R.N.G.P.I.T, Bardoli
Electrical Engineering Department

Subject: Electrical Machine-I

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Subject: Electrical Machine-I

- This Lecture contains

- Basic Principle of Transformer
- Phasor Diagram of Transformer

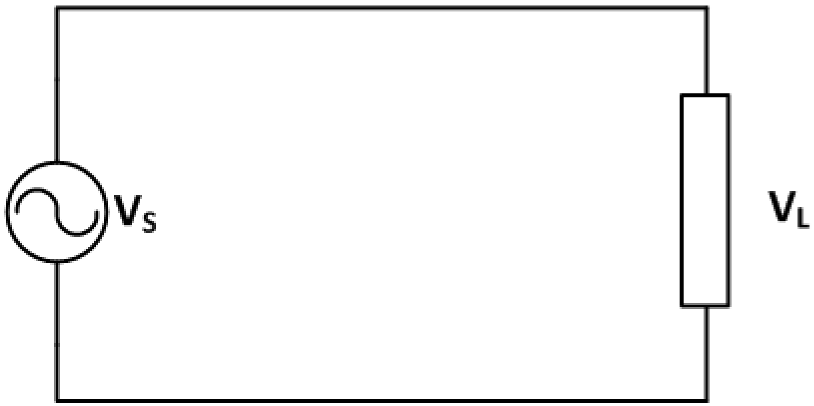
Syllabus·

Transformers:

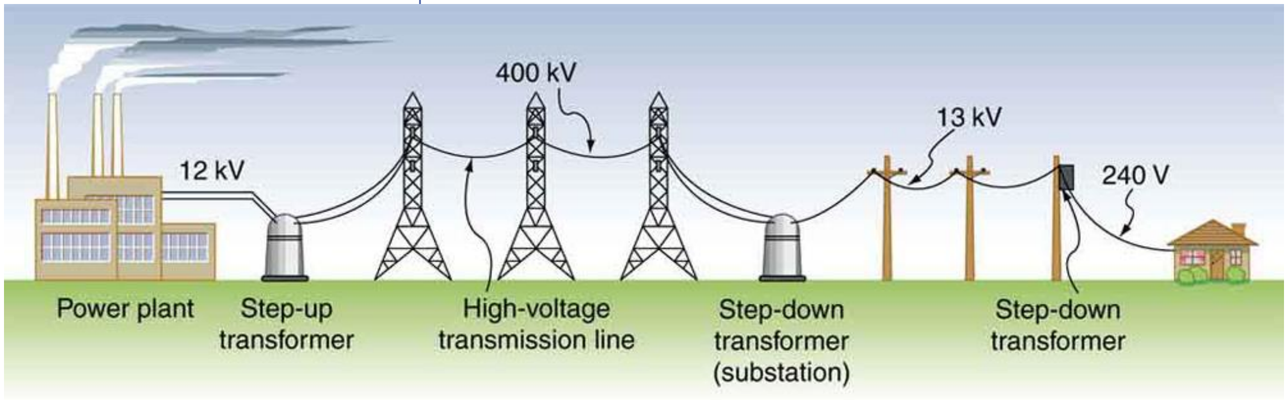
Review of construction and working principle of single-phase and three-phase transformers, equivalent circuit, phasor diagram, voltage regulation, losses and efficiency. Testing - open circuit and short circuit tests, polarity test, back-to-back test, separation of hysteresis and eddy current losses

Three-phase transformer - construction, types of connection and their comparative features, Vector groups, Parallel operation of single-phase and three-phase transformers, Autotransformers - construction, principle, applications and comparison with two winding transformer, Magnetizing current, effect of nonlinear B-H curve of magnetic core material, harmonics in magnetization current, Phase conversion - Scott connection, three-phase to six-phase conversion, Tap-changing transformers - No-load and on-load tap-changing of transformers, Three-winding transformers. Cooling of transformers.

- Problem associated with High voltage generation or utilization



If generator voltage increases then amount of insulation is also increases



- Application of transformer

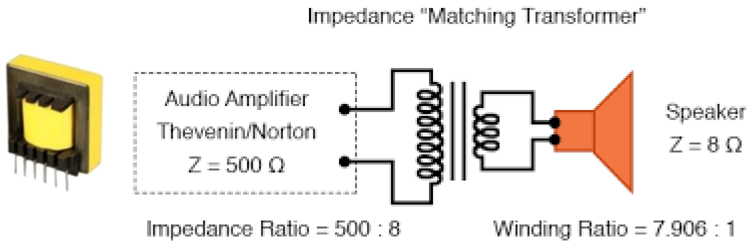
High Power Transmission

Impedance matching transformer

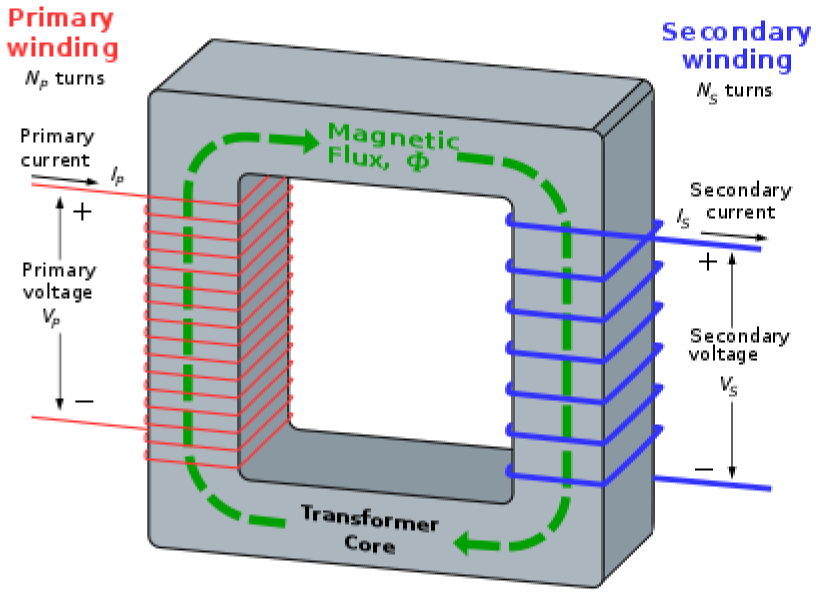
Isolation Transformer

High frequency transformer

Auto transformer, Current Transformer, Pulse transformer



- Transformer: Transfer electrical energy from one electrical circuit to another without electrical connection between two circuit
- This electrical circuit are magnetically coupled through a common core.
- Principle: Electromagnetic induction
- Voltage, Power , frequency?

