Lecture-27

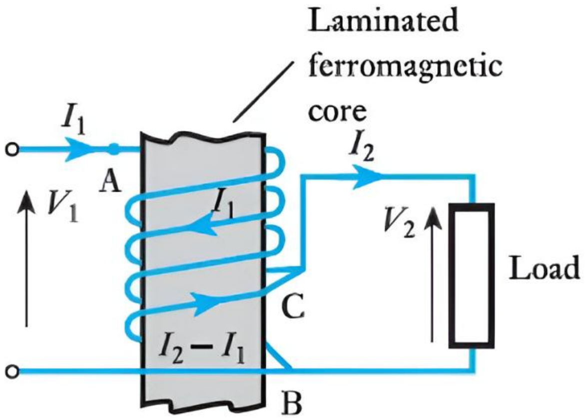
On

INTRODUCTION TO ELECTRICAL ENGINEERING (ESO203)

- Auto Transformer.
- PU System.
- Special Transformer.

Auto Transformer

❑ Auto Transformer:



An auto-transformer is a transformer having a part of its winding common to the primary and secondary circuits

I_1 and I_2 = primary and secondary currents respectively

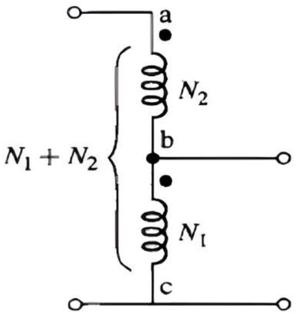
N_1 = No. of turns between A and B

N_2 = No. of turns between B and C

n = ratio of the smaller voltage to larger voltage

$$n = \frac{V_2}{V_1} = \frac{I_1}{I_2} = \frac{N_2}{N_1}$$

Effective turns ratio

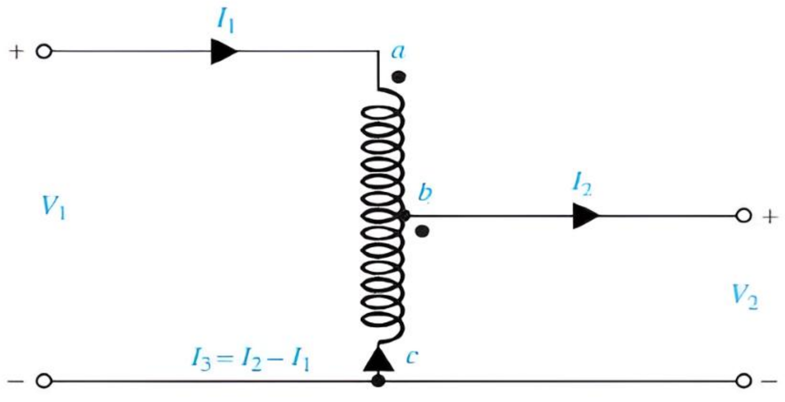


$$V_{H_{rated}} = V_{1_{rated}} + V_{2_{rated}} = \frac{N_1 + N_2}{N_1} V_{1_{rated}}$$

Auto Transformer (Cont…)

The input apparent power $S_1 = V_1 I_1$

The output apparent power $S_2 = V_2 I_2$



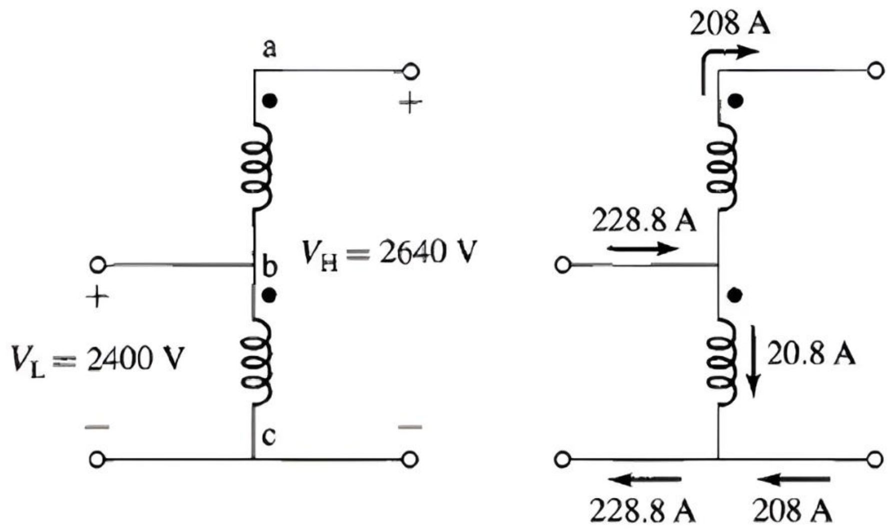
The apparent power transformed by electromagnetic induction (or transformer action)

$$S_{ind} = V_2 I_3 = V_2 (I_2 - I_1)$$

The output transferred by electrical conduction (because of the direct electrical connection between primary and secondary windings)

$$S_{cond} = V_2 I_2 - V_2 I_3 = V_2 I_1$$

Auto Transformer (Cont…)



$$V_{bc} = 2400V$$

$$V_{ab} = 240V$$

$$50kVA$$

The rated current of 240V winding $= \frac{50000}{240} = 208A$

The kVA rating as an autotransformer $\frac{V_H I_H}{1000} = \frac{2640\times 208}{1000} = 550kVA$

$$I_L = \left(\frac{2640}{2400}\right) \times 208 = 229A$$

- The higher rating as an autotransformer is a consequence of the fact that not all the 550 kVA has to be transformed by electromagnetic induction.
- Efficiency is high because the losses are those corresponding to transforming only 50 kVA.

PU System

❑ PER UNIT (p.u.) Quantities

- A typical power system is a complex, interconnected network of parallel and series circuits containing many transformation steps.
- The common technique used by power system engineers is to use a per unit system of currents, voltages, impedances and power. In this system, each value is expressed as a fraction of its own nominal or rated value.

$$V_{pu} = \frac{V_{actual}}{V_{base}} \qquad I_{pu} = \frac{I_{actual}}{I_{base}}$$

- The base value of the voltage is normally the rated line to line voltage of the system.
- Base value is not a constant value throughout a system as a transformer would have a different rated voltage on the primary to that of the secondary.
- Thus a 33/11 kV transformer would have a base voltage on the 11 kV side of 11 kV and on the 33 kV side, of 33 kV.
- This applies to voltage, current, impedance and apparent power (V A).

$$\text{per-unit value (pu)} = \frac{\text{actual value}}{\text{base value}}$$

PU System (Cont...)

- The base value of voltage in volts (rated voltage) is defined as 1 pu and the base value of current in amps (full-load current) is also defined as 1 pu.

$$\text{Base impedance } (\Omega) = \frac{V_{\text{base}}}{I_{\text{base}}}$$

- Line to line voltage= 3464 V $\qquad V_{\text{base}} = 3464 \text{ V}$

- full-load current = 500A, $\qquad I_{\text{base}} = 500 \text{ A}$

$$Z_{\text{base}} = \frac{3464}{\sqrt{3}} \Big/ 500 = 4\ \Omega$$

- **Note:** per unit conversion affects magnitudes, not the angles. Also, per unit quantities no longer have units (i.e., a voltage is 1.0 p.u., not 1 p.u. volts)
- A transmission line having a per-unit impedance of 0.125 pu means that the magnitude of the voltage drop along the line when full load current is flowing is 0.125 pu or 12.5 per cent.

PU System (Cont...)

❑ Per unit change of MVA base

- Parameters for equipment are often given using power rating of equipment as the MVA base.
- To analyze a system all per unit data must be on a common power base

$$Z_{pu}^{OriginalBase} \times \frac{V_{base}^{2}}{S_{Base}^{OriginalBase}} \Big/ \frac{V_{base}^{2}}{S_{Base}^{NewBase}} = Z_{pu}^{NewBase}$$

$$Z_{pu}^{OriginalBase} \times \frac{S_{Base}^{NewBase}}{S_{Base}^{OriginalBase}} = Z_{pu}^{NewBase}$$

PU System (Cont...)

❑ Change of base example

A 54 MVA transformer has a leakage reactance or 3.69%. What is the reactance on a 100 MVA base?

$$X_e = 0.0369 \times \frac{100}{54} = 0.0683 \text{ p.u.}$$

PU System (Cont...)

❑ Example:

- Calculate the ohmic impedance of two 0.1 pu transformers: one is a 11 kV/400 V transformer having a rating of 2 MVA, the other is a 33 kV/400 V transformer having a rating of 10 MVA.

2 MV A transformer

$$Z_{pu} = Z_\Omega \frac{\sqrt{3}\, I_{base}}{V_{base}} \quad \text{or} \quad Z_\Omega = Z_{pu} \frac{V_{base}}{\sqrt{3}\, I_{base}}$$

$$V_{base} = 11\ \text{kV}$$

$$I_{base} = \frac{S_B}{\sqrt{3} \cdot V_B} = \frac{2 \cdot 10^6}{\sqrt{3} \cdot 11 \cdot 10^3} = 105\ \text{A}$$

S_B is the rated MVA = 2 MVA

$$Z_\Omega = j0.1 \cdot \frac{11 \cdot 10^3}{\sqrt{3} \cdot 105} = j6.05\ \Omega$$

Referred to 11 kV

$$I_B = 105 \cdot \frac{11\,000}{400} = 2887.5\ \text{A}$$

$$Z_\Omega\ (\text{referred to 400 V}) = j6.05 \times \left(\frac{400}{11\,000}\right)^2 = j0.08\ \Omega$$

$$Z_{pu} = j0.08 \times \sqrt{3} \times \frac{2887.5}{400} = j1.0pu$$

PU System (Cont...)

