Course: EEL 2043 Principles of Electric Machines
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كلّيات التقنية العليا
HIGHER COLLEGES OF TECHNOLOGY

LO 2: Transformers

LO-2: Analyze the operation of single-phase and three-phase electrical transformers

1: Describe the construction of a single -phase transformer.

2: Explain the operational principle of the ideal electrical transformer.

3: Identify the various power losses and voltage drops in a practical transformer.

4: Use a single -phase transformer circuit model to calculate the associated voltage, current and power under various loading conditions. Determine the associated phasor diagrams.

5: Measure the loading characteristics of a single-phase transformer under resistive, inductive and capacitive loads.

Transformers

- Single – phase
- Three – phase





What is the Transformer?

The transformer is a device that has two or more coils wound on an iron core.

The transformer *is an electrical device that, by electromagnetic induction, transforms electric energy from one or more circuits to one or more other circuits at the same frequency, but usually at a different voltage and current level.*

The transformer is an electrical device that changes voltage in direct proportion to the ratio of the number of turns of its primary and secondary windings.

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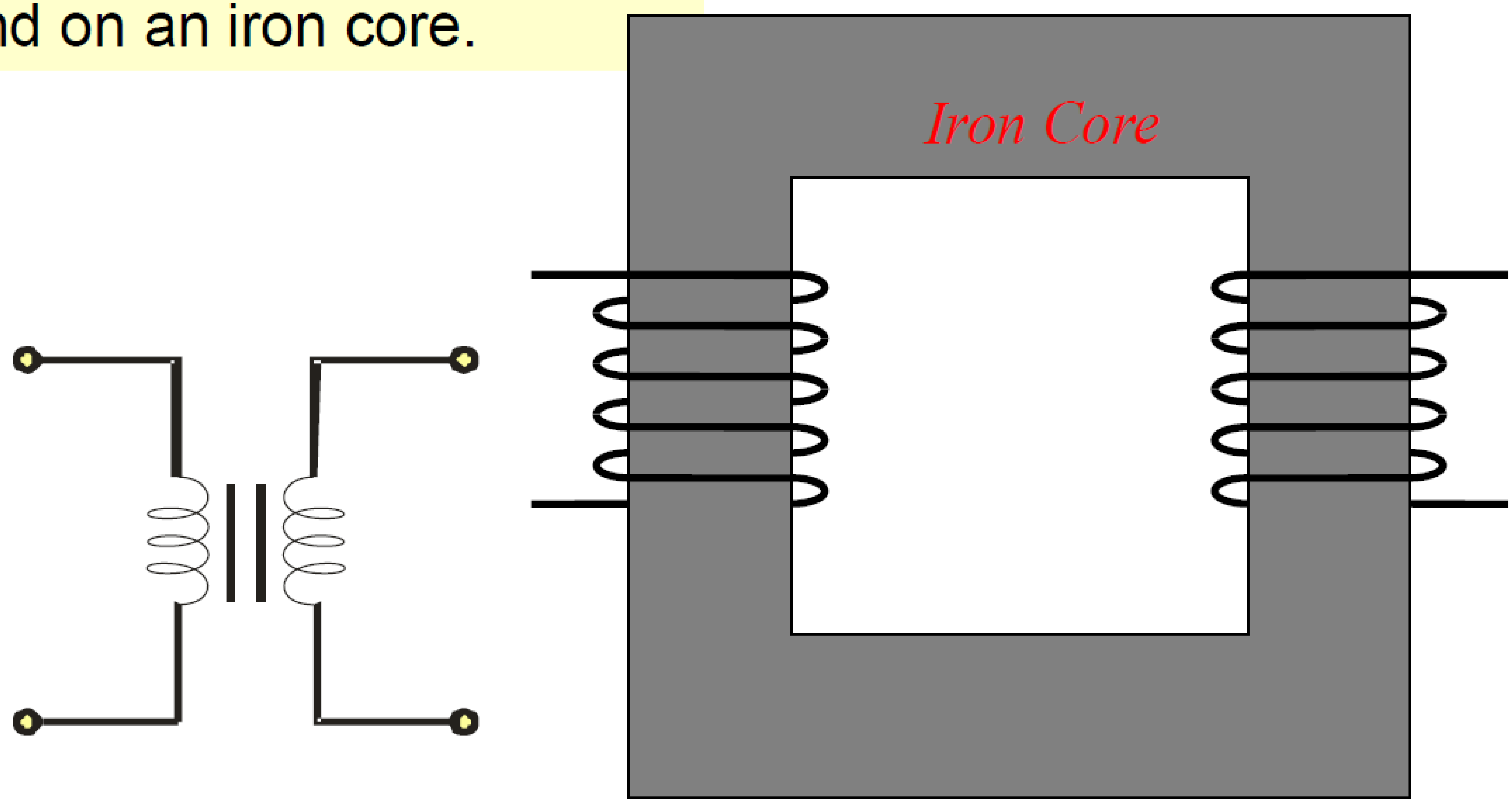

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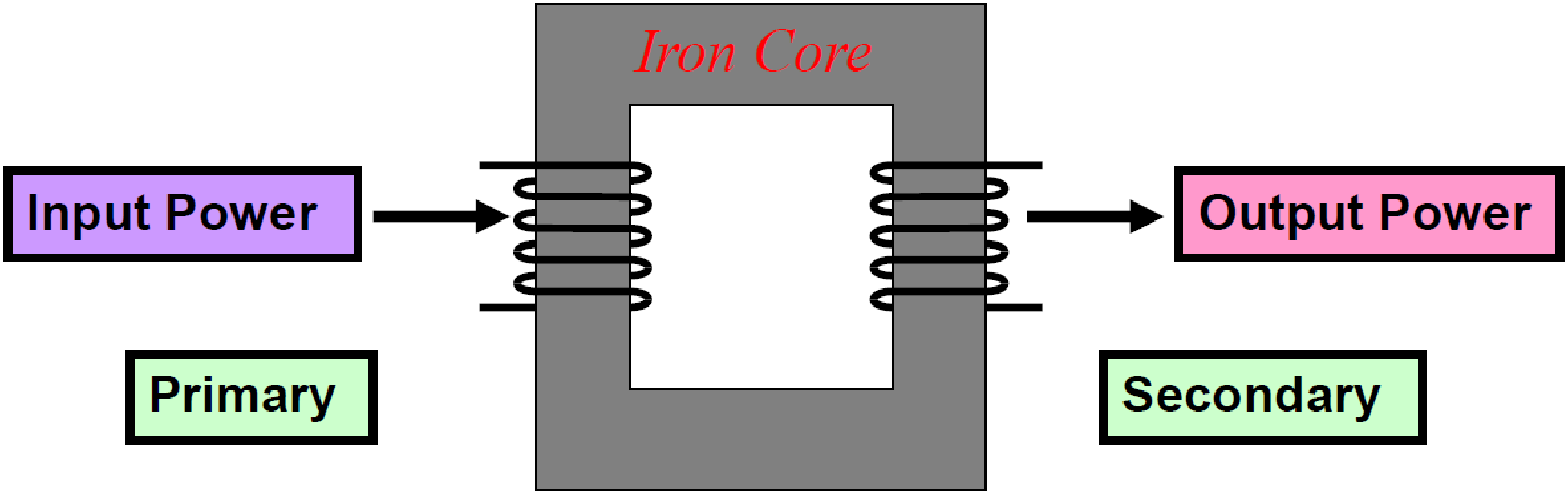
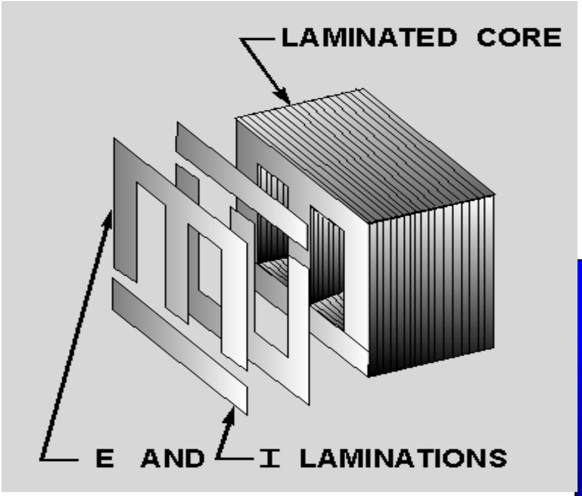
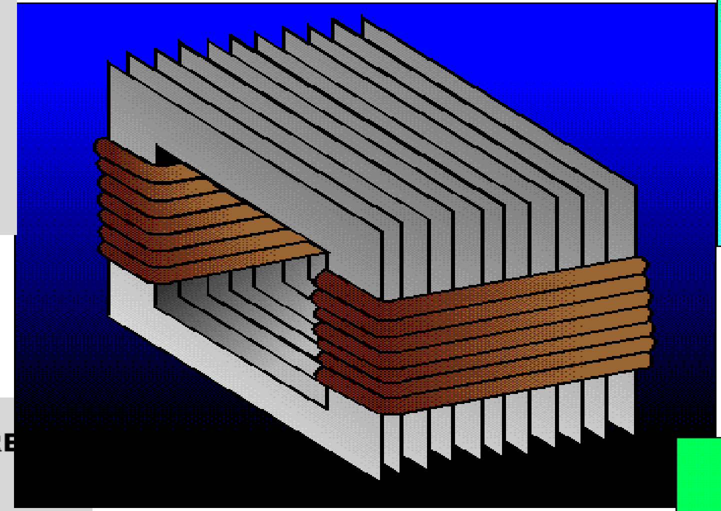
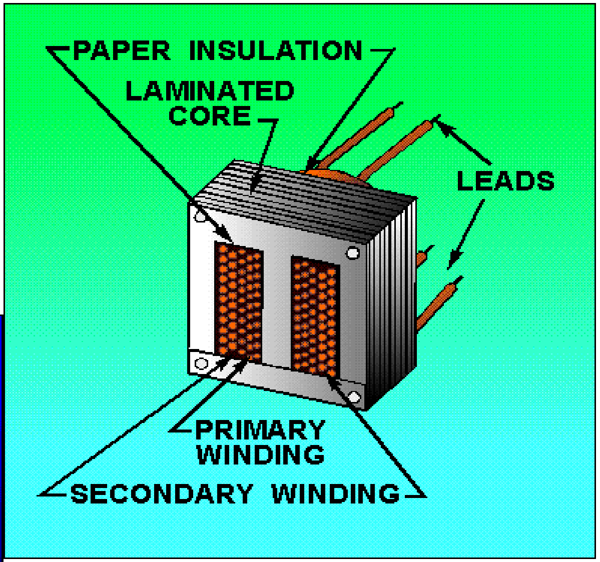
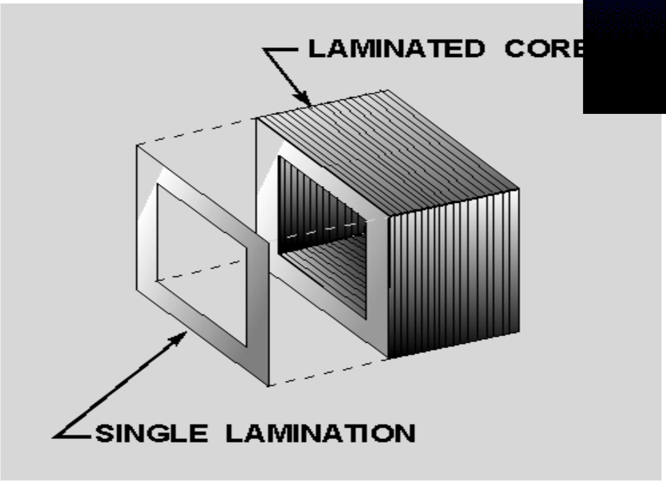


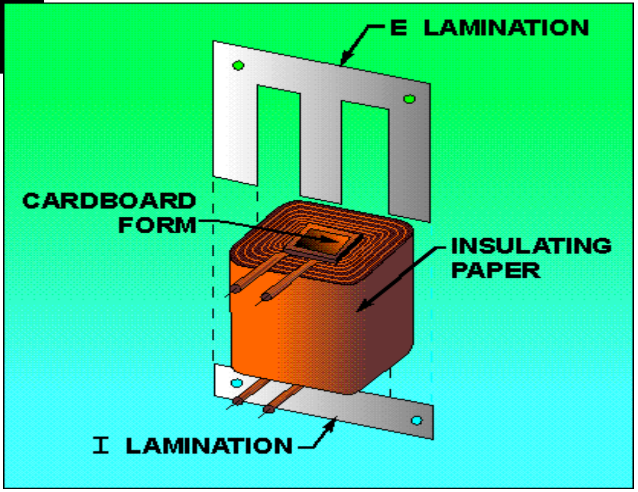
Transformers









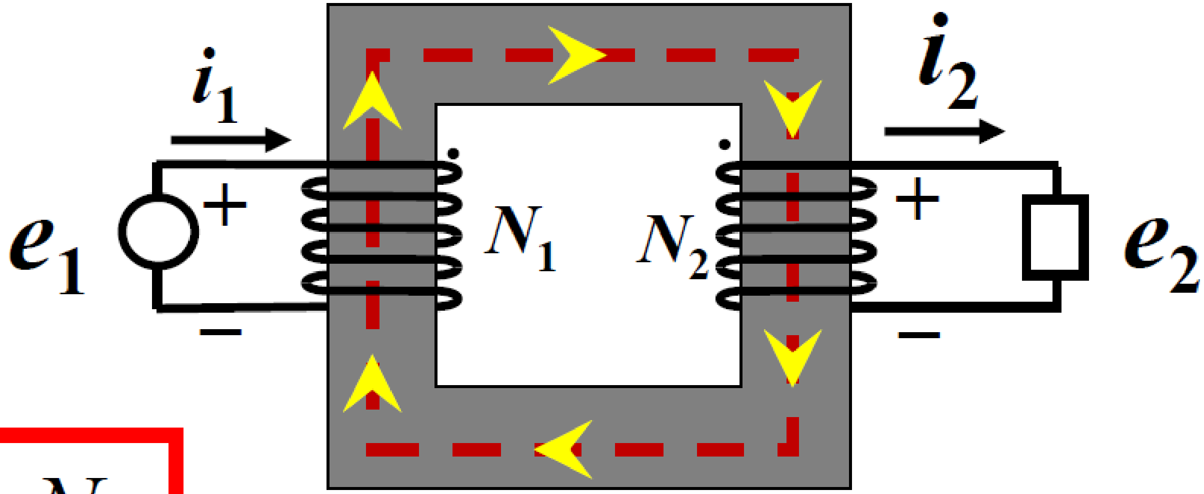


What is the Transformer?

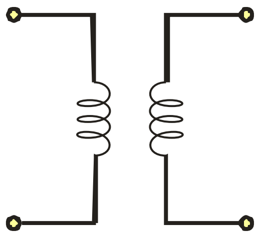
The transformer is an electrical device that changes voltage in direct proportion to the ratio of the number of turns of its primary and secondary windings.

$$\boxed{\frac{\vec{E}_1}{N_1} = \frac{\vec{E}_2}{N_2}}$$

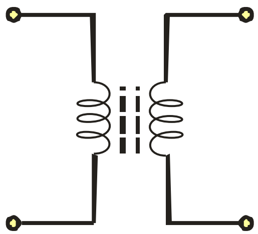
$$\boxed{\frac{\bar{I}_1}{\bar{I}_2} = \frac{N_2}{N_1}}$$



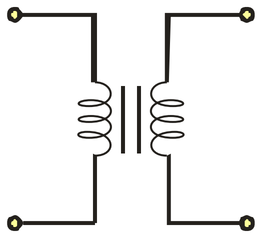
The basic transformer is formed from two coils that are usually wound on a common core to provide a path for the magnetic field lines. Schematic symbols indicate the type of core.