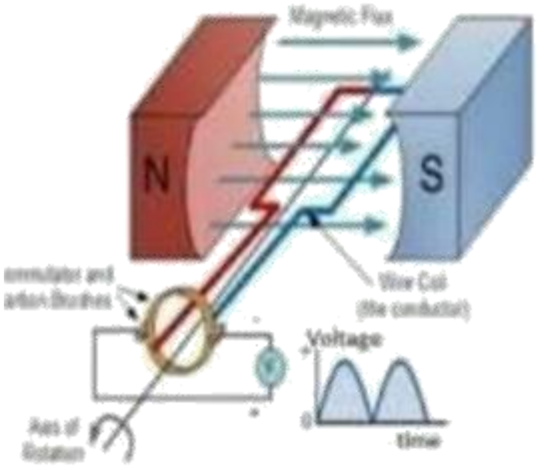


- *Emf induced in the transformer is statically induced emf*

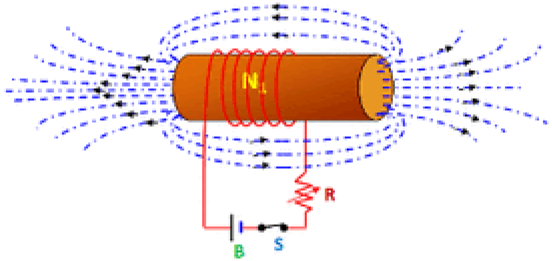
- *Statically induced emf= conductor is stationary and field is varying with the time*
- *Faradays second law:*

$$E_s \propto \text{rate of change of flux linkages}$$

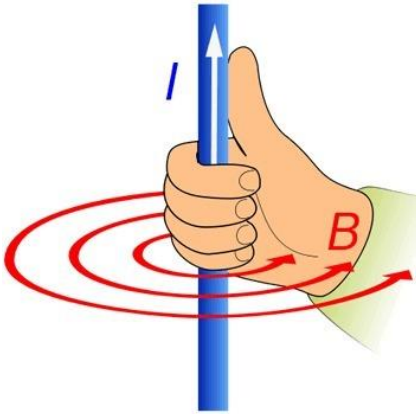
$$E_s \propto -\frac{d}{dt}(N\phi) \qquad E_s \propto -N\frac{d\phi}{dt}$$

