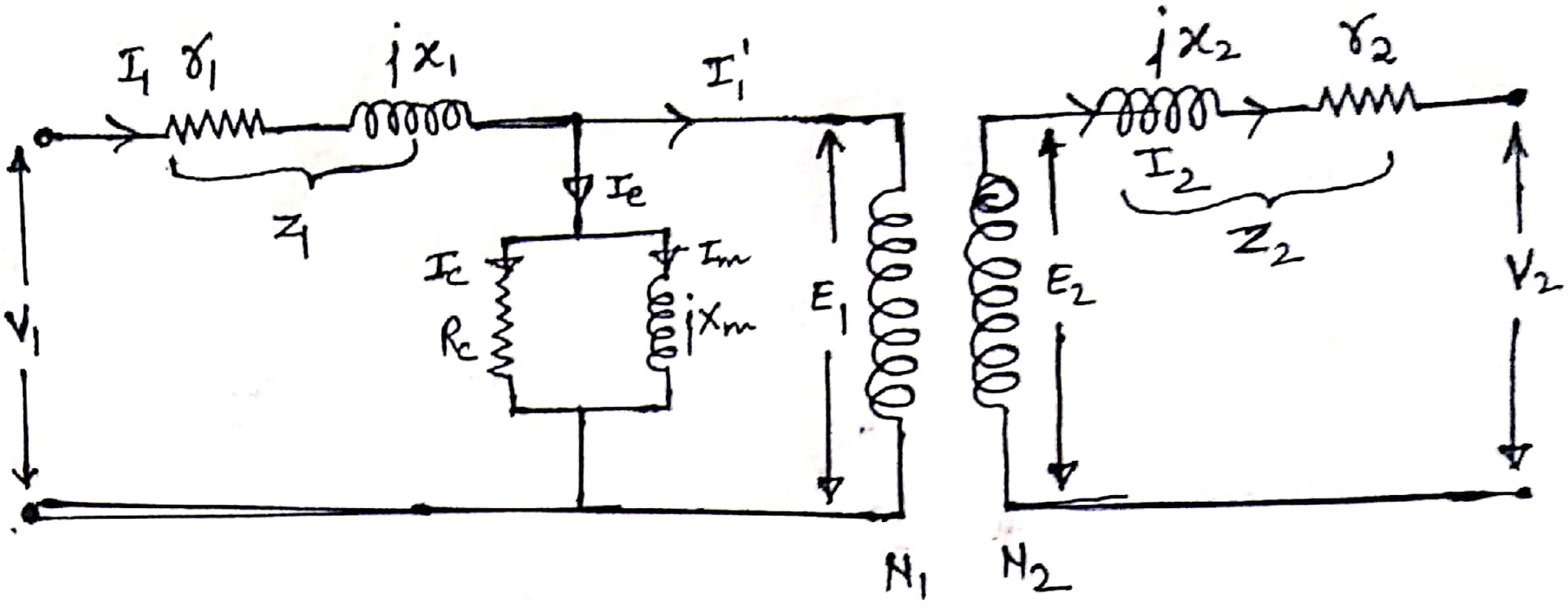
4.11 Equivalent circuit of a transformer.



