Basic Electrical Engineering
KEE101/201

Department of Engineering

Uttar Pradesh Textile Technology Institute

Session 2019-20

Semester-II

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Transformers

Text Book

(1) I. J. Nagrath and D. P. Kothari

Basic Electrical Engineering- Tata McGraw Hill

Reference Books:

(2) Alexander S. Langsdorf

Theory of Alternating Current Machinery-TMGH

(3) D. P. Kothari , I. J. Nagrath

Electric Machines-Tata McGraw Hill

Transformer

We understand electrical machines as electro-mechanical energy conversion devices.

Transformer is not really an electro-mechanical energy conversion device

.... It basically converts Voltage!

So first we have to understand.......

...........why voltage transformation is necessary??

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Transformer

- The power industry survives on the economics of cost recovery.
- The larger the power plant is, the more economical power generation is.
- Large power plants may be built at the locations where resources like coal or water or gas etc are available in abundance.
- These may be at very far places from the load centers.
- So the power needs to be transported over the long distances from generation stations to load centers.

Why need high Transmission Voltage

- Lines are designed to operate at constant current density J
- $R = \rho \frac{l}{a} = \rho \frac{l}{I} J$
- $Transmission\ Power\ Loss\ P_l = I^2 R$
- $Transmission\ Power\ Loss\ P_l = I^2 \rho \frac{l}{I} J$
- $Transmission\ Power\ Loss\ P_l = I\ \rho\ l\ J$
- $Transmission\ Power\ Loss\ P_l = \frac{P}{V}\ \rho\ l\ J$
- $P_l = \frac{l}{V}\ X(Constant)$
- So to reduce line loss P_l we need to increase Voltage.

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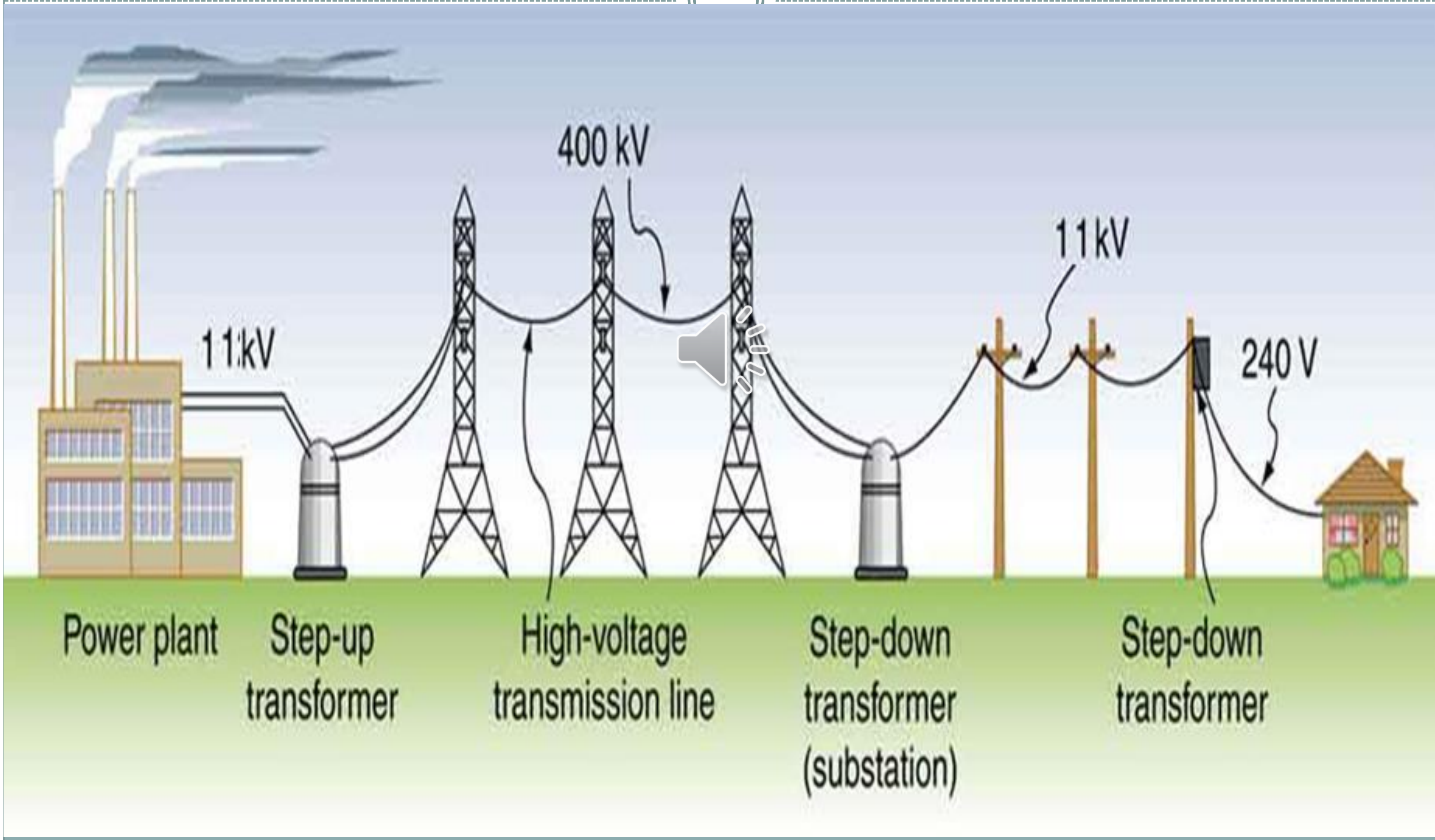
Why need Transformer

- It is not convenient to generate at high voltage say at 400 kV. Generation is normally done at 11 or 22 kV and not more than that.
- Therefore Voltage needs to be stepped up for transmission.
- It is not convenient and safe to design common load devices which operate at high voltages
- So we need to step down the transmission voltage.
- That's why we need **Transformer !!!!**