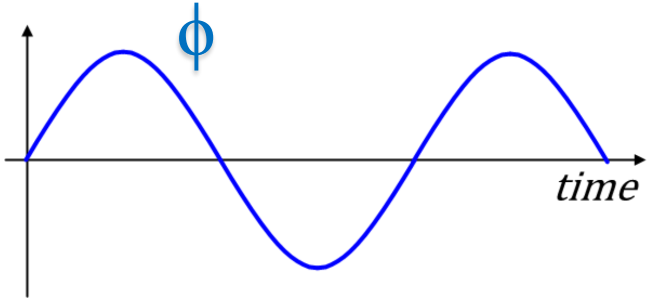


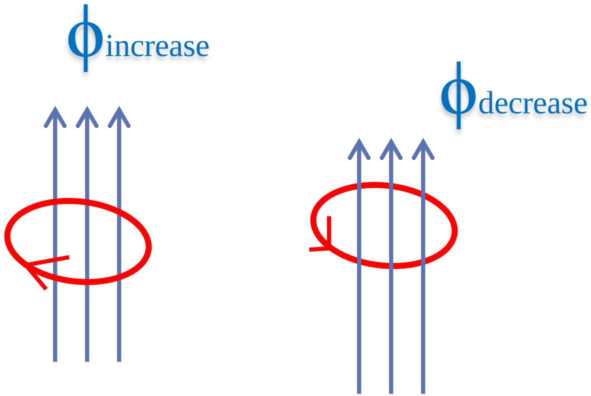
DC Generator



- Negative sign is due to Lenz's law
- Right hand thumb rule





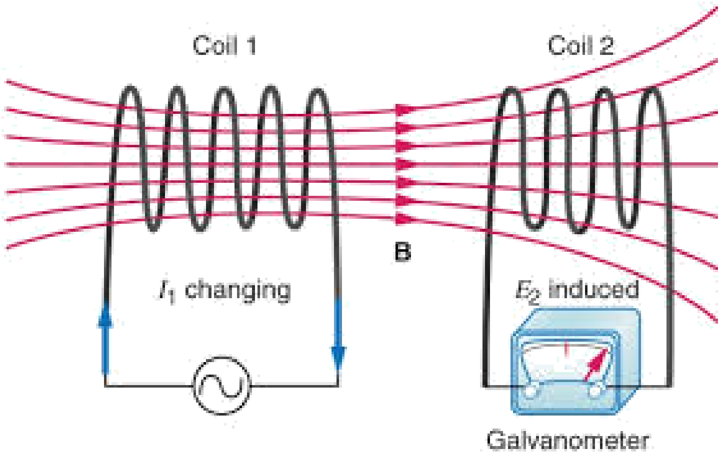


- Statically induced emf type: 1) self induced emf and 2) mutually induced emf

- Self induced emf

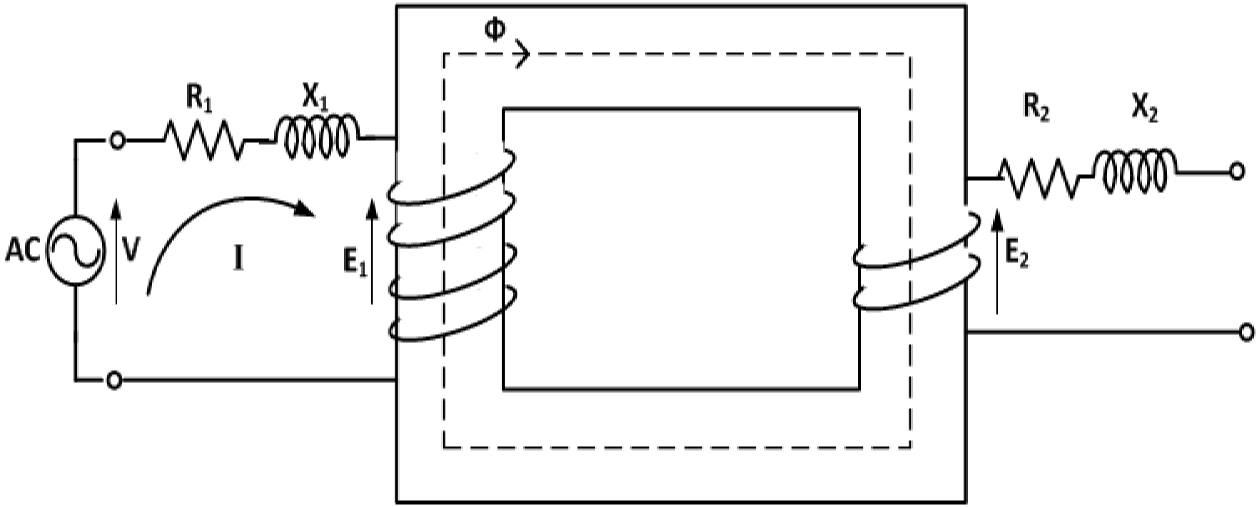
- Mutually induced emf

- When two coils are inductively coupled & if current in one coil changed uniformly then emf gets induced in the other coil



- Emf induced in the primary of transformer is self induced emf

- Emf induced in the secondary is due to mutual inductance



- *EMF equation of Transformer:*

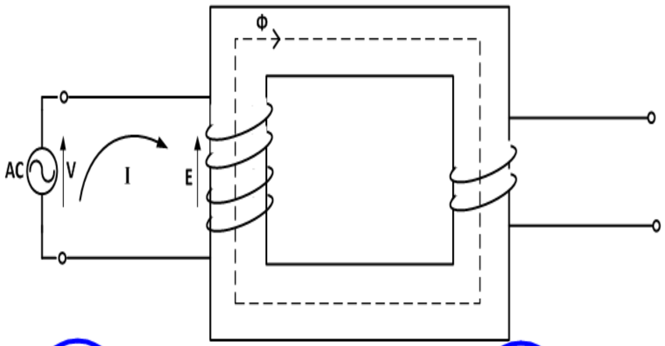
- N_1= No. of turns in primary
- N_2= No. of turns in secondary
- Φ_m =maximum flux in the core=Bm*A
- F =frequency of ac input

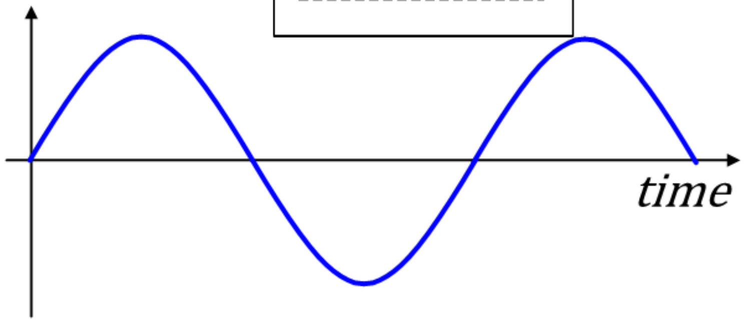
$$Average\ rate\ of\ change\ of\ flux = \frac{\phi_m}{1/4f} = 4f\phi_m \text{ wb/s or volt}$$

$$Average \text{ emf/}turn = 4f\phi_m \text{ volt}$$

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Mean value}} = 1.11$$

$$RMS\ value\ of\ emf\ /\ turn = 4.44f\phi_m \text{ volt}$$





$$RMS\ value\ of\ emf\ induced\ in\ primary = 4.44f\phi_m N_1 \text{ volt}$$

$$RMS\ value\ of\ emf\ induced\ in \text{ secondary} = 4.44f\phi_m N_2 \text{ volt}$$

- ## *EMF equation of Transformer:*

$$E_1 = 4.44\, f \phi_m N_1 \text{ volt}$$

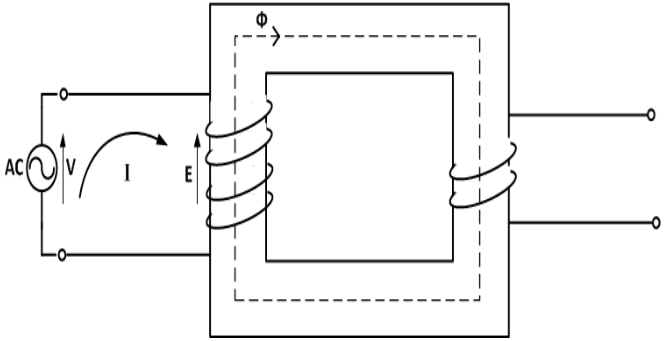
$$E_2 = 4.44\, f \phi_m N_2 \text{ volt}$$