r_1 → Resistance of Primary winding

x_1 → leakage Reactance of Primary winding

I_e → No load current or exciting current

I_c → Core loss current

I_m → magnetizing current

R_c → core loss resistance

X_m → magnetizing reactance

r_2 → Resistance of Secondary winding

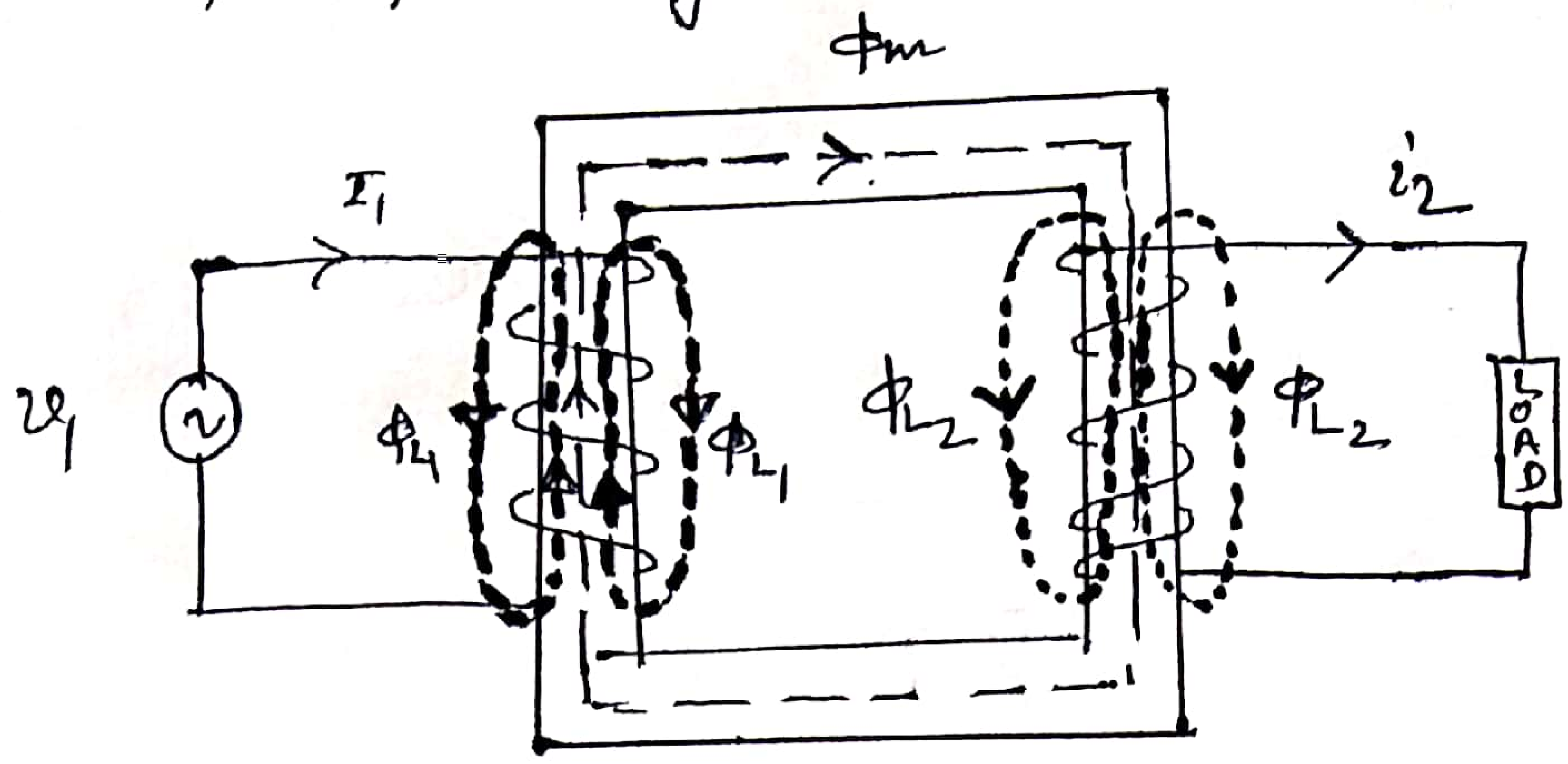
x_2 → Leakage reactance of secondary winding