10 MV A transformer

$$Z_{\Omega} = Z_{pu}\frac{V_B^2}{\sqrt{3}I_B V_B}$$

$$= Z_{pu}\frac{(V_B)^2}{S_B}$$

$$Z_{pu} = \frac{Z_{\Omega} \cdot S_B}{(V_B)^2}$$

In this case V_{base} is 33 kV.

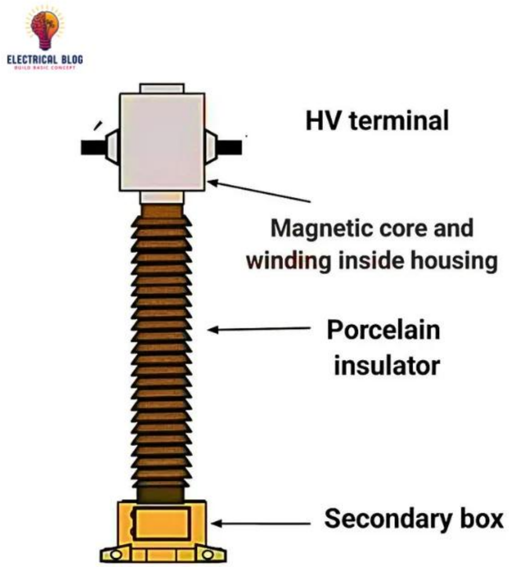
$$Z_{\Omega} = j1.0 \times \frac{33^2}{10}$$

$$Z_{\Omega} = j108.9 \text{ referred to 33kV}$$

Special Transformer

❑ Potential/Voltage Transformer (PT):

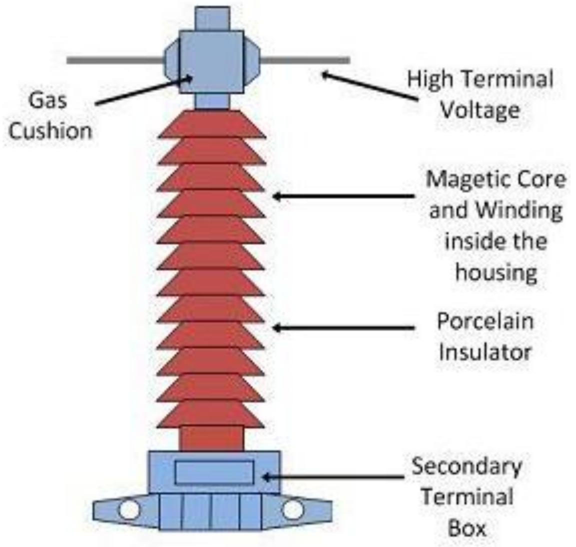
- The potential transformer may be defined as an instrument transformer used for the transformation of voltage from a higher value to the lower value.
- This transformer step down the voltage to a safe limit value which can be easily measured by the ordinary low voltage instrument like a voltmeter, wattmeter and watt-hour meters, etc.



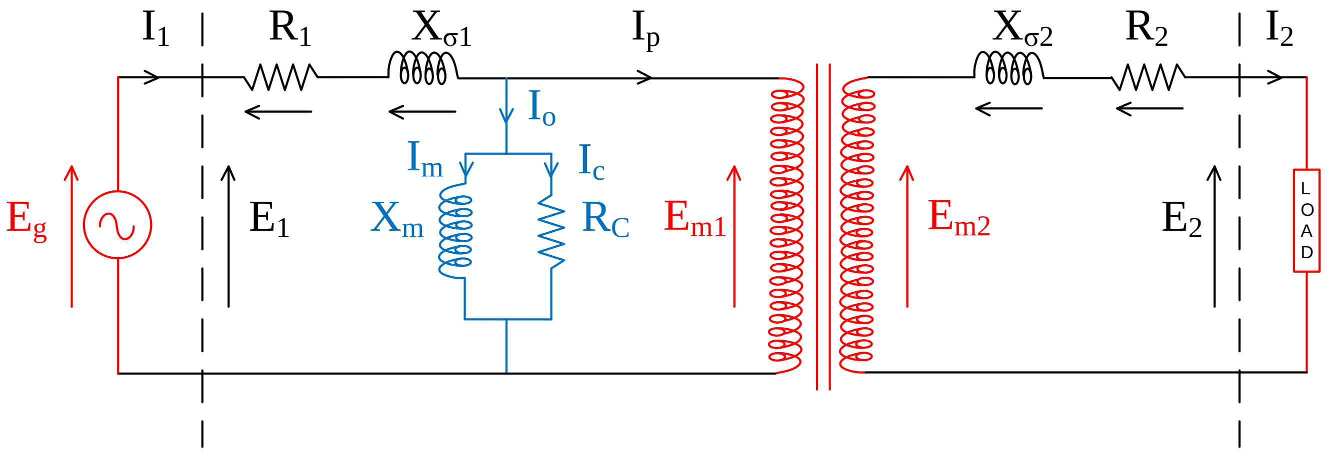
Special Transformer (cont...)

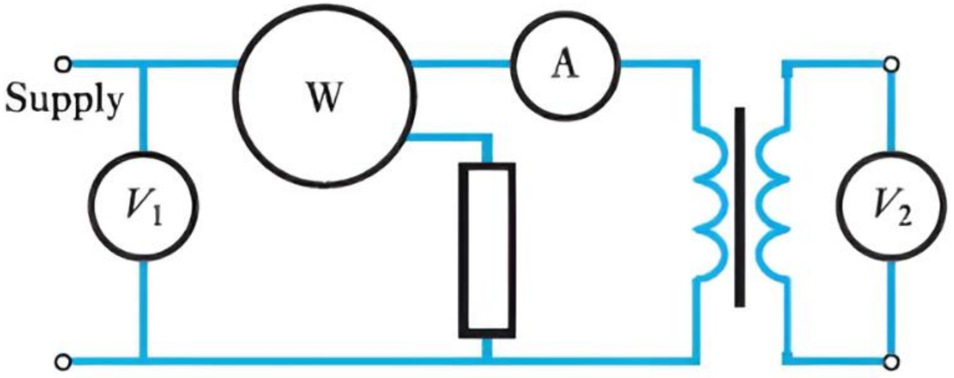
❑ Current Transformer (CT):

- A current transformer is a device that is used for the transformation of current from a higher value into a proportionate current to a lower value.
- It transforms the high voltage current into the low voltage current due to which the heavy current flows through the transmission lines is safely monitored by the ammeter.



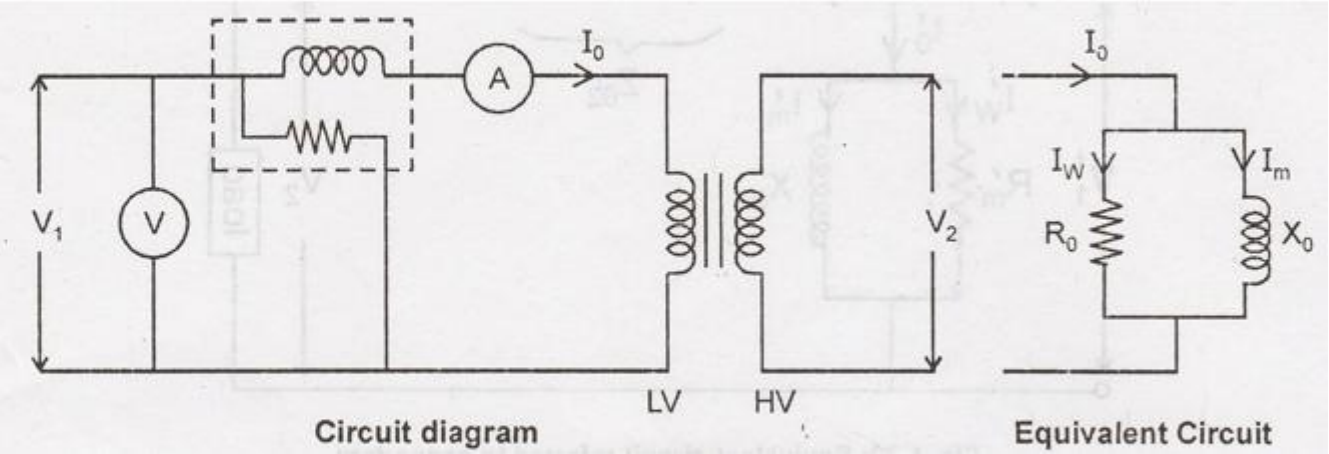
Open Circuit Test





- Primary supplied at rated voltage and frequency.
- The primary current on no load is usually less than 3 to 5 percent of the full-load current.
- Wattmeter reading ≅ the core loss of the transformer.