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

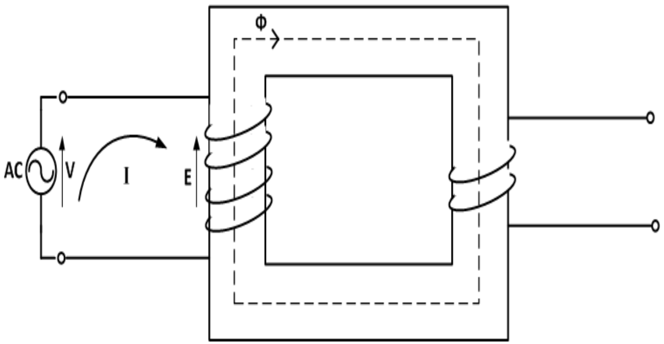
For an ideal transformer input VA=output VA

$$V_1 I_1 = V_2 I_2$$

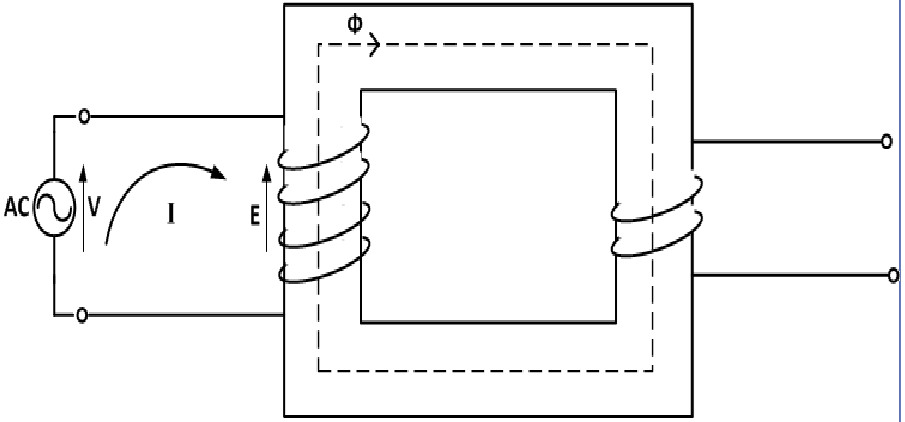
$$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$



- A 25 KVA transformer has 500 turns on the primary and 50 turns on the secondary windings. The primary is connected to 3000-V, 50 Hz supply. Find the full load primary and secondary currents, the secondary emf and the maximum flux in the core. Neglect leakage drop and no load primary current.



- *Ideal Transformer*
- *No Ohmic resistance, No Loss*
- *Permeability of the transformer core is infinite (no magnetizing current required to established the flux)*
- *Hysteresis & eddy current losses are zero*
- *No magnetic leakage (X1=X2=0)*
- *Magnetization curve is linear*



- *Transformer with finite permeability*
- *magnetizing component of current*

$$i_\mu = I_m \sin \omega t$$

$$\text{Primary MMF} = N_1 \cdot i_\mu$$

$$\text{Primary MMF} = N_1 \cdot i_m \sin \omega t$$

$$\text{Flux} = \frac{MMF}{\text{Reluctance}} = \frac{N_1 \cdot i_m \sin \omega t}{R} = \phi_m \sin \omega t$$

$$E_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt} \phi_m \sin \omega t$$

$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$

- *The primary induce emf lags the flux by 90⁰*

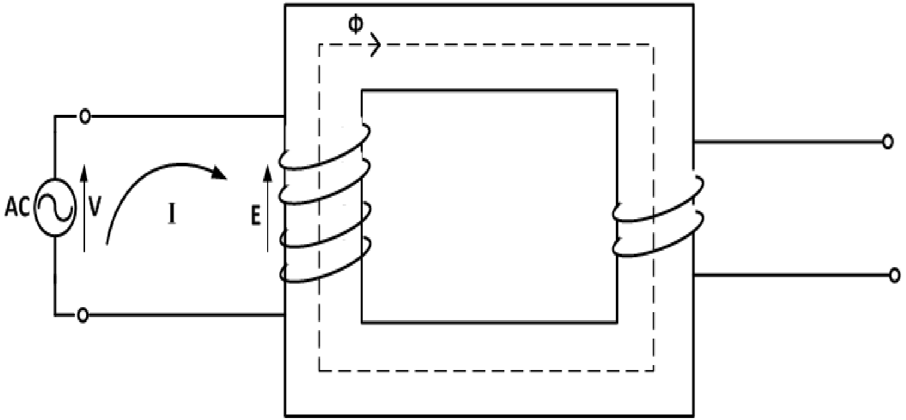
$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$

$$E_{1max} = N_1 \omega \phi_m$$

$$E_1 = \frac{E_{1max}}{\sqrt{2}} = N_1 2\pi f \phi_m / \sqrt{2}$$

$$E_1 = 4.44 N_1 f \phi_m$$

$$E_1 = 4.44 N_1 f B_m A$$



$$E_2 = -N_2 \frac{d\phi}{dt}$$

$$E_2 = 4.44 N_2 f B_m A$$

$$\frac{E_1}{N_1} = 4.44 f B_m A = \frac{E_2}{N_2}$$

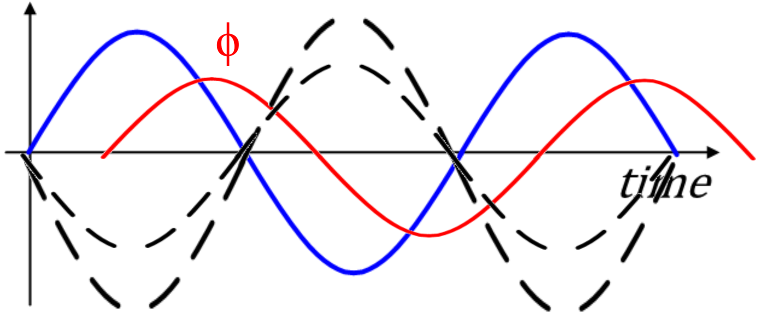
$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k$$