$Z_1 = (r_1 + jx_1)$ → impedance of primary winding

$Z_2 = (r_2 + jx_2)$ → impedance of secondary winding

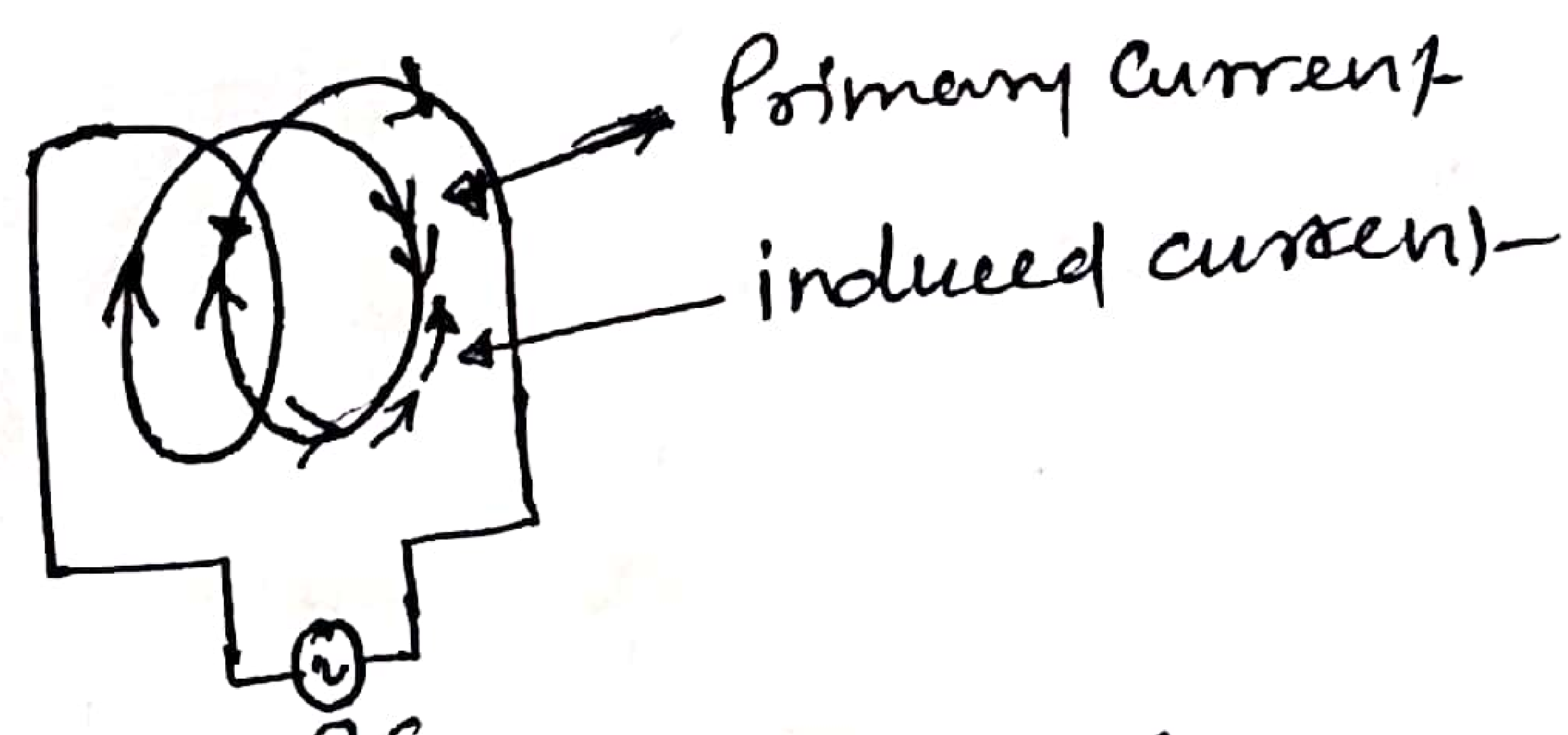
4.11 Equivalent Circuit of a Transformer, Continued -

ⓐ Concept of leakage reactance :-



(I) Part of the total flux of a winding that links only with the winding itself and/or metallic body parts of transformer such as tank wall, core clamps etc. is called leakage flux.
ϕ_{L_1} & ϕ_{L_2} are leakage flux associated with primary and secondary winding respectively

(II) Part of total flux linking both winding on HV and LV side is called mutual flux ϕ_m.