Open Circuit Test (cont…)



Circuit diagram

Equivalent Circuit

- Iron losses, P_1 = Wattmeter reading (W_0)
- No load current = Ammeter reading (I_0)
- Applied Voltage = Voltmeter reading (V_1)
- Input Power (W_0) = V_1 I_0 cos θ_0.

No load Power factor $\cos\theta_0 = \dfrac{W_0}{V_1 \cdot I_0}$

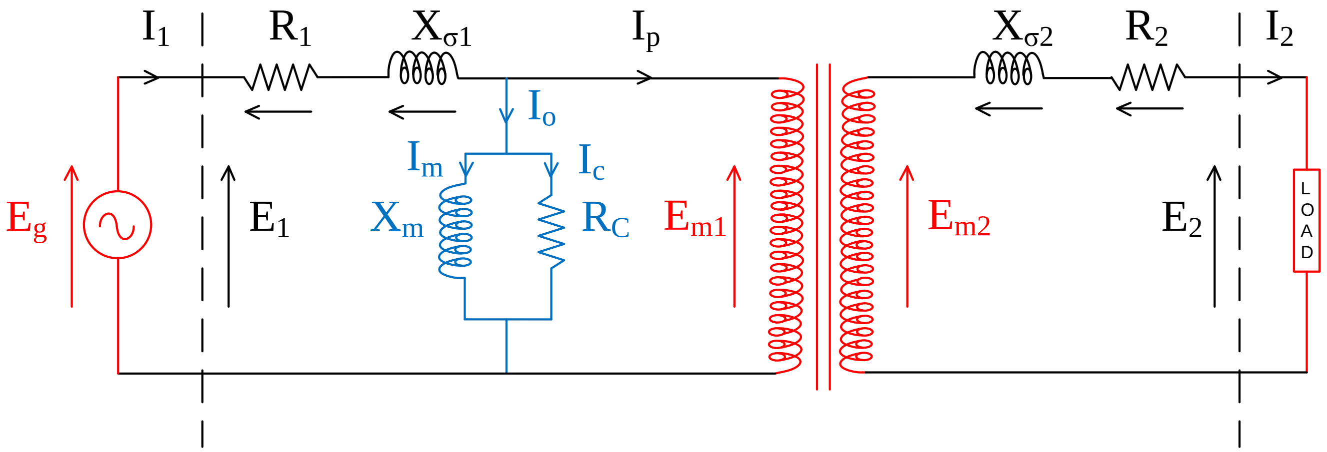
$$I_w = I_0 \cos\theta_0;$$

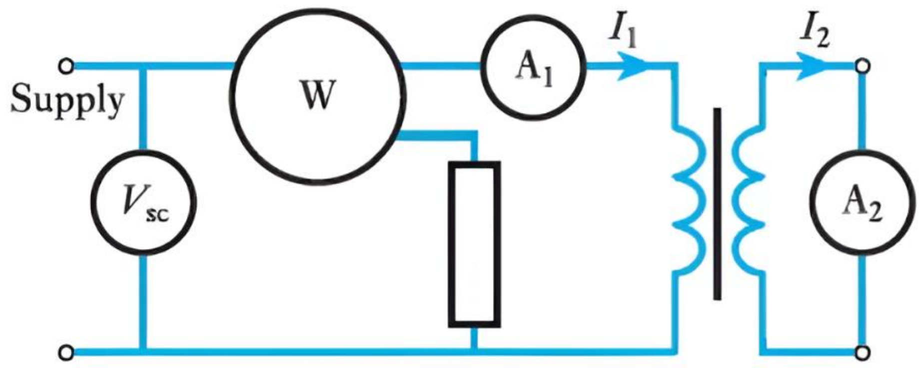
$$I_m = I_0 \sin\theta_0$$

$$R_0 = \frac{V_1}{I_w} \quad \text{and} \quad X_0 = \frac{V_1}{I_m}$$

- In OC test enables to determine iron losses and parameters R_0 and X_0 of the transformer.

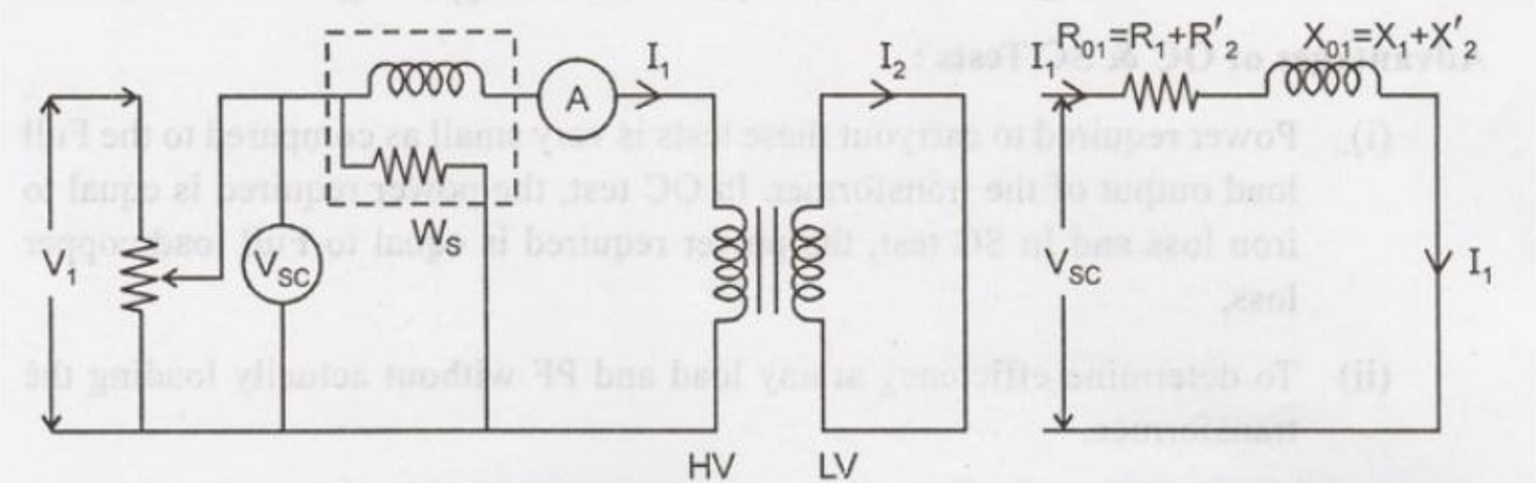
Short Circuit Test





- The primary supplied with a low voltage sufficient to circulate full-load currents in the primary and secondary circuits.
- The core loss is negligibly small, since the applied voltage and therefore the flux are only about one-twentieth to one-thirtieth of the rated voltage and flux.
- Wattmeter reading $\cong$ the copper loss of the transformer.

Short Circuit Test (cont…)



Circuit diagram

Equivalent Circuit

- Full load Copper loss P_C = Wattmeter Reading (W_S)
- Applied Voltage = Voltmeter reading (V_{SC})
- F.L. Primary current = Ammeter reading (I_1)

$$P_C = I_1^2 \cdot R_1 + I_1^2 \cdot R_2' = I_1^2 \cdot R_{01}$$

$$R_{01} = \frac{P_C}{I_1^2}$$

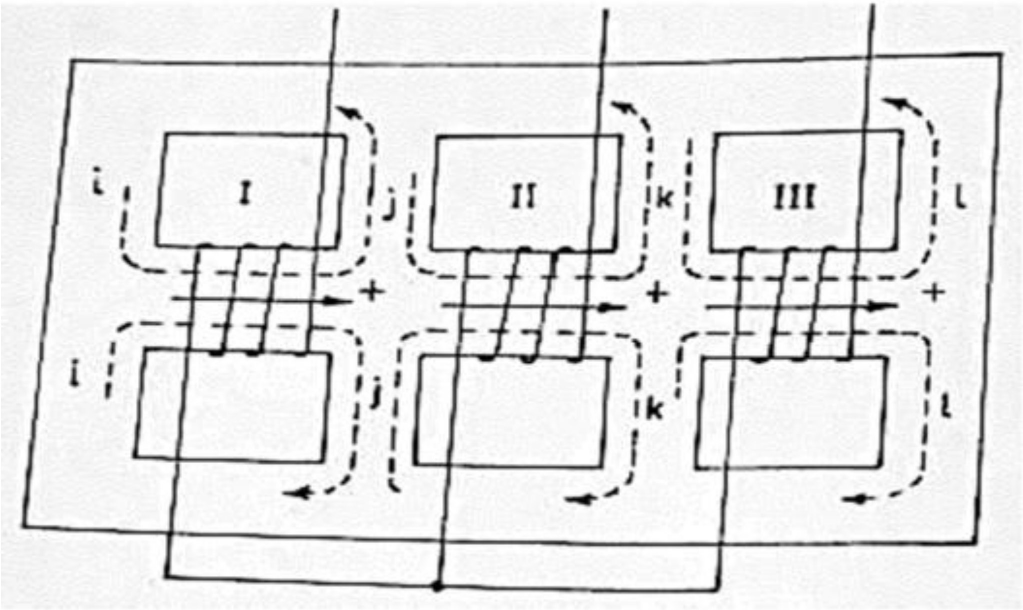
- Where R_{01} - Total resistance of transformer referred to Primary.
- Total impedance referred to Primary, $Z_{01} = V_{SC} / I_1$

