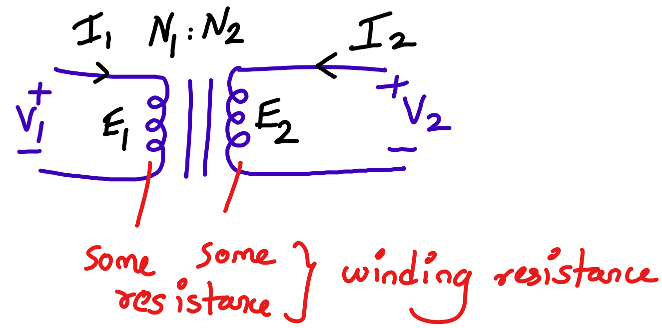
EEEE lec 43b 23/06/23

Transformer losses :

↳ Main losses that occur in a transformer are Copper loss and Iron loss

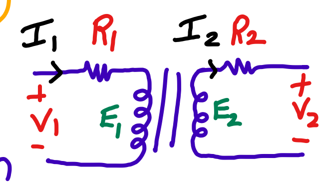


A) Copper loss (W_{Cu}) :

i) In a transformer, windings are not Ideal

ii) Every winding has some resistance

iii) The loss that takes place due to winding resistance is called "Copper loss" (as windings are made of Copper)



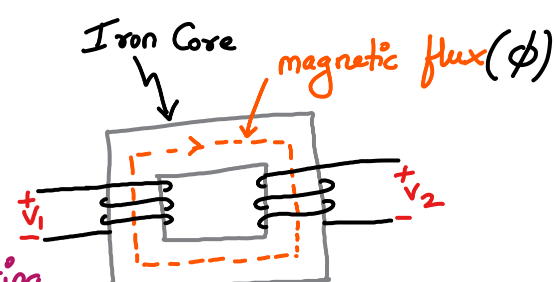
iv) If R_1 is resistance of the primary winding and R_2 is resistance of the secondary winding, then

Primary Cu loss $= I_1^2 R_1$ W — (1)

Secondary Cu loss $= I_2^2 R_2$ W — (2)

∴ Total Copper loss, $W_{Cu} = (I_1^2 R_1 + I_2^2 R_2)$ W — (3)

v) From the above equations ⟶ it is clear that copper loss varies with square of the current



B) Iron loss or Core loss (W_i) :

i) Due to applied AC voltage ⟶ an alternating flux is produced in the core

ii) When any magnetic material is placed in alternating magnetic field ⟶ the hysteresis loss & eddy current loss take place

iii) Thus, the hysteresis loss and eddy current loss take place inside the magnetic core of a transformer

iv) Hysteresis loss + Eddy current loss = Core loss

v) These two losses are together called 'Core loss'

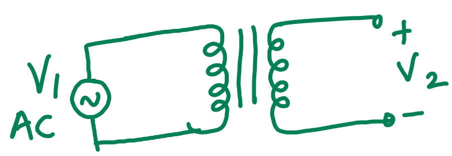
vi) Since the core is made of iron → it is also termed as 'Iron loss'

→ Core loss is proportional to applied voltage

Since, applied voltage is almost constant

Thus, core loss remains constants for all loads

I] Hysteresis loss :



a) Since the supply to the primary is alternating (ie V_1 is AC signal) → the core gets alternately magnetized and de-magnetized → causing loss of energy → This is called 'Hysteresis loss'

b) This loss is given by,

$$\boxed{W_h = \eta B_{max}^{1.6} f V} \quad W$$

→ Hysteresis loss in Watts

B_{max} – max value of flux density in Tesla

f – frequency of magnetic reversal in Hz

V – Volume of the material

η – Steinmetz constant

c) This loss can be minimized by selecting material for the core that has low hysteresis co-efficient