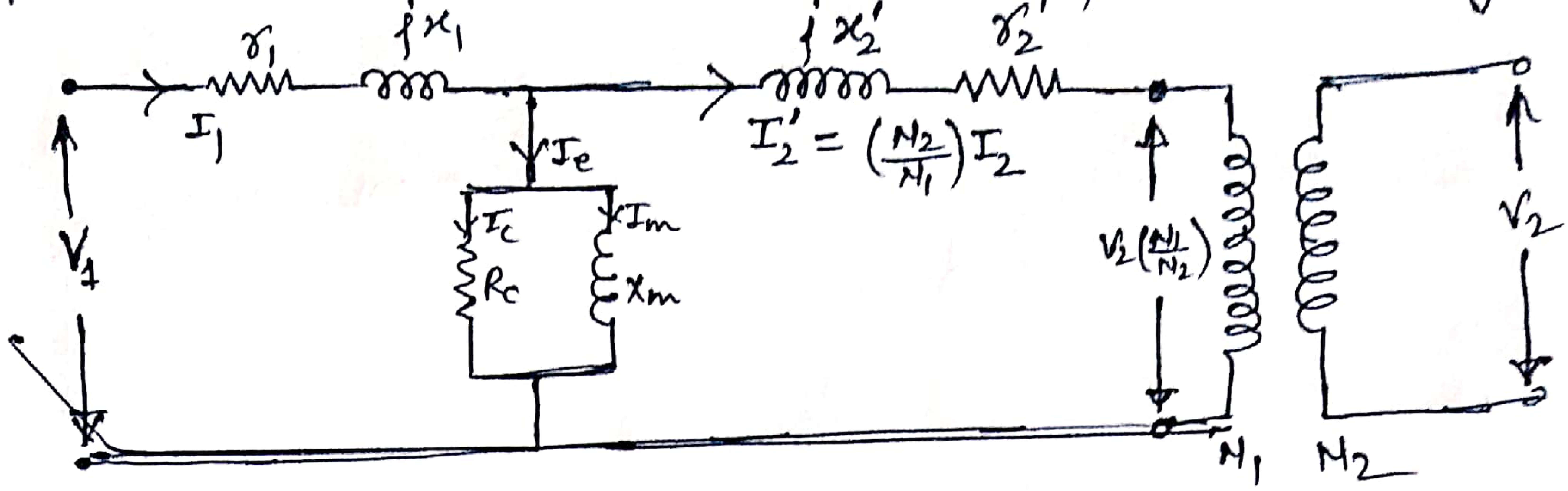


(III) Since time varying leakage flux links with the concerned winding itself, by electromagnetic induction it induces an emf (effect) through self induction in order to oppose the cause i.e. time varying current that created leakage flux.
An electrical element that exhibits this property of self-inductance is an inductor. That is why inductor is used to account for effect of leakage flux in the form of inductive reactance in the model circuit.

(b) **Concept of Shunt branch :-**

- The Shunt resistance in the transformer equivalent circuit represents the loss taking place in the core.
- The Shunt inductance represents the magnetising component
- Actually when current is passed through primary winding some of the total current is used up to produce the working magnetic field and some current is used up as heat dessipation in the core of the transformer. The magnetic field production is represented as some current flowing through a pure inductor (Shunt) producing the working magnetic field. The core loss is represented through some heat dessipation due to current flowing through a fictious resistance (Shunt core resistance.)
- Now as out of the total current flowing into the transformer primary, only a part is consumed as core loss component and magnetising component, thus these components are required to be represented seprately from the remaining current which flows in series and is used to transfer electric power from primary to secondary. And we know that current gets divided into two components in a network having two shunt branches. Thus Shunt (parallel) representation allow as to seprate the core loss and magnetising component of current from remaining total Current in the Primary.

