a two winding T/F and a stepdown auto T/F, as show in given diagram.



(a) T/F - two wdg



(b) Step down Auto T/F

$V_2 < V_1$
$I_2 > I_1$

Note-

wt of cu = Volume x density

Wt cu = $Al\rho$

$\therefore$ wt of cu $\propto A \cdot l$ $\qquad$ $l \propto N$

wt of cu $\propto I.N$ $\qquad$ $A \propto I$ → area of wire.

→ In two winding T/F, wt. of cu $= N_1 I_1 + N_2 I_2$ —— (1)

→ In autotransformer, wt of cu = weight of AB + Wt of BC

$= (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ —— (2)

Now,

$$\frac{\text{Wt of two wdg T/F}}{\text{Wt of Auto T/F}} = \frac{N_1 I_1 + N_2 I_2}{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 + N_2 I_2 - 2 N_2 I_1} \quad \text{—— (3)}$$

We know

$$\frac{N_2}{N_1} = K = \frac{I_1}{I_2}$$

$N_2 I_2 = N_1 I_1$

$\therefore N_2 = K N_1$

Putting $N_1 I_1$ in eq (3)

$$\Rightarrow \frac{N_1 I_1 + N_1 I_1}{N_1 I_1 + N_1 I_1 - 2 N_1 I_1}$$

$\therefore N_2 = K N_1$

$$\Rightarrow \frac{2 N_1 I_1}{N_1 I_1 + N_1 I_1 - 2 K N_1 I_1}$$