II] Eddy current loss :

i) This loss is due to eddy current induced in the transformer core

ii) It is seen in the form of heat in the core

iii) This loss is given by,

$$\boxed{W_e = K B_{max}^2 f^2 t^2 V} \text{ W}$$

W_e → Eddy current loss in Watts

K – eddy current co-efficient

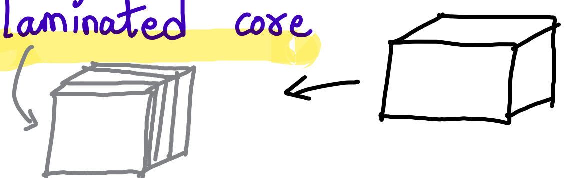
B_{max} – max value of flux density

t – thickness of lamination

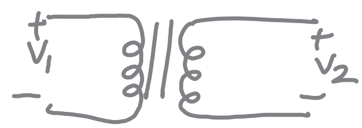
f – frequency of flux reversal

V – volume of material

iv) This loss can be minimized by using laminated core



Note : a) When a magnetic material is linked with a alternating flux → an emf is induced in the magnetic material itself as per Faraday's law



b) This induced emf 'circulates' a current in the body of the magnetic material

c) These circulating currents are called "eddy current"

— x —

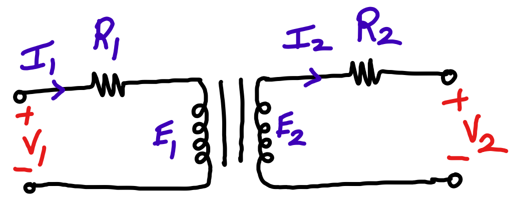
Transformer parameters:

- → Winding resistance (R_1 & R_2)
- → Leakage reactance (X_1 & X_2)
- → Impedance (Z_1 & Z_2)

A] Winding Resistance (R_1 & R_2):

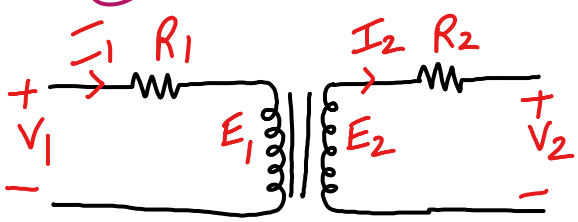
1) R_1 : primary winding resistance
   R_2 : secondary winding resistance

2) In practical transformer → there is always some resistance of primary & Secondary winding

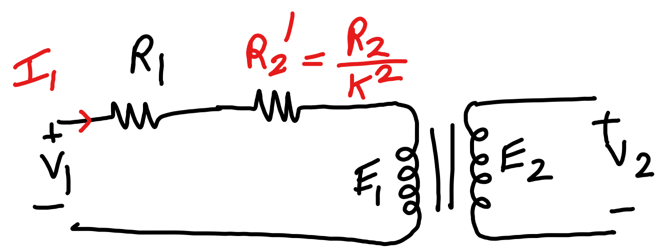


Transformer with winding resistance

3) The resistances (R_1 & R_2) of the two windings can be transferred to either of the two windings. → Advantage: Calculation become very simple & easy



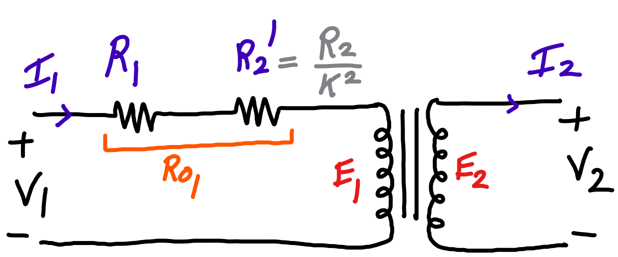
→



4) It can be proved that a resistance R_2 in secondary → is equivalent to $\frac{R_2}{K^2}$ in primary (i.e $R_2' = \frac{R_2}{K^2}$)

5) Value of $\frac{R_2}{K^2}$ is denoted by R_2'