(c) Equivalent Circuit when secondary circuit referred to Primary



Total equivalent resistance referred to Primary -

$$r_{e_1} = r_1 + r_2' = r_1 + \left(\frac{N_1}{N_2}\right)^2 r_2$$

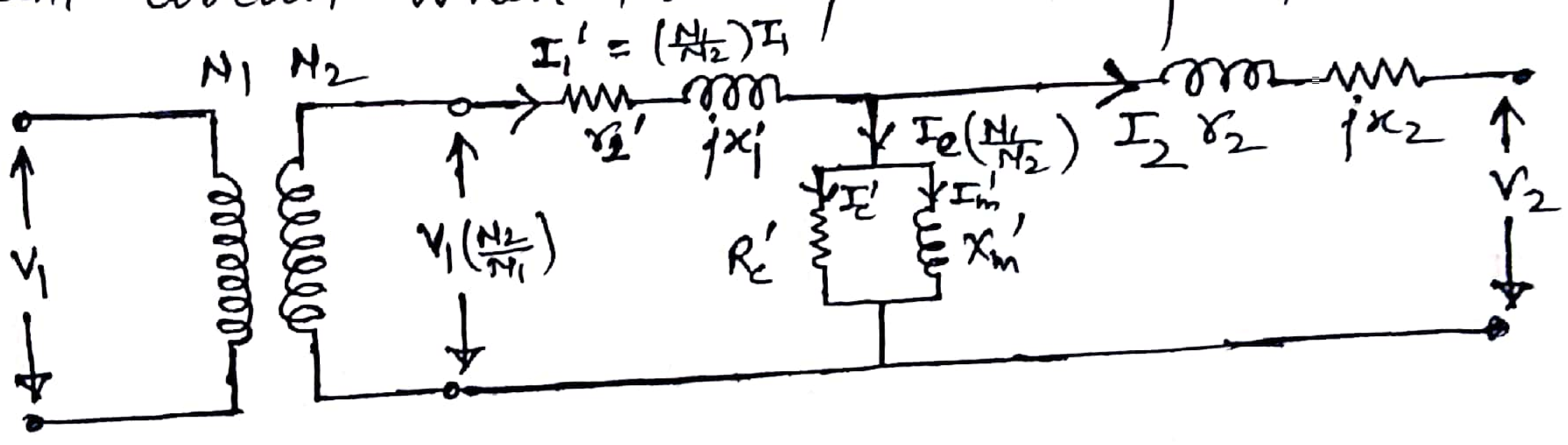
Total equivalent leakage reactance referred to Primary