Why need Transformer

- Of course the transformer losses come into picture.
- But fortunately we have the transformer efficiency more than 85 % in normal cases.
- So general conception is that we need to have a power system as:

Transformer in Power System



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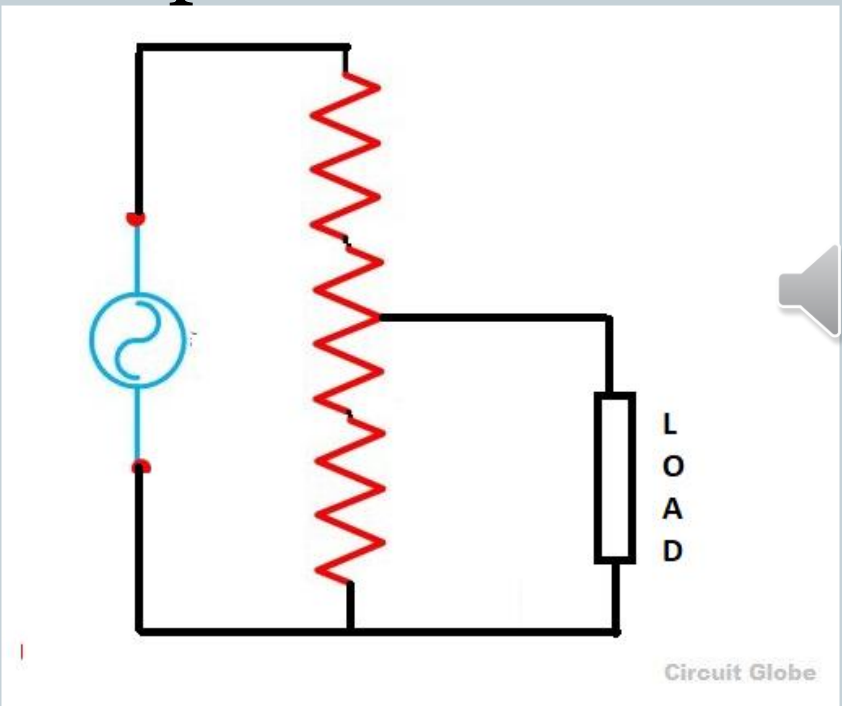
How to transform Voltage ?

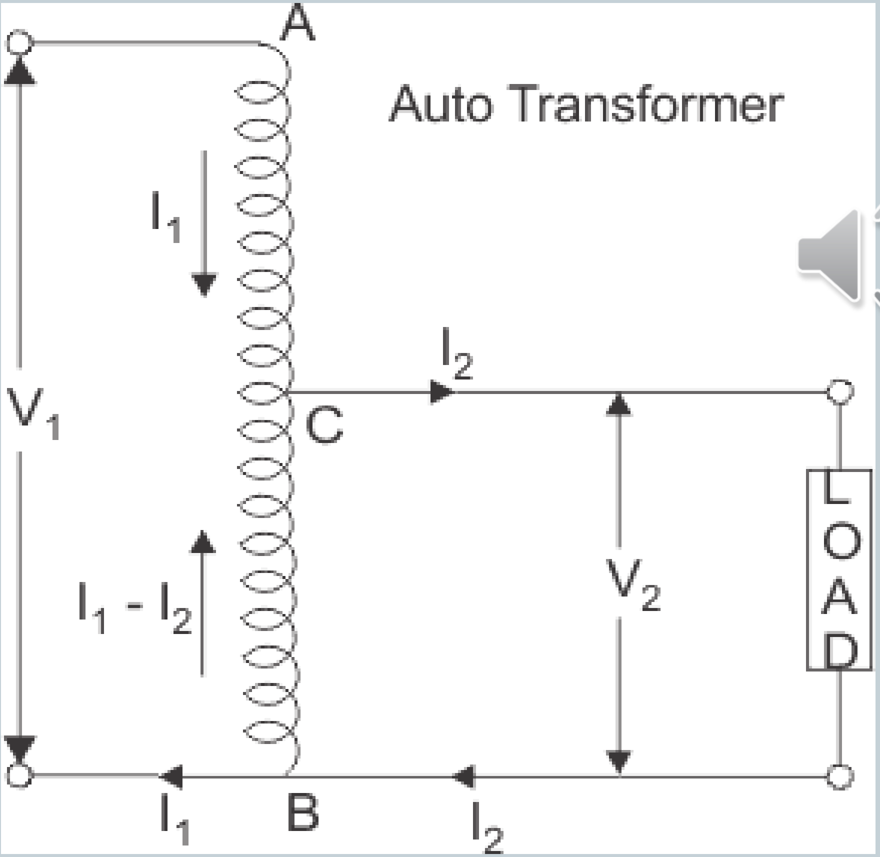
- Simplest method is to use potential divider



- But here we cannot step up the voltage
- And there will be huge losses in resistance

How to transform Voltage ?