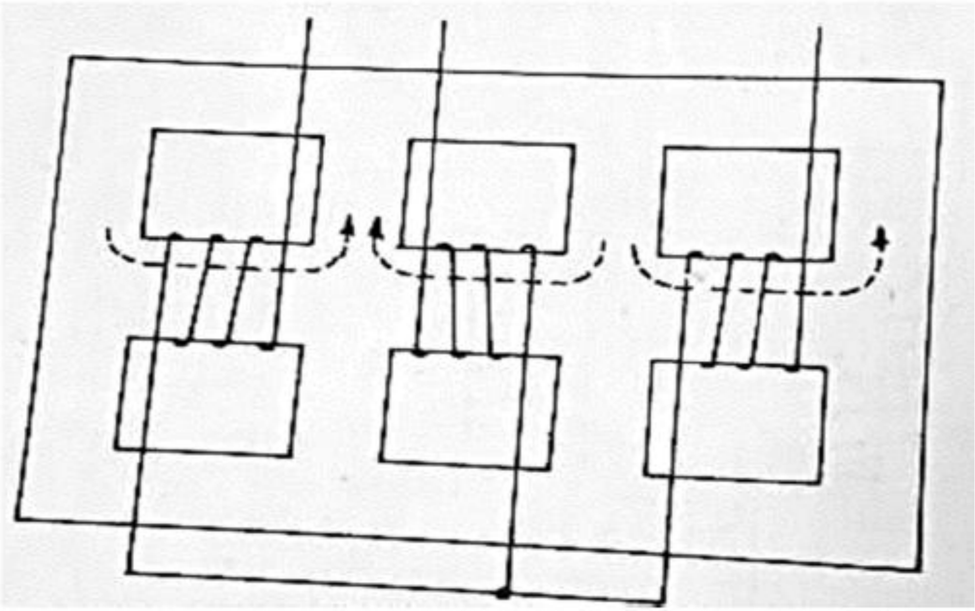
Total leakage reactance referred to Primary, $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

Short circuit PF $\cos\phi_S = \dfrac{P_C}{V_{SC} \cdot I_1}$

Thus S.C. test gives Full load copper loss and R_{01} & X_{01}

Three Phase Transformer

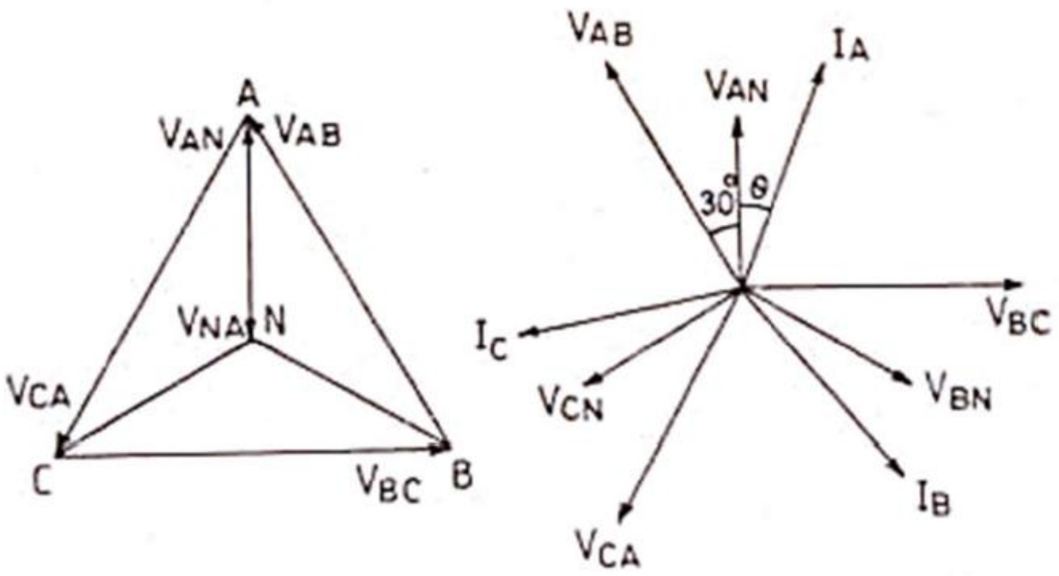




- In part j and k, the phasor difference of the flux would be $\frac{\sqrt{3}}{2}\phi$ while in in I and l would be only $\frac{1}{2}\phi$
- So, to achieve uniform flux density throughout, parts j and k would be 73% wider than i or l
- If, in the central winding, the direction is reversed, the magnetic flux is also reversed.
- The resultant flux in part j and k will be phasor sum. Hence resultant flux in j and k will be $\frac{1}{2}\phi$

Three Phase Transformer (Cont…)

- Phasors of a balanced 3-phase system:



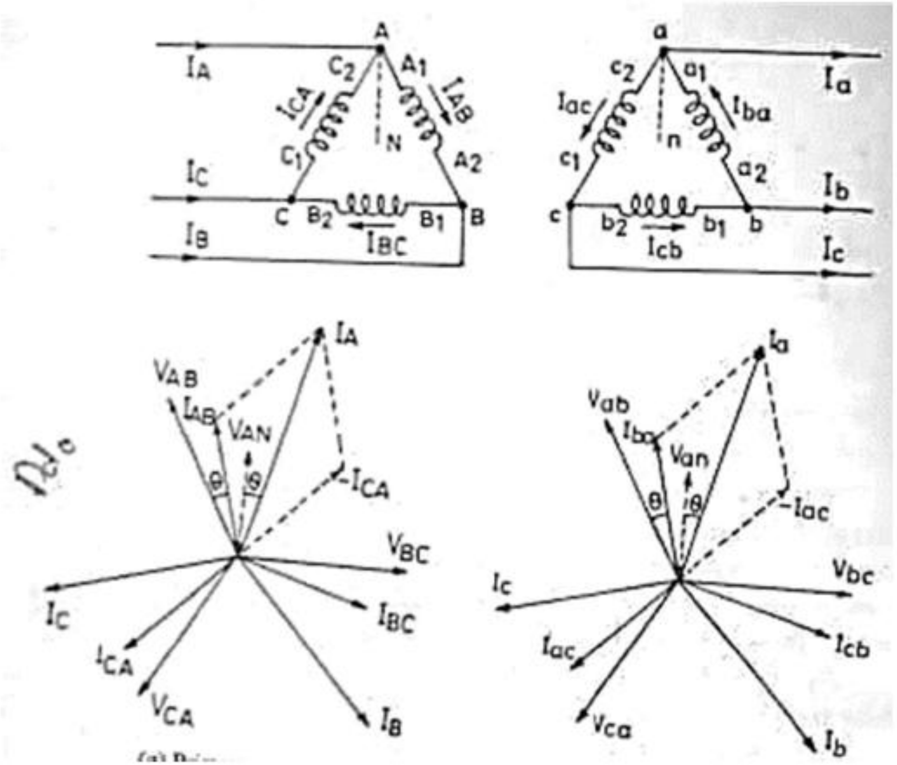
Three Phase Transformer (Cont…)

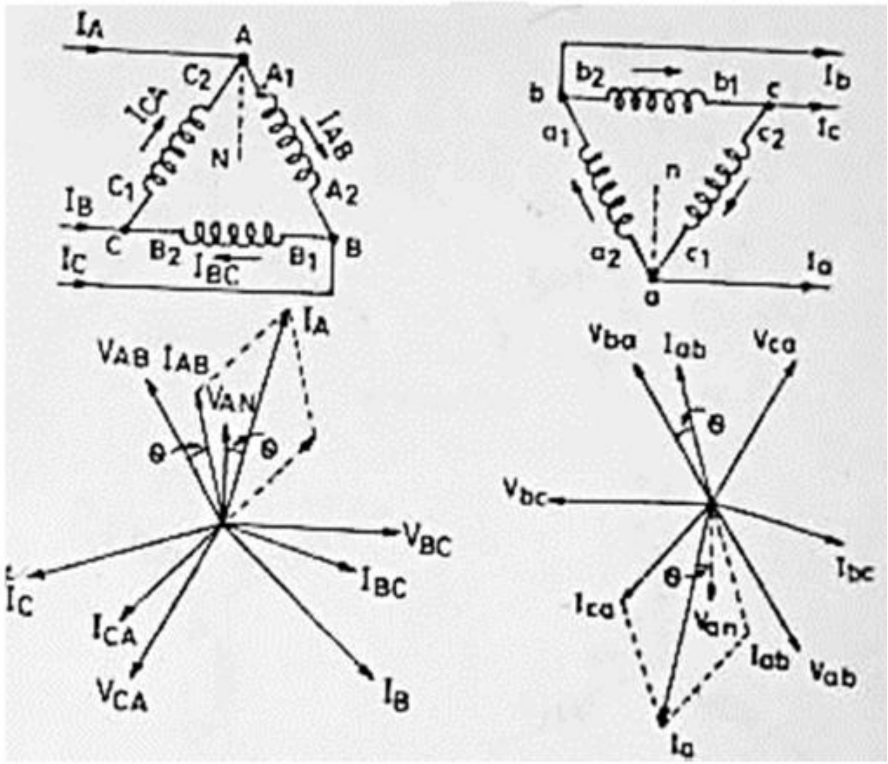
❑ 3-Phase Transformer Connections:

