EEEE lec 43c 23/6/23

Equivalent circuit of a Practical transformer:

→ It provides complete details of the current & their components, voltages, winding parameters of primary as well as secondary windings of a transformer → all represented in one common electric circuit

→ It is helpful in predetermining the behaviour of the transformer under various conditions of operation

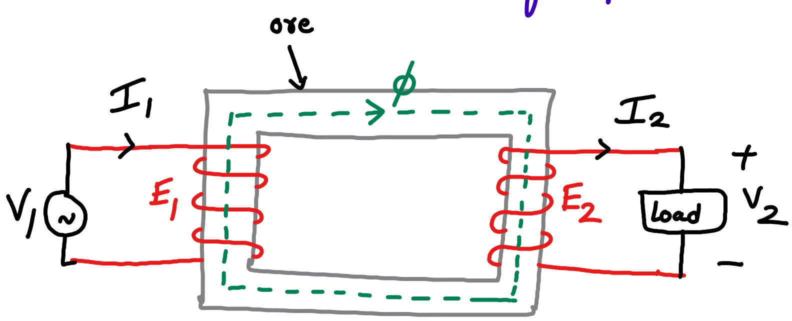


fig1: Practical Transformer (with Load)

① The practical transformer shown in fig1 → can be represented as an equivalent circuit shown in fig2

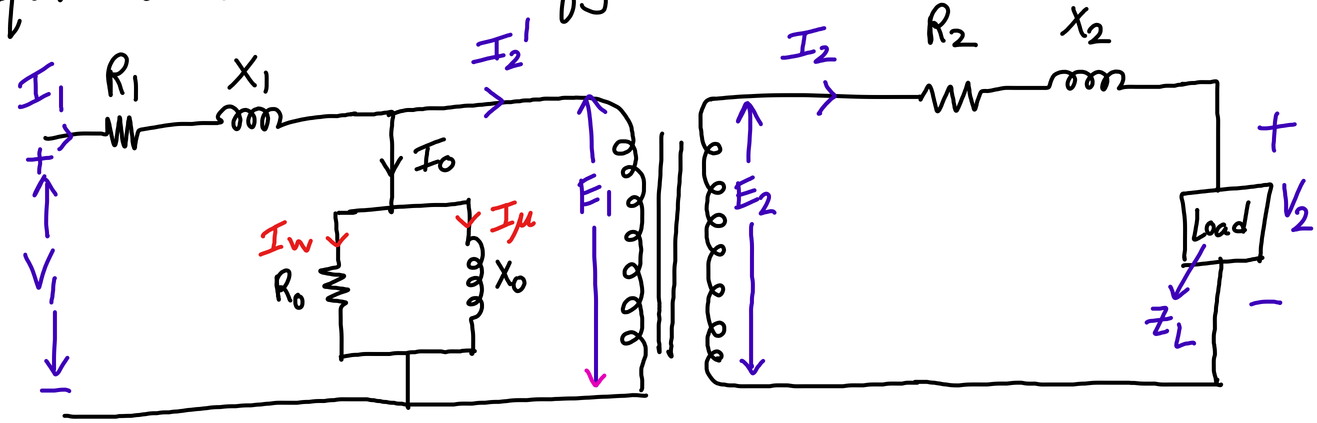


fig2: Equivalent circuit of a Practical Transformer

② Winding resistances are represented as R_1 & R_2

③ Leakage reactance are represented as X_1 & X_2

④ No load current 'I_0' has two current component's:

a) Current I_w is in phase with voltage V_1

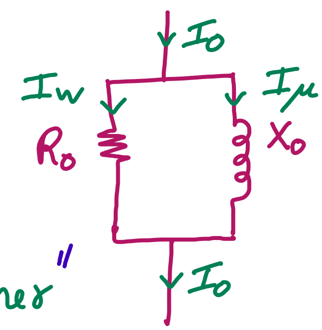
b) Current I_μ lags behind the voltage V_1 by 90°