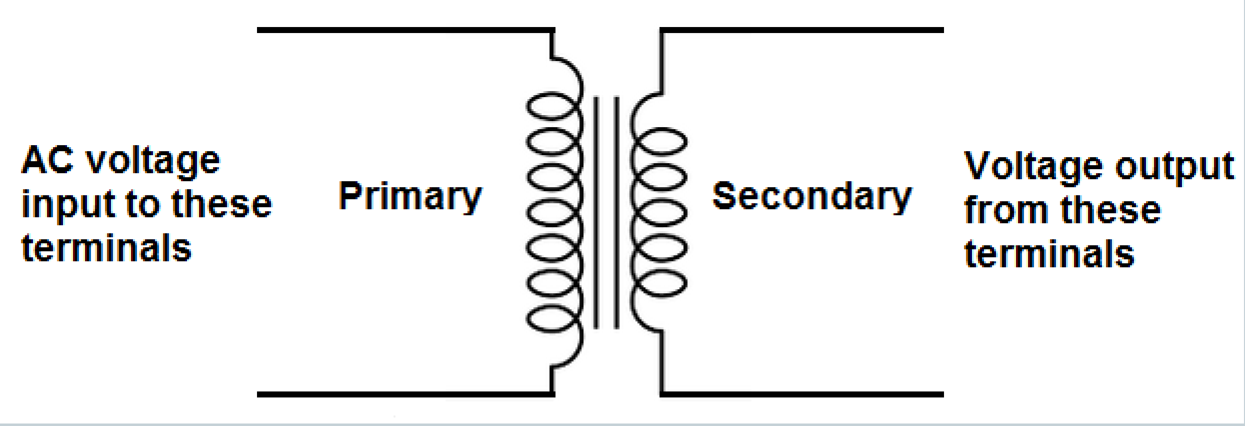
- Next option is to use a coil (Inductor)



- Now it is low loss method We may step up the voltage also if we interchange the position of load and source
- possibility of damage to the load during short circuit of A to C or fault.

How to transform Voltage ?

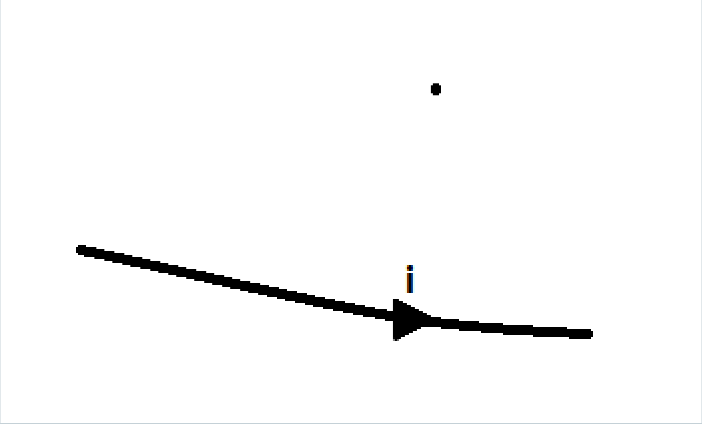
- The circuit was basically known as auto transformer.
- Now as magnetic circuits do not need physical connection, we may separate these two coils and couple them magnetically to do the same function.
- Less Probability of Damage to the load during short circuit of two coil terminals.



Magnetic Circuits

AT any point P near to a wire carrying current i:

- The Magnetic Field intensity vector will be $\vec{H}$ and
- Magnetic flux density vector will be $\vec{B}$



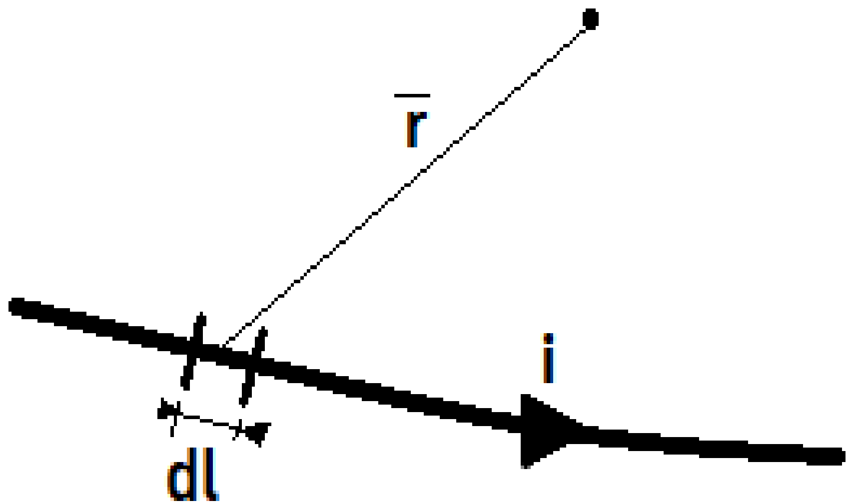
$$\vec{B} = \mu_r \mu_o \vec{H}$$

Magnetic Circuits

The Magnetic flux density at the point P due to an incremental length of wire dl will be given by Biot Savart's Law as :

$$d\vec{B} = \frac{\mu_r \mu_o}{4\pi} \frac{i d\vec{l} \, x \, \vec{r}}{r^3}$$

$$\vec{B} = \oint \frac{\mu_r \mu_o}{4\pi} \frac{i d\vec{l} \, x \, \vec{r}}{r^3}$$

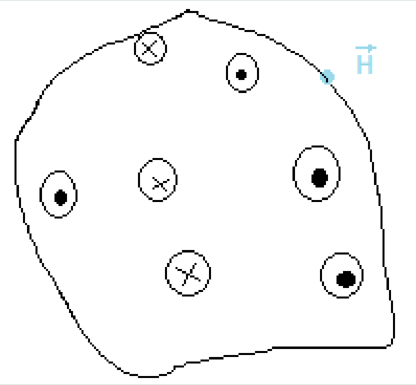


The flux density due to wire of length l will be given by the integral over length l.