6) R_2' : Equivalent secondary resistance as referred to primary



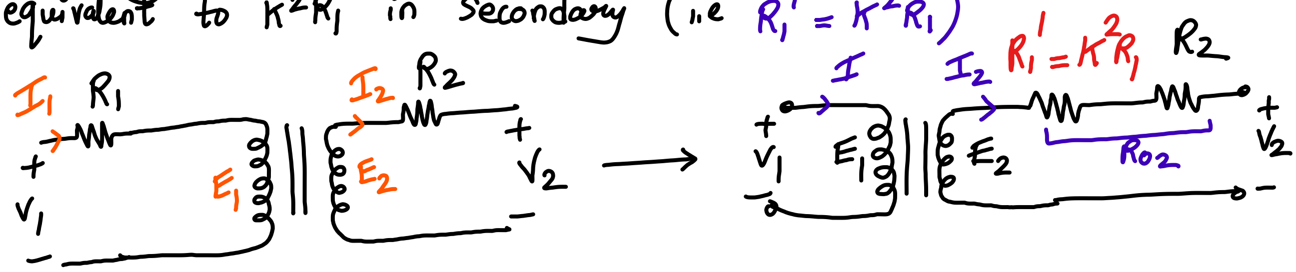
Shifting of winding resistance to primary

7) $$R_{o_1} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

R_{o_1} : Equivalent resistance of the transformer as referred to primary

→ Copper loss $\boxed{W_{Cu} = I_1^2 R_{o_1}}$ W

8. Similarly, it can be proved that a resistance of R_1 in primary is equivalent to K^2R_1 in secondary (i.e $R_1' = K^2R_1$)



9. Value of K^2R_1 is denoted by R_1'

10. R_1' : Equivalent primary resistance as referred to secondary

→ Copper loss : $\boxed{W_{Cu} = I_2^2 R_{02}}$ W

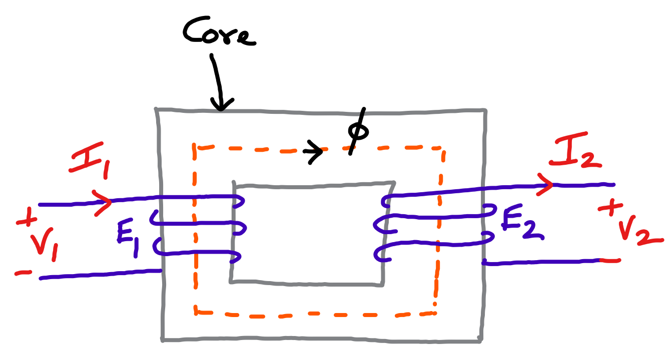
11. $R_{02} = R_2 + R_1' = R_2 + K^2R_1$

R_{02} : Equivalent resistance of the transformer as referred to secondary

—x—

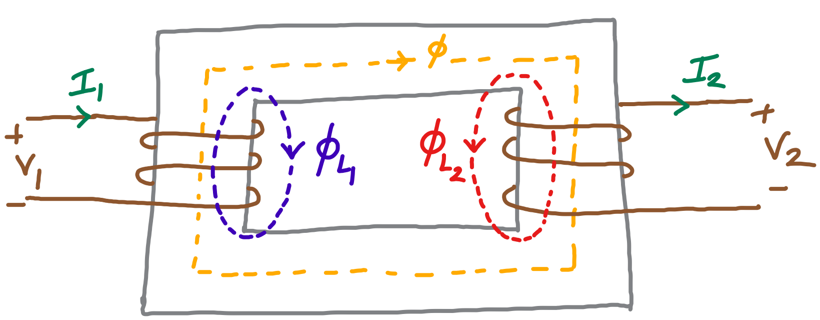
B] Leakage Reactance (X_1 & X_2) :

i) In an ideal transformer → it is assumed that all the flux produced by the primary winding Links → both the primary and secondary windings



ϕ - main flux Linking primary & secondary winding

ii) In practise, all the flux linked with primary does not Link with secondary

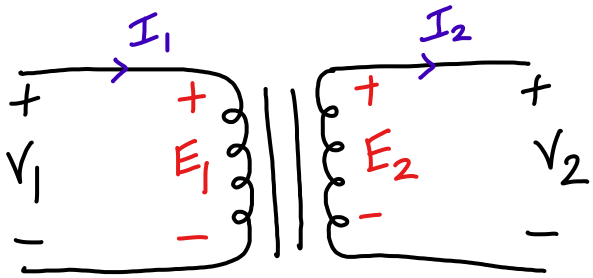


Magnetic leakage

iii) As shown in figure, some part of primary flux 'ϕ_{L_1}' completes it's path by passing through the air rather than around the core

iv) Flux ϕ_{L_1} is called 'primary leakage flux' which Links to primary winding & does not Link to secondary winding

v) Similarly, ϕ_{L2} is called 'secondary leakage flux' → which links to secondary winding and does not link to primary winding



vi) Flux 'ϕ' which passes through the core & links both windings is called '<u>Mutual flux</u>'