Air core

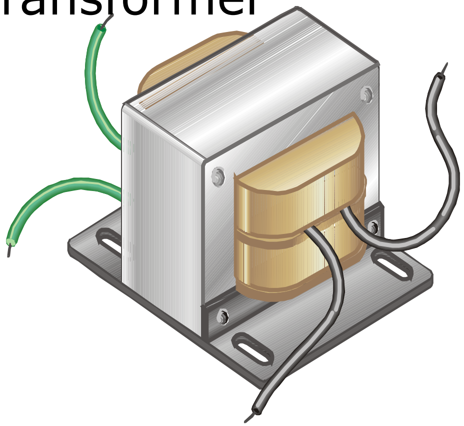


Ferrite core



Iron core

Small power transformer



Turns ratio

A useful parameter for ideal transformers is the turns ratio defined as

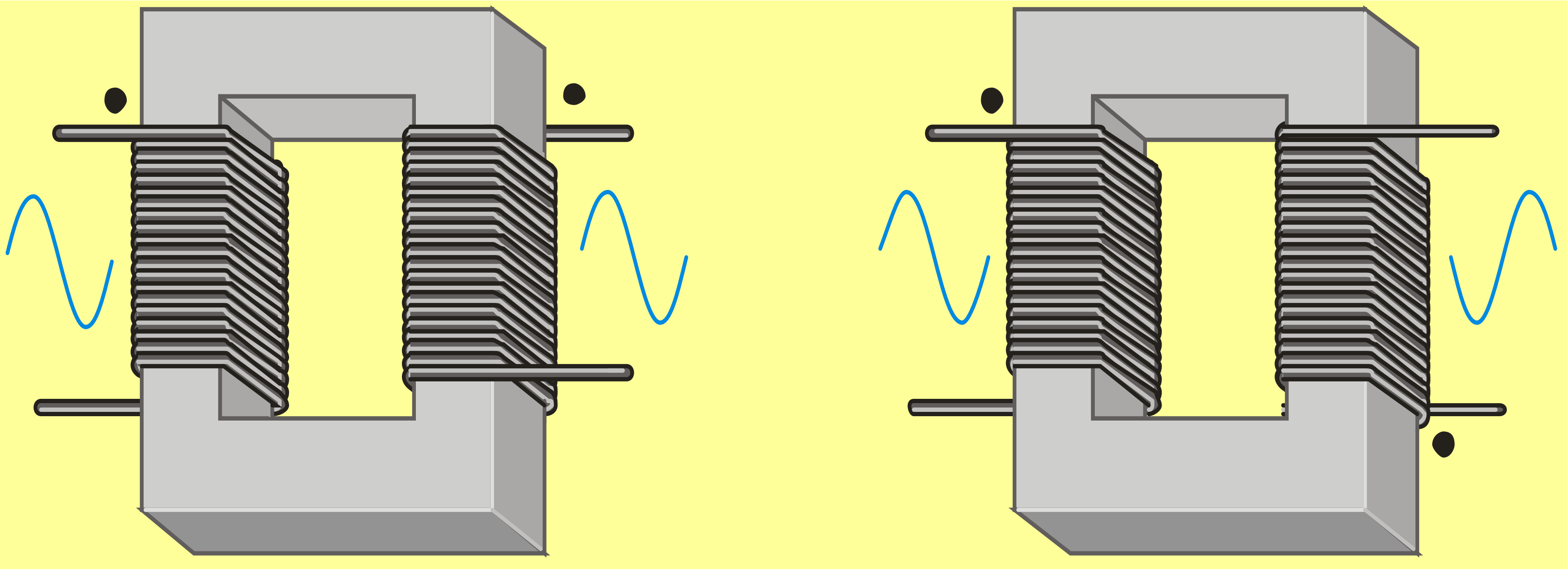
$$\boxed{n = \frac{N_{sec}}{N_{pri}}}$$

N_{sec} = number of secondary windings

N_{pri} = number of primary windings

Direction of windings

The direction of the windings determines the polarity of the voltage across the secondary winding with respect to the voltage across the primary. Phase dots are sometimes used to indicate polarities.



In phase

Out of phase

Why do we need Transformers?

- Increase voltage of generator output
  - *Transmit power at low current*
  - *Reduce cost of transmission systems*
- Adjust voltage to a usable level
- Create electrical isolation

Transformers

The electrical energy is always transferred without a change in frequency, but may involve changes in magnitudes of voltage and current. Because a transformer works on the principle of electro - magnetic induction, it must be used with an input source voltage that varies in amplitude.

Transformers

TRANSFORMER POWER FLOW

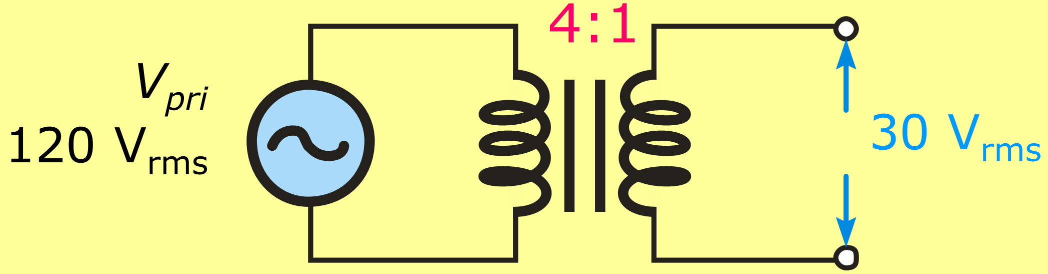
ELECTRICAL POWER IN	The primary current I_P turns N_P Create the primary magnetic flux $\varnothing_P$, $[\varnothing_P = N_P \times I_P]$
MAGNETIC POWER TRANSFER	The primary flux $\varnothing_P$ and the secondary flux considered equal, $\varnothing_P = \varnothing_S$ in an ideal transformer
ELECTRICAL POWER OUT	The secondary flux $\varnothing_S$ and the secondary turns N_S create the secondary current I_S, $[I_S = \varnothing_S / N_S]$

Step-up and step-down transformers

In a **step-up transformer**, the secondary voltage is greater than the primary voltage or *n (turns ratio)* > 1.

In a **step-down transformer**, the secondary voltage is less than the primary voltage and *n (turns ratio)* < 1.

Find out the secondary voltage and Turns ratio of the following transformer



Transformers Overview

- Power systems are characterized by many different voltage levels, ranging from 765 kV down to 240/120 volts.
- Transformers are used to transfer power between different voltage levels.
- The ability to inexpensively change voltage levels is a key advantage of ac systems over dc systems.
- In this section we'll development models for the transformer and discuss various ways of connecting three phase transformers.

What is an Ideal transformer?

An ideal transformer has no power loss; all power applied to the primary is completely delivered to the load. Actual transformers depart from this ideal model. Some loss mechanisms are:

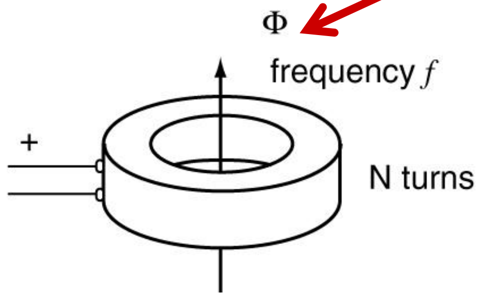
- **Winding resistance** (causing power to be dissipated in the windings.)
- **Hysteresis loss** (due to the continuous reversal of the magnetic field.)
- **Core losses** due to circulating current in the core (eddy currents).
- **Flux leakage** flux from the primary that does not link to the secondary
- **Winding capacitance** that has a bypassing effect for the windings.

Voltage Induced in a coil

Applied magnetic flux for a given Frequency and number of turns

Induced voltage

(a)



A voltage is induced in a coil when it links a variable flux.

$$E = 4.44fN\Phi max$$

Where

E- Effective Voltage induced (V

F- Frequency in Hz

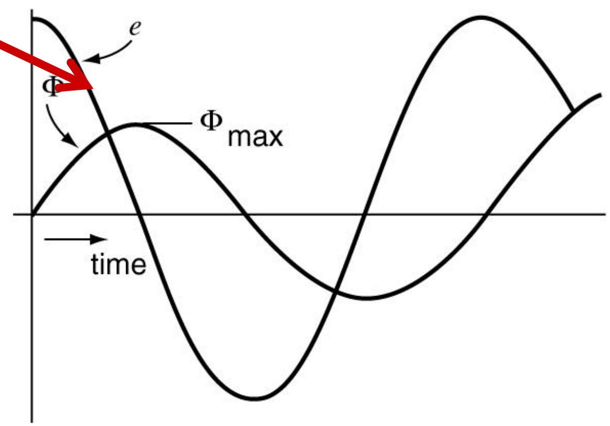
N- number of turns

Φmax- Flux (in Wb)

Instantaneous induced voltage

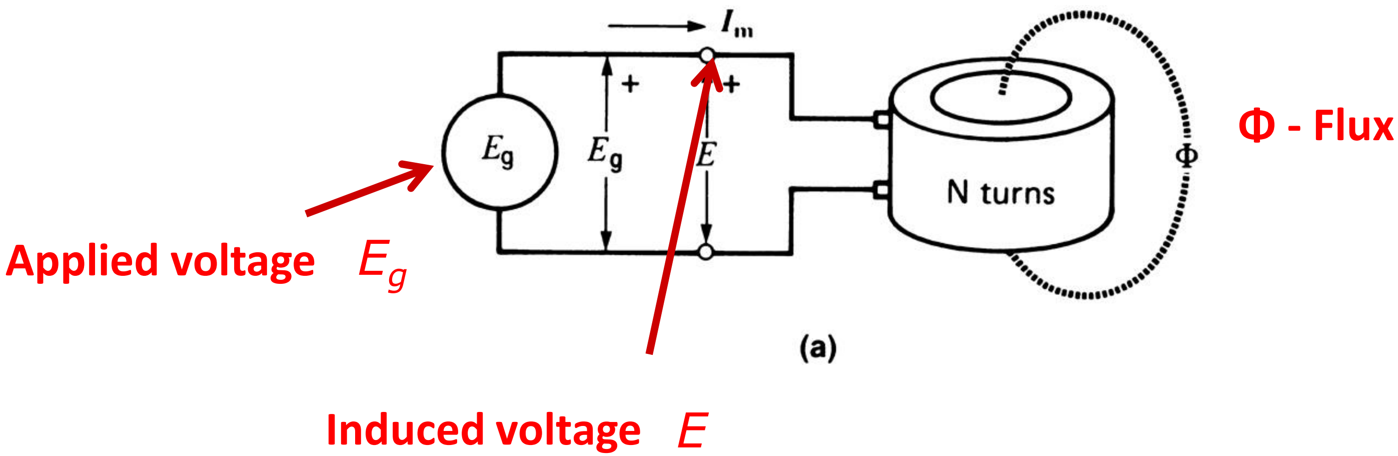
Induced voltage lags the flux by 90°

(b)



b. A sinusoidal flux induces a sinusoidal voltage.

Applied and Induced Voltage



a. The voltage E induced in a coil is equal to the applied voltage E_g.

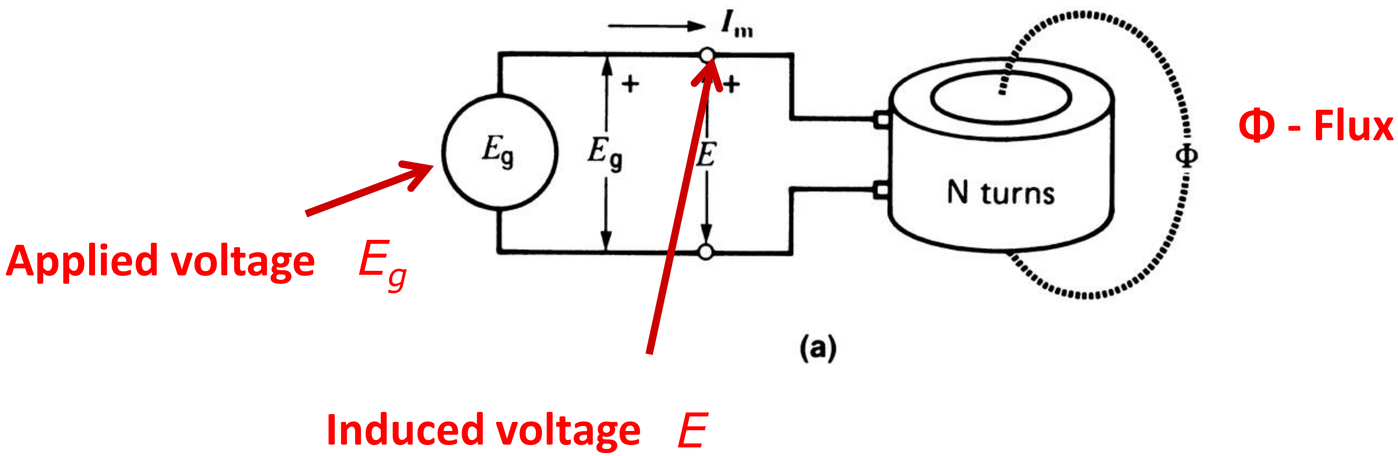
The sinusoidal current I_m produces a sinusoidal mmf which is equal to $N*I_m$ Which in turn produces a flux Φ

[**mmf-Magneto Motive Force-The physical driving force that produces magnetic flux**]

$$\mathbf{I_m = E_g/X_m}$$

Where I_m-Current drawn by coil or magnetizing current
E_g- Applied Voltage and X_m – Reactance of the coil

Applied and Induced Voltage



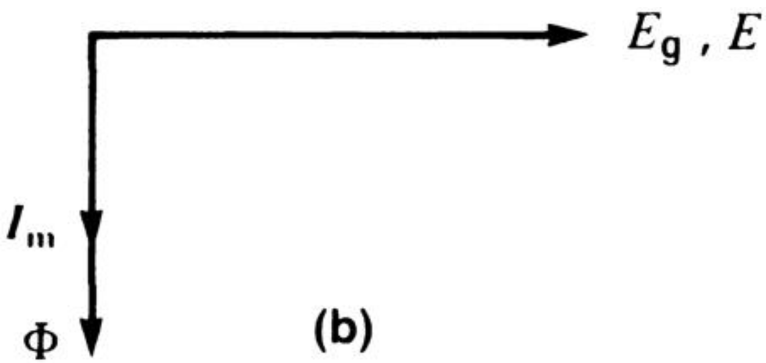
As $E_g = E$(Applied Voltage = Induced Voltage) They appear between the same pair of conductors

$$Eg = 4.44\, fN\phi \max$$

$$OR$$

$$\phi \max = Eg / 4.44\, fN$$

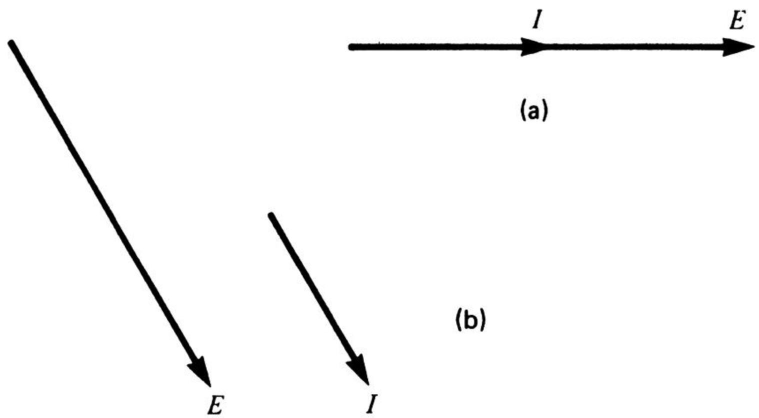
Phasor relationships among E_g, E, I_m, and Φ.