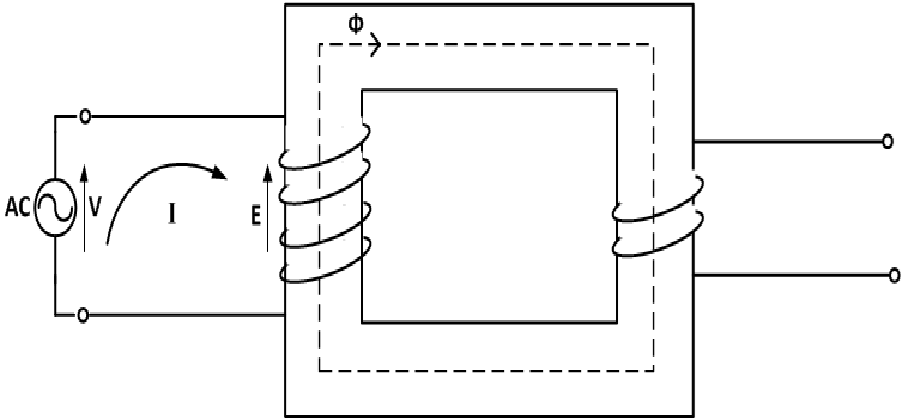
- *Phasor diagram*

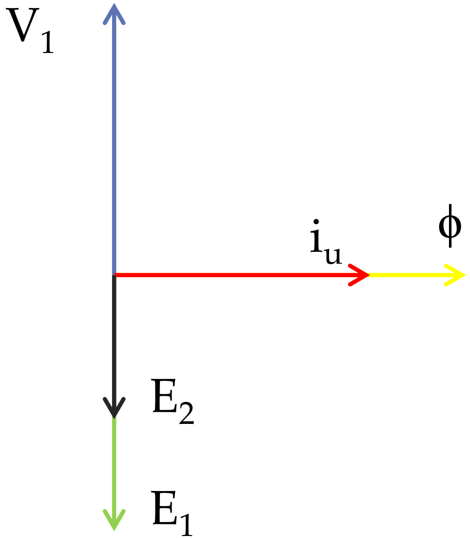
$$\phi = \phi_m \sin \omega t$$

$$i_\mu = I_m \sin \omega t$$

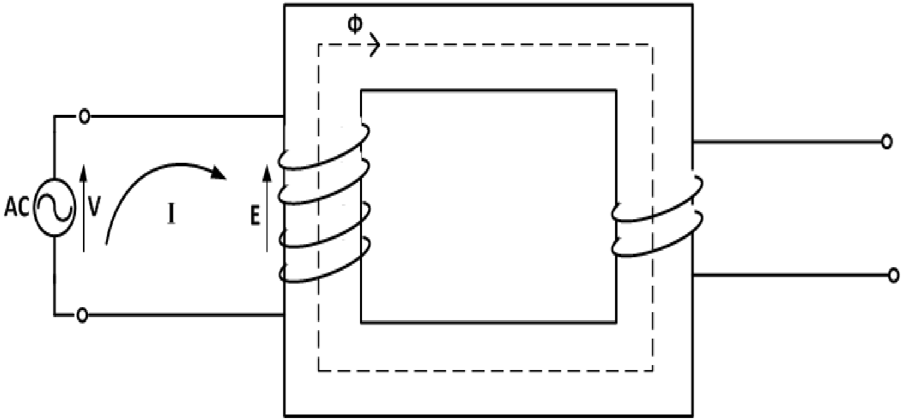
$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$







- *Transformer with iron loss*



- *Magnetizing component of current* i_μ
- *Iron loss component of current* i_ω
- *No load current is the summation of these two components*

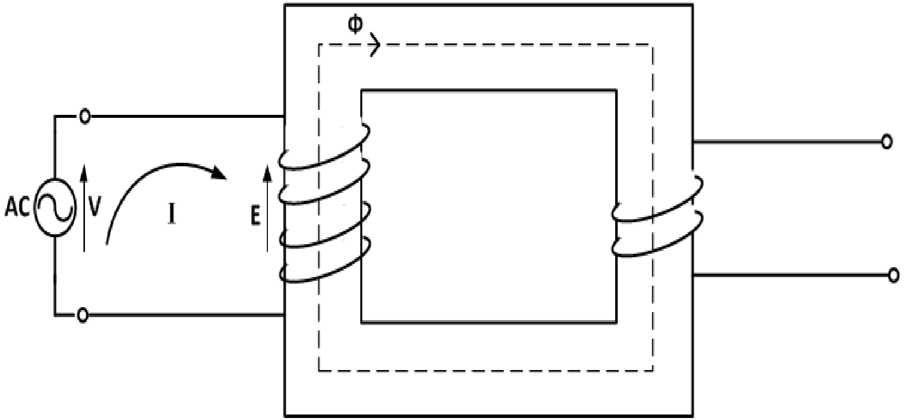
$$\overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

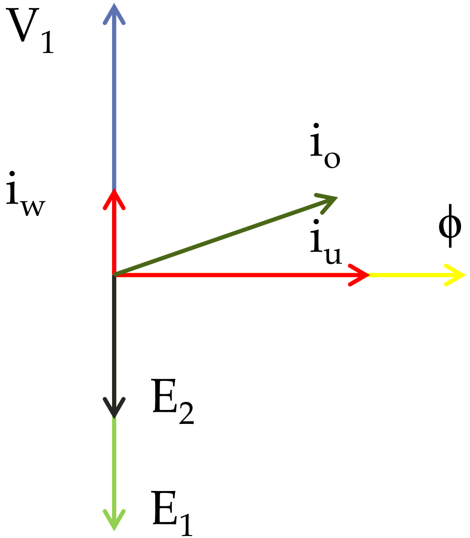
- *Phasor diagram with iron loss*

$$\phi = \phi_m \sin \omega t$$

$$i_\mu = I_m \sin \omega t \qquad \overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$