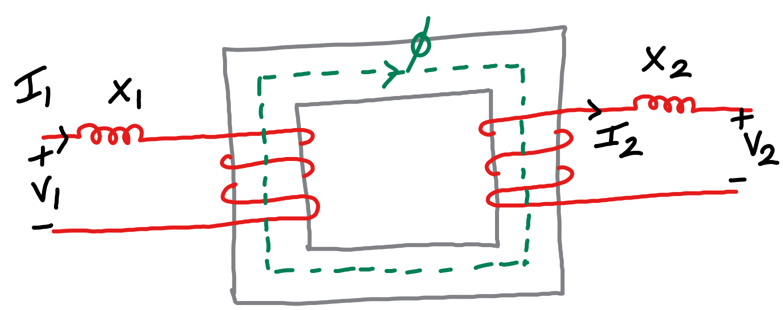
vii) EMF's induced voltages E_1 & E_2 are caused by the main flux 'ϕ'

viii) Flux 'ϕ_{L_1}' is in time phase with I_1 & induces an emf E_{L_1} in primary but not in secondary

ix) Flux 'ϕ_{L_2}' is in time phase with I_2 & induces an emf E_{L2} in secondary but not in primary

x) The leakage flux linking with each winding → produces a self-induced emf in that winding → i.e it is equivalent to a <u>small inductive coil in series</u> with each winding such that

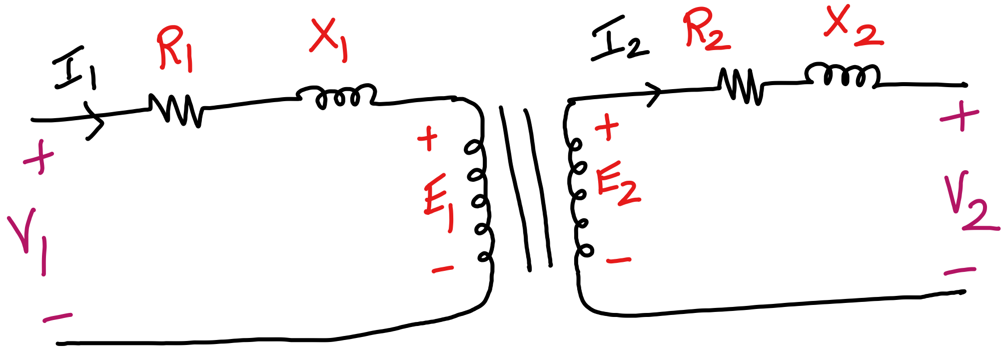
$$\boxed{\begin{aligned} E_{L_1} &= I_1 X_1 \\ \text{and} \quad E_{L2} &= I_2 X_2 \end{aligned}}$$



Transformer with leakage reactance

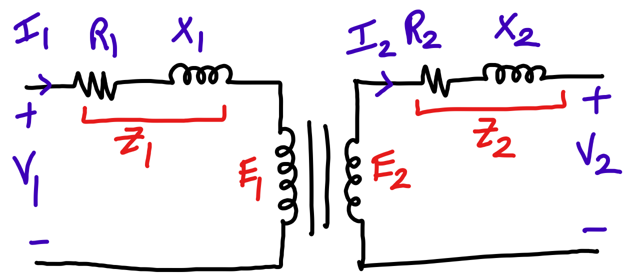
xi) X_1 and X_2 are known as primary and secondary leakage reactances

Note: X_1 and X_2 represents the effects of primary and secondary leakage fluxes



Transformer with winding resistance and leakage reactance

C] Impedance :