Possible connections –

- Delta-Delta, Star-Star, Star-Delta, Delta-Star, Delta-Zigzag, Star-Zigzag, Open-Delta, T Connection

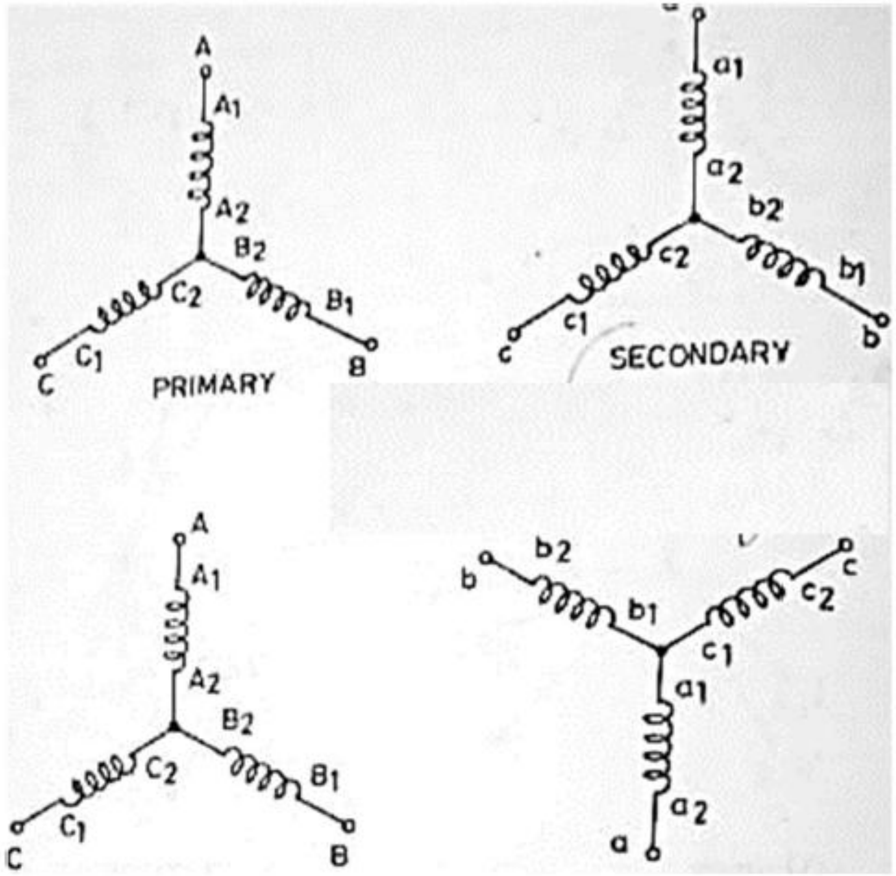
❑ Delta-Delta:

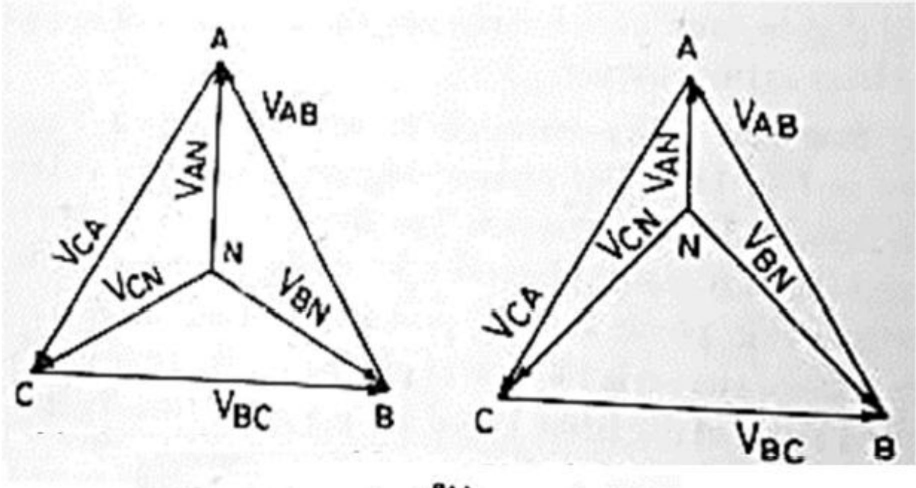


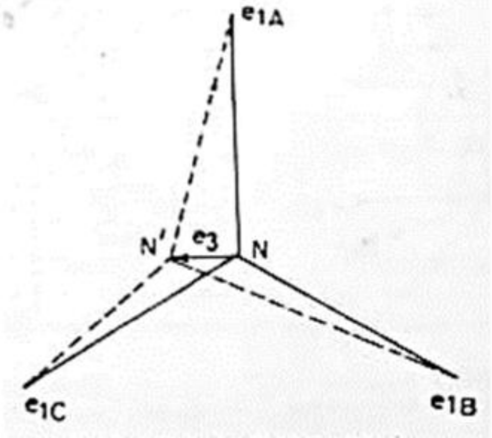


Three Phase Transformer (Cont…)

- Star-Star:

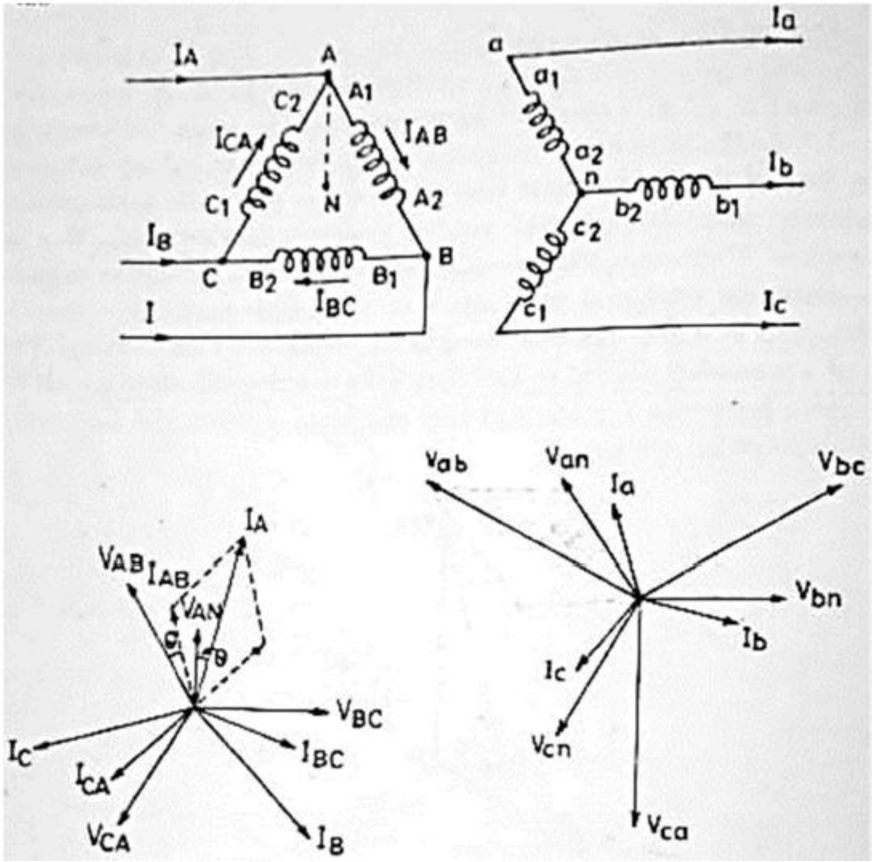


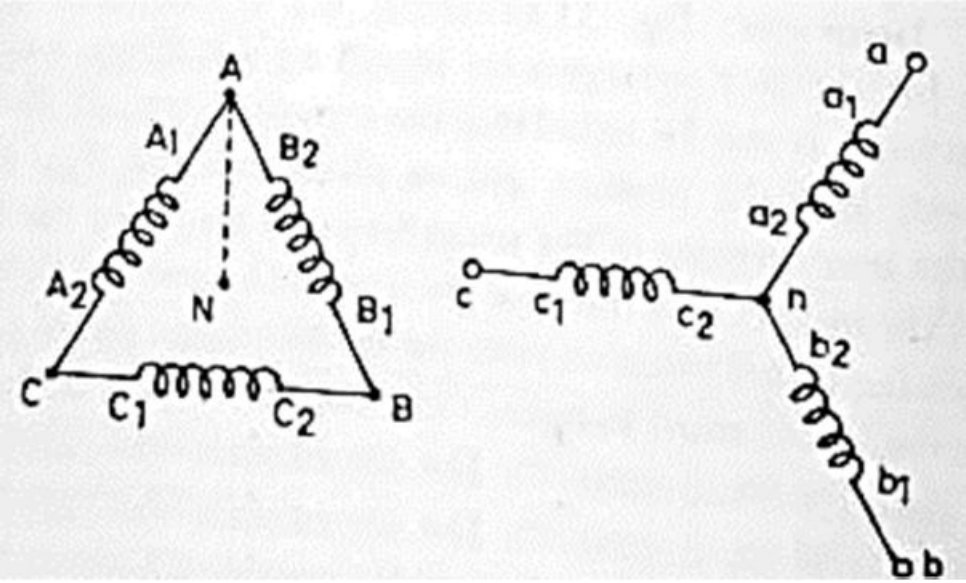




Three Phase Transformer (Cont…)