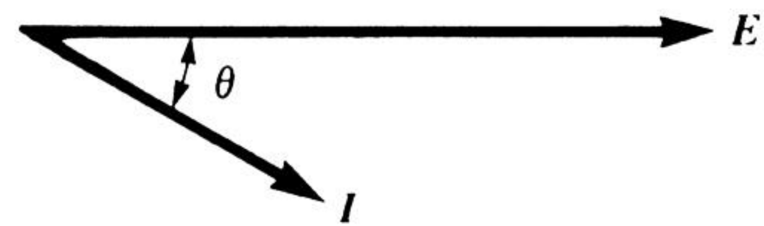
We have seen that Induced voltage E lags the flux by 90°
As in any inductive circuit **I_m lags 90° behind E_g**

Rules apply to Phasors

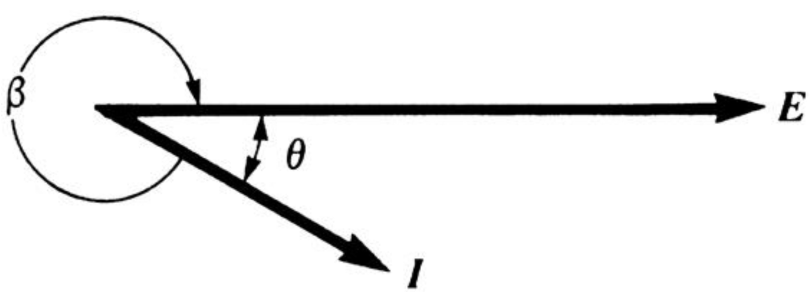
Phasors do not have to start from a common origin to show their magnitudes and phase relationships



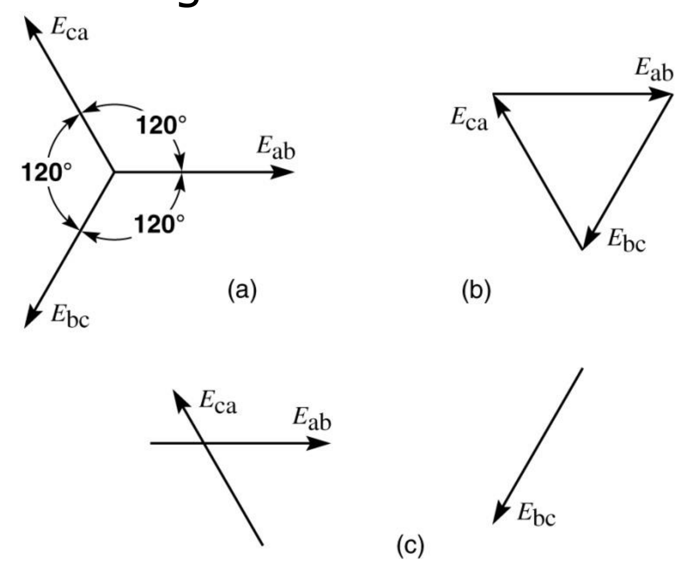
The current phasor *I* and voltage phasor *E* are in phase



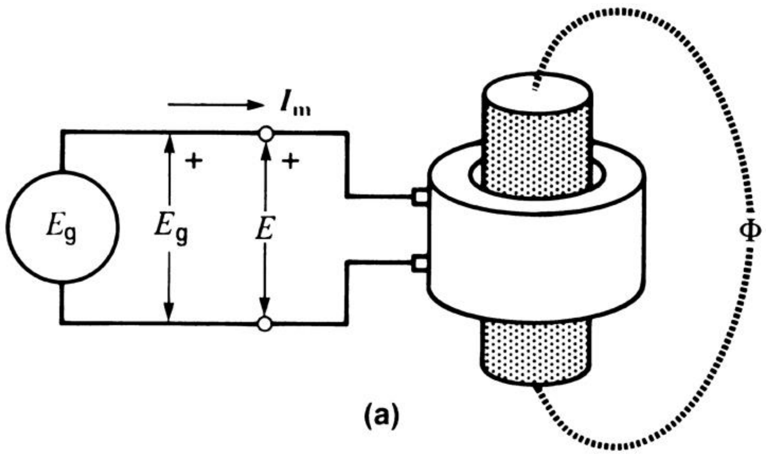
Phasor *I* lags behind phasor *E* by an angle of θ degrees

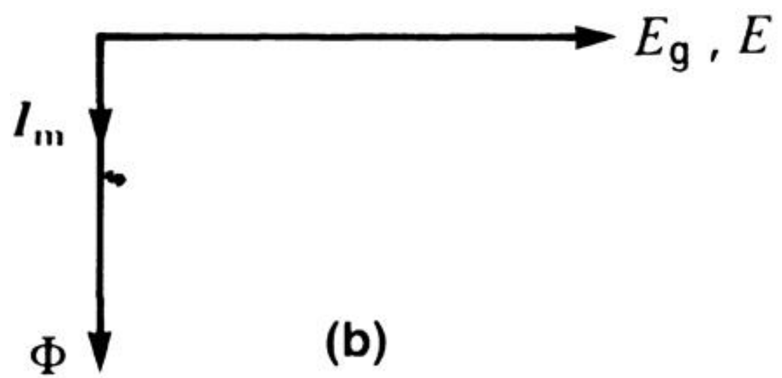


Phasor *I* leads phasor *E* by β degrees. But phasor *I* also lags *E* by θ degrees



Different ways of showing the phase relationships between three voltages that are mutually displaced at 120°.





a. The flux in the coil remains constant so long as ***E_g*** **is constant**

b. Phasor relationships

When an iron core is inserted inside the coil Keeping the E_g-Applied voltage fixed, So E will remain the same

Φ_{max} remains the same

However the magnetizing current I_m will be reduced.

Or with an iron core, same amount of flux can be produced with less current I_m

Example

A coil having 90 turns is connected to a 120V,60Hz source.
If the effective value of magnetizing current is 4A, calculate:

a. The peak value of flux

$$\emptyset_{max} = \frac{E_g}{(4.44fN)}$$

b. The peak value of mmf (magneto motive force)

$$Im(peak) = \sqrt{2} \times I$$

The peak mmf $U = NI_m$

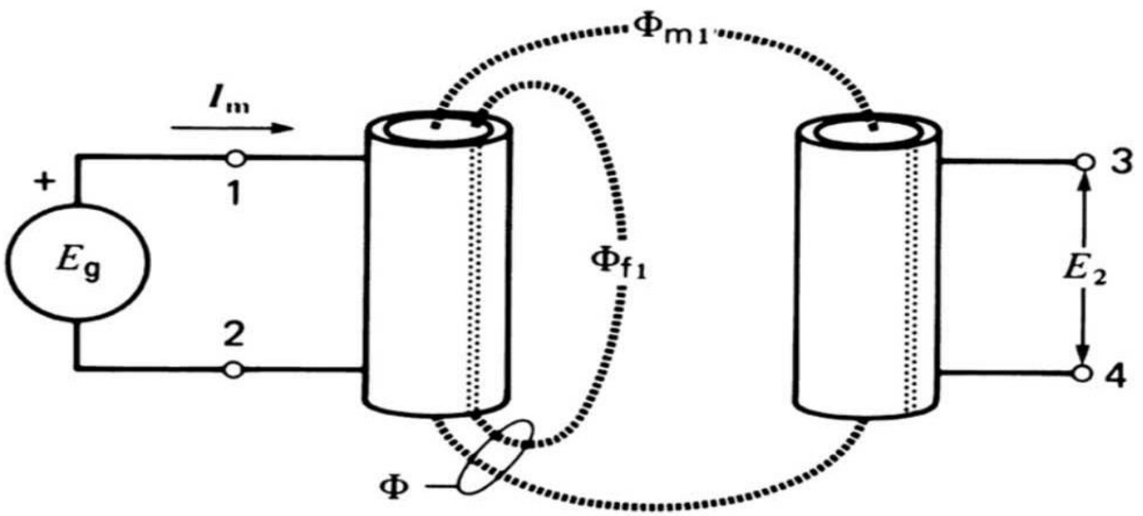
c. The inductive reactance of the coil

The inductive reactance $Xm = \frac{E_g}{I_m}$

d. The inductance of the coil L

The inductance $L = \frac{X_m}{2\pi f}$

Elementary Transformer:



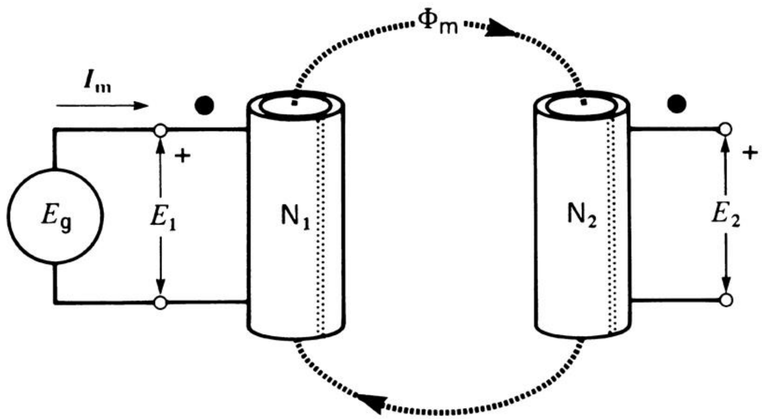
Φ_{m1} Mutual flux (links both coils)

Φ_{f1} Leakage flux (links primary only)

If the coils are far apart, mutual flux is very small compared to total flux Φ**,** or we can say **coupling** between two coils is weak

In some industrial transformers coupling is improved by Winding primary and secondary on top of each other

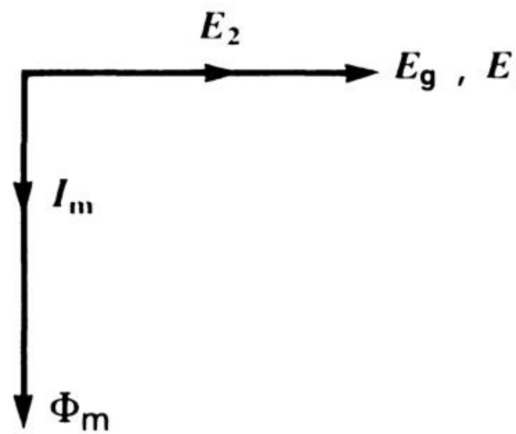
Ideal Transformer at No Load: voltage ratio



(a)

a. The ideal transformer at no-load. Primary and secondary are linked by a mutual flux

(b)

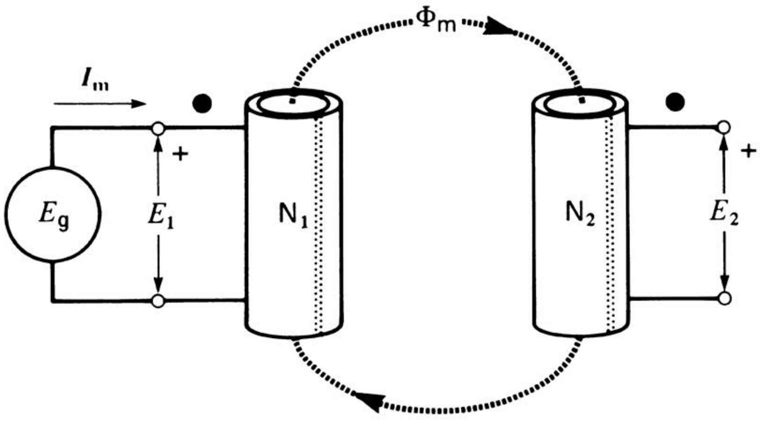


b. Phasor relationships at no-load.

Ideal transformer has no losses and the flux produced by the primary terminal is completely linked by the secondary terminal and vice versa

Consequently, Ideal transformer has **no leakage flux** of any kind.

Ideal Transformer at No Load: voltage ratio



(a)

$$E_1 = 4.44 f N_1 \emptyset_{max}$$

$$E_2 = 4.44 f N_2 \emptyset_{max}$$

So, for an **Ideal Transformer**

Enl

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

Where

E_1 = Voltage induced in the primary
E_2 = Voltage induced in the secondary
N_1 = Number of turns on the primary
N_2 = Number of turns on the secondary
a = Turns ratio

Example

An ideal transformer having 90 turns on the primary and 2250 turns on the secondary is connected to a 120V,60Hz source. The coupling between the primary and secondary is perfect, but the magnetizing current is 4A.

Calculate:

a) The effective voltage across the secondary terminal

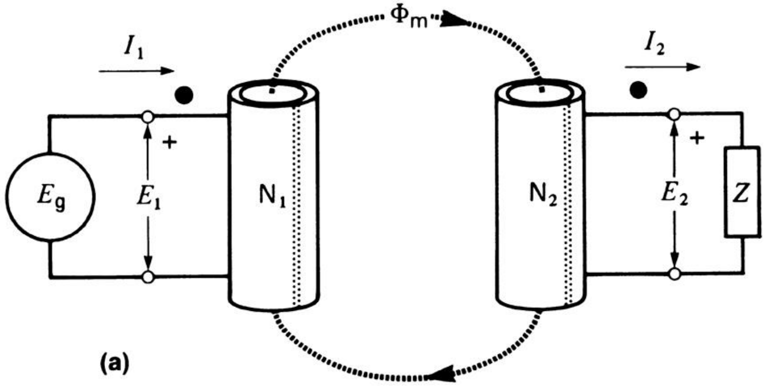
b) The peak voltage across the secondary terminal

c) The instantaneous voltage across the secondary when the instantaneous voltage across the primary is 37V

Given: N1=90, N2=2250, E1= 120V

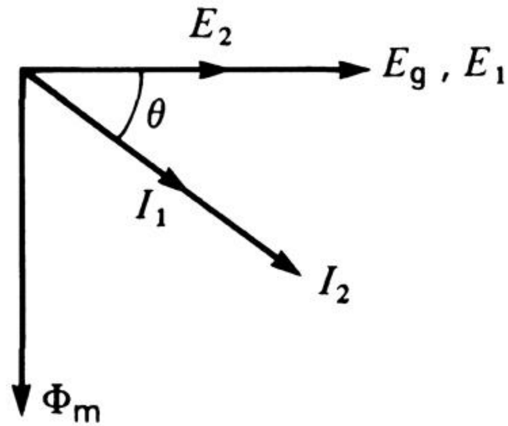
Find: $\boldsymbol{E_2}$, $\boldsymbol{E_2}$(peak), $\boldsymbol{e_2}$ (instantaneous)

Ideal Transformer Under Load: Current Ratio



(a)

(b)



When we connect a load Z to the secondary of the transformer, a current I_2 flows to the load. $I_2 = \frac{E_2}{z}$

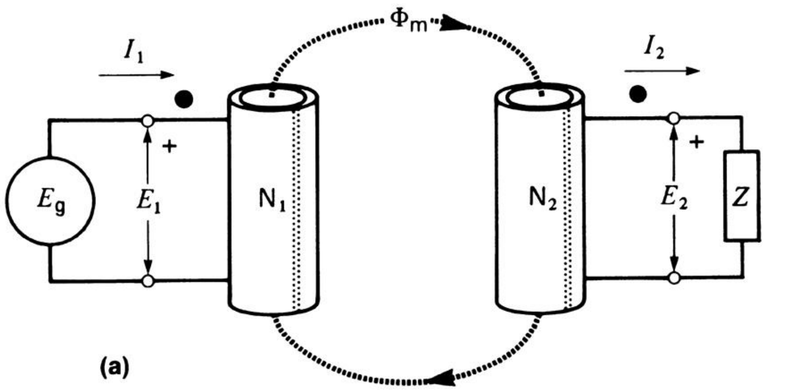
Will E_2 decrease when we connect a load?