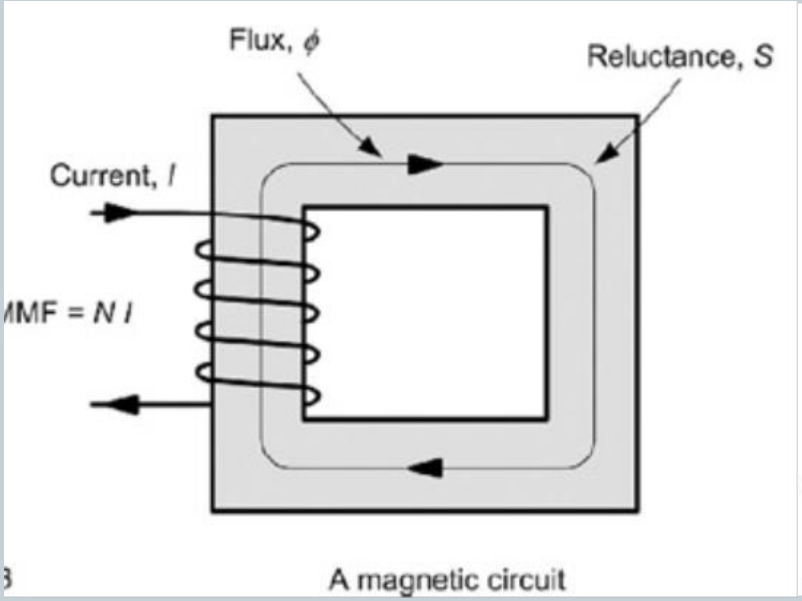
Magnetic Circuits

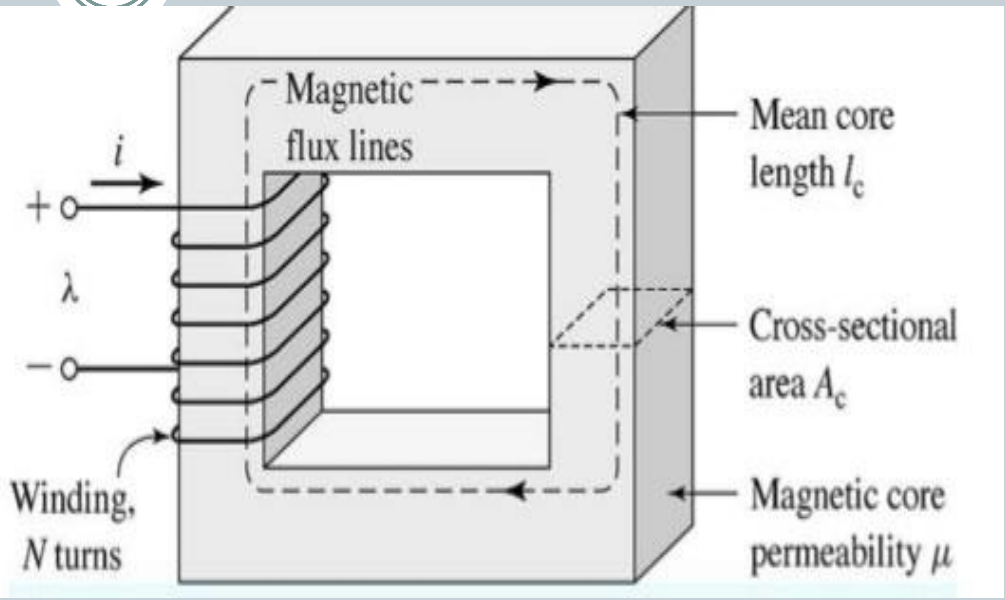
- As solution of magnetic circuit using Biot Savart is not convenient we will use another method which is **Amperes Circuital Law.**
- According to this law the Line integral of magnetic field intensity along a closed path will be sum of all the currents enclosed within the loop.

$$\oint \vec{H} . d\vec{l} = \mathrm{I}$$



Magnetic Circuits





We have a core of regular shape on which some winding is put.