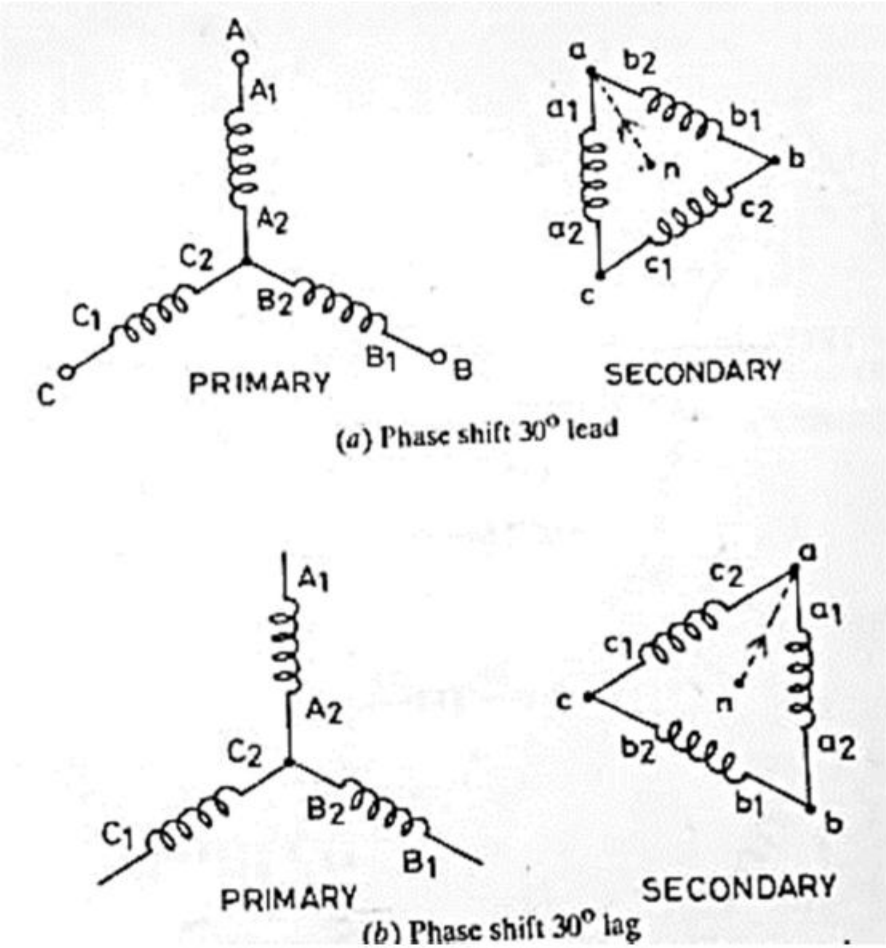
- Delta-Star:





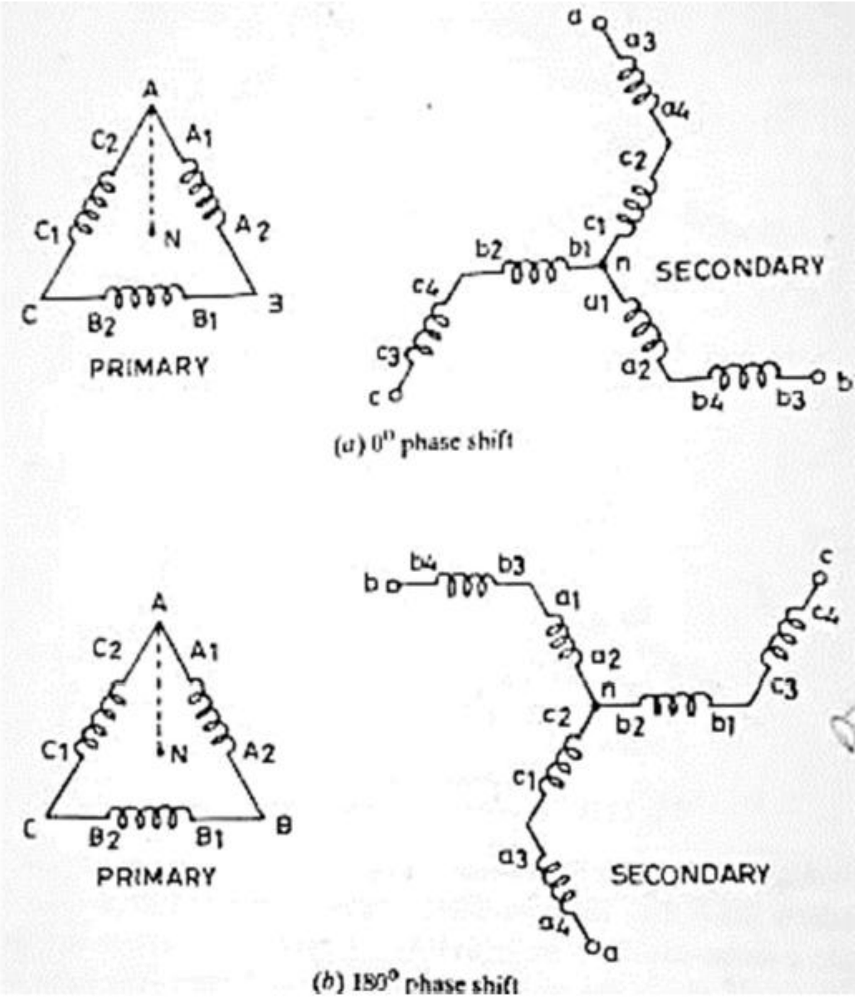
Three Phase Transformer (Cont…)

- Star-Delta:



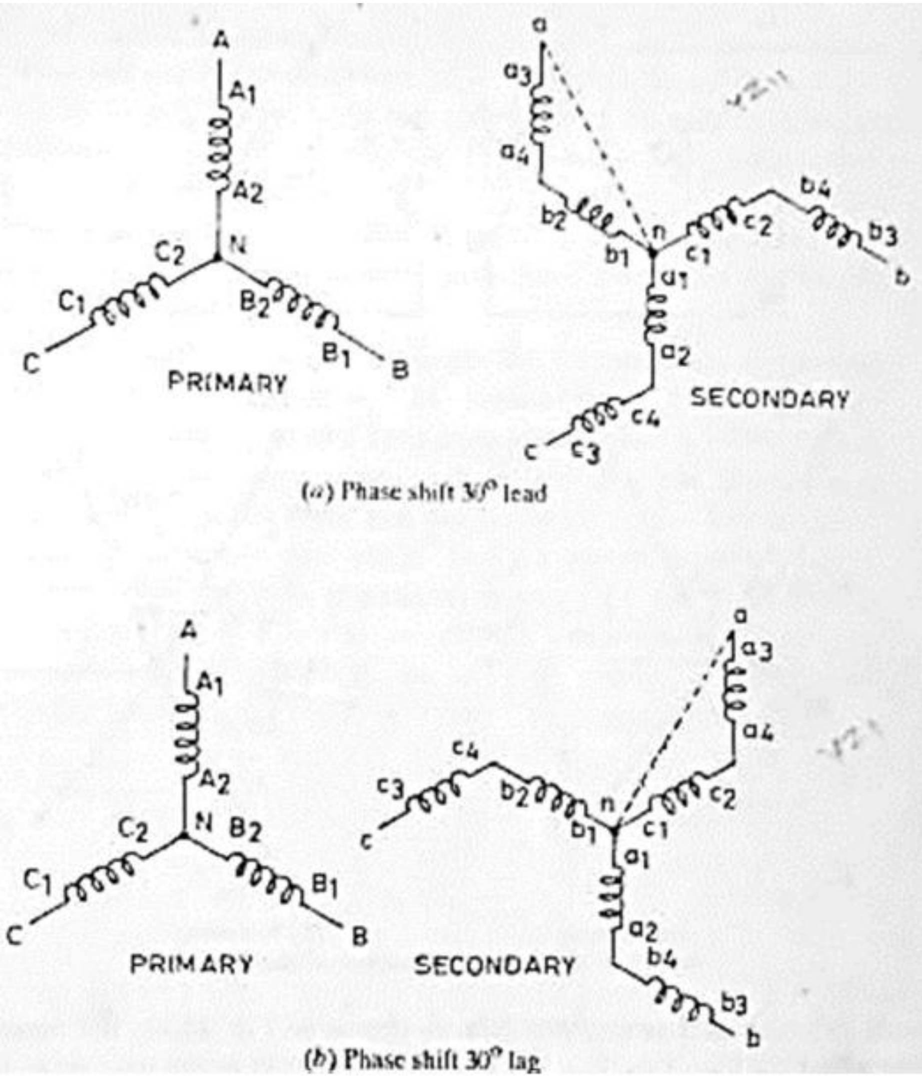
Three Phase Transformer Connections

- Delta-Zigzag:



Three Phase Transformer Connections (Cont…)

- Star-Zigzag:

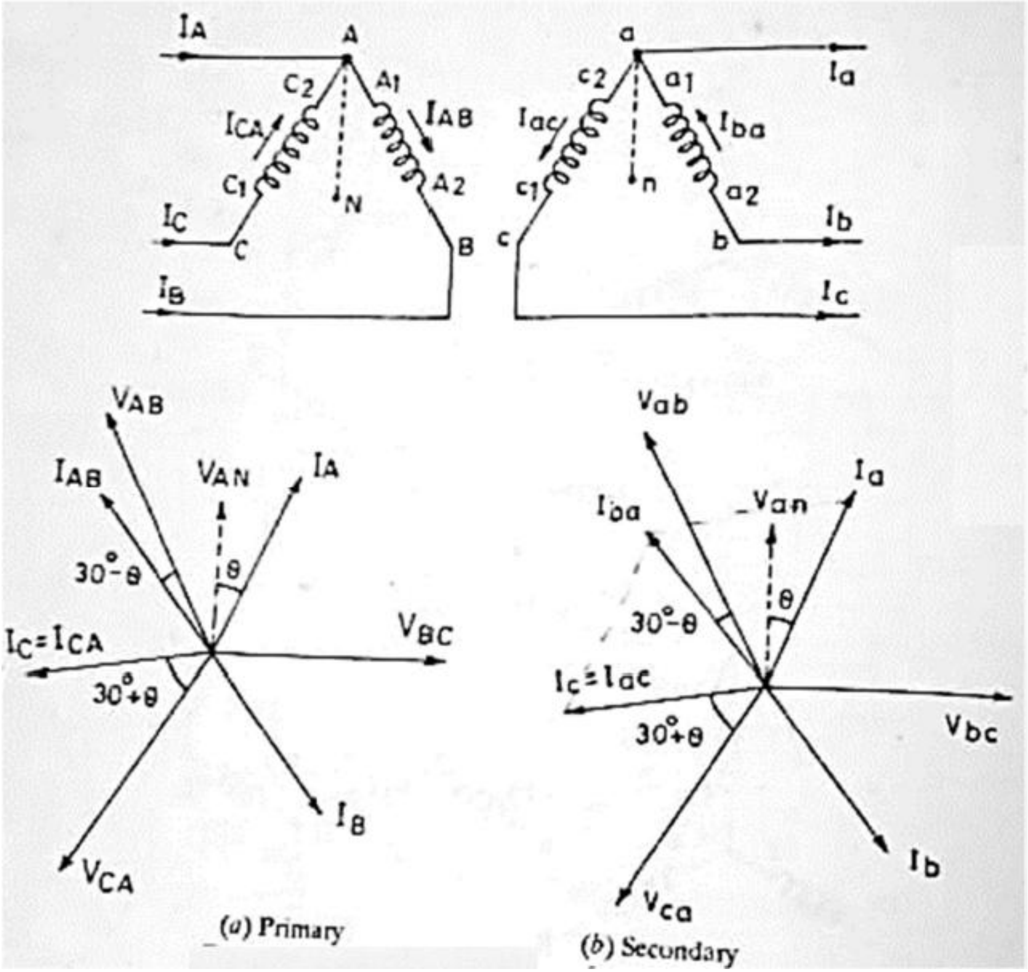


(a) Phase shift 30° lead

(b) Phase shift 30° lag

Three Phase Transformer Connections (Cont…)

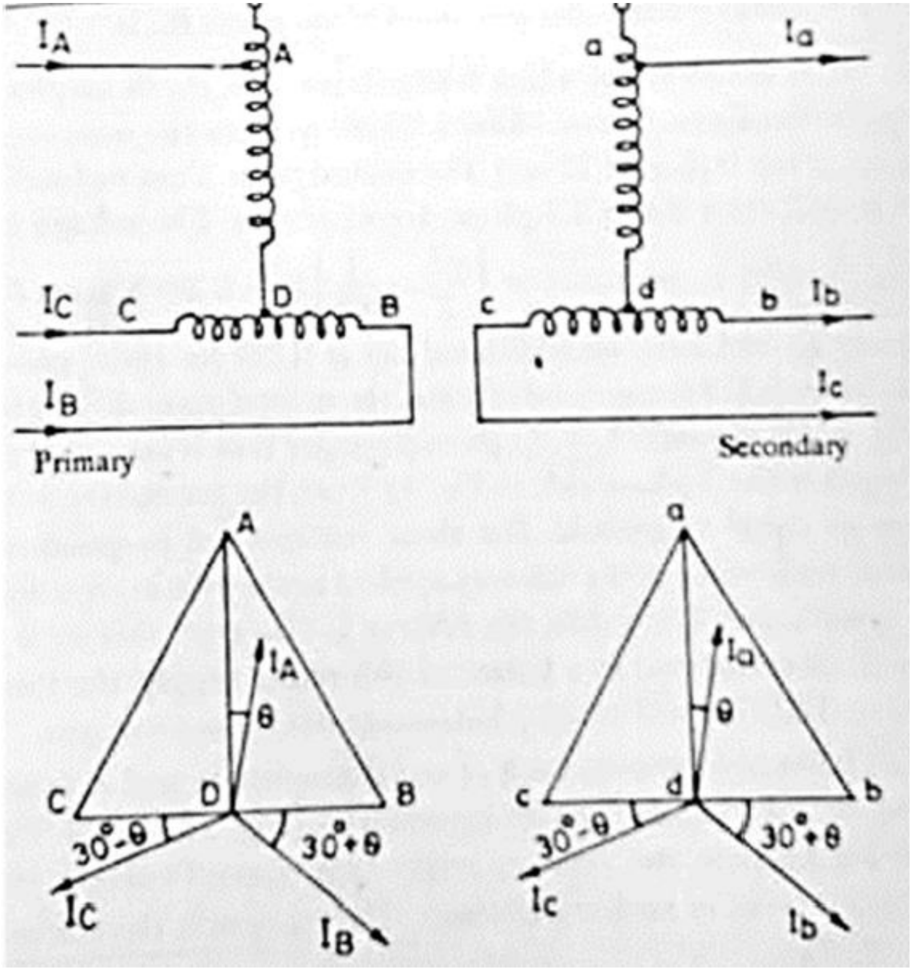
- Open-Delta:



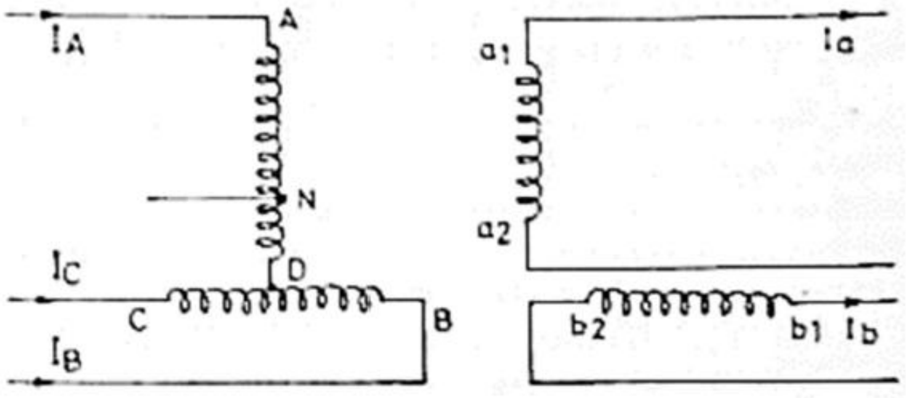
(a) Primary (b) Secondary

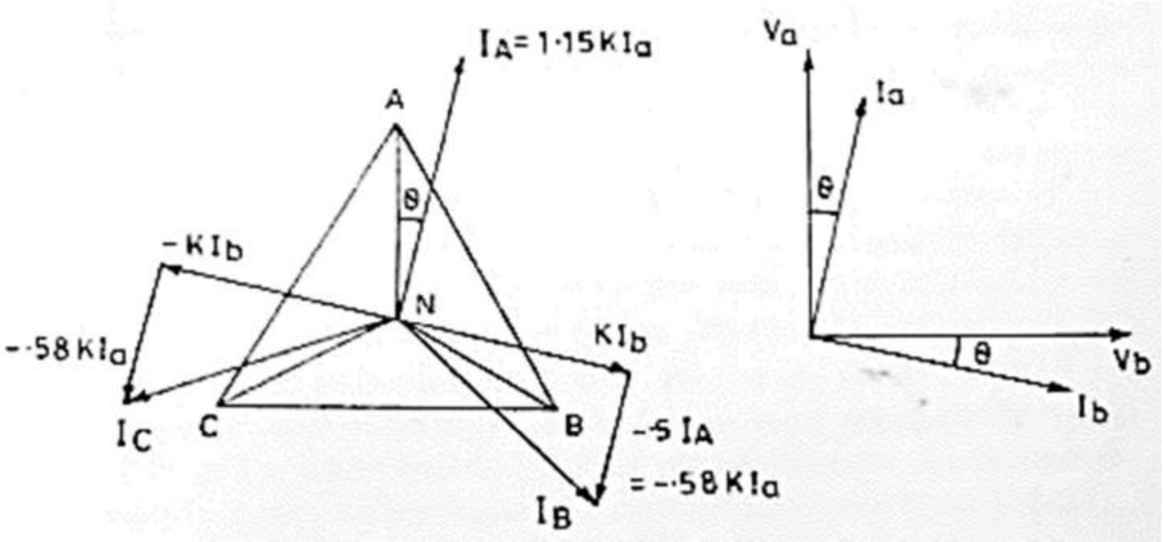
Three Phase Transformer Connections (Cont…)