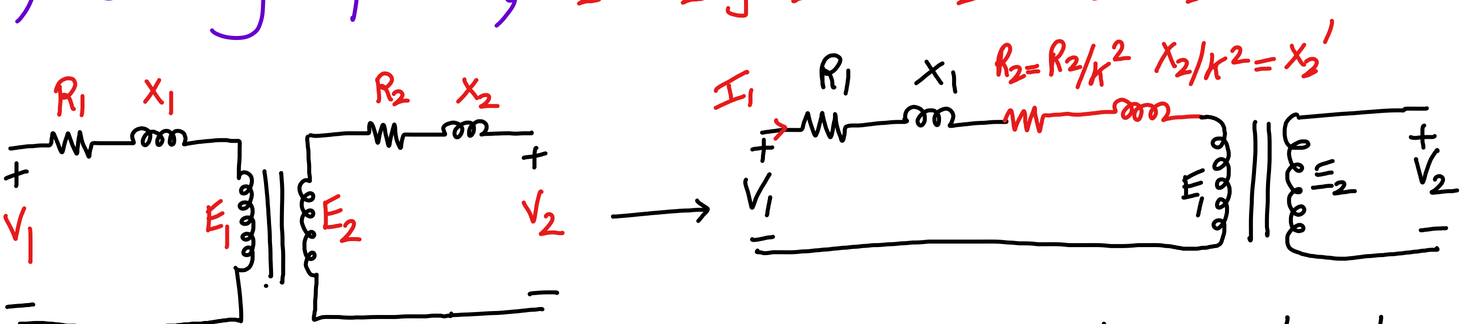
i) In practical transformer, winding has some resistance (R_1 & R_2)

ii) Also in a practical transformer, there is some leakage flux present near the primary and secondary winding

iii) Effect of primary & secondary leakage fluxes are represented by reactances X_1 and X_2

iv) Primary impedance, $Z_1 = R_1 + jX_1 \rightarrow Z_1 = \sqrt{R_1^2 + X_1^2}\ \Omega$

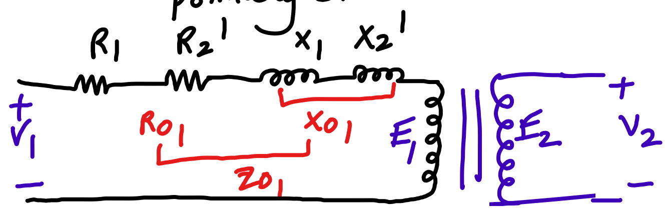
v) Secondary impedance, $Z_2 = R_2 + jX_2 \rightarrow Z_2 = \sqrt{R_2^2 + X_2^2}\ \Omega$



vi) The equivalent resistance of transformer as referred to primary is,

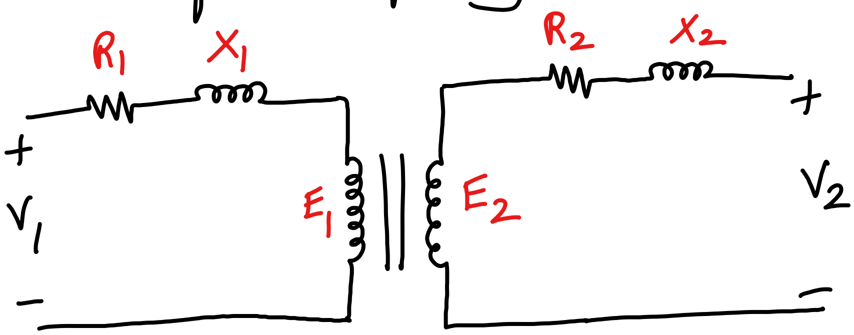
$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

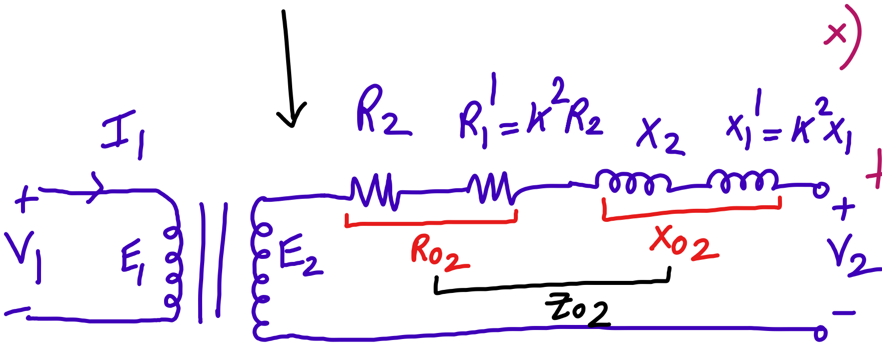
Shifting of parameters to primary side



vii) Similarly, the equivalent reactance of transformer as referred to primary is $X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$

viii) The equivalent impedance of transformer as referred to primary is $Z_{01} = R_{01} + jX_{01}$; $Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}$