$$\Rightarrow \frac{2 N_1 I_1}{2 N_1 I_1 - 2 K N_1 I_1}$$

$$\Rightarrow \frac{\cancel{2 N_1 I_1}}{\cancel{2 N_1 I_1}(1-K)}$$

$$\Rightarrow \frac{1}{1-K}$$

So, $\dfrac{\text{Wt of two wdg T/F}}{\text{Wt of auto T/F}} = \dfrac{1}{1-K}$

TW = Two wdg T/F

$$\frac{W_{AT}}{W_{TW}} = (1-K)$$

$$\boxed{W_{AT} = (1-K) W_{TW}}$$

Where $K = \dfrac{N_2}{N_1}$

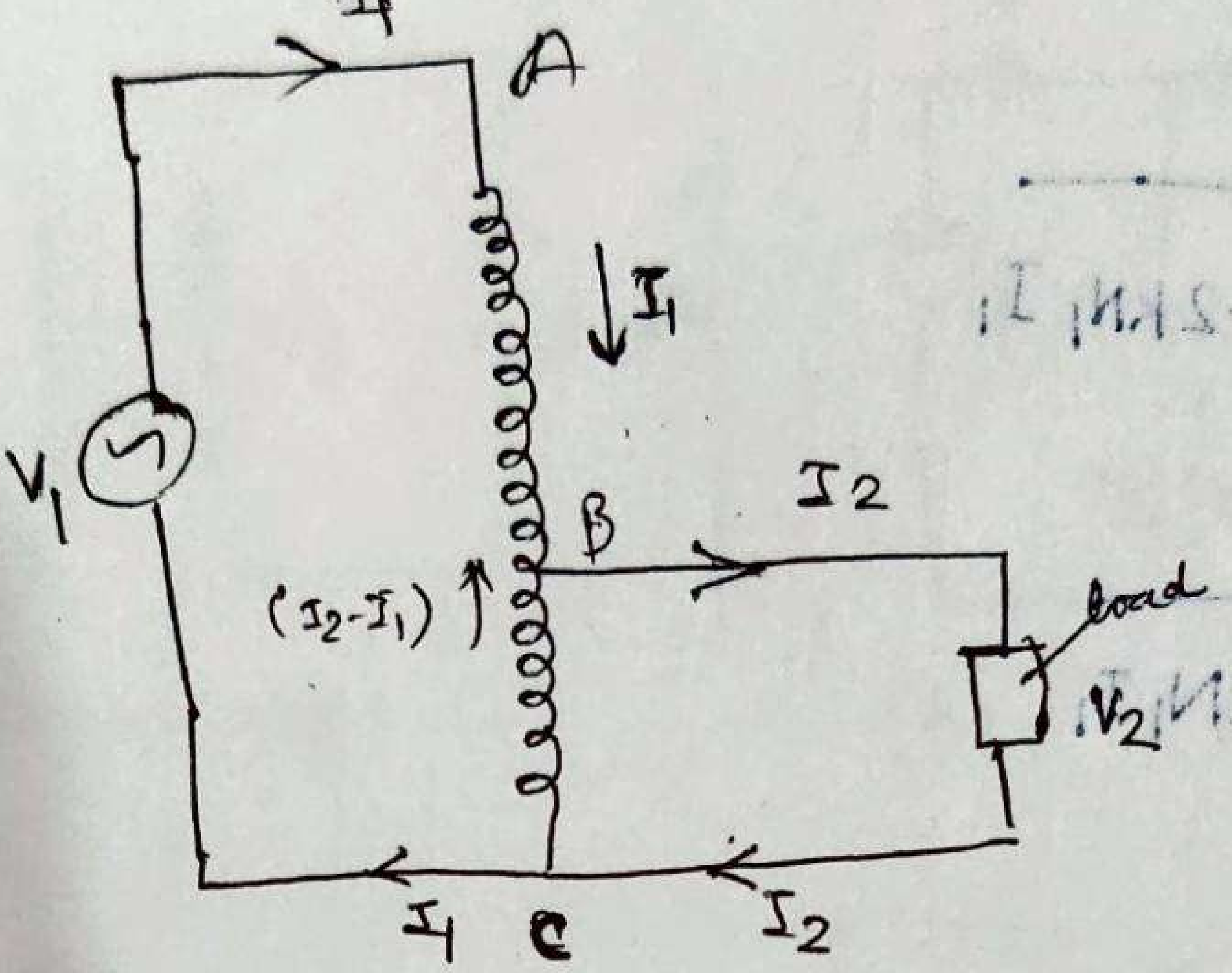
$K < 1$ for stepdown AT/F

Note- If $K = \frac{1}{2}$ then $W_{AT} = \frac{1}{2} W_{TW}$

* Amount of volt and ampere in load → Rating of T/F or (KVA) capacity of T/F, V multiply by Ampere → known as KVA rating.
* small T/F → rating → VA
  Big T/F → " → KVA $(K = 10^3) = 10^3$ VA
* Biggest T/F → " → MVA $(M = 10^6) = 10^6$ VA.

* POWER TRANSFER IN AUTOTRANSFORMER-

Consider a step-down auto-transformer.



Here, $I_2 > I_1$ (∵ step down Auto T/F (↑ current, ↓ V))

→ Power transferred inductively (through T/F action)

P_t = Power in secondary wdg.