E_2 will not change because

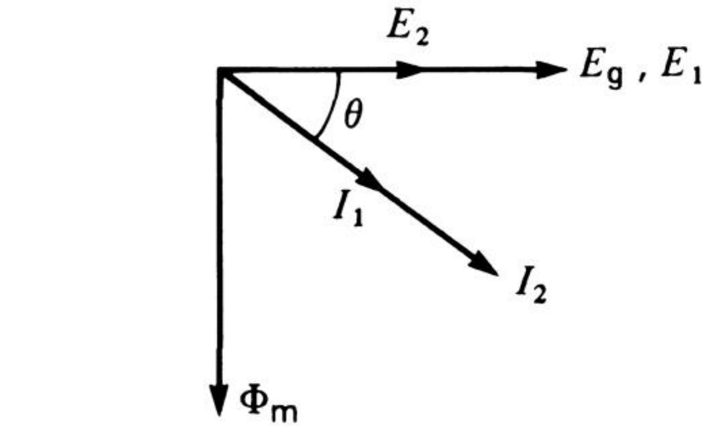
1. For an ideal transformer, as no leakage flux, $E_1 = E_2$ and
2. If the supply voltage $E_g\ is\ kept\ fixed E_1$ will remain fixed

So the input current will increase to meet the required out put current. Or$N_1 I_1 = N_2 I_2\ (The\ mmf\ at\ Input = mmf\ at\ Output)$

Ideal Transformer Under Load: Current Ratio



(b)



a. Ideal transformer under load. The mutual flux remains unchanged

b. Phasor relationship under load.

From the above equation we get $\frac{I_1}{I_2} = \frac{N_2}{N_1} =$**n**

The phasor diagram shows both $\boldsymbol{I_1}$ and $\boldsymbol{I_2}$ are in phase then only it is possible to meet the output requirement instantaneously.
In Diagram (a) $\boldsymbol{I_1}$ is entering in to a polarity mark (●) and $\boldsymbol{I_2}$must flow out of the polarity mark on the secondary side
θ is the angle as $\boldsymbol{I_2}$ lags behind $\boldsymbol{E_2}$ in an inductive-resistive load.

Power Factor = Cos(θ) if power factor =70, θ=cos^{-1}(70).

Example

An ideal transformer having 90 turns on the primary and 2250 turns on the secondary is connected to a 200V,50Hz source. The load across the secondary draws a current of 2A at a power factor 80% lagging as in the figure below.

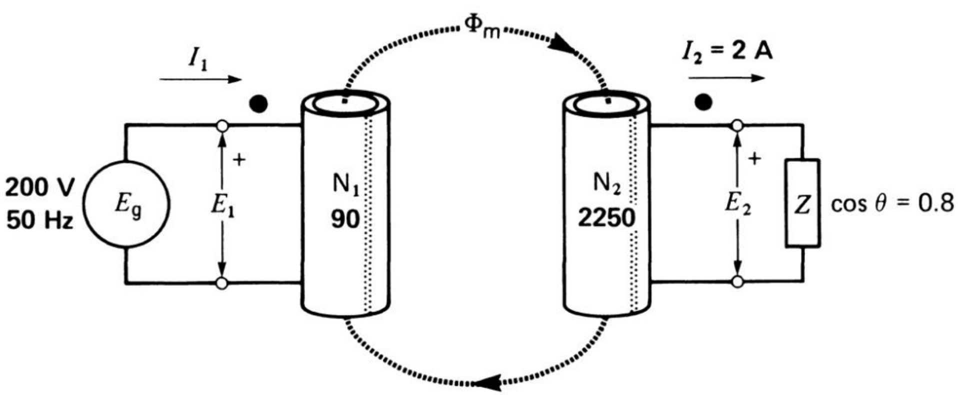
Calculate:

a) The effective value of the primary current

b) The instantaneous current in the primary when the instantaneous current in the secondary is 100mA.

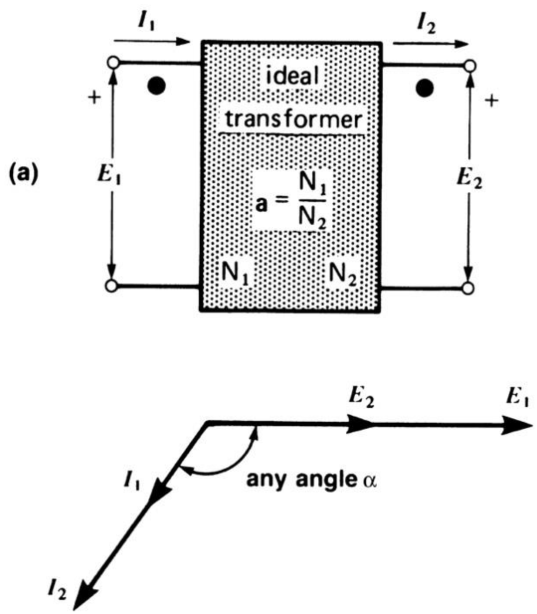
c) The peak flux linked by the secondary winding

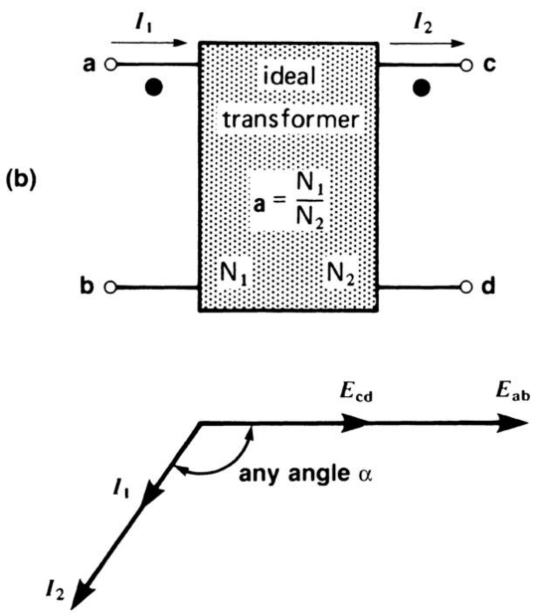
d) Draw the phasor diagram



(a)

Circuit Symbol for an Ideal Transformer



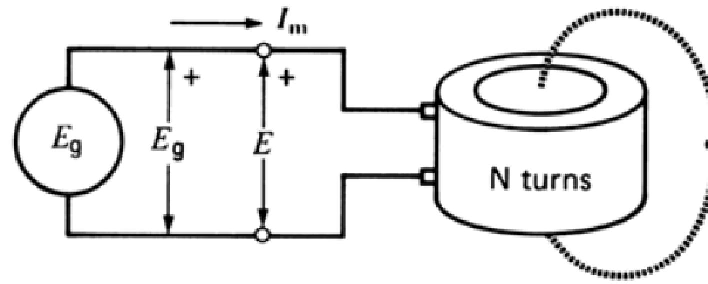


a. Symbol for an ideal transformer and phasor diagram using **sign notation**.

b. Symbol for an ideal transformer and phasor diagram using **double-subscript notation**.

Questions and Problems

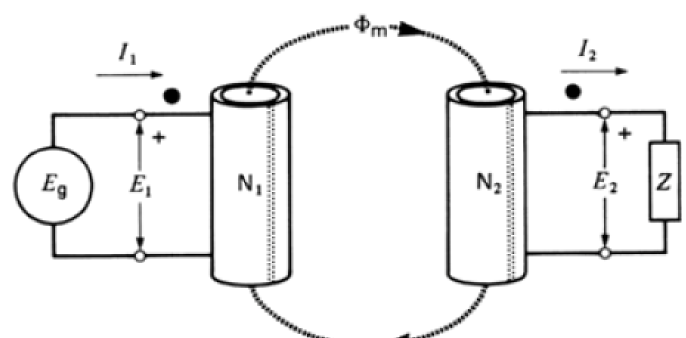
1. The coil in the figure has 500 turns and a reactance of 60 Ω, but negligible resistance. If it is connected to a 120 V, 60 Hz source E_g, calculate the following:
   a. The effective value of the magnetizing current, I_m.
   b. The peak value of I_m.
   c. The peak mmf produced by the coil.
   d. The peak flux φ_{max}.



2. In problem 1 if E_g is reduced to 40 V, calculate the new mmf developed by the coil and the peak flux φ_{max} .

3. What is meant by the mutual flux and by the leakage flux?

4. The ideal transformer in the figure has 500 turns on the primary side and 300 turns on the secondary. The source voltage E_g is 600 V and the load Z is a resistance of 12 Ω. Calculate the following:
   a. The voltage E_2.
   b. The current I_2.
   c. The current I_1.
   d. The power delivered to the primary [W].
   e. The power output from the secondary [W].

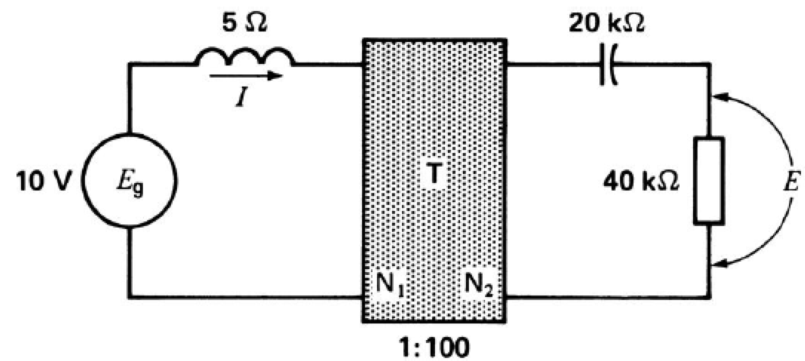


Ideal transformer under load.

Questions and Problems

5. In problem 4 what is the impedance seen by the source E_g?

6. In the figure shown calculate the voltage across the capacitor and the current flowing through it.



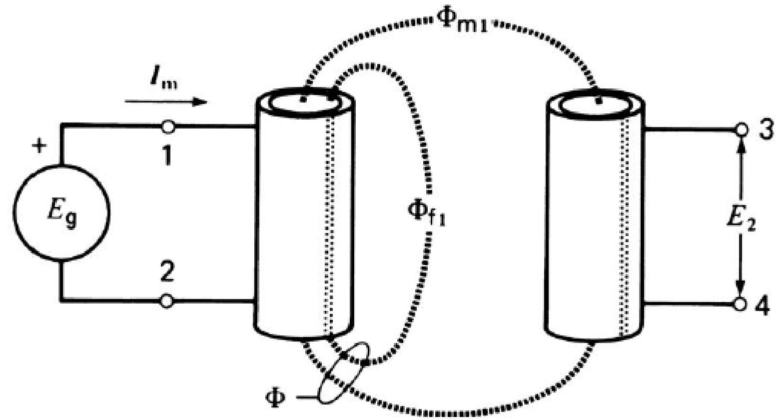
7. A coil with an air core has a resistance of 14.7 Ω. When it is connected to a 42 V, 60 Hz ac source, it draws a current of 1.24 A. Calculate the following:
   a. The impedance of the coil.
   b. The reactance of the coil and its inductance.
   c. The phase angle between the applied voltage and the current.

8. The nameplate on a 50 kVA transformer shows a primary voltage of 480 V and a secondary voltage of 120 V. We wish to determine the approximate number of turns on the primary and secondary windings.
   If, three turns of wire are wound around the external winding and a voltmeter is connected to this 3-turn coil. A voltage of 76 V is then applied to the 120 V winding and the voltage across the 3-turn coil is 0.93 V. How many turns are there on the 480 V and 120 V windings (approximately)?

Questions and Problems

9. Two coils are set up as shown in the figure. Their resistances are negligible. The primary coil has 320 turns while the secondary has 160 turns. It is found that when 56 V, 60 Hz is applied to the primary, the voltage across the secondary is 22 V.

   Calculate the peak value of the φ, φ_{f1}, φ_{m1}.



10. A 40 μF, 600 V capacitor is available, but we need 300 μF. It is proposed to use a transformer to modify the 40 μF so that it appears as 300 μF. The following transformer ratios are available: 120 V/330 V, 60 V/450 V, 480 V/150 V.

    Which transformer is the most appropriate and what is the reflected value of the 40 μF capacitor? To which side of the transformer should the 40 μF capacitor be connected?

1. Solution

a. $I_m = \dfrac{E_g}{X_L} = \dfrac{120}{60} = 2\ \text{A}$

b. $I_{m(peak)} = \sqrt{2}\, I_m = \sqrt{2} \times 2 = 2.83\ \text{A}$

c. $U_{(peak)} = NI_{m(peak)} = 500 \times 2.83 = 1415\ \text{A}$

d. $\phi_{max} = \dfrac{E_g}{4.44\, fN} = \dfrac{120}{4.44 \times 60 \times 500} = 0.9\ \text{mWb}$

2. Solution

$U = 1415 \times 40/120 = 472\ \text{A}$

$\phi_{max} = 0.9 \times 40/120 = 0.3\ \text{mWb}$

3. Solution

Page 186 E-text

The flux Φ created by the primary can be broken up into two parts: a *mutual flux* Φ_{m1}, which links the turns of both coils; and a *leakage flux* Φ_{f1}, which links only the turns of the primary. If the coils are far apart, the mutual flux is very small compared to the total flux Φ; we then say that the *coupling* between the two coils is weak.