⑤ ∴ In equivalent circuit (fig 2), 'I_0' is represented by

a) pure inductance 'X_0' → taking the magnetizing component I_μ &

b) a resistance 'R_0' taking the working component I_w

c) R_0 and X_0 are connected in parallel across the primary circuit



d) Resistance R_0 represents the core loss

$I_w^2 R_0$ → "Core loss of practical transformer"

⑥ An exact equivalent circuit of a transformer referred to the primary side → can be obtained by transferring the entire secondary circuit to primary side as follows:

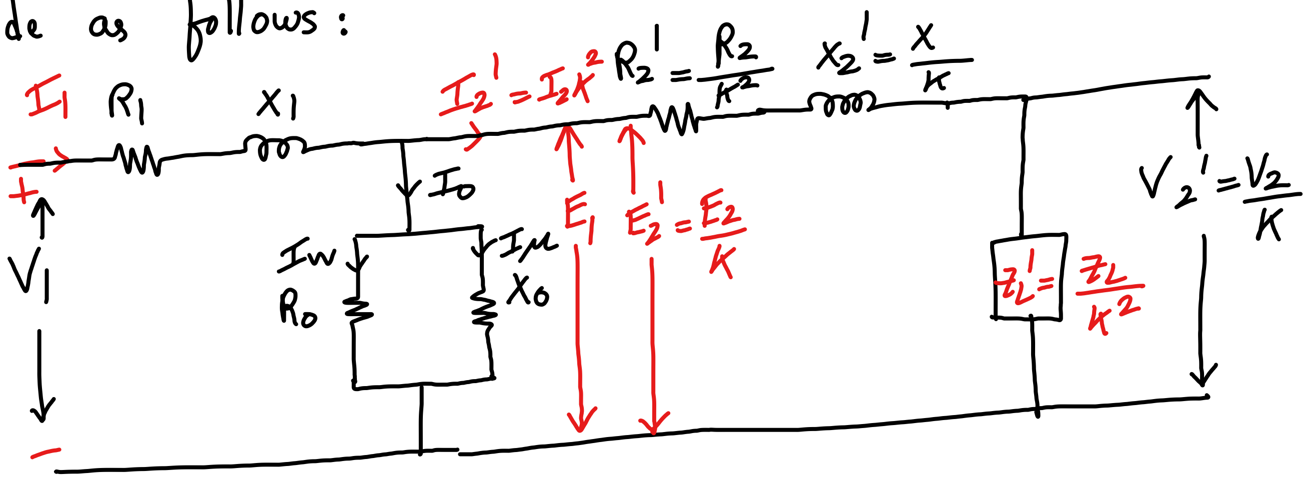


fig 3: Exact equivalent circuit of the transformer referred to the primary side

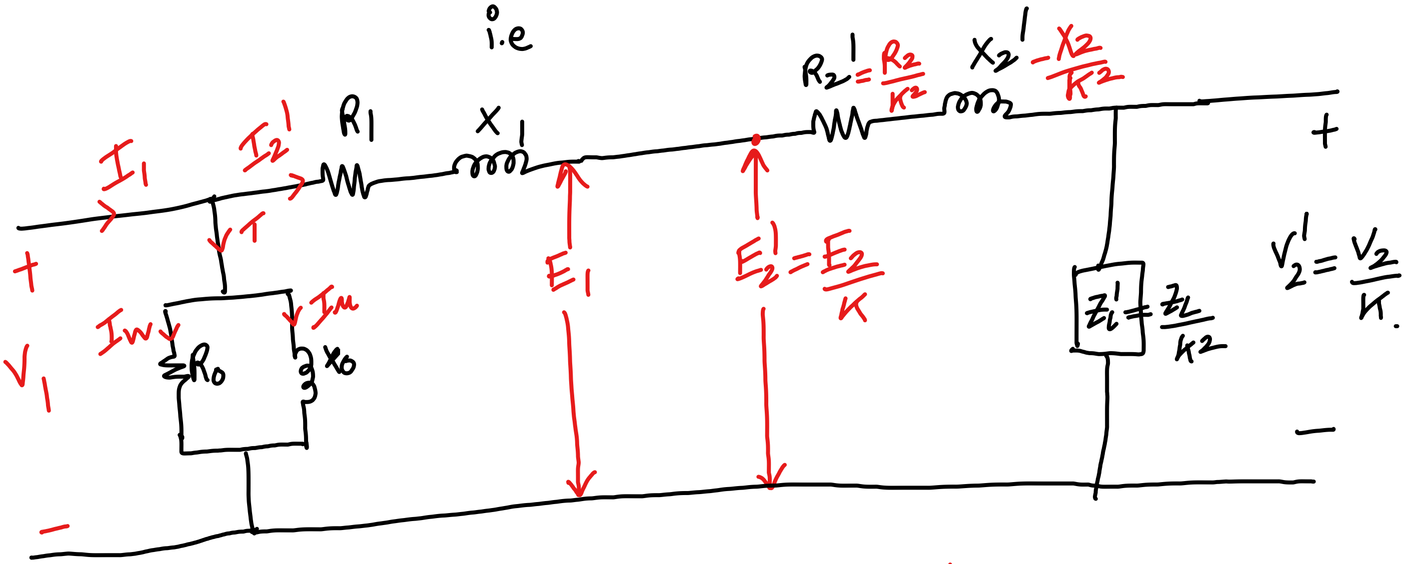
7. For fig 3, all secondary winding resistance (R_2) & reactances (X_2) are transferred to the primary by dividing them by K^2
→ Square of transformation ratio

8. E_2 & V_2 in secondary becomes $\frac{E_2}{K}$ & $\frac{V_2}{K}$

9. Secondary current is transferred to the primary by multiplying it by K^2