Here $N.i = H.l$ or $H = \frac{Ni}{l}$

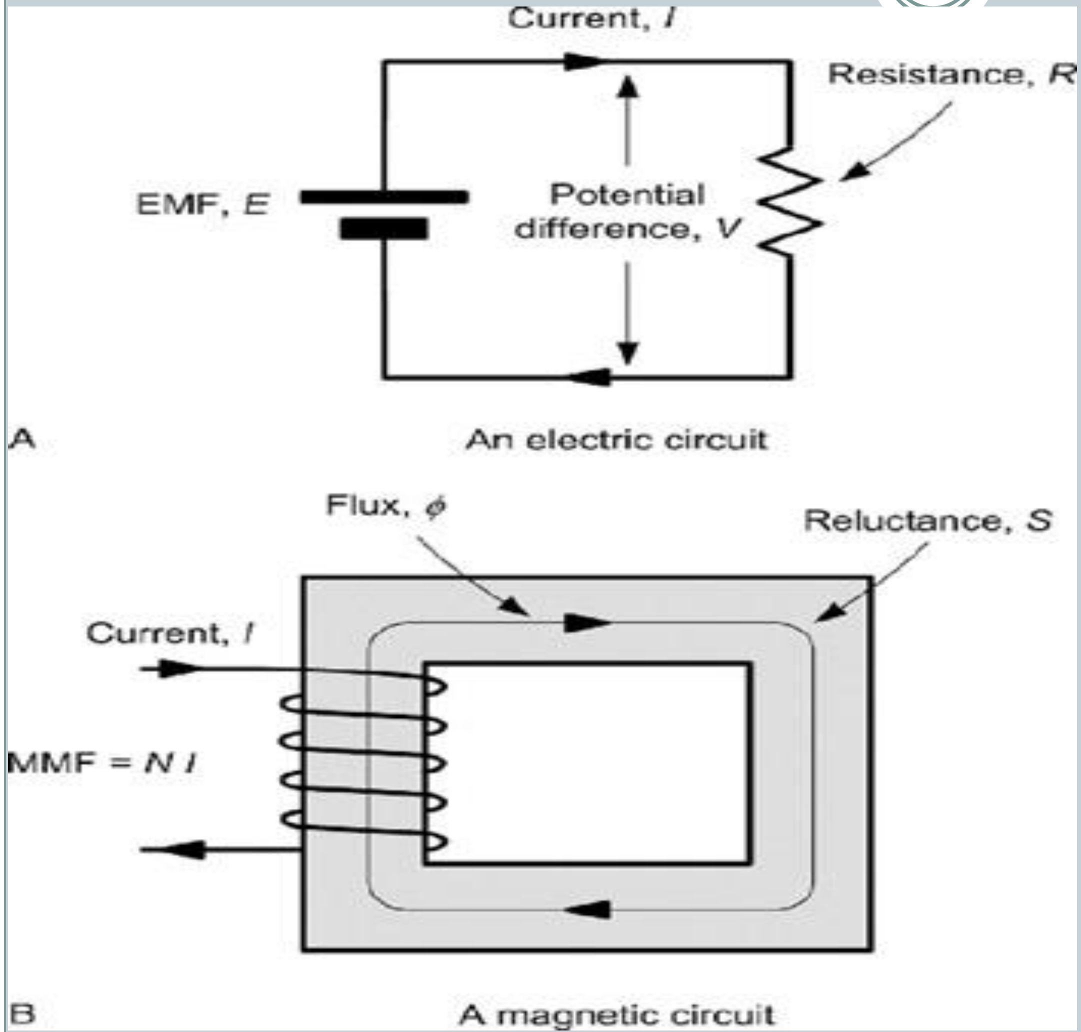
Magnetic Circuits

$$H = \frac{Ni}{l}$$

$$\vec{B} = \mu_r \mu_o \vec{H}$$

- So finding out B is relatively easier in this way.
- we have assumption that due to high permeability of iron core all the flux is confined to the core
- Hence leakage flux outside the core in negligible

Magnetic Circuits : Analogy with Electrical Circuit



- $\phi = B.A$
- $\phi = \mu_r\mu_o H.A$
- $\phi = \mu_r\mu_o \frac{Ni}{l}.A$
- $\phi = \frac{Ni}{\left(\frac{l}{\mu_r\mu_o A}\right)}$
- $\phi = \frac{Ni}{\Re}$
- $\phi = \frac{MMF}{\Re}$
- $MMF = \phi.\Re$
- Compare with
- $V = I.R$ (Elect Ckt)

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will be dc. If ac is applied it will alternate

- Faraday's Law of Electromagnetic Induction:

Emf induced will be equal to the rate of change of flux.