4. Solution

a. $$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \therefore E_2 = \frac{600 \times 300}{500} = 360 \text{ V}$$

b. $$I_2 = \frac{E_2}{Z} = \frac{360}{12} = 30 \text{ A}$$

c. $$\frac{I_1}{I_2} = \frac{N_2}{N_1} \quad \therefore I_1 = \frac{300 \times 30}{500} = 18 \text{ A}$$

d. $P_1 = E_1 I_1 = 600 \times 18 = 10.8 \text{ kW}$

e. $P_2 = E_2 I_2 = 360 \times 30 = 10.8 \text{ kW}$

5. Solution $$Z_x = a^2 Z = (500/300)^2 \times 12 = 33.3\ \Omega$$

6. Solution $$I_c = aI = 1/100 \times 2 = 0.02\ \text{A}$$

$$V_c = X_c I_c = 20\,000 \times 0.02 = 400\ \text{V}$$

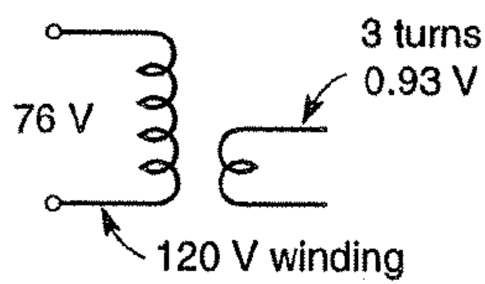
7. Solution (a) $Z = 42\ \text{V}/1.24\ \text{A} = 33.87\ \Omega$

(b) $X_L = \sqrt{33.87^2 - 14.7^2} = 30.5\ \Omega$

$$L = 30.5/(2\,\pi \times 60) = 0.0809\ \text{H} = 80.9\ \text{mH}$$

(c) $\theta = \arctan \dfrac{X_L}{R} = \arctan \dfrac{30.5}{14.7} = 64.3°$

8. Solution



$$0.93\ \text{V} = 3\ \text{turns}$$

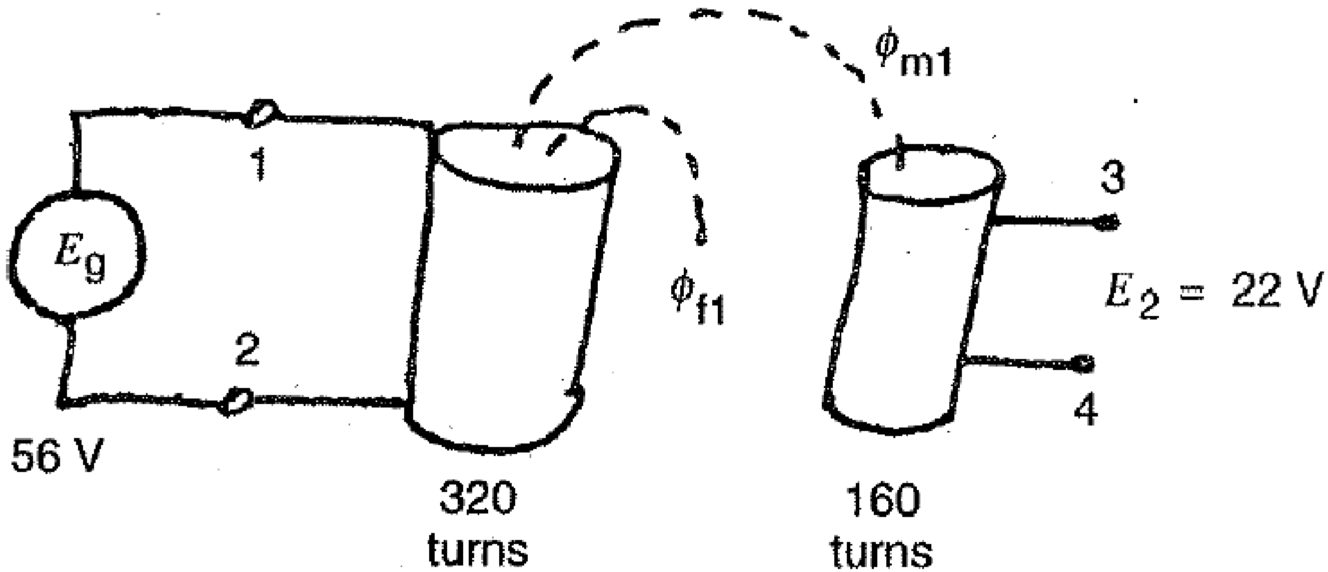
$$\therefore 1\ \text{V} = \frac{3}{0.93} = 3.226\ \text{turns}$$

76 V = 76 × 3.226 = 245 turns.

The 120 V winding has therefore 245 turns.

The 480 V winding has $245 \times \dfrac{480}{120} = 980$ turns.

9. Solution



$E = 4.44\ fN_1\phi$

$56 = 4.44 \times 60 \times 320 \times \phi \rightarrow \therefore\ \phi = 0.000657$ Wb

also on secondary side = 0.657 mWb

$22 = 4.44 \times 60 \times 160 \times \phi_{m1} \rightarrow \phi_{m1} = 0.516$ mWb

Consequently, $\phi_{f1} = \phi - \phi_{m1}$

$= (0.657 - 0.516) = 0.141$ mWb

10. Solution

$$\text{Ratio of capacitances} = \frac{300\ \mu\text{F}}{40\ \mu\text{F}} = 7.5$$

$$\text{Hence ideal transformer turns ratio} = \sqrt{7.5} = 2.7386$$

$$\text{Ratios available} = \frac{330\ \text{V}}{120\ \text{V}} = 2.75$$

$$\text{and} = \frac{450}{60} = 7.5$$

$$\text{and} = \frac{480}{150} = 3.2$$

The 330 V/130 V transformer is the most appropriate choice. The 40 μF capacitor must be connected to the 330 V winding.

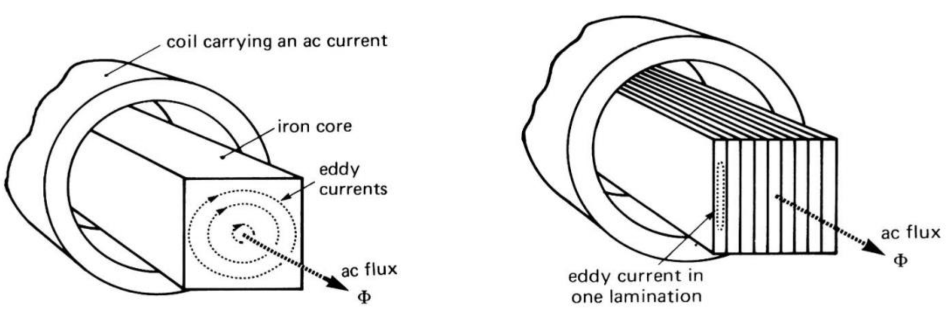
Practical Transformer

1. The windings of a practical transformer have resistance
2. The flux produced by the primary is not completely captured by the secondary (Leakage Flux)
3. The iron-core produce **eddy-current** which contributes to the temperature rise of the transformer

Eddy currents:

It is a kind of unwanted (can be very large) currents produced in the iron core of the transformer due to passing flux causing energy loss.

How to avoid it?



Eddy current can be reduced by:

1. Splitting the core in to many stacked laminations each of 1mm thickness

2. A small amount of Silicon is alloyed with steel to increase its resistivity (Silicon-Iron)

In practical transformers energy is dissipated in the windings, core, and surrounding structures.

1. Loss of magnetic flux:

The coupling between the coils is seldom perfect. So whole of magnetic flux produced by primary coil does not get linked with the secondary.

2. Iron losses:

In actual iron cores, in spite of lamination, some heat is still produced by the eddy currents.

3. Copper Losses:

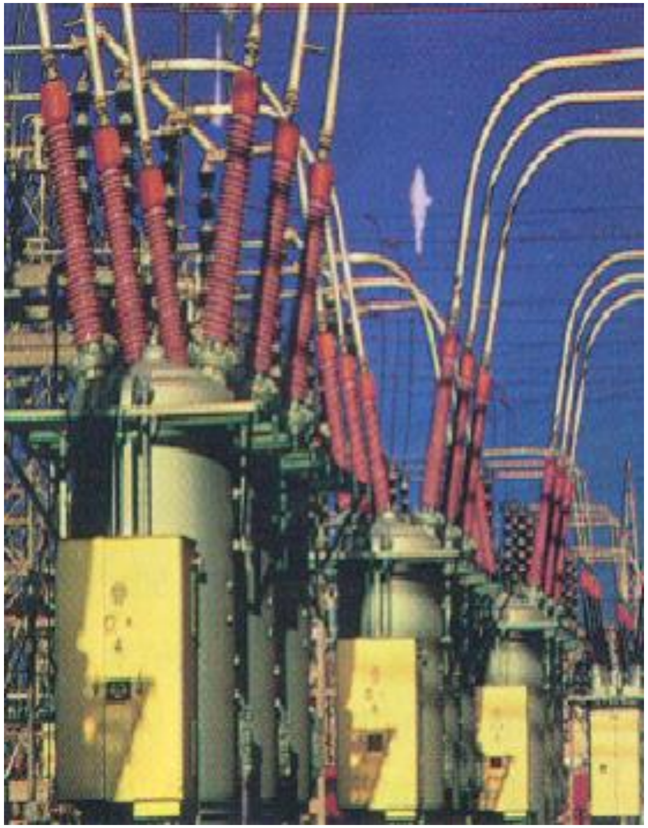
In actual practice, coils of the transformer possess some resistance. So a part of energy is lost due to heat produced by the resistance of the coils.

4. Hysteresis losses:

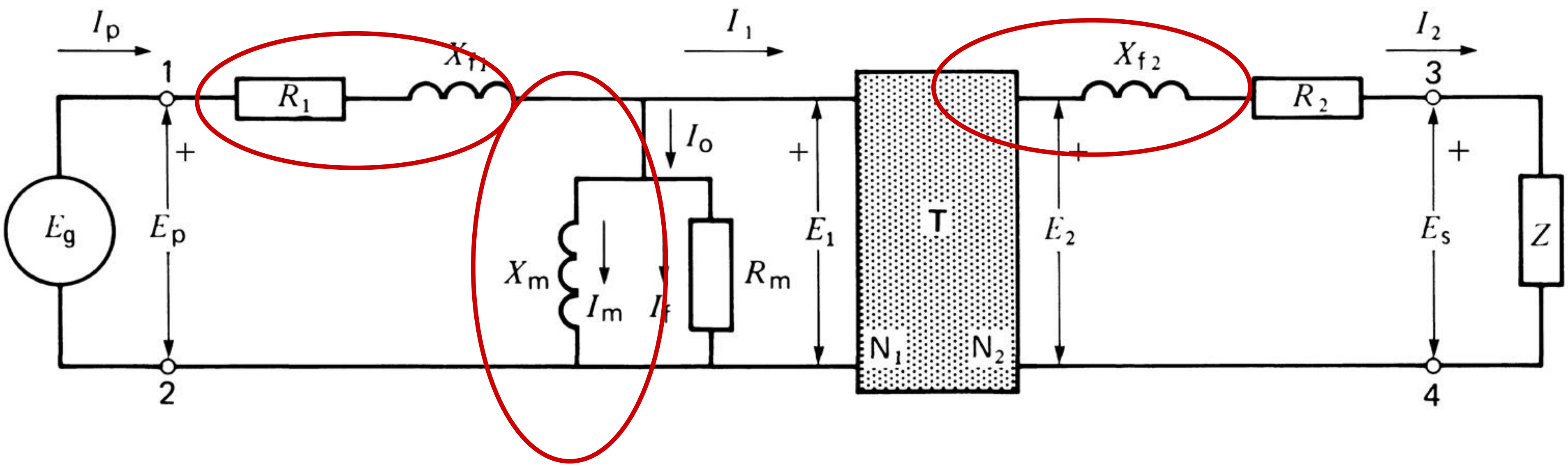
The alternating current in the coils repeatedly takes the iron core through complete cycle of magnetization. So energy is lost due to hysteresis.

5. Humming losses:

The alternating current in the transformer may set its parts into vibrations and sound may be produced. This sound produced is called humming. Thus a part of energy is lost in the form of sound energy.



Equivalent Circuit of a practical Transformer



Complete equivalent circuit of a practical transformer. The shaded box T is an ideal transformer

Xm and ***Rm*** represents losses due to an imperfect Core

R1,Xf1 and ***R2 ,Xf2*** represents Resistance and Leakage reactance at the primary and secondary windings

Transformer Tests

1- No load test,

The open circuit test, or "no-load test", is one of the methods used in to determine the no load impedance in the secondary of transformer

2- Short circuit test,

Is conducted on the primary keeping the secondary side short circuited. This is to determine the reactive power absorbed and hence the leakage reactance of primary and secondary of the transformer

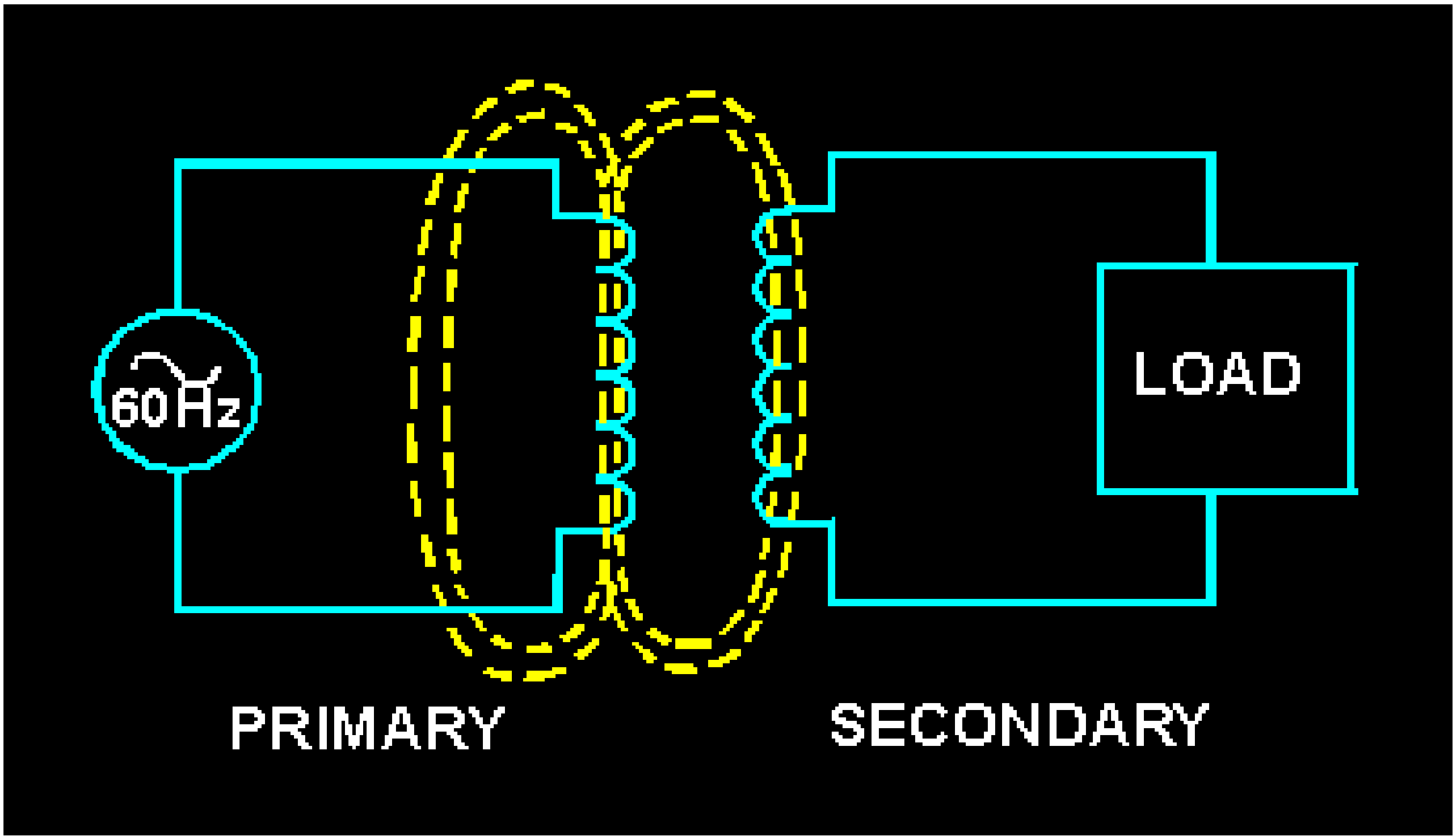
3- Load test.