10. Now, we shift the parallel branch ($R_0 \parallel X_0$) to input side gives
→ Due to this, the primary & secondary impedances & resistances referred to the primary → can be added conveniently

i.e



$R_1 + R_2' = R_{01}$ & $X_1 + X_2' = X_{01}$

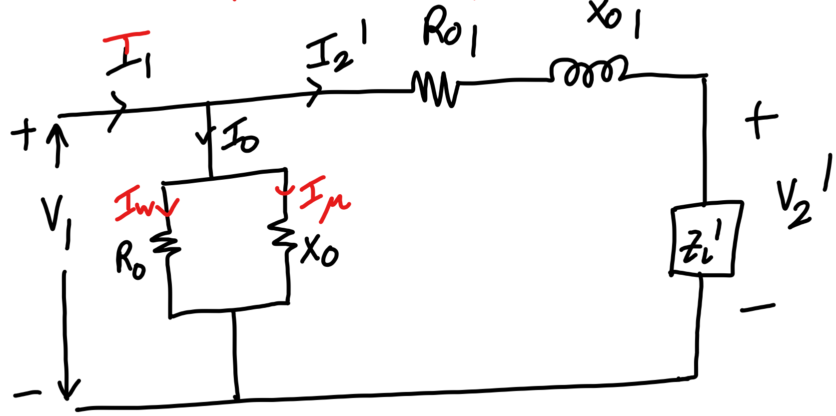


fig a

(11) Thus, we get the approximate equivalent circuit of the transformer as referred to the primary side as shown in fig a

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$$

$$Z_{01} = R_{01} + jX_{01} \rightarrow Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$$

fig 4: Approximate equivalent circuit of a transformer referred to primary

(12) Main parameters of the equivalent circuits are:

a) R_{01} : equivalent resistance of transformer as referred to primary side

b) X_{01} : equivalent reactances —||—

c) R_0 : equivalent core loss resistance

d) X_0 : Magnetizing reactance

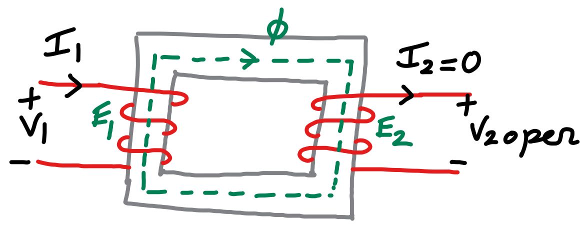
—x—

↓

"Topic below"