$$x_{e_1} = x_1 + x_2' = x_1 + \left(\frac{N_1}{N_2}\right)^2 x_2$$

Total equivalent impedance referred to Primary

$$z_{e_1} = r_{e_1} + j x_{e_1}$$

(d) Equivalent Circuit when Primary circuit referred to ~~Primary~~ Secondary



Total equivalent resistance referred to Secondary

$$r_{e_2} = r_2 + r_1' = r_2 + \left(\frac{N_2}{N_1}\right)^2 r_1$$

Total equivalent leakage reactance -

$$x_{e_2} = x_2 + x_1' = x_2 + \left(\frac{N_2}{N_1}\right)^2 x_1$$

Total impedance -

$$z_{e_2} = r_{e_2} + j x_{e_2}$$

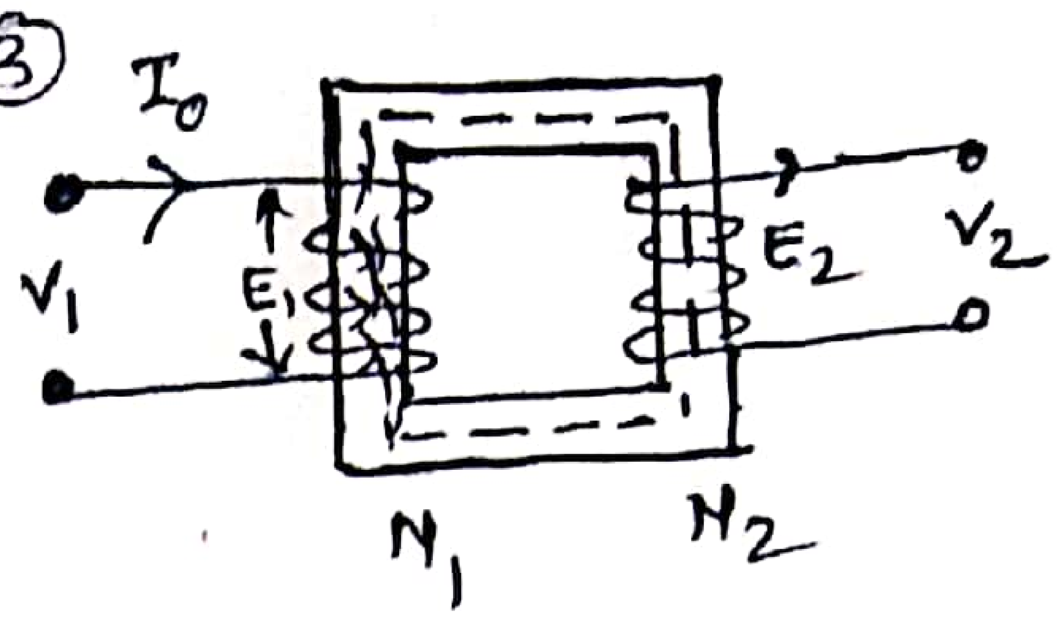
4.12 Phasor diagram of an ideal transformer at No load