in a coil wound over a core: $\phi = \phi_m \cos \omega t$

$$e = N\frac{d\phi}{dt}$$

$$e = N\omega\phi_m \sin \omega t$$

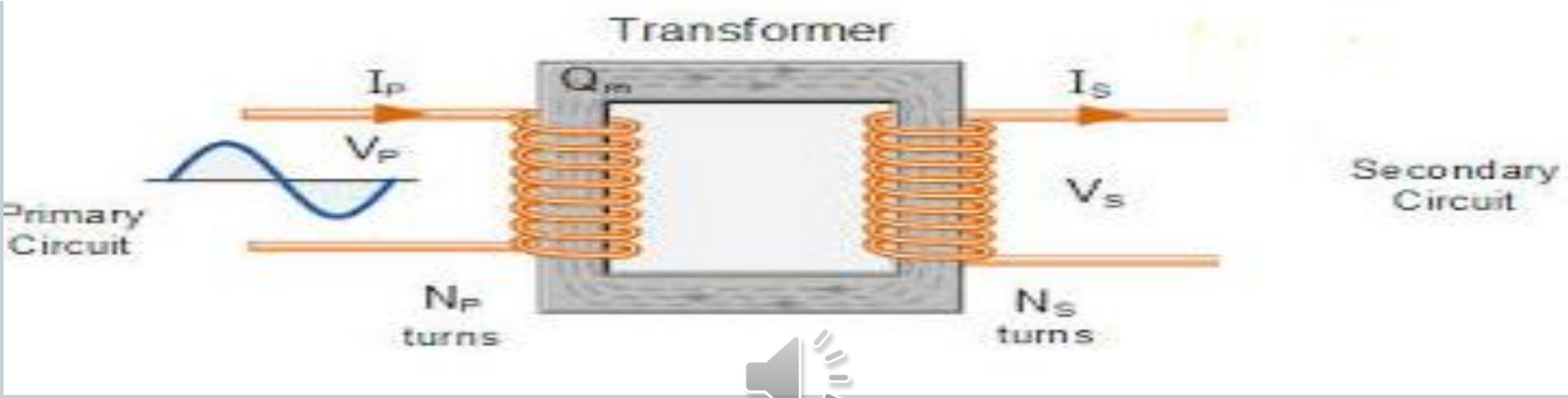
$$e = N2\pi f\phi_m \sin \omega t$$

$$E_m = N2\pi f\phi_m$$

$$E_{rms} = \frac{N2\pi f\phi_m}{\sqrt{2}}$$

$$E_{rms} = 4.44f\phi_m N$$

Ideal Transformer

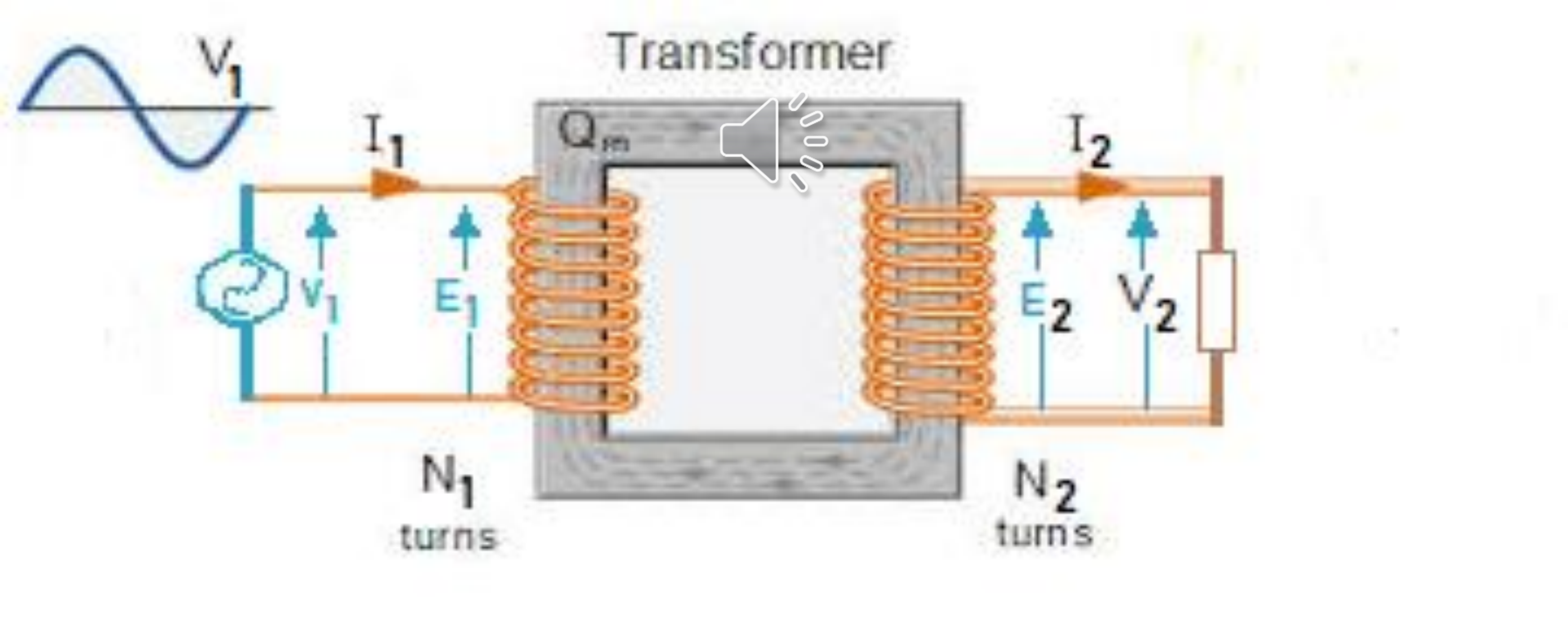


Ideal Transformer is a conceptual Device with following Assumptions:

- Coil resistance is zero (Lossless)
- Core material has infinite permeability
- No flux Leakages (All flux is linked with the core)
- No eddy current losses, No Hysteresis Losses.

Ideal Transformer

Principle of Operation of a conceptual Ideal Transformer



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- We must understand that there is no such thing like ‘Ideal Transformer’. It is only a conceptual device.
- If an ac voltage is applied at one side terminals of transformer, This side is known as primary side.
- Another side is called Secondary side.
  - Secondary side : if terminals are left open then transformer is said to be at “No Load”
  - Secondary side : If Load is connected across the terminals the transformer is said to be “ On Load”

Ideal Transformer on Load

- $V_1 = Applied\ ac\ Voltage(RMS)$
- $E_1 = 4.44 f \phi_m N_1$
- $E_2 = 4.44 f \phi_m N_2$
- $E_1 = Induced\ Voltage\ in\ Primary(RMS)$
- $E_2 = Induced\ Voltage\ in\ Secondary(RMS)$
- $V_2 = Terminal\ ac\ secondary\ Voltage(RMS)$
- $\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{V_1}{V_2}$

Ideal Transformer on Load

- *Excitation current is zero for primary Ni*
- $I_2 =$ *Secondary current when load is connected*
- $N_2 I_2 =$ *Secondary mmf*
- $N_1 I_1 =$ *Primary counter mmf*
- $N_2 I_2 = N_1 I_1$
- $\frac{N_1}{N_2} = \frac{I_2}{I_1}$
- **Draw Phasor Diagram**