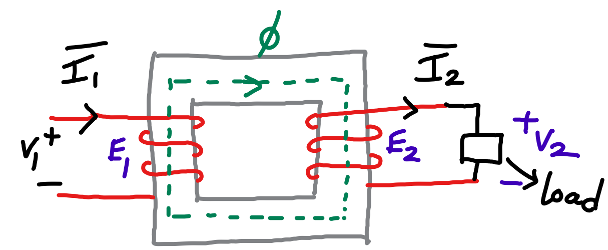
Transformer on load :

① When transformer is on no-load (i.e when secondary winding is open-circuit & $I_2 = 0$), primary winding draws a very small current 'I_0' and 'ϕ' is the main flux in the core



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

② When secondary winding is loaded → the secondary current 'I_2' is set-up



③ The magnitude & phase of I_2 w.r.t to V_2 is determined by nature of the load

④ When transformer is connected to load → the primary winding has two current components in it

a) One is I_0 → I_w, I_μ

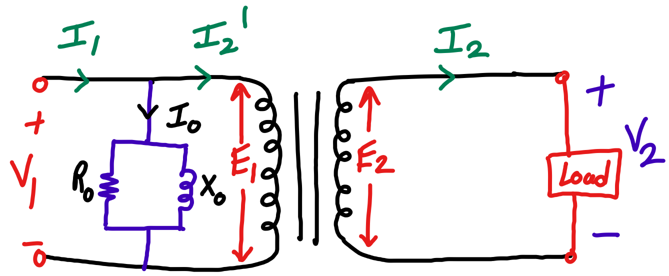
b) other is I_2'

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

⑤ Total primary current I_1 is the phasor sum of I_0 and I_2'

Phasor diagram of Transformer : (without considering winding resistance & leakage reactances)

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



$E_2 = 2$

① On primary side, $E_1 = -V_1$ but antiphase with each other

② On secondary side → $V_2 = E_2$ & E_2 & V_2 are in phase

③ Let us draw the phasor diagram for the following loads:

a) Resistive b) Inductive c) Capacitive

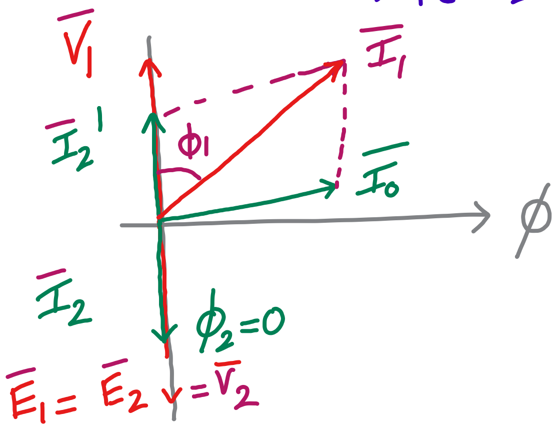
A] Load is resistive (unity p.f) & (K=1) → i.e $E_2 = E_1$

As we have resistive load → I_2 is in phase with V_2

ϕ - reference phasor

$E_1 = -V_1$

$\bar{I}_1 = \bar{I}_2' + \bar{I}_0$



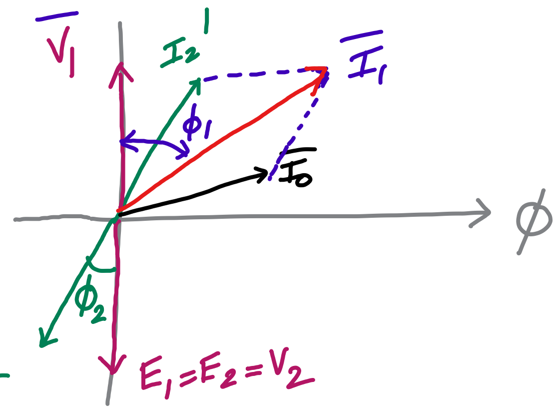
ϕ_1 - phase angle betn $\bar{V}_1$ & $\bar{I}_1$