Load Test helps to determine the total loss that takes place, when the transformer is loaded. Unlike the tests described previously, in the present case nominal voltage is applied across the primary and rated current is drown from the secondary.

Load test is used mainly
1. to determine the rated load of the machine and the temperature rise
2. to determine the voltage regulation and efficiency of the transformer.

Transformers

Transformer Action



Transformers

Exciting current serves two functions:

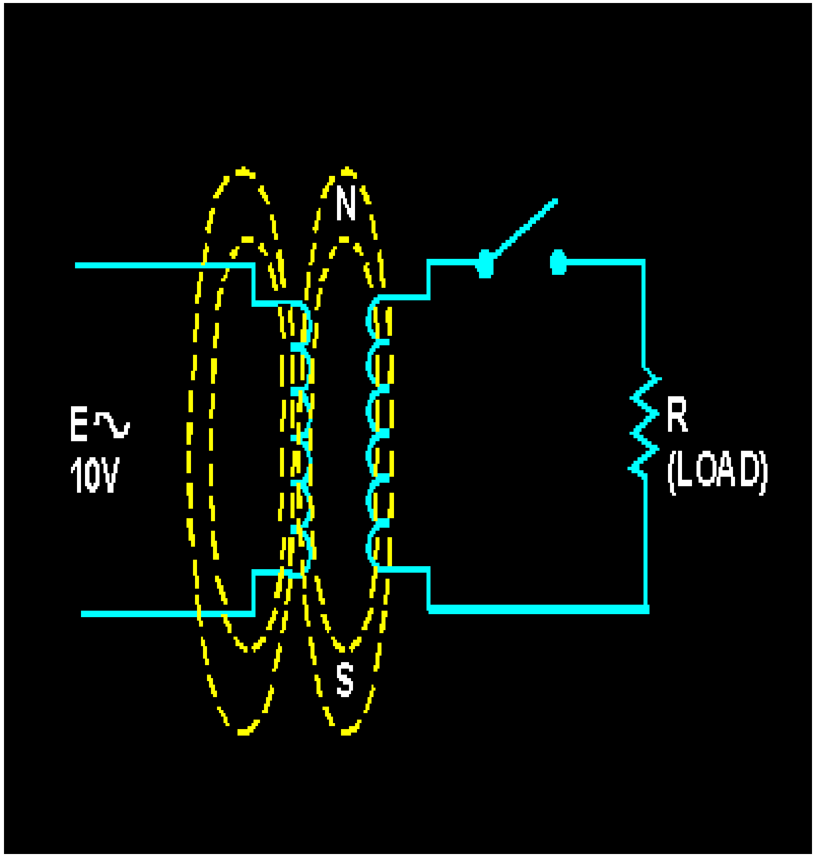
- Most of the exciting energy is used to maintain the magnetic field of the primary.
- A small amount of energy is used to overcome the resistance of the wire and core losses which are dissipated in the form of heat (power loss).

No transfer of energy will take place as long as the secondary circuit is open.

Transformers

NO-LOAD CONDITION

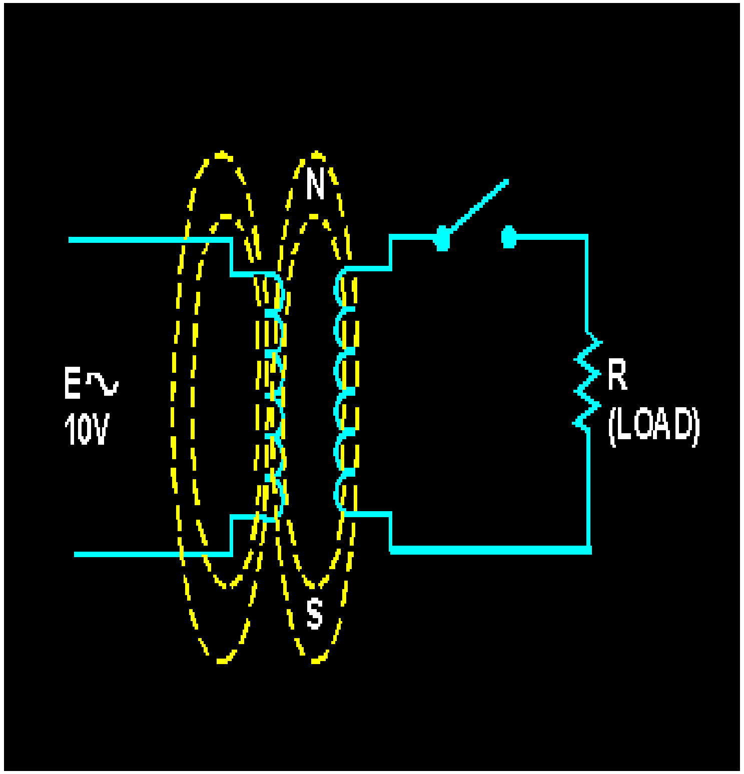
Exciting current is determined by 3 factors: Voltage applied (E), Primary coil's losses(R) losses(X_L)



Transformers

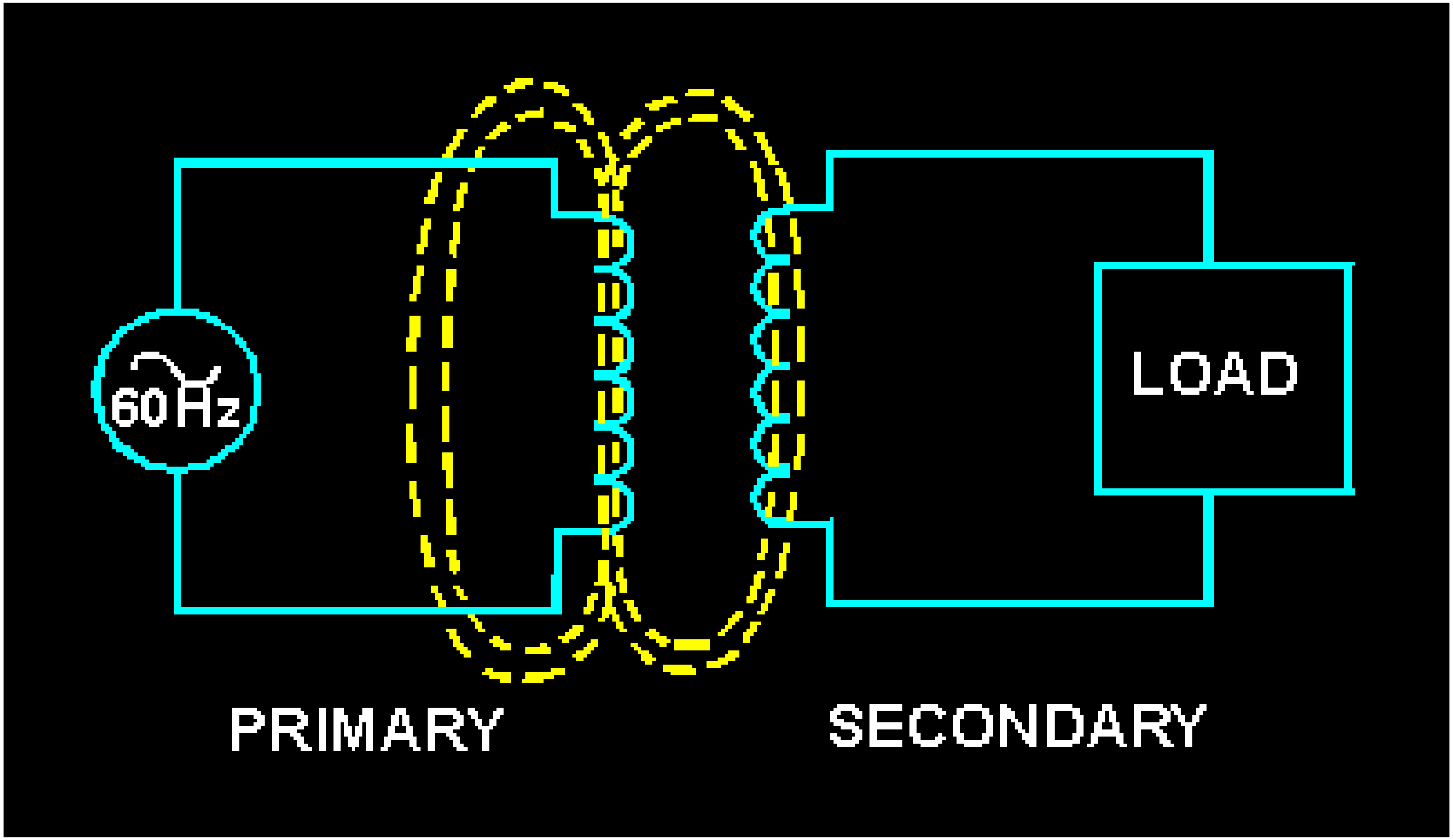
NO-LOAD CONDITION

A no-load condition is said to exist when a voltage is applied to the primary, but no load is connected to the secondary, as illustrated below.



Transformers

LOAD CONDITION



Voltage Regulation

An important attribute of a transformer is its voltage regulation. With the primary voltage held constant at its rated value, the voltage regulation in percent is defined as:

$$((E_{NL}-E_{FL})/E_{FL})x100$$

Where

E_{NL} **-** Secondary Voltage at No Load

E_{FL} **-** Secondary Voltage at Full Load

Voltage regulation depends upon the **power factor** of the load.

The **power factor** of an AC electric power system is defined as the ratio of the real power flowing to the load to the apparent power.

$$Power\,Factor = \frac{\mathrm{Re}\,al\,Power}{Apparent\ Power} = \frac{P}{S} = \cos\phi$$

Real (Active) Power Apparent Power Reactive Power

If the loads are purely reactive, then the voltage and current are 90 degrees out of phase. For half of each cycle, the product of voltage and current is positive, but on the other half of the cycle, the product is negative, indicating that on average, exactly as much energy flows toward the load as flows back.

There is no net energy flow over one cycle. In this case, only reactive energy flows—there is no net transfer of energy to the load.

Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. Power engineers measure apparent power as the magnitude of the vector sum of real and reactive power.

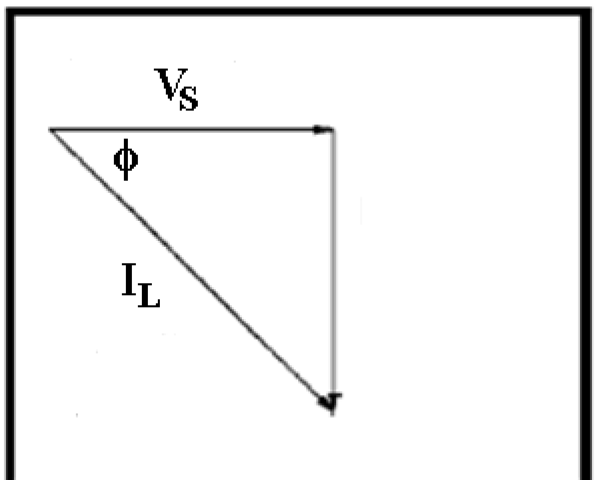
Apparent power is the product of the root-mean-square of voltage and current. ***Vrms* Irms***

Real (Active) Power **Apparent Power** **Reactive Power**

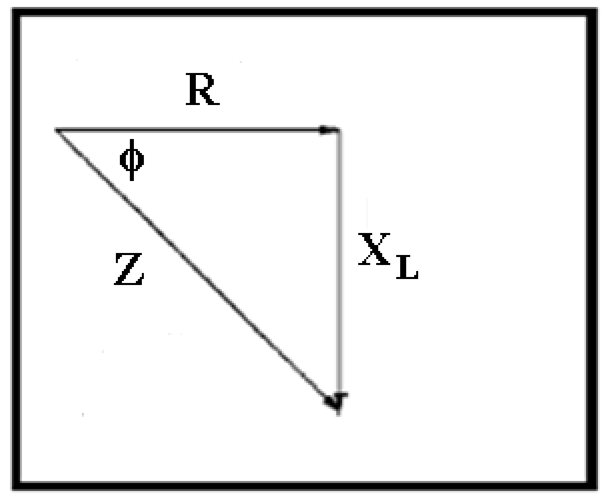
$$\mathrm{Re}\,al\ Power = P = VI\cos\phi$$ (**Watt**)

$$\mathrm{Re}\,active\ Power = Q = VI\sin\phi$$ (**VAR**)

$$Apparent\ Power = S = VI$$ (**Volt-Amperes**)

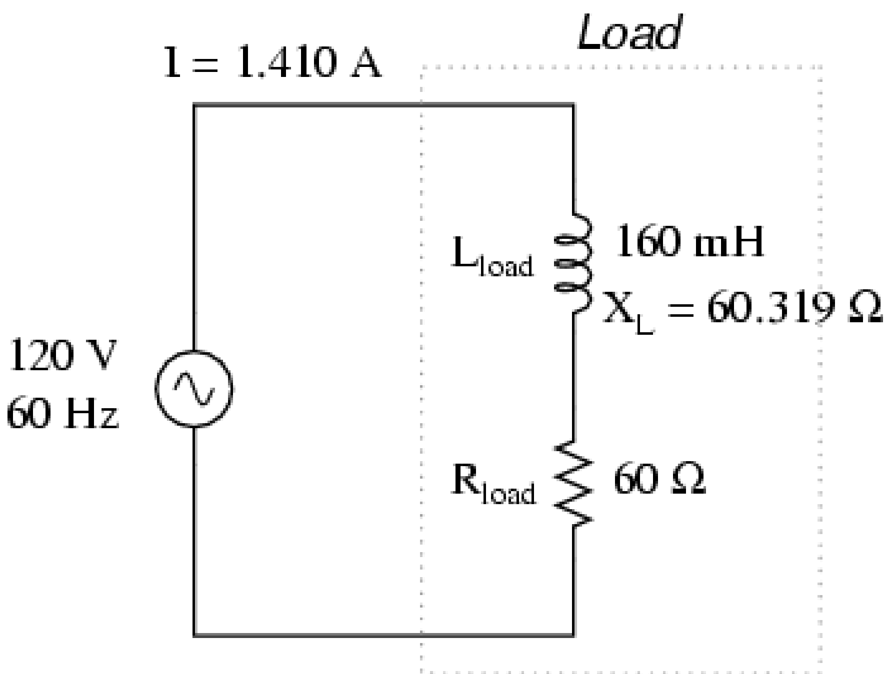


$$PF = \cos\phi$$



$$PF = \cos\phi = \frac{R}{Z}$$

Power Triangle

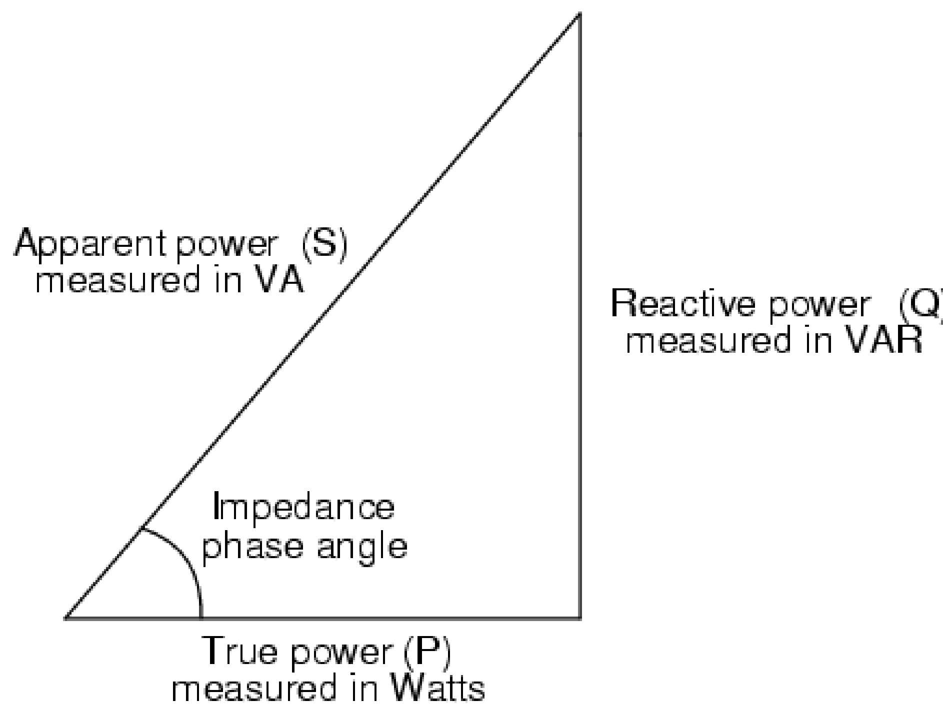


$P = \text{true power} = I^2R = 119.365\ \text{W}$

$Q = \text{reactive power} = I^2X = 119.998\ \text{VAR}$

$S = \text{apparent power} = I^2Z = 169.256\ \text{VA}$

The "Power Triangle"



Example:

Draw the power triangle of the circuit given on the left

Example

A 3/4 HP electric motor has a power factor of 0.85. The nameplate current is 5 Amps at 230 Volts. Calculate the capacitor placed on parallel with this motor to compensate for the reactive power?