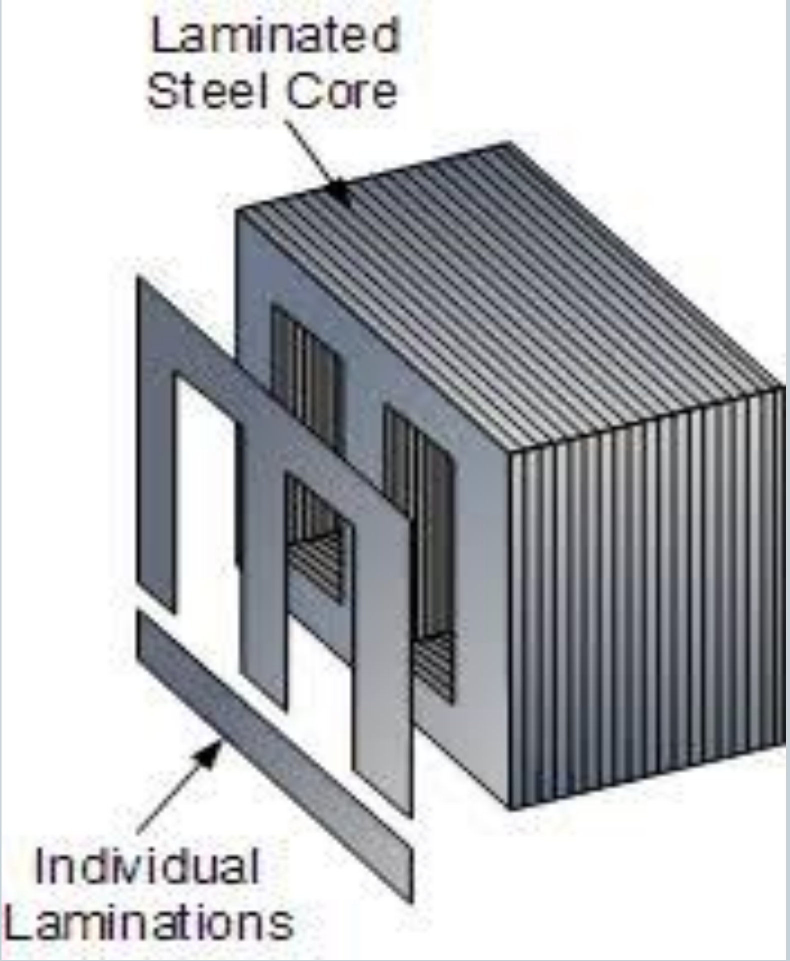
Ideal Vs Practical Transformer

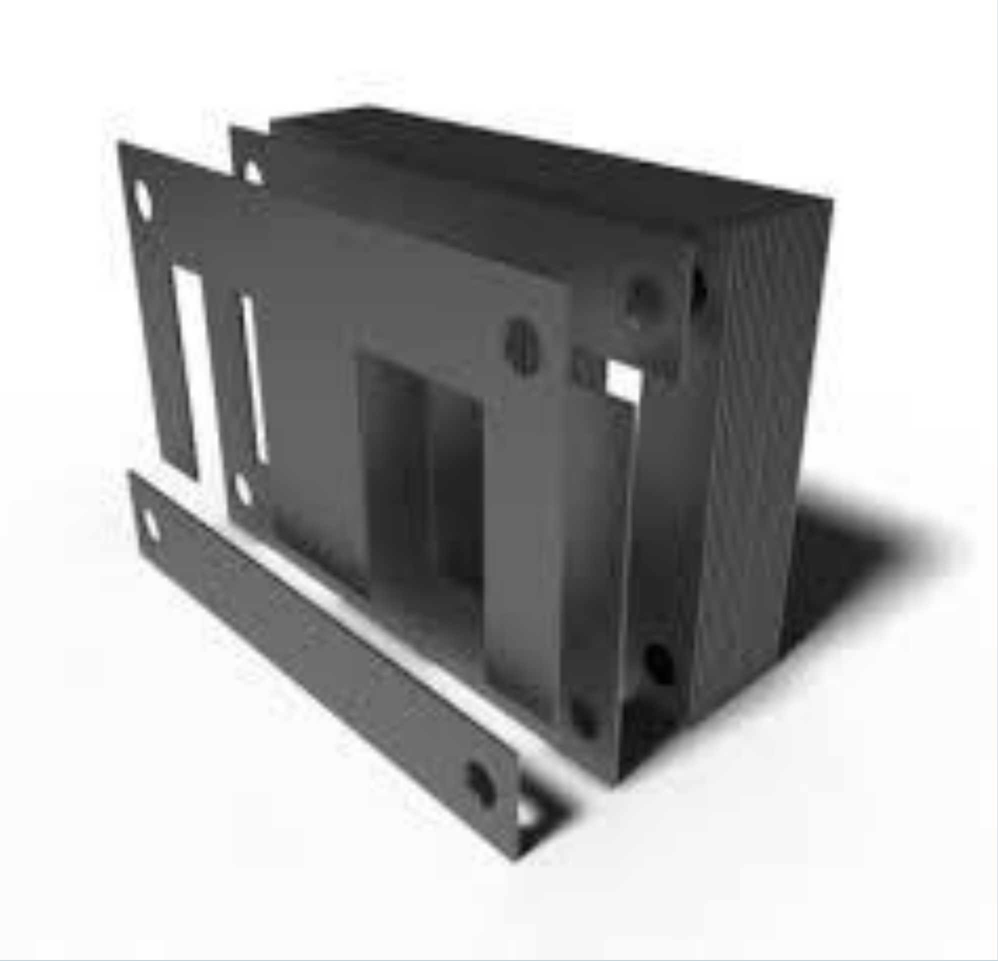
- Coil resistance is zero (Lossless)
- Core material has infinite permeability
- No flux Leakages (All flux is linked with the core)
- No eddy current losses, No Hysteresis Losses.

- Coil resistance is present though it is low.
- Core material has finite permeability
- Some Flux Leakages occur through air. Represented by Leakage reactance.
- Eddy current and Hysteresis Losses are present. (core or Fixed Losses)