ϕ_2 - phase angle betn $\bar{V}_2$ & $\bar{I}_2$

B] Load is inductive (lagging p.f) & (K=1) → $E_2 = E_1$

I_2 lags behind V_2 by an angle ϕ_2 90°

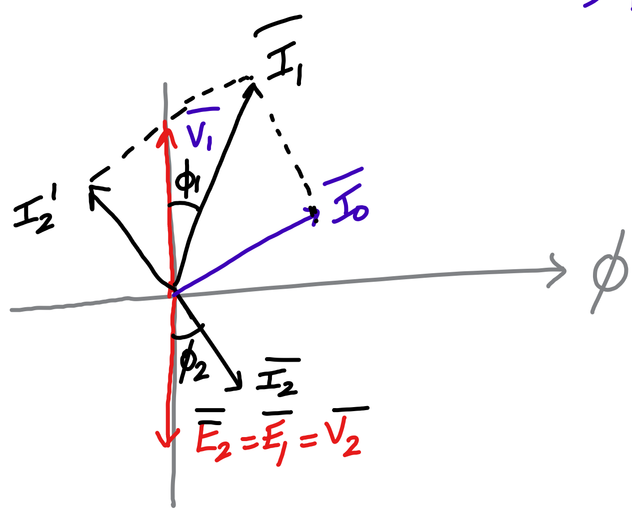
$\bar{I}_1 = \bar{I}_0 + \bar{I}_2'$



C] Load is capacitive (leading p.f) & (K=1) → $E_2 = E_1$

I_2 leads V_2 by ($\phi_2 < 90°$)

$\bar{I}_1 = \bar{I}_0 + \bar{I}_2'$



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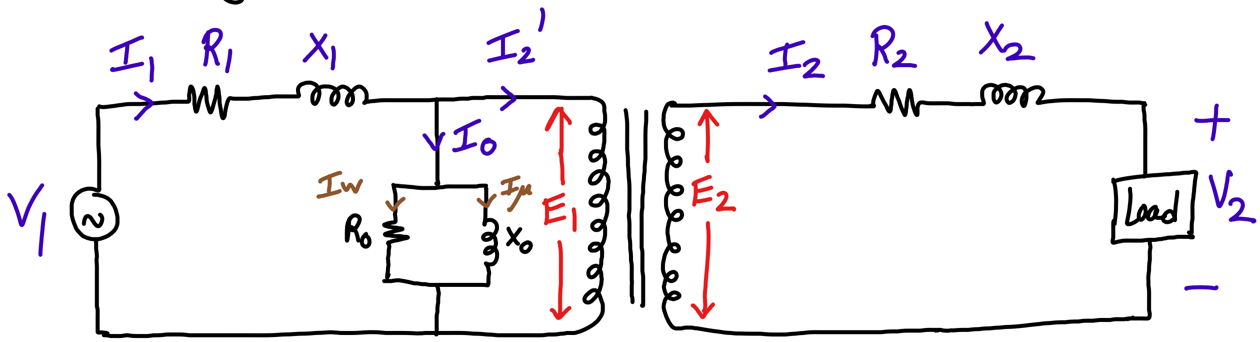
Phasor diagram of a Practical Transformer :



① $\bar{V_1} = \bar{I_1}\bar{R_1} + \bar{I_1}\bar{X_1} + (-\bar{E_1})$

② $\bar{E_2} = \bar{I_2}\bar{R_2} + \bar{I_2}\bar{X_2} + \bar{V_2}$

③ $\bar{I_1} = \bar{I_0} + \bar{I_2}'$

→ Phasor diagram can be drawn with the help of these 3 equations

A) When load is resistive (unity p.f)