- Apparent power = 1150 VA= 1.15 KVA
- Active power (P) = 0.85 x 1150 = 977.5 Watts
- Reactive Power (Q) = $\sqrt{S^2 - P^2} = \sqrt{1150^2 - 977.5^2} = 605\,VAR$

Calculating the required impedance from $Q = \dfrac{V^2}{X_C}$, where Q is the reactive power needed and

$$X_C = \frac{1}{2\pi f C}$$

To make the P ≅ S, which means the P.F. ≅ 1, the parallel Capacitor will be 36.4μF.

TRANSFORMER EFFICIENCY

Transformer efficiency is defined as (applies to motors, generators and transformers):

$$\eta = \frac{P_{out}}{P_{in}} \times 100 \ \%$$

$$\eta = \frac{P_{out}}{P_{out} + P_{loss}} \times 100\%$$

Types of losses incurred in a transformer:

Copper I^2R losses

Hysteresis losses

Eddy current losses

Therefore, for a transformer, efficiency may be calculated using the following:

$$\eta = \frac{V_S I_S \cos\theta}{P_{Cu} + P_{core} + V_S I_S \cos\theta} x100\%$$

Transformer Cooling

- Transformer ratings can be increased if their windings are cooled by some external means
- The most common cooling mediums are in direct with transformer windings;

Air and/or **Oil**

- The most common methods of circulation are

Forced and/or **Natural**

Transformer Classification

Type **AN** Air Natural

Type **AF** Air Forced

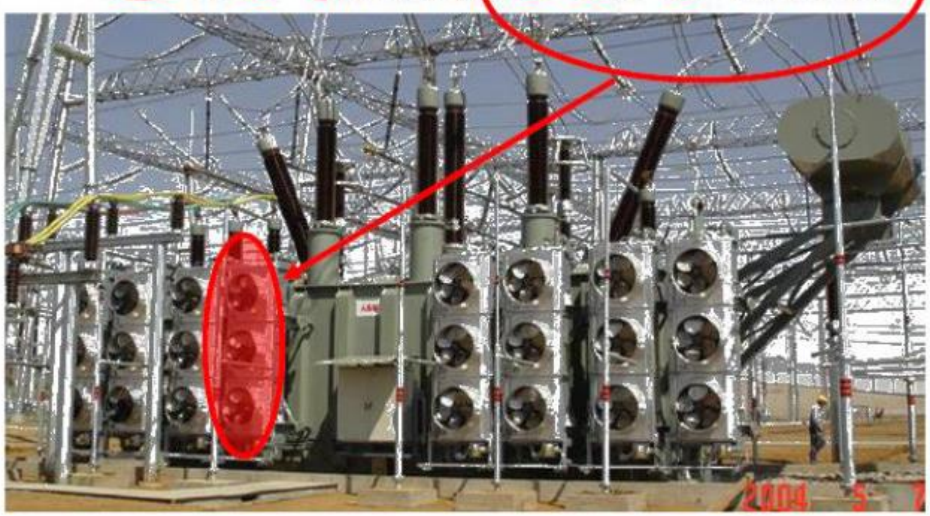
Oil Natural Air Natural

Type **ONAF**

Oil Natural Air Forced

Type **OFAF**

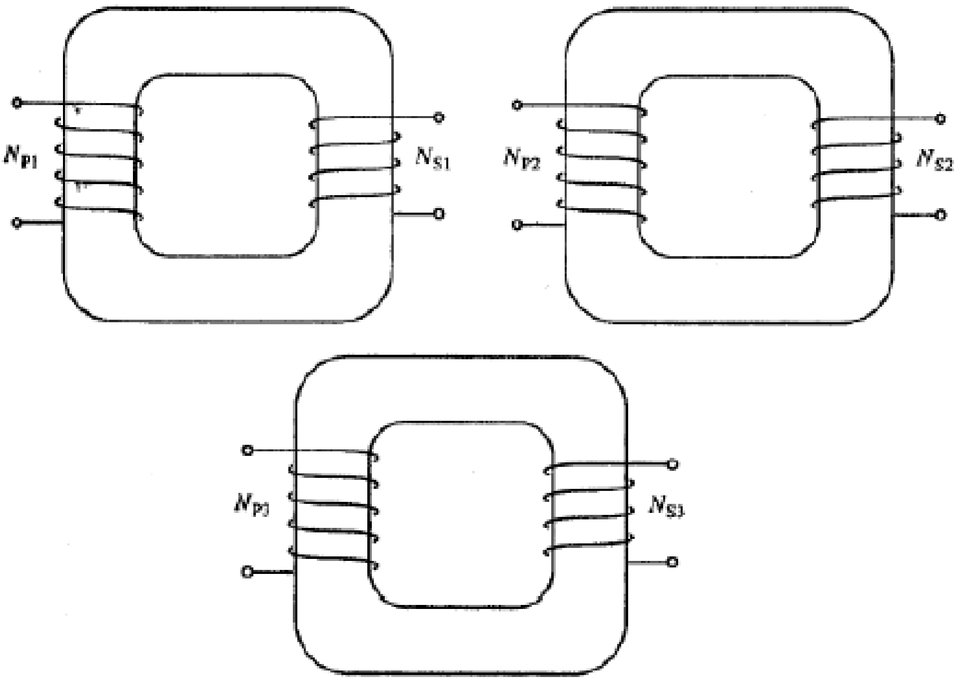
Oil Forced Air Forced

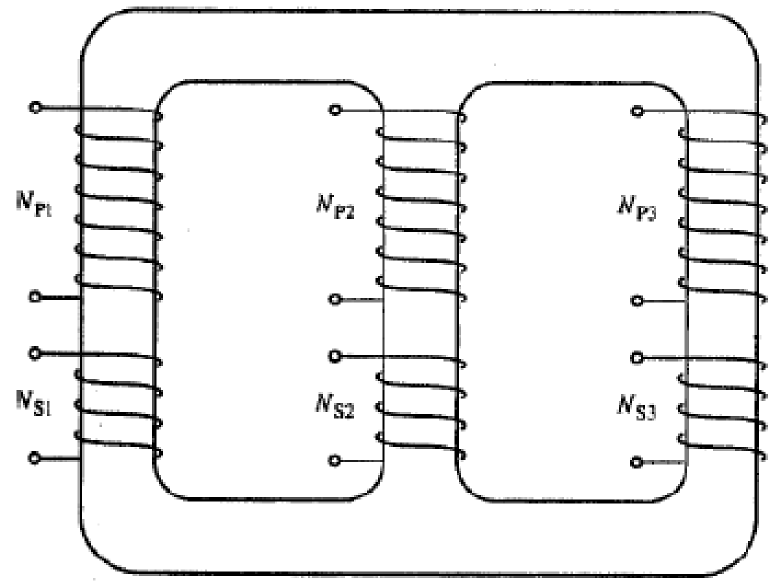


3 - Phase Transformer

- The construction of a common core three phase transformer is the preferred today, as:1-it is lighter, 2-smaller, 3-cheaper, and 4-slightly more efficient.
- There is an advantage that each unit in the bank could be replaced individually in the event of a fault.

Three Phase Transformers





3 single phase transformer bank	***Common core for the three sets of windings of the three phases***

Three Phase Transformers

Figure 3–35 I A three-phase transformer bank composed of independent transformers.

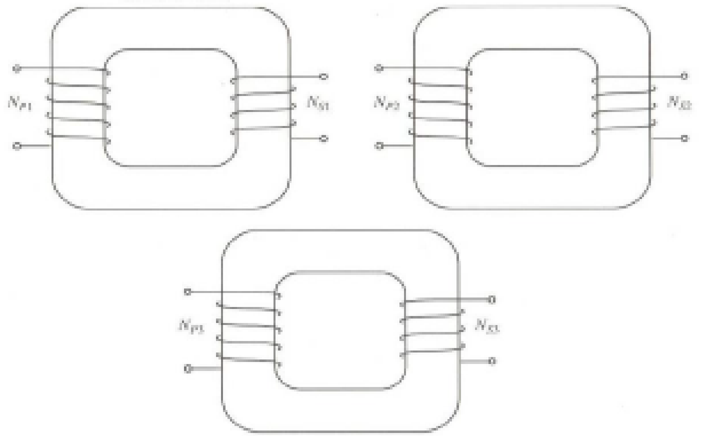
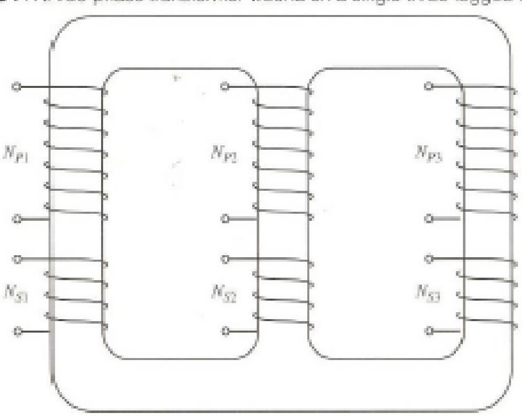


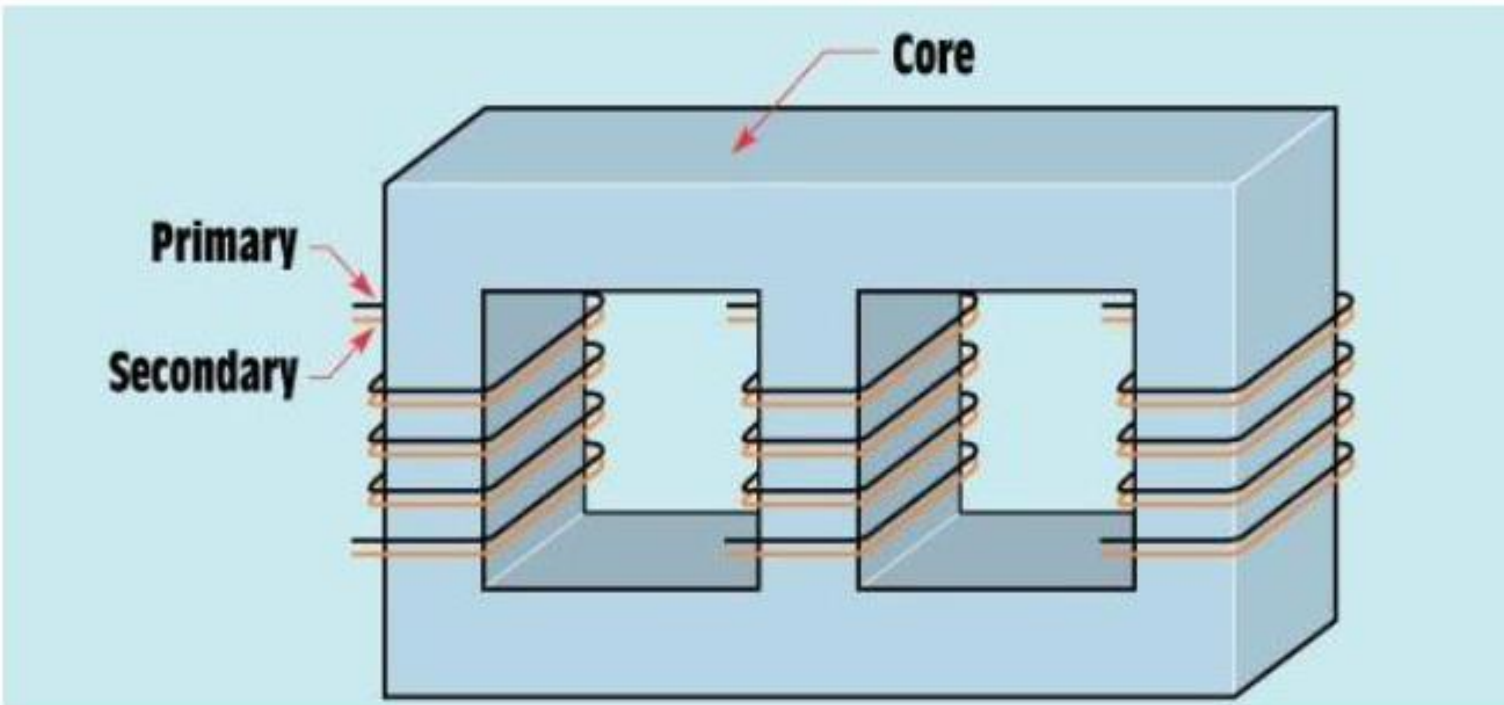
Figure 3–36 I A three-phase transformer wound on a single three-legged core.



Three phase transformers can be constructed in two different ways i.e. :-

1. A transformer bank consists of three single phase transformers.
2. Three windings wrapped around a common core.

- A three-phase transformer is constructed by winding three single-phase transformers on a single core.



Three-phase transformer construction.

Three-Phase Transformers

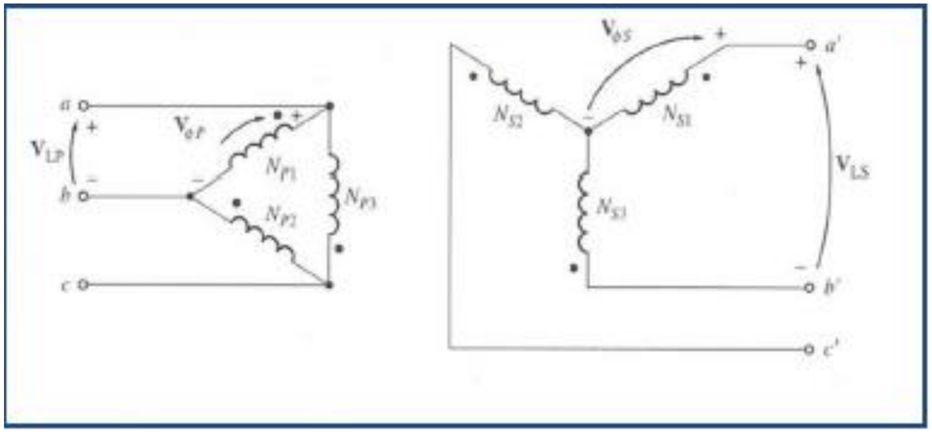
Primary and Secondary Connections

- The primary (input) side of a three-phase transformer can be connected in a wye or delta configuration.
- The secondary (output) side of a three-phase transformer can also be connected in a wye or delta configuration.