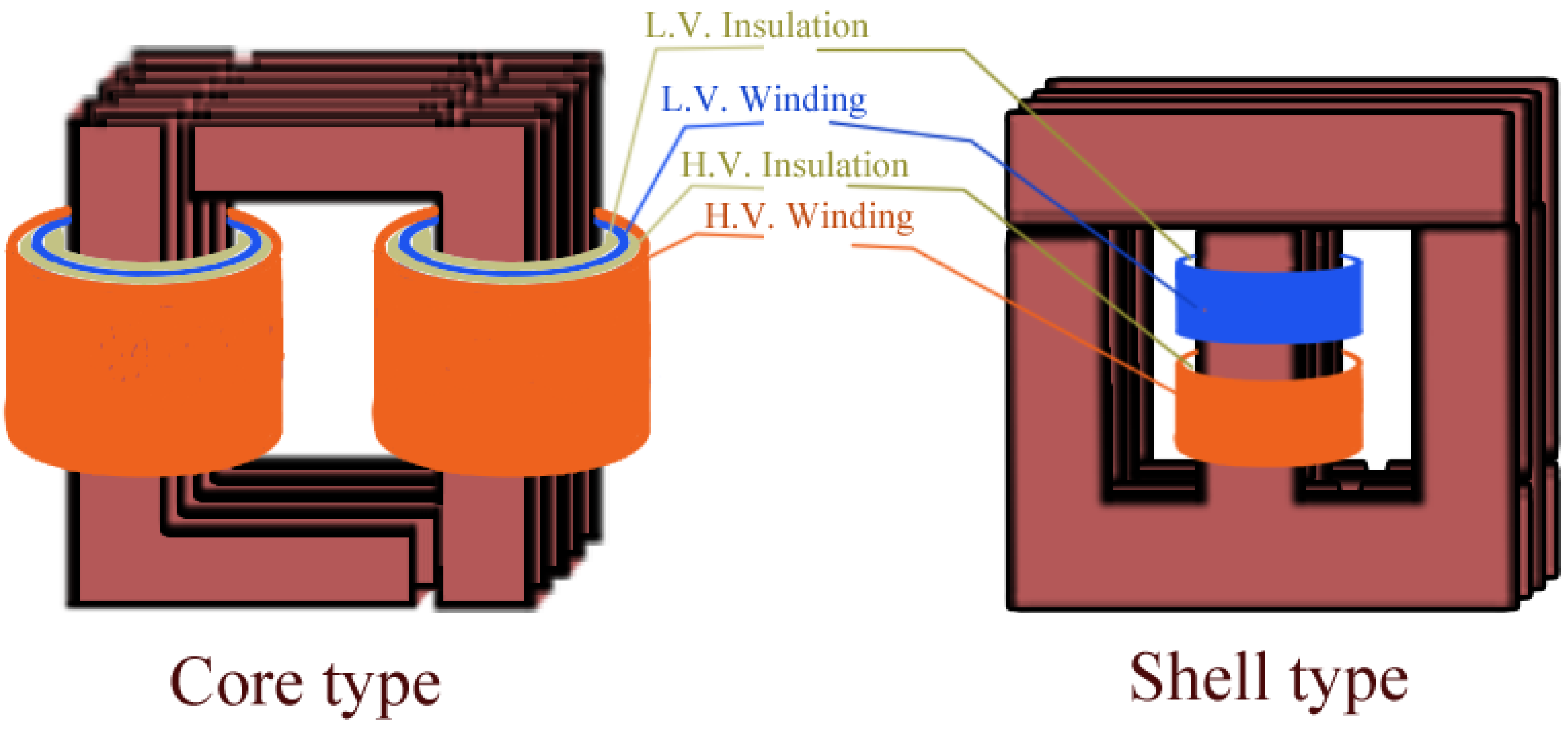
Practical 1-Phase Transformer: Construction

Transformer: Construction





Transformer: Construction



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3 Phase Transformer: Construction

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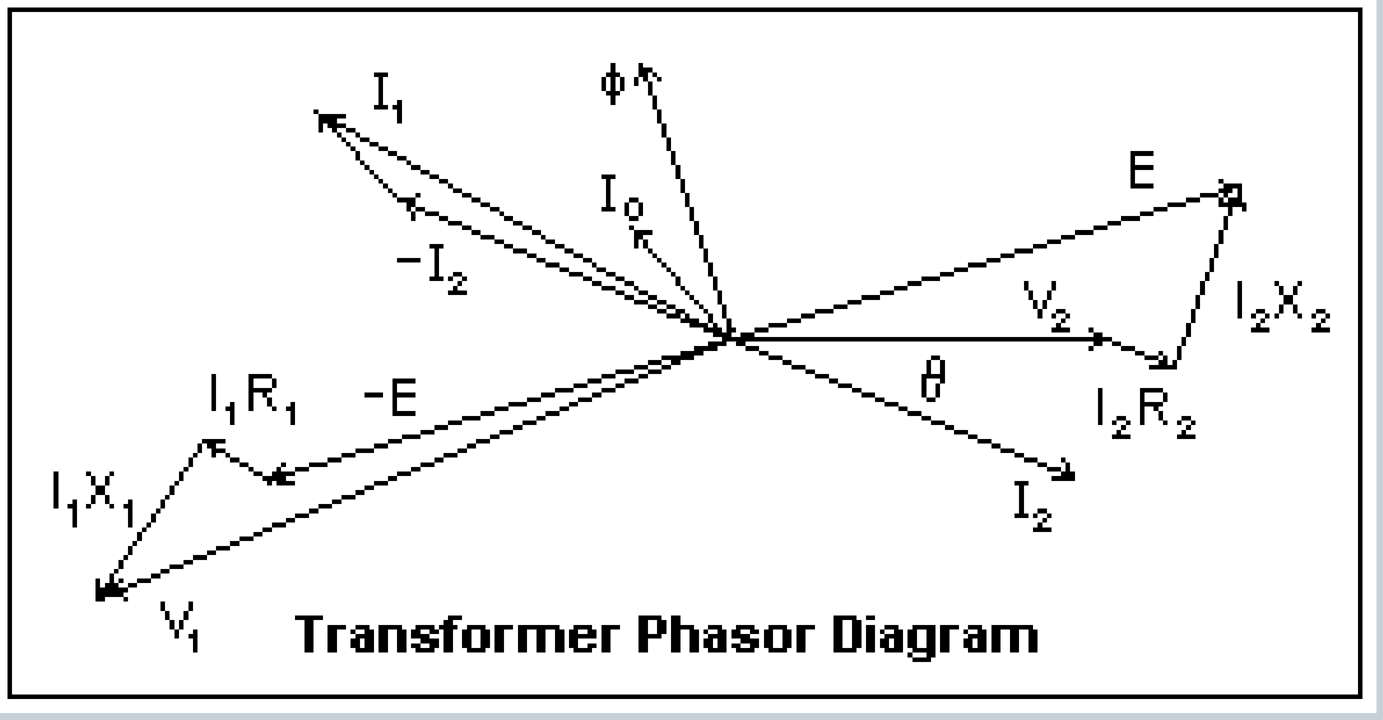
I1
ϕ
I0
E
−I2
V2
I2X2
θ
I2R2
I1R1
−E
I1X1
I2
V1
Transformer Phasor Diagram