∀ $\phi = \phi_m \sin \omega t$ → Common to both Primary and secondary —①

$E_1 = E_{1max} \sin(\omega t - \frac{\pi}{2})$ —②

$E_2 = E_{2max} \sin(\omega t - \frac{\pi}{2})$ —③

$V_1 = -E_1$ —④



Here $N_1 = N_2$

exciting Current / No load Current $\bar{I_0} = \bar{I_c} + \bar{I_m}$ —⑤

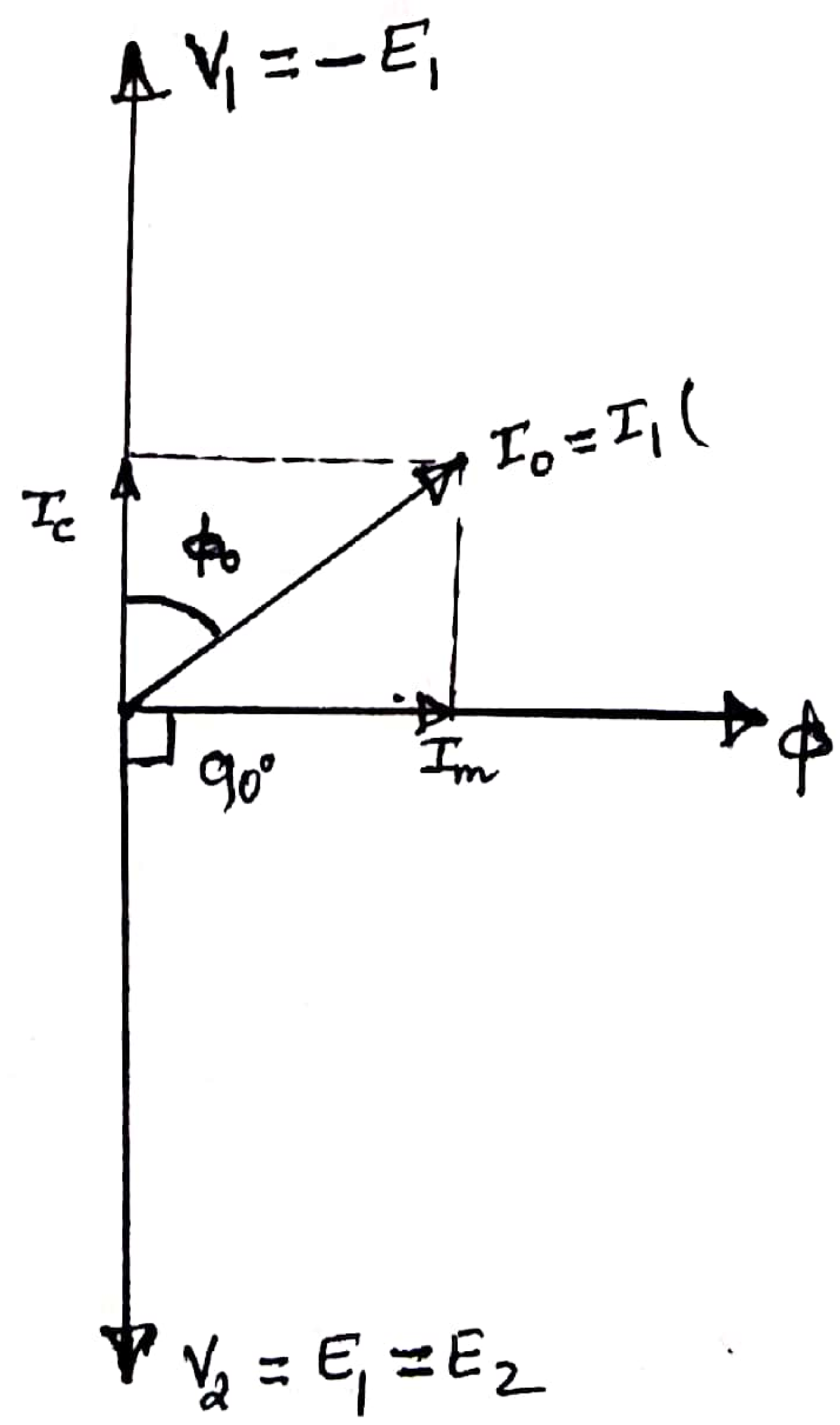
for No load $I_2 = 0$

$I_1 = I_0$.

$V_2 = E_2$ —⑥

I_m → is the reactive or magnetizing current since its function is to provide the required magnetic flux ϕ

I_c → core loss current component



ϕ_0 = No load phase angle

$I_c = I_0 \cos\phi_0$

$I_m = I_0 \sin\phi_0$

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

for ideal transformer

$r_1 = 0$

$r_2 = 0$

$I_1 r_1 = 0$, $I_2 r_2 = 0$] drop zero

No load means secondary terminal is open circuited.

4.13 Phasor diagram of an ideal transformer at load conditio

$\phi = \phi_m \sin \omega t$ ——— (I)

$E_1 = E_{1max} \sin(\omega t - \frac{\pi}{2})$ ——— (II)

$E_2 = E_{2max} \sin(\omega t - \frac{\pi}{2})$ ——— (III)

