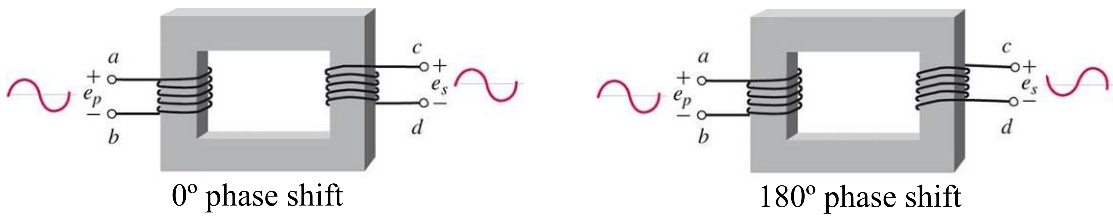
EE301 – MAGNETISM AND TRANSFORMERS

Learning Objectives

a. Analyze the relationship between the transformation ratio, voltage ratio, current ratio, and impedance ratio.
b. Construct a circuit equivalent of a transformer and calculate primary and secondary voltage, current and polarity.
c. Explain the relationship between the power developed in the primary and secondary of a transformer.

Transformer overview. A transformer is a **magnetically coupled** circuit, whose operation is governed by Faraday's Law. A time-varying current in the primary **windings** induces a magnetic flux in an iron core. The flux flows through the core and induces a current the secondary **windings**. Thus power flows via the magnetic field without the winding being electrically connected.

Winding direction The polarity of ac voltages can easily be changed by changing the direction of the windings.

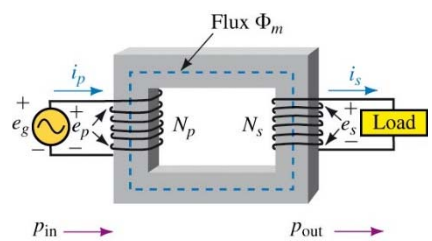


Iron-core transformers We will consider the **ideal transformer** which

- Neglects coil resistance
- Neglects core losses
- Assumes all flux is confined to the core
- Assumes negligible current required to establish core flux.

Transformation ratio

"The ratio of the primary voltage to secondary voltage is equal to the ratio of primary turns to secondary turns."



$$\frac{E_p}{E_s} = \frac{N_p}{N_s}$$

This ratio is called the **transformation ratio** (or the turns ratio) and is given by the symbol *a*.

$$a = \frac{E_p}{E_s} = \frac{N_p}{N_s}$$

Step-up and Step-down Transformers are used to change or "transform" voltage.

Step-up transformer

- The secondary voltage is higher than the primary voltage.
- There are fewer primary windings then secondary windings ($a < 1$)

Step-down transformer

- The secondary voltage is lower than the primary voltage.
- There are more primary windings then secondary windings ($a > 1$)

<u>**Current ratio**</u> Because we are considering an ideal transformer, power in equals power out.

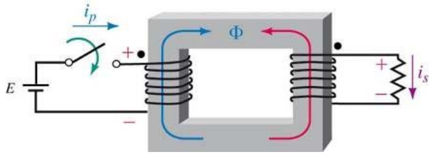
$$S_{in} = S_{out}$$

$$E_{pri} I_{pri} = E_{\sec} I_{\sec}$$

$$\frac{I_{pri}}{I_{\sec}} = \frac{E_{\sec}}{E_{pri}} = \frac{1}{a}$$

If the voltage is stepped ***up***, then the current is stepped ***down***, and vice versa.

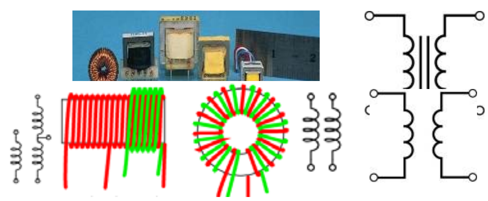
<u>**The Dot Convention**</u> The direction of the windings is not obvious looking at a transformer; therefore we use the **dot convention**. Dotted terminals have the same polarity at all instants of time.



<u>**Power Transformer Ratings**</u> Just like ac motors and generators, power transformers are rated in terms of **voltage** and **apparent power**. For example, suppose a transformer is rated 2400/120 volt, 48 kVA.

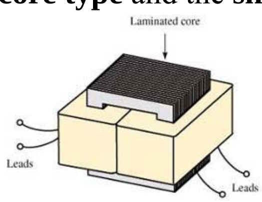
On the primary winding, the current rating is 48,000 VA / 2400 V = 20 A.

On the secondary winding, the current rating is 48,000 VA / 120 V = 400 A.

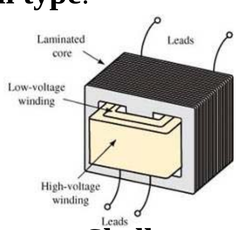


<u>**Iron-core transformers**</u>

Iron-core transformers are used for low frequency applications such as power and audio. There are two basic types of iron-core transformers: the **core type** and the **shell type**.



Core type

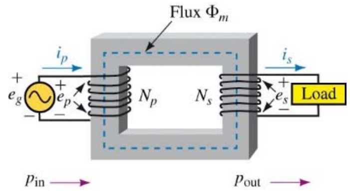


Shell type

In both, the core is constructed of laminated sheets of steel to reduce eddy current losses. At high frequency, iron-core transformers suffer considerable power loss.

Air-core transformers are used for high frequency applications such as communications equipment (f > 50-kHz

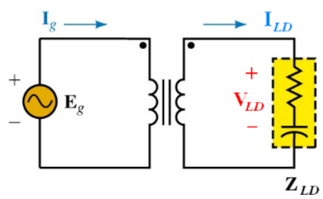
Example: A transformer with 4000 turns on its primary winding and 1000 turns on its secondary.



a. Determine the transformer's turns ratio. Is it step-up or step-down?
b. If the primary voltage e_p = 480 sin ωt, what is the secondary voltage?

Solution:

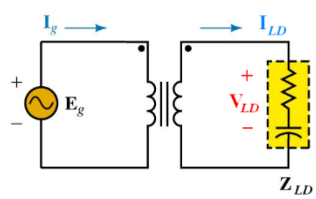
Example: In the transformer shown below, $\mathbf{E}_g$ = 120 V ∠0º, the turns ratio is 6:1, and $\mathbf{Z}_{LD}$ = 100-100j. The transformer is ideal.



Determine V_{LD}, I_{LD}, I_G, P_{LD}, P_G

Solution:

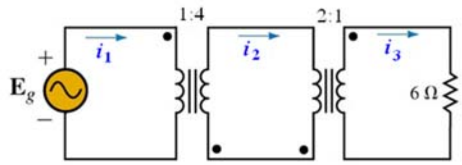
Example: In the transformer shown below, $\mathbf{I}_g$ = 25 mA ∠30º, V_{LD} = 60∠0º, and the turns ratio is 4:1. The transformer is ideal.



Determine I_{LD}, Z_{LD}, E_G, P_{LD} and Q_{LD}

Solution:

Example: In the diagram shown below, i_1 = 100 sin (ωt) mA. The transformer is ideal.



Determine and graph i_2 and i_3

Solution:

Example: A 7.2 kV, a = 0.2 transformer has a secondary winding rated current of 3 A. What is its kVA rating?

Solution: