Transformers

- A transformer is a device that changes AC electric power at one voltage level to AC electric power at another voltage level through the action of magnetic field.

- It consists of two or more coils of wire wrapped around a common ferromagnetic core. These coils are called primary winding and secondary winding. They are usually not connected to each other. The only connection between the coils is the common magnetic flux present within the core.

- One winding (usually the primary is connected to the source) and the other (usually the secondary) is connected to the load.
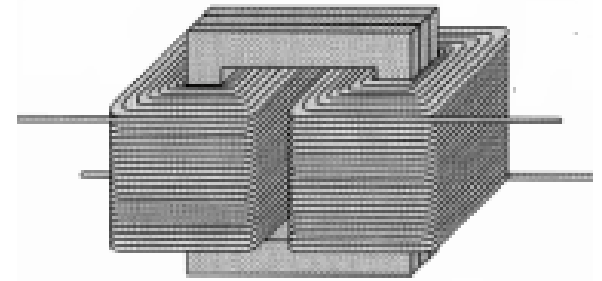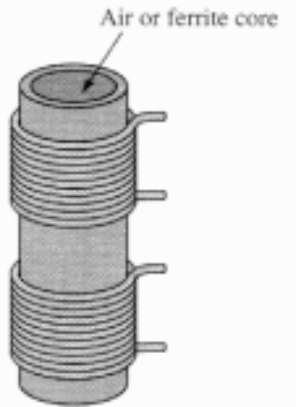
Why Transformers?

- High power transmission at low voltages requires high current which causes huge voltage drops and power loseses in the transmission line.

- The invention of the transformer and accordingly raising the level of the voltage eliminated forever these restrictions on the range and power level of power systems.

- In modern power system, electric power is generated at voltages of 12 to 25 kV. Transformers set up the voltage to between 110kV and nearly 1000kV for transmission over long distances at very low losses. Transformers then step down the voltage to the 12- to 34-kV range for local distribution.

What is a Transformer?

- Transformers are devices that consist of two or more coils of wire that are wound on a magnetically conductive material (the core).

- When alternating current flows in one coil it generates a magnetic flux that flows through the core and engages the other coil(s) in which it induces a corresponding potential.

- If the second coil (referred to as the secondary winding(s) have more turns than the first coil (referred to as the primary winding) the induced voltage is proportionately greater and it is referred to as a "step-up" transformer.

More About Transformer!

Air or ferrite core

The principle parts of a transformer and their functions are:

- The core, which makes a path for the magnetic flux.

- The primary coil, which receives energy from the ac source.

- The secondary coil, which receives energy from the primary winding and delivers it to the load.

- The enclosure, which protects the transformer from dirt, moisture, and mechanical damage.

Applications of Transformers

- Transformers have many applications in power transmission and electronics:

- They may be used to minimise energy losses due to voltage drop in transmitting electricity over long distances.

- They match loads with internal resistance so that there is maximum power transfer.

- They couple signals between electronic stages.

Transformer Core

- The composition of a transformer core depends on voltage, current, and frequency. Commonly used core materials are air, ferrite, soft iron, and steel. Each of these materials is suitable for certain applications. Generally, air-core and ferrite transformers are used when the source has a high frequency (above 20 kHz). Iron-core transformers are usually used when the source frequency is low (below 20 kHz).

- A soft-iron-core transformer is very useful where the transformer must be physically small, yet efficient. The iron-core transformer provides better power transfer than does the air-core transformer. A transformer whose core is constructed of laminated sheets of steel dissipates heat readily; thus it provides for the efficient transfer of power.

- The majority of transformers contain laminated-steel cores. These steel laminations are insulated with a nonconducting material, such as varnish, and then formed into a core. It takes about 40 laminations to make a core of 2 cm thick. The purpose of the laminations is to reduce losses which will be discussed later in this chapter.

- The most efficient transformer core is one that offers the best path for the most lines of flux with the least loss in magnetic and electrical energy.

Example 1: A transformer reduces voltage from 120 volts in the primary to 6 volts in the secondary. If the primary winding has 300 turns and the secondary has 15 turns, find the voltage and turns ratio.

Example 2: Example 2: An iron core transformer with a primary voltage of 240 volts has 250 turns in the primary and 50 turns in the secondary. Find the secondary voltage.

Example 3: When operated at 120 V in the primary of an iron core transformer, the current in the primary is 4 A. Find the current in the secondary if the voltage is stepped up to 500 V.

Losses in Transformers

All transformers have copper and core losses, and flux leakage. Copper loss is ohmic power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss, in watts, may be found using the following equation

$$I_P^2 R_P + I_S^2 R_S$$

Where, I_p is the primary current, I_s is the secondary current, R_p is the primary resistance, and R_s is the secondary resistance.

Core losses are caused by two factors: **hysteresis** and **eddy** current losses. Hysteresis loss is that energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction. Eddy current loss is a result of induced currents circulating in the iron core. It can be used by laminations!

Efficiency of Transformer

$$\text{Efficiency} = \frac{\text{Power Output}}{\text{Power Input}} \times 100\%$$

$$\text{Efficiency} = \frac{\text{Power Outpt}}{\text{Power Output} + \text{Copper Losses} + \text{Core Losses}} \times 100\%$$

- Example 4:   A 5:1 step-down transformer has a full-load secondary current of 20 amps. A short circuit test for copper loss at full load gives a wattmeter reading of 100 W. If $R_P = 0.3$, find R_S and power loss in the secondary.

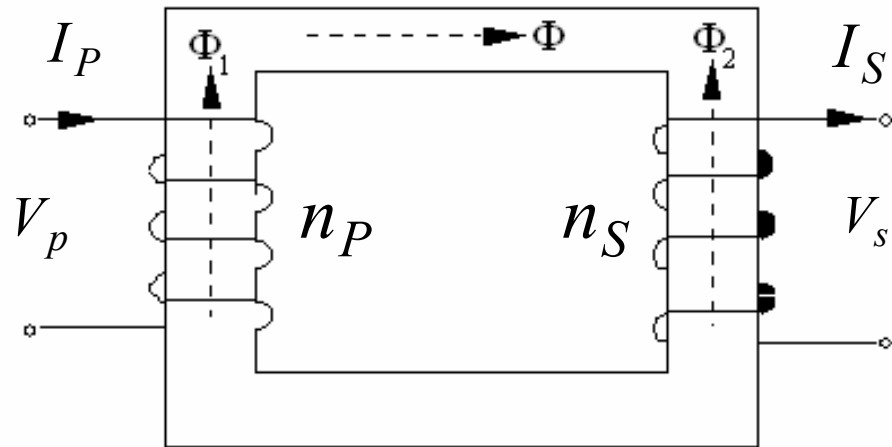 Ans: = R_S = 0.24; Power Loss in the secondary = $I_s^2 R_s$ = 96 W.

Ideal Transformer

The principle of transformer is based on the work of Michael Faraday (1791-1867): Given two magnetically coupled coils, a changing current in one coil will induce an electromotive force in the other coil.

$$\frac{V_P}{n_P} = \frac{V_S}{n_S}$$

$$n_P I_P = n_S I_S$$

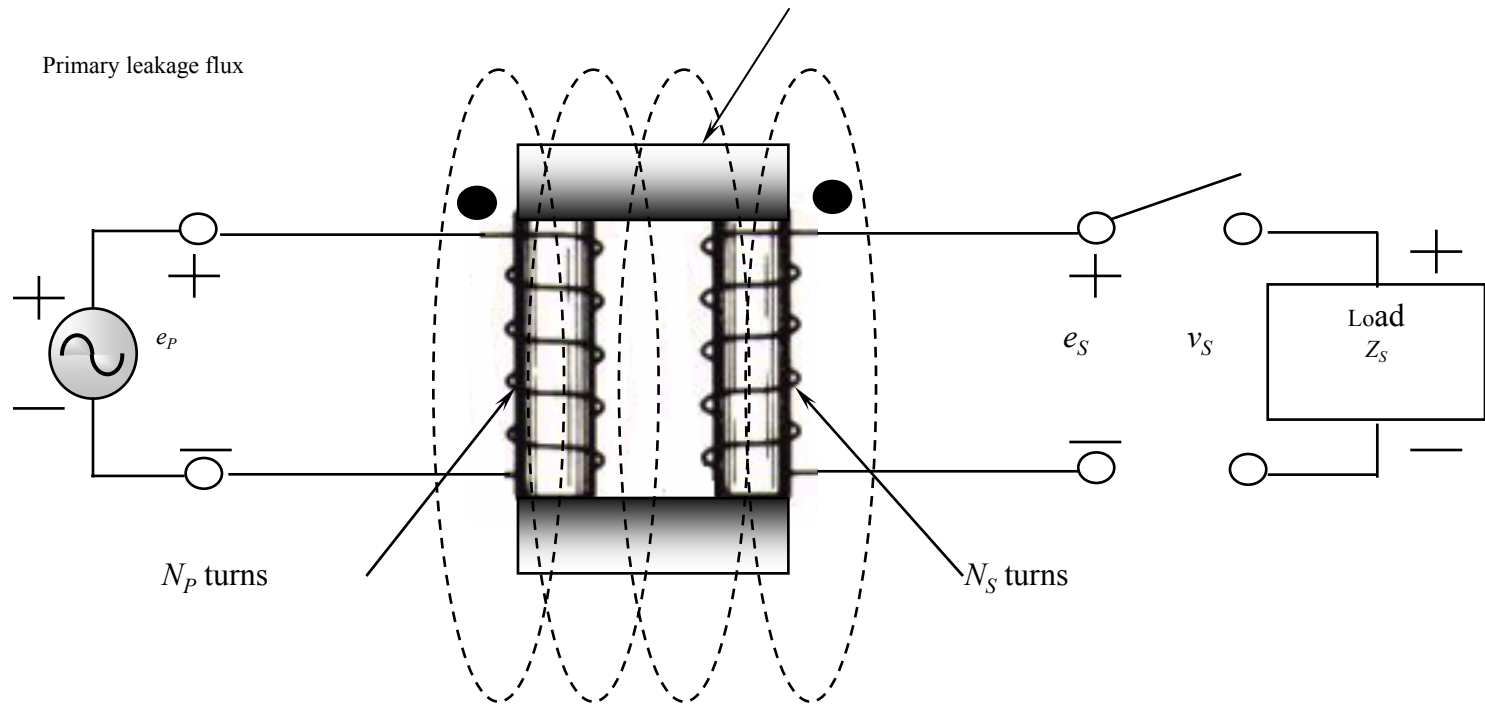$$a = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

Modified from Sam Rosemberg Notes, 2001

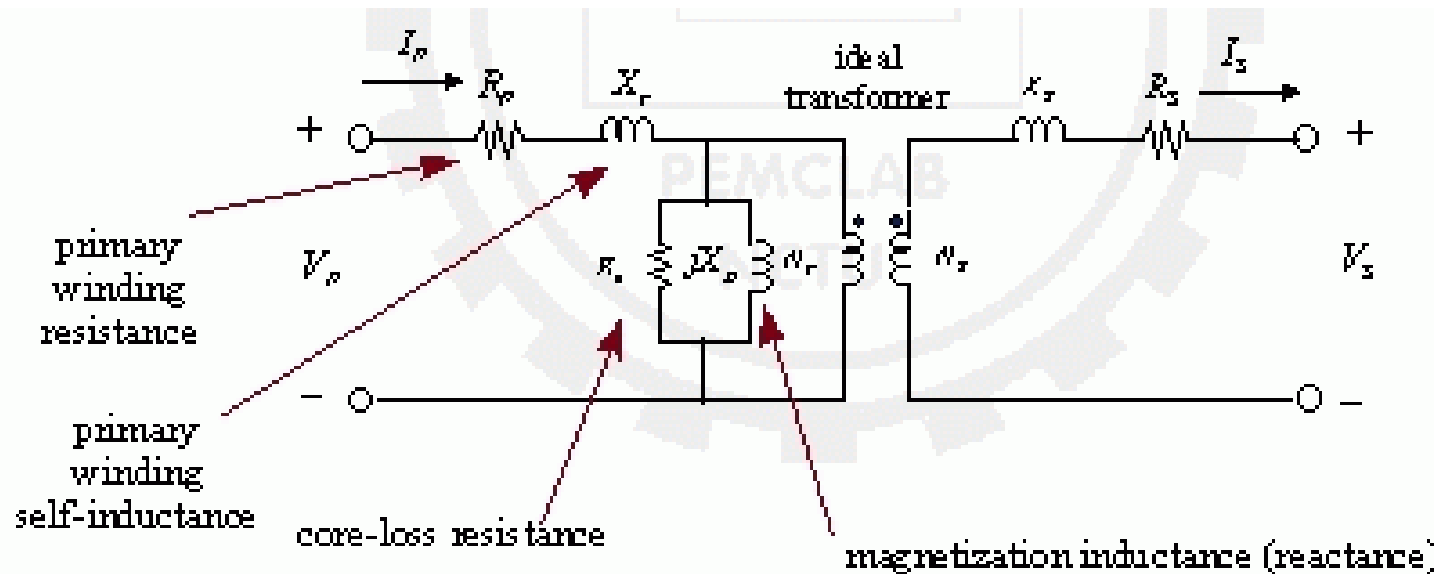$$P_{in} = V_P I_P \cos\theta_P \quad P_{out} = V_S I_S \cos\theta_S$$

$$\theta_P = \theta_S; P_{in} = P_{out}; Q_{in} = Q_{out}; S_{in} = S_{out}$$

A Simple Transformer

Primary leakage flux

e_P

N_P turns

e_S v_S

Load Z_S

N_S turns

Transformer Equivalent Circuit

- Iron Losses
  - Eddy currents; Hysteresis Loss
- Copper Losses
  - Primary winding; Secondary winding
- Leakage Flux
- Excitir

primary
winding
resistance

primary
winding
self-inductance

core-loss resistance

magnetization inductance (reactance)

From Yind - Tu Tzou (NCTU)

Transformer Equivalent Circuit.