- *Phasor diagram with Resistive load*

$$\phi = \phi_m \sin \omega t \qquad \overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

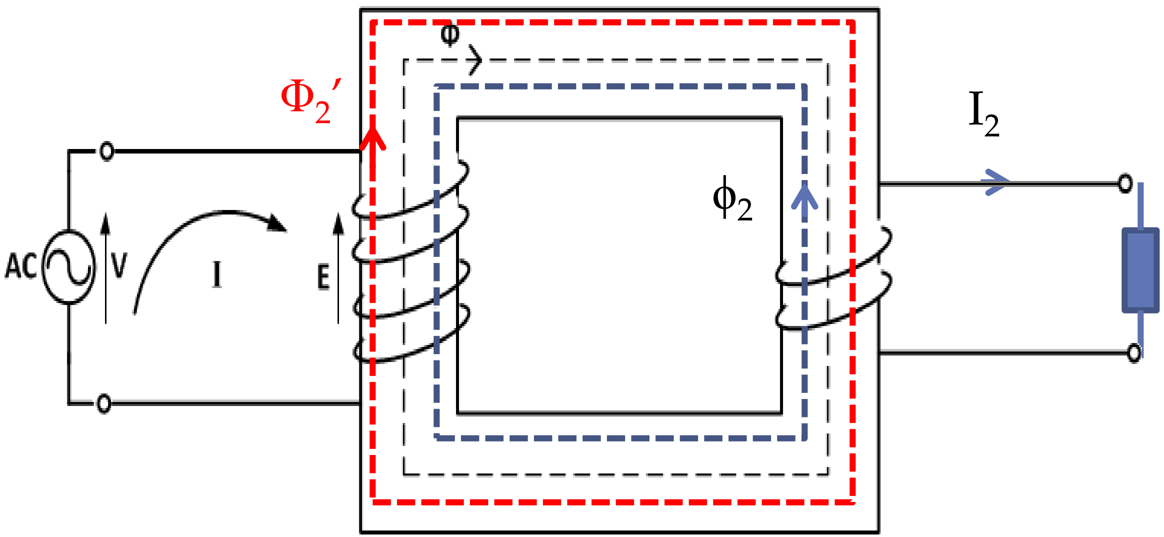
$$i_\mu = I_m \sin \omega t \qquad \overline{i_1} = \overline{i_0} + \overline{i_2^{'}}$$

$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$

$$\phi_2 = \phi_2^{'}$$

$$N_2 I_2 = N_1 I_2^{'}$$

$$I_2^{'} = K I_2$$



- *Phasor diagram with Resistive load*

$$\phi = \phi_m \sin \omega t \qquad \overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

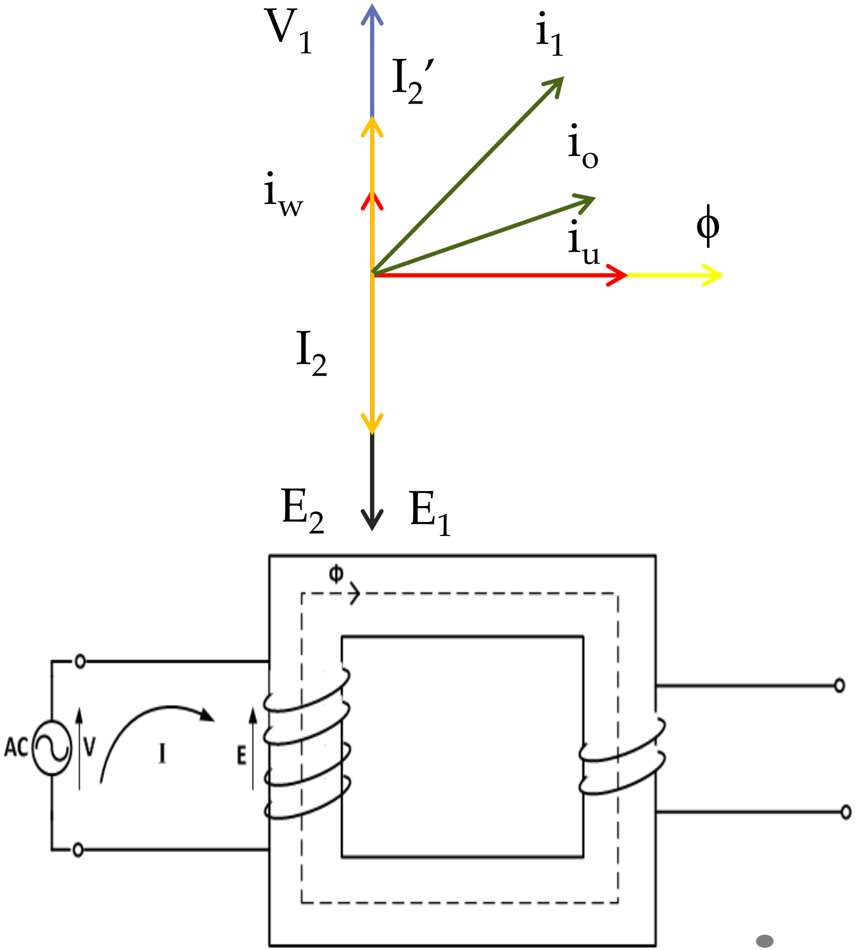
$$i_\mu = I_m \sin \omega t \qquad \overline{i_1} = \overline{i_0} + \overline{i_2'}$$