Shifting of parameters to secondary side

ix) The equivalent resistance of the transformer as referred to secondary is,

$$R_{02} = R_2 + R_1' = R_2 + K^2 R_1$$

x) The equivalent reactance of the transformer as referred to secondary is,

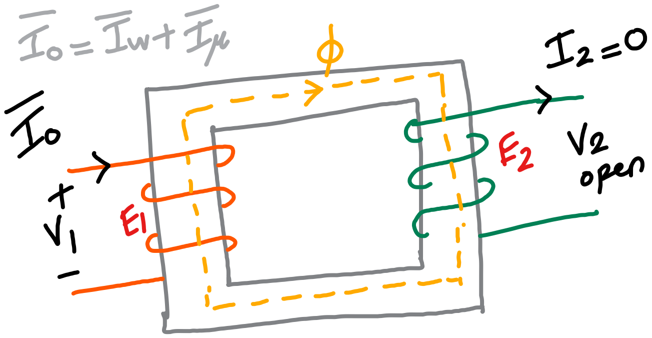
$$X_{02} = X_2 + X_1'$$
$$X_{02} = X_2 + K^2 X_1$$

xi) The equivalent impedance of the transformer as referred to secondary is,

$$Z_{02} = R_{02} + jX_{02}$$
$$Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}\ \Omega$$

—— × ——

Transformer on No Load :



Transformer (on No Load)

① A transformer is on 'No Load' when its secondary winding → is open-circuited i.e $I_2 = 0$

② Under such a condition → the primary input current 'I_1' has to supply

a) Iron loss in the core and

b) Copper loss in primary winding only

③ Primary winding has some winding resistance → thus no load primary input current (I_0) lags behind V_1 by angle $\phi_0 < 90°$

④ Primary current 'I_0' under no-load condition can be split into two components

a) Iron loss component 'I_w'

b) Magnetizing component 'I_μ'

⑤ Iron loss (Active or Working) component (I_w) is in phase with V_1

⑥ I_w supplies for iron losses

⑦ Magnetizing component (I_μ) in quadrature with V_1

⑧ I_μ current component is Wattless & it's function is to sustain (or maintain) the alternating flux in the core.

⑨ Current I_0 is vector sum of I_w & I_μ

⑩ From phasor diagram, since the main flux ϕ is common to both the winding → ϕ is cho as reference phasor

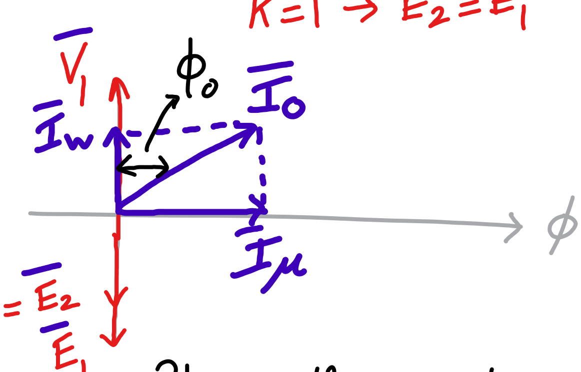
ϕ_0 – phase betn $\bar{V_1}$ & $\bar{I_0}$

$$I_0^2 = I_w^2 + I_\mu^2$$

$$I_w = I_0 \cos\phi_0$$

$$I_\mu = I_0 \sin\phi_0$$

$K = 1 \rightarrow E_2 = E_1$



Phasor diagram at "no load"

(11) No-load power input is, $\boxed{W_0 = V_1 I_0 \cos\phi_0}$ W

$\cos\phi_0 \rightarrow$ p.f at o load

(12) Iron loss, $W_i = V_1 I_0 \cos\phi_0$

(13) From phasor diagram $\rightarrow$ since the flux ϕ is common to both the windings $\longrightarrow$ flux ϕ is chosen as reference

a) ϕ_0 : No load p.f angle

— x —