→ Assume $K=1$ → $E_2 = E_1$

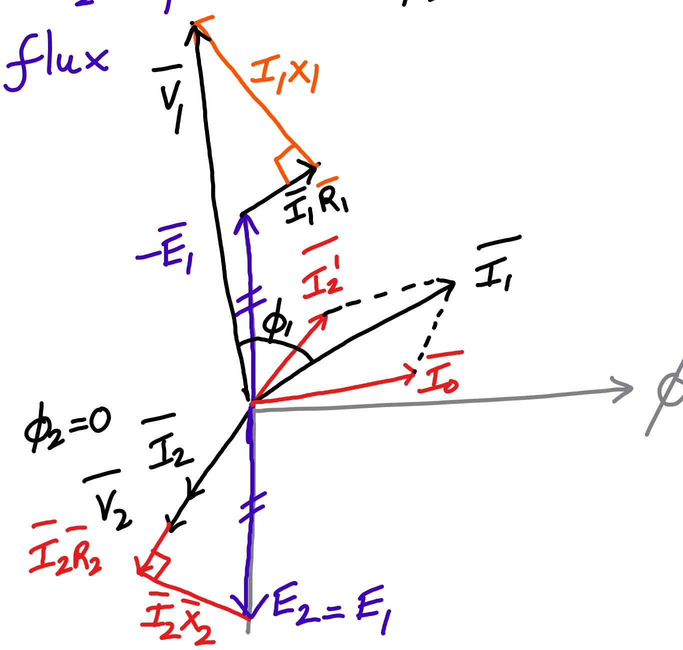
→ ϕ is reference flux

$\phi_2 = 0$ → Phase difference betn I_2 & V_2 is 0

✓ $\bar{V_1} = \bar{I_1}\bar{R_1} + \bar{I_1}\bar{X_1} - \bar{E_1}$

✓ $\bar{E_2} = \bar{I_2}\,{}_2 + \bar{I_2}\bar{X_2} + \bar{V_2}$

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



ϕ_1 → $\bar{V_1}$ & $\bar{I_1}$

ϕ_0 → $\bar{I_0}$ & $\bar{V_1}$

ϕ flux leads $\bar{E_1}$ & $\bar{E_2}$ by 90°

B] When load is inductive (lagging p.f)

→ Assuming $K = 1$ → $E_2 = E_1$

Due to inductive load → I_2 lags behind V_2 by ($\phi_2 < 90°$)

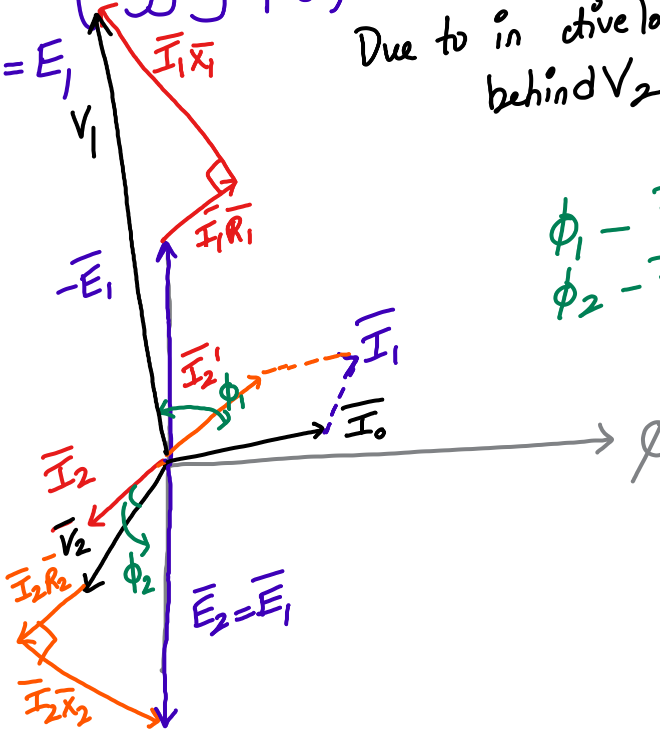
ϕ_1 – $\overline{V_1}$ & $\overline{I_1}$