$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$

$$\phi_2 = \phi_2'$$

$$N_2 I_2 = N_1 I_2'$$

$$I_2' = K I_2$$

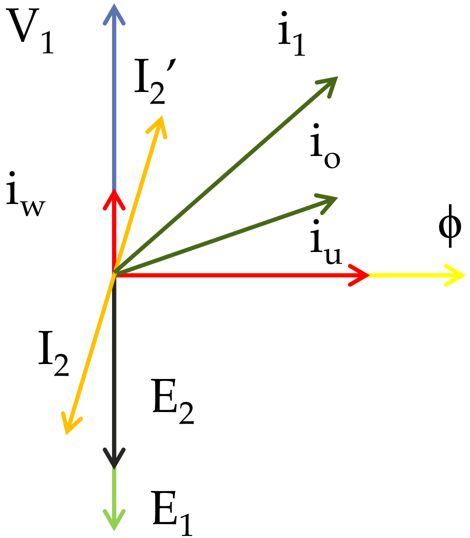


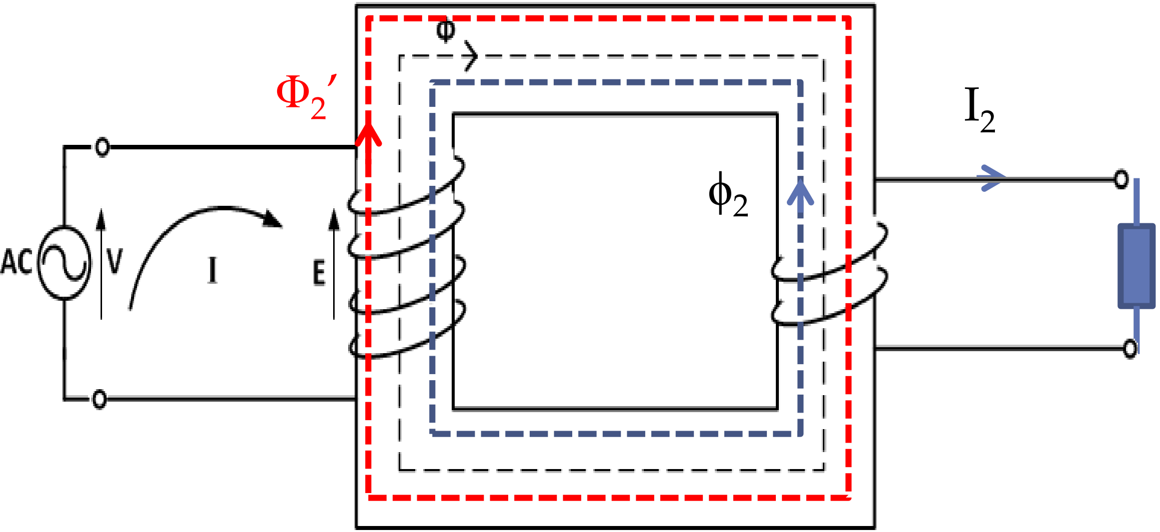
- *Phasor diagram with lInductiveoad*

$$\phi = \phi_m \sin \omega t \qquad \overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

$$i_\mu = I_m \sin \omega t \qquad \overline{i_1} = \overline{i_0} + \overline{i_2^{'}}$$

$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$





- *Transformer with winding Resistance*

$$\phi = \phi_m \sin \omega t \qquad \overline{i_o} = \overline{i_\mu} + \overline{i_\omega}$$

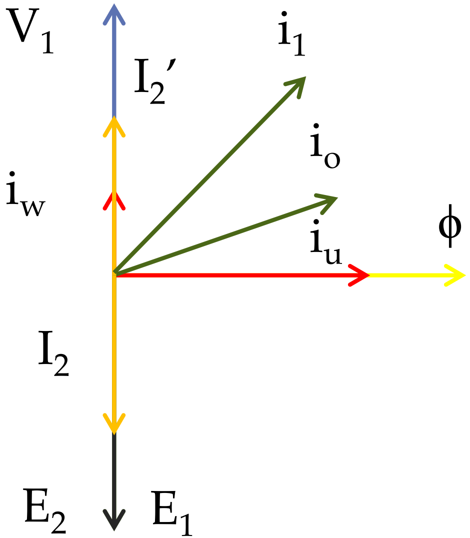
$$i_\mu = I_m \sin \omega t \qquad \overline{i_1} = \overline{i_0} + \overline{i_2'}$$

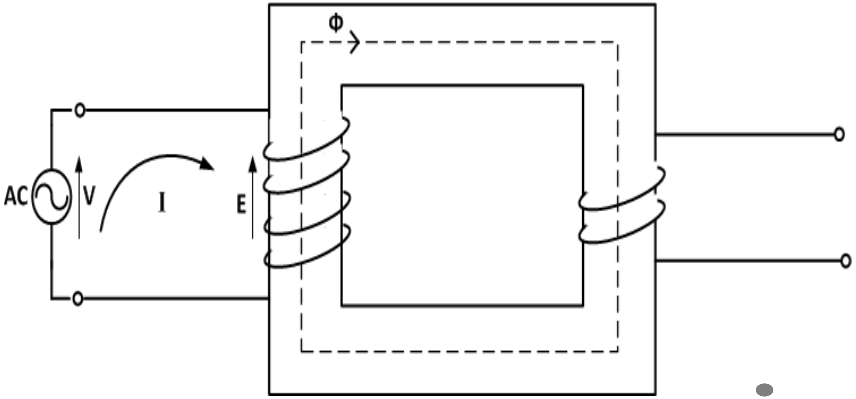
$$E_1 = N_1 \omega \phi_m \sin(\omega t - \frac{\pi}{2})$$