- T Connection:

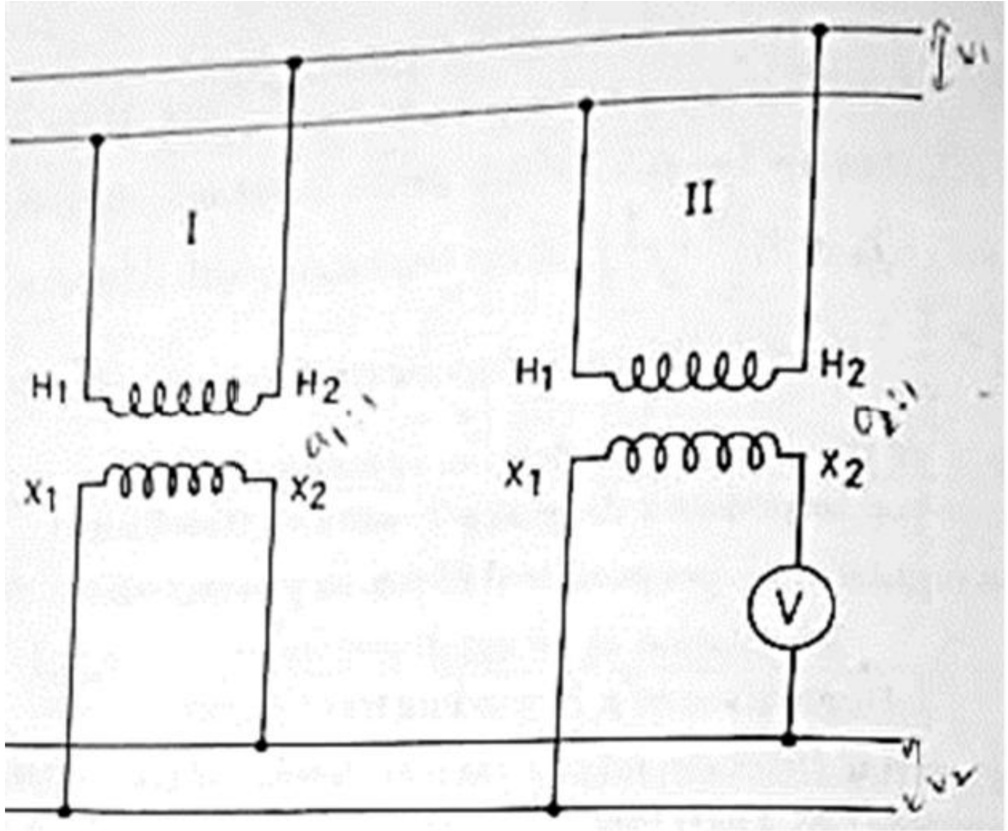


- T Connection:





❑ Parallel Operation of Transformer:



Introduction to Machines

❑ Electromagnetic energy conversion:

- An electromagnetic machine is one that links an electrical energy system to another energy system by providing a reversible means of energy flow in its magnetic field.
- The magnetic field is therefore the coupling between the two systems and is the mutual link.
- The energy transferred from the one system to the other is temporarily stored in the field and then released to the other system.

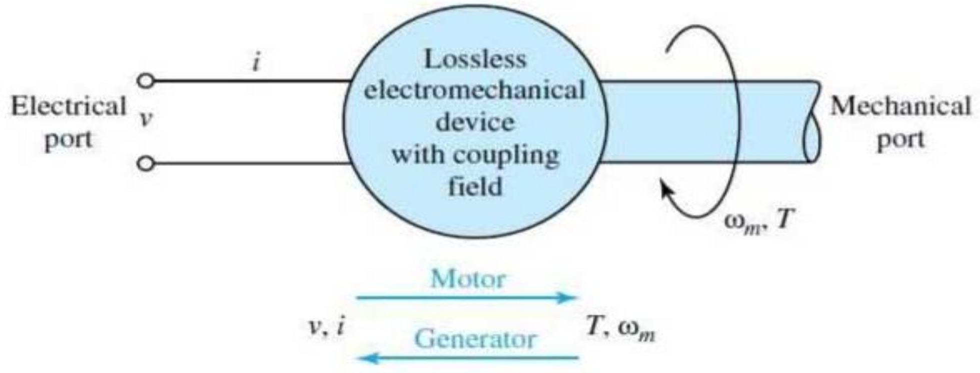
Usually the energy system coupled to the electrical energy system is a mechanical one

Electric energy $\underset{\textbf{Generator}}{\overset{\textbf{Motor}}{\rightleftarrows}}$ Mechanical energy

Usually, the energy system coupled to the electrical energy system is a mechanical one

❑ Electromagnetic energy converters:

1. A mechanical system,
2. An electric system,
3. A coupling field.



Electric input(or output) energy $vi\Delta t = mechanical\ output\ (or\ input) energy\ T\omega_m\Delta t$

Both electric and magnetic fields store energy, from which useful mechanical forces and torques can be derived.

All industrial electric machines are magnetic field devices

The change in flux linkage →

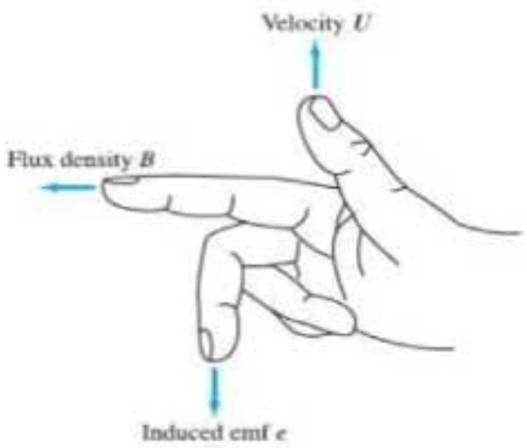
1. Transformer emf: The coil remaining stationary with respect to the flux, the flux varies in magnitude with time.

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

2. Motional emf : The flux remaining constant, the coil moves through it. A conductor or a coil moving through a magnetic field will have an induced voltage.

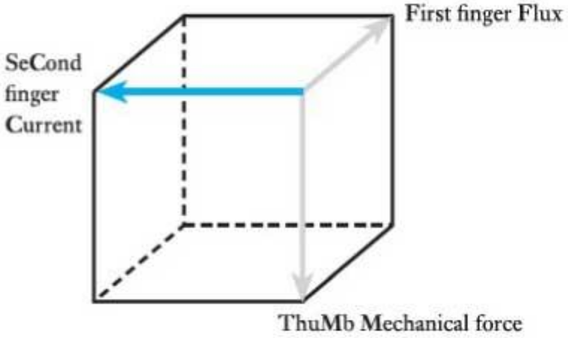
$$Motional\ EMF\ e = BlU$$

3. The coil may move through a time-varying flux



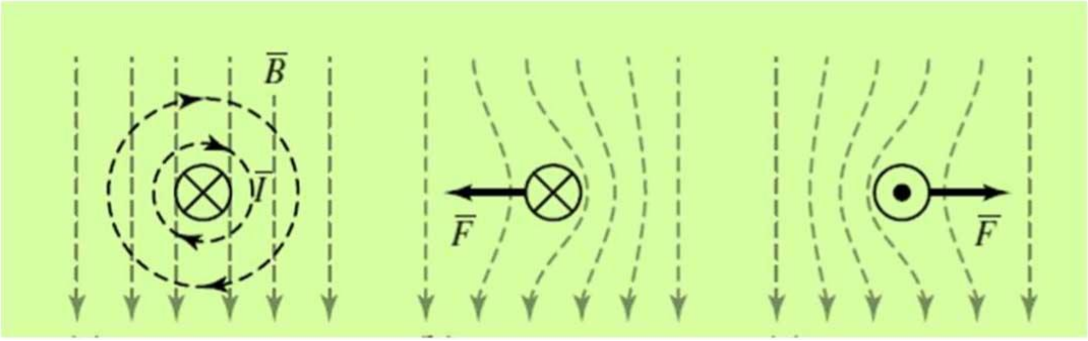
- Current-carrying conductors, when placed in magnetic fields, experience mechanical force.

$$F = BlI \qquad Lorentz\ Force\ Equation$$

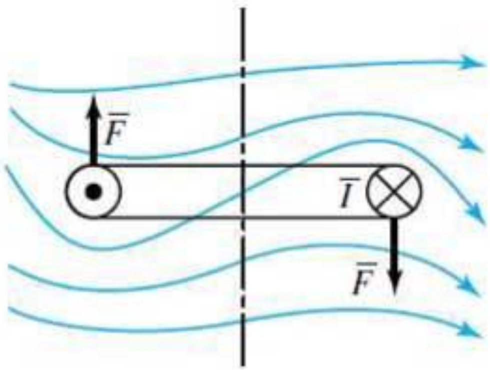


- If magnetic poles occur in pairs (north and south) and the movement of a conductor through a natural north– south sequence induces an emf that changes direction in accordance with the magnetic polarity (i.e., an alternating emf), the devices are inherently ac machines.

❑ Force of Alignment:



The force is always in such a direction that the energy stored in the magnetic field is minimized.



Torque produced by forces caused by interaction of current-carrying conductors and magnetic fields


THANKS
FOR YOUR
ATTENTION