ϕ_2 – $\overline{V_2}$ & $\overline{I_2}$

$$\overline{V_1} = \overline{I_1}\,\overline{R_1} + \overline{I_1}\,\overline{X_1} - \overline{E_1}$$

$$\overline{E_2} = \overline{I_2}\,\overline{R_2} + \overline{I_2}\,\overline{X_2} + \overline{V_2}$$

$$\overline{I_1} = \overline{I_0} + \overline{I_2}'$$



C] When load is capacitive (leading p.f):

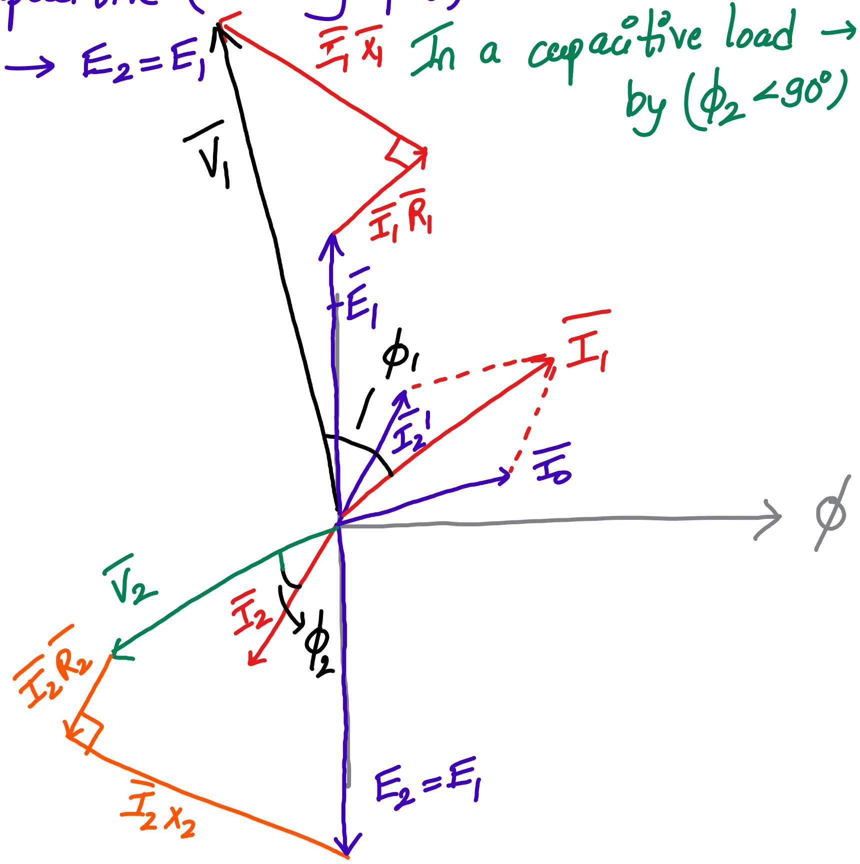
→ Assuming $K = 1$ → $E_2 = E_1$

In a capacitive load → I_2 leads V_2 by ($\phi_2 < 90°$)

$$\overline{V_1} = \overline{I_1}\,\overline{R_1} + \overline{I_1}\,\overline{X_1} - \overline{E_1}$$

$$\overline{E_2} = \overline{I_2}\,\overline{R_2} + \overline{I_2}\,\overline{X_2} + \overline{V_2}$$

$$\overline{I_1} = \overline{I_0} + \overline{I_2}'$$



$\phi_2 \rightarrow \overline{V_2}$ & $\overline{I_2}$

$\phi_1 \rightarrow \overline{V_1}$ & $\overline{I_1}$

— X —