$$\phi_2 = \phi_2'$$

$$N_2 I_2 = N_1 I_2'$$

$$I_2' = K I_2$$

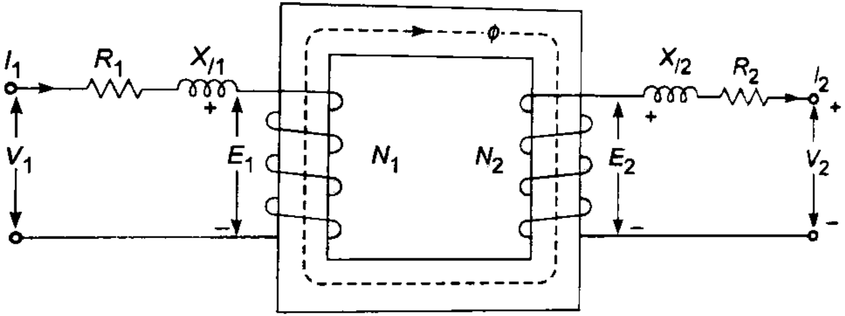


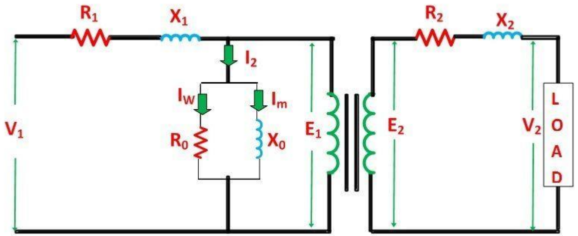


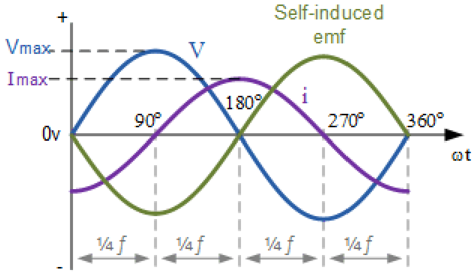
➢ *Transformer phasor diagram*

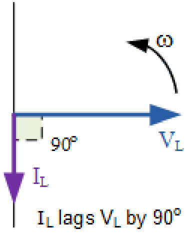
Including the resistance and inductances of the windings:

$$\overline{V_1} = -\overline{E_1} + \overline{I_1}R_1 + j\overline{I_1}X_1$$
$$\overline{E_2} = \overline{V_2} + \overline{I_2}R_2 + j\overline{I_2}X_2$$









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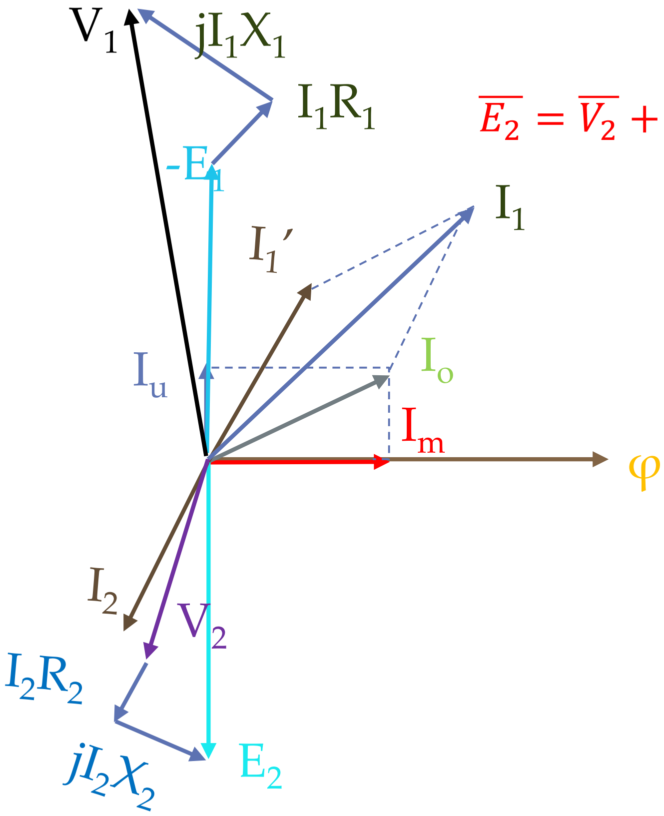
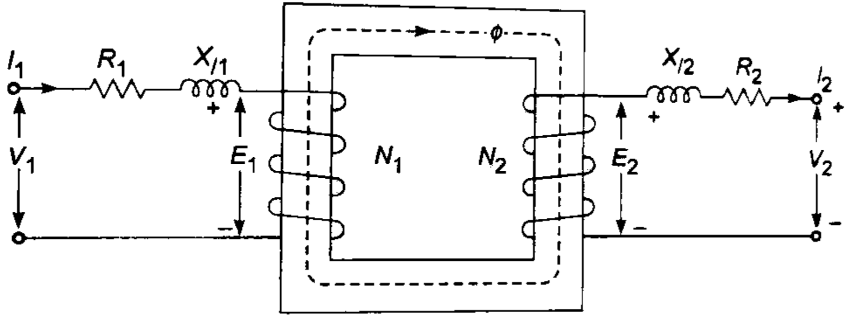
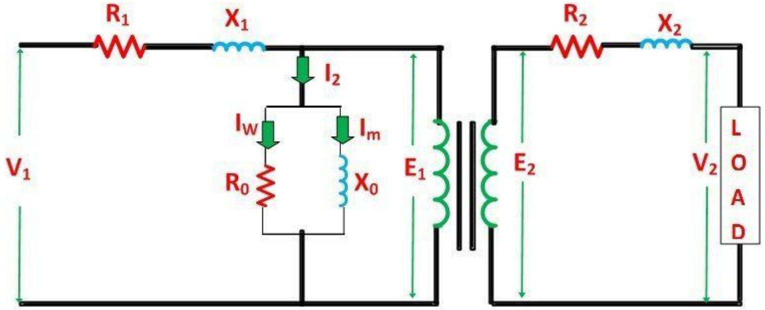
Including the resistance and inductances of the windings:



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

$$\overline{E_2} = \overline{V_2} + \overline{I_2}R_2 + j\overline{I}$$





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