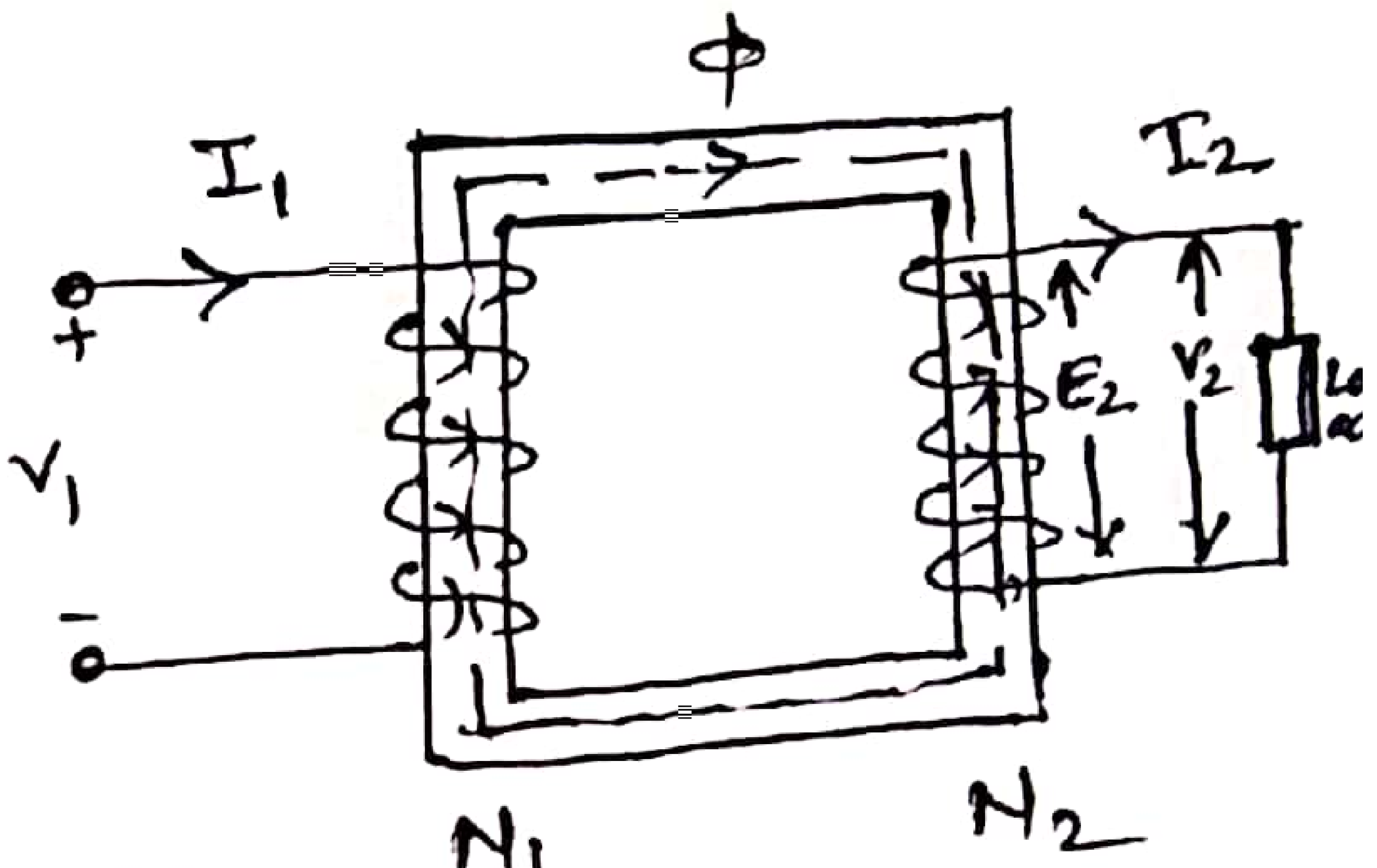
$V_1 = -E_1$ ——— (IV)

$I_1' N_1 = I_2 N_2$

$F_1 = F_2$

Total Primary Current $I_1 = I_1' + I_e$ ——— (V)

I_1' = compensating current required for maintaining the flux ϕ constant



→ When a load connected across the secondary terminals then according to Lenz's law, the direction of secondary current I_2 should be such that the secondary mmf $F_2 = N_2 I_2$ is opposite to mutual flux ϕ. This will result reduction in flux ϕ.

To neutralize the demagnetizing effect of secondary mmf, the primary current (I_1) draws extra current I_1' from the supply and make the mutual flux constant.

Constant flux is necessary for maintaining the value of E_1 & E_2