$= V_2(I_2 - I_1)$

$= V_2 I_2 - V_2 I_1$

$= V_1 I_1 - (KV_1) I_1$

$\boxed{P_t = V_1 I_1 (1-K)}$

∴ $K = \frac{V_2}{V_1} = \frac{I_1}{I_2}$

∴ ⇒ $V_2 I_2 = V_1 I_1$

∴ $P_{in} = V_1 I_1$

$P_{in} = P_{I/P}$

$\boxed{P_t = (1-K) P_{in}}$

$P_t = P_{in} - K P_{in}$

$\boxed{P_{in} = P_t + K P_{in}}$

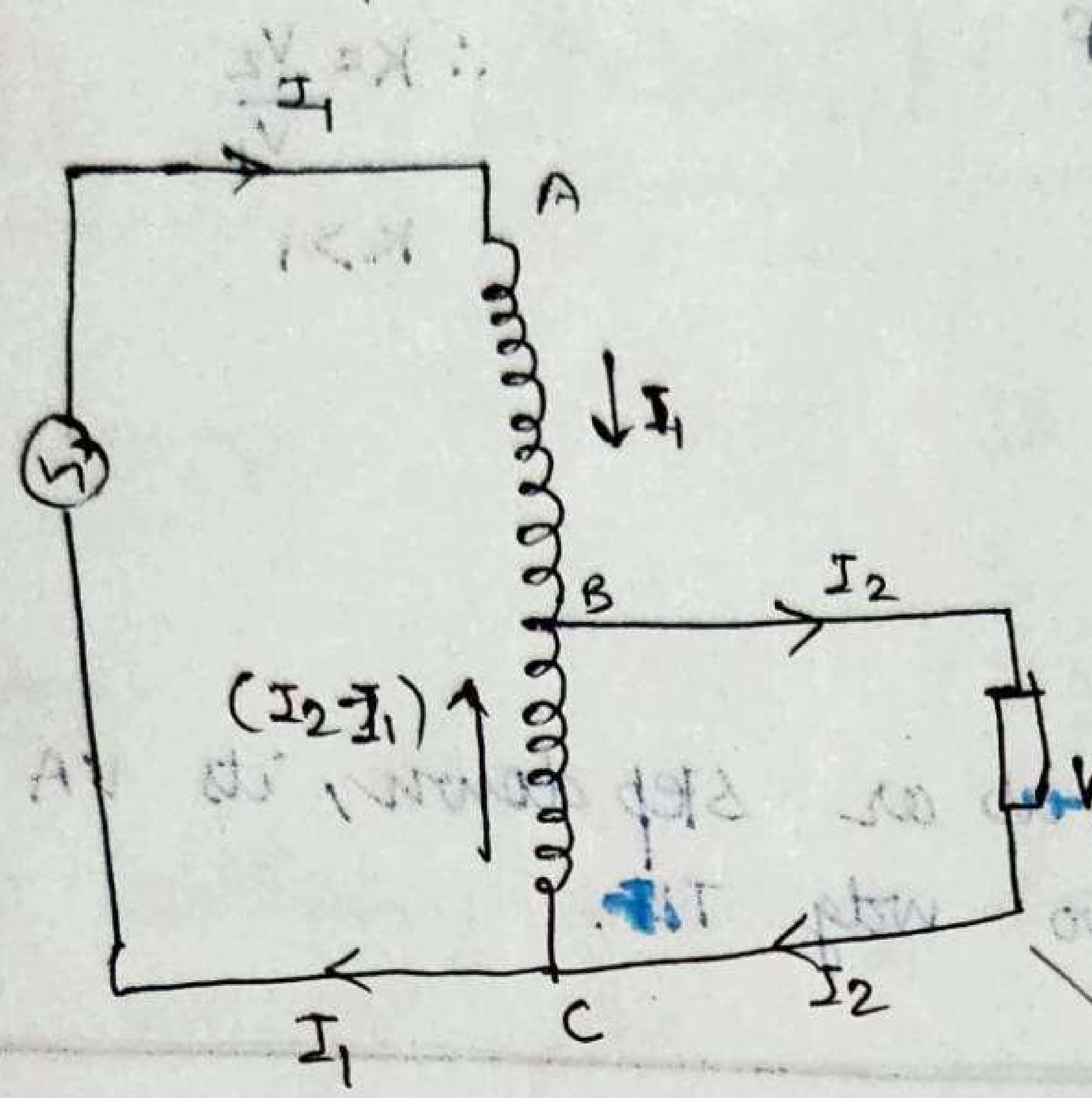
Where, P_t = inductively transferred

P_c = conductively transferred

$\boxed{P_{in} = P_t + P_c}$

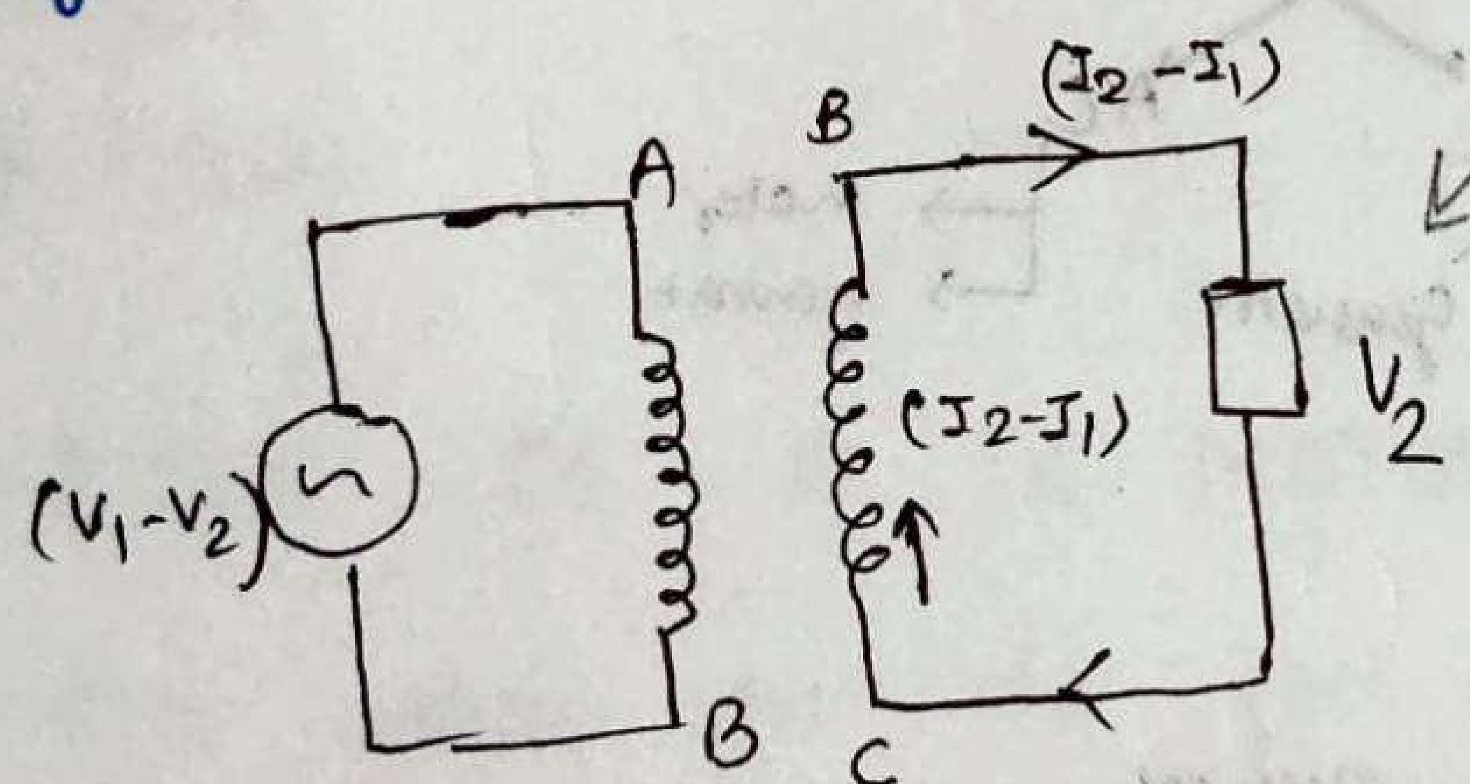
* VA RATING OF AUTOTRANSFORMER-

Consider a step-down Auto T/F



- VA rating of stepdown auto T/F
- $(VA)_{AT} = V_2 I_2$
- If this Auto transformer is converted into two winding T/F with primary as AB & secondary as BC.

Stepdown AT/F breaks into two parts to form a new T/F



- NOW VA rating of this two wdg T/F
- $(VA)_{TW} = V_2(I_2-I_1)$

$$= V_2 I_2 - V_2 I_1$$

$$= V_1 I_1 - K V_1 I_1$$

$$= (1-K) V_1 I_1$$

$$\boxed{(VA)_{TW} = (1-K)(VA)_{AT}}$$

$\therefore K = \frac{N_2}{N_1} \Rightarrow N_2 < N_1$

so, $(VA)_{TW} < (VA)_{AT}$, as $K<1$

or

$(VA)_{AutoT/F} > (VA)_{TW}$

→ Autotransformers is better becase it have more VA rating