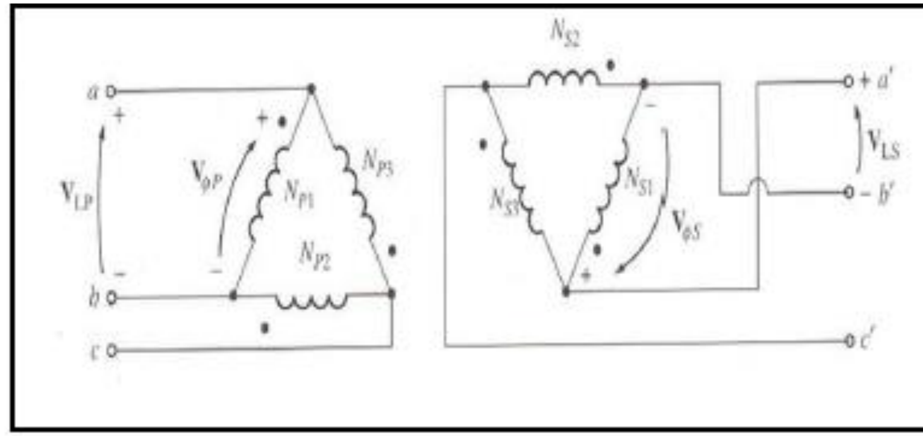
  This allows four basic connection patterns:

  - Wye-Wye
  - Wye-Delta
  - Delta-Delta
  - Delta-Wye

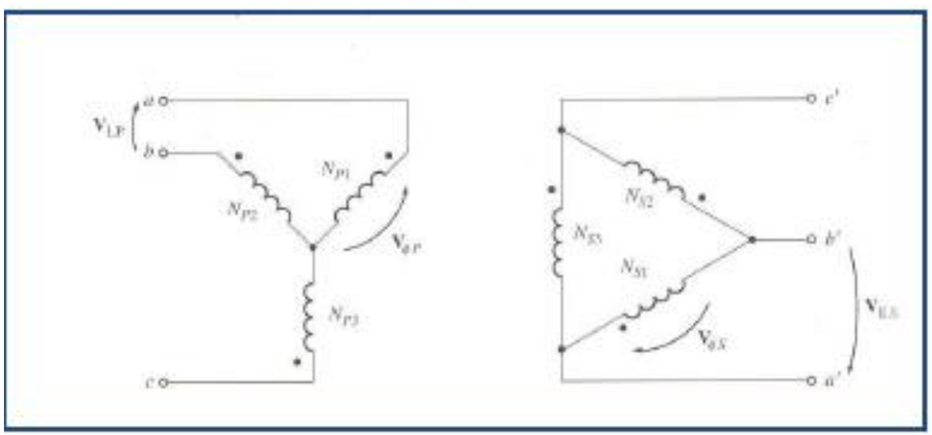
THREE PHASE TRANSFORMER CONNECTIONS



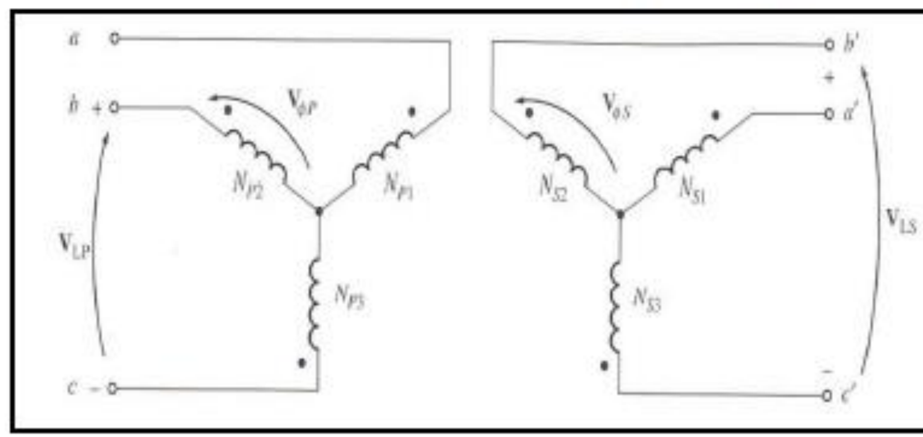
Delta – wye (Δ – Y)



Delta – delta (Δ – Δ)

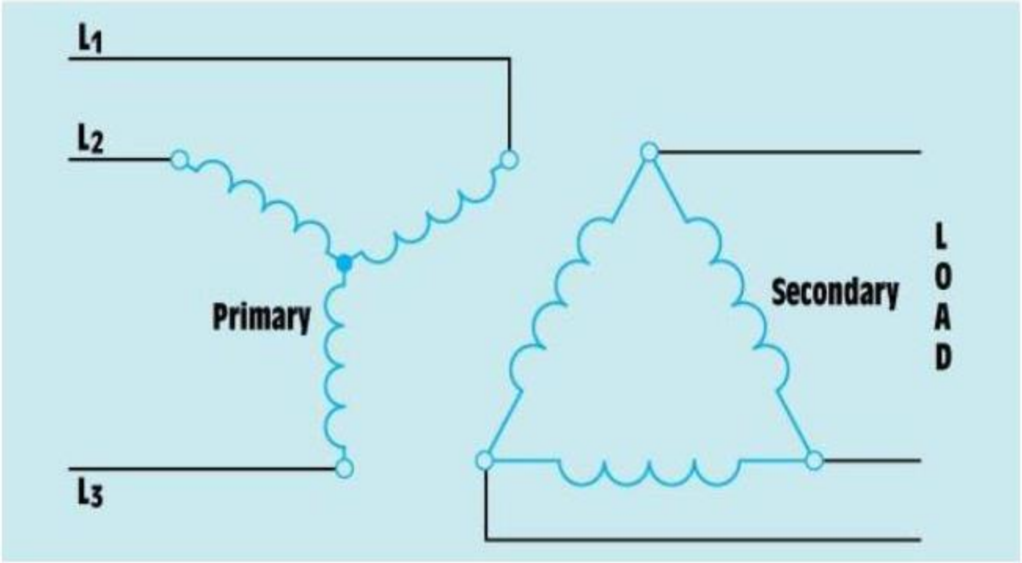


Wye – delta (Y- Δ)

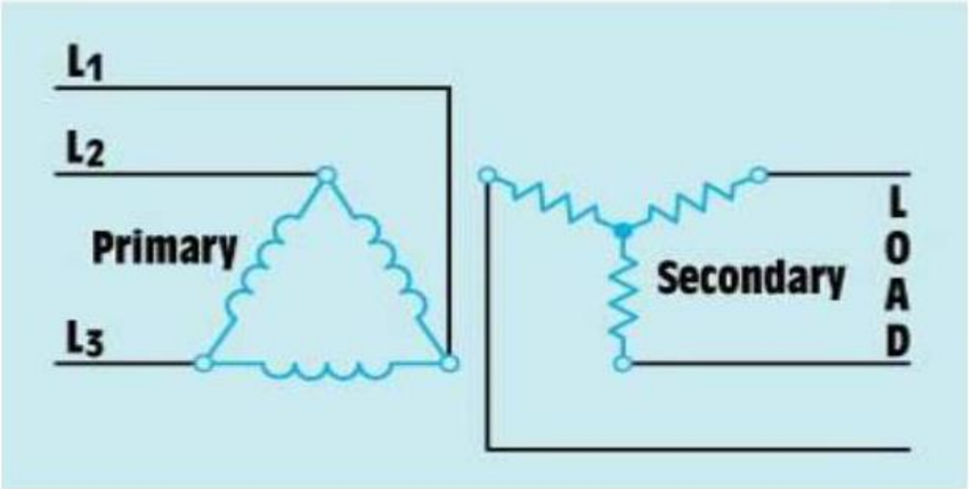


Wye – wye (Y – Y)

Three-Phase Transformers

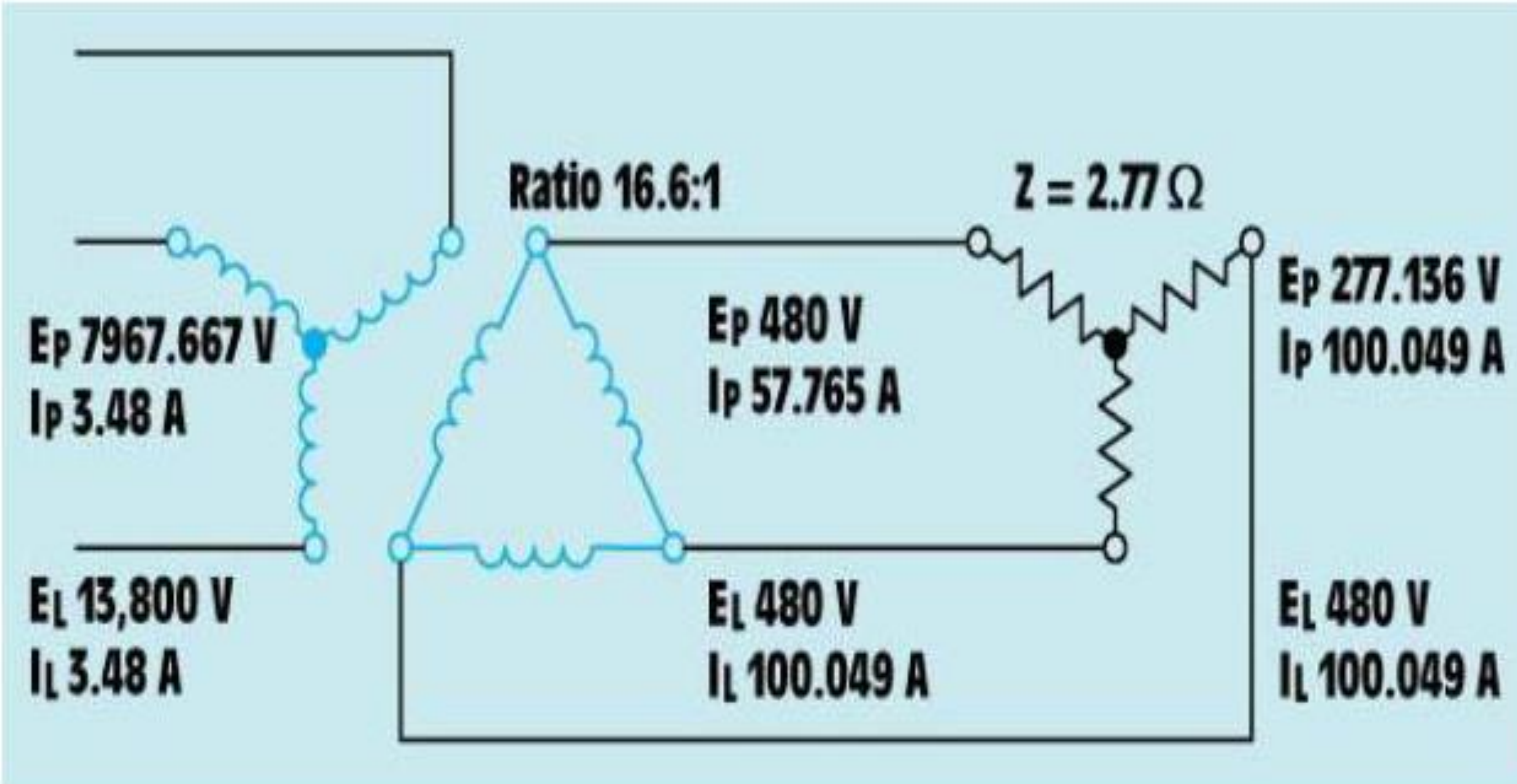


Wye-delta three-phase connection schematic.



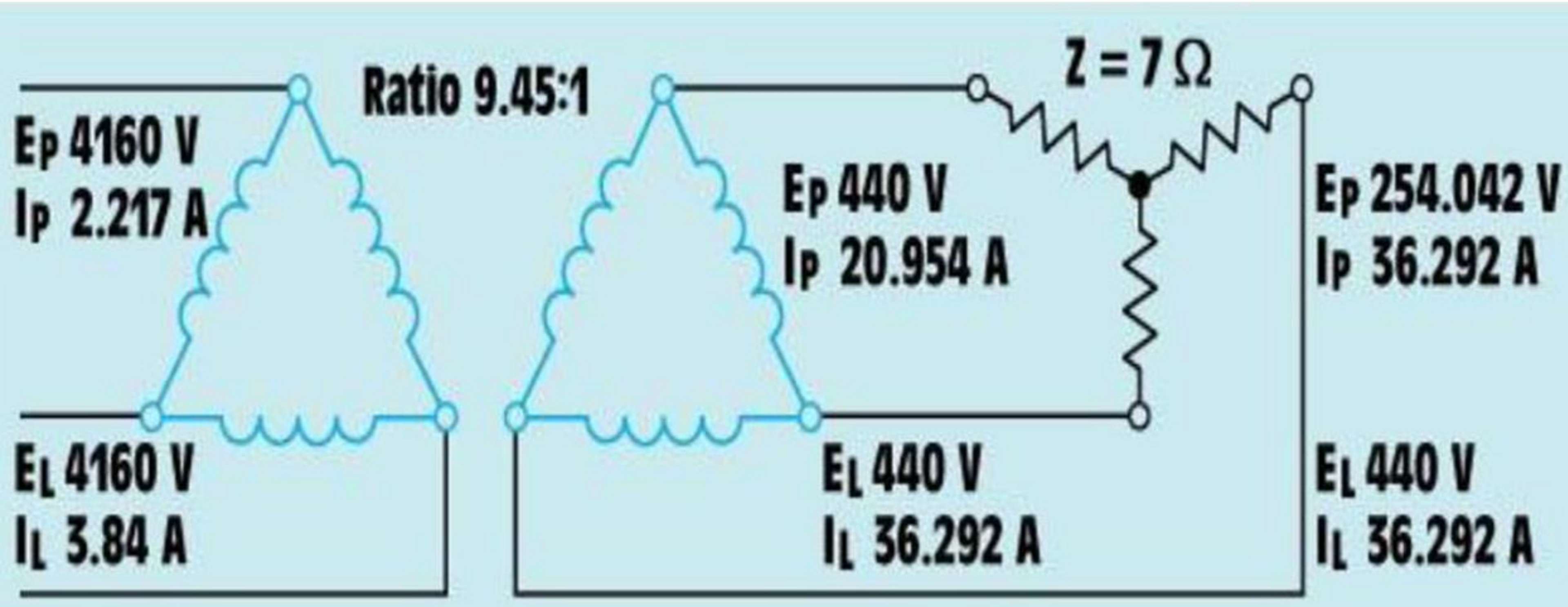
Delta-wye three-phase connection schematic.

Three-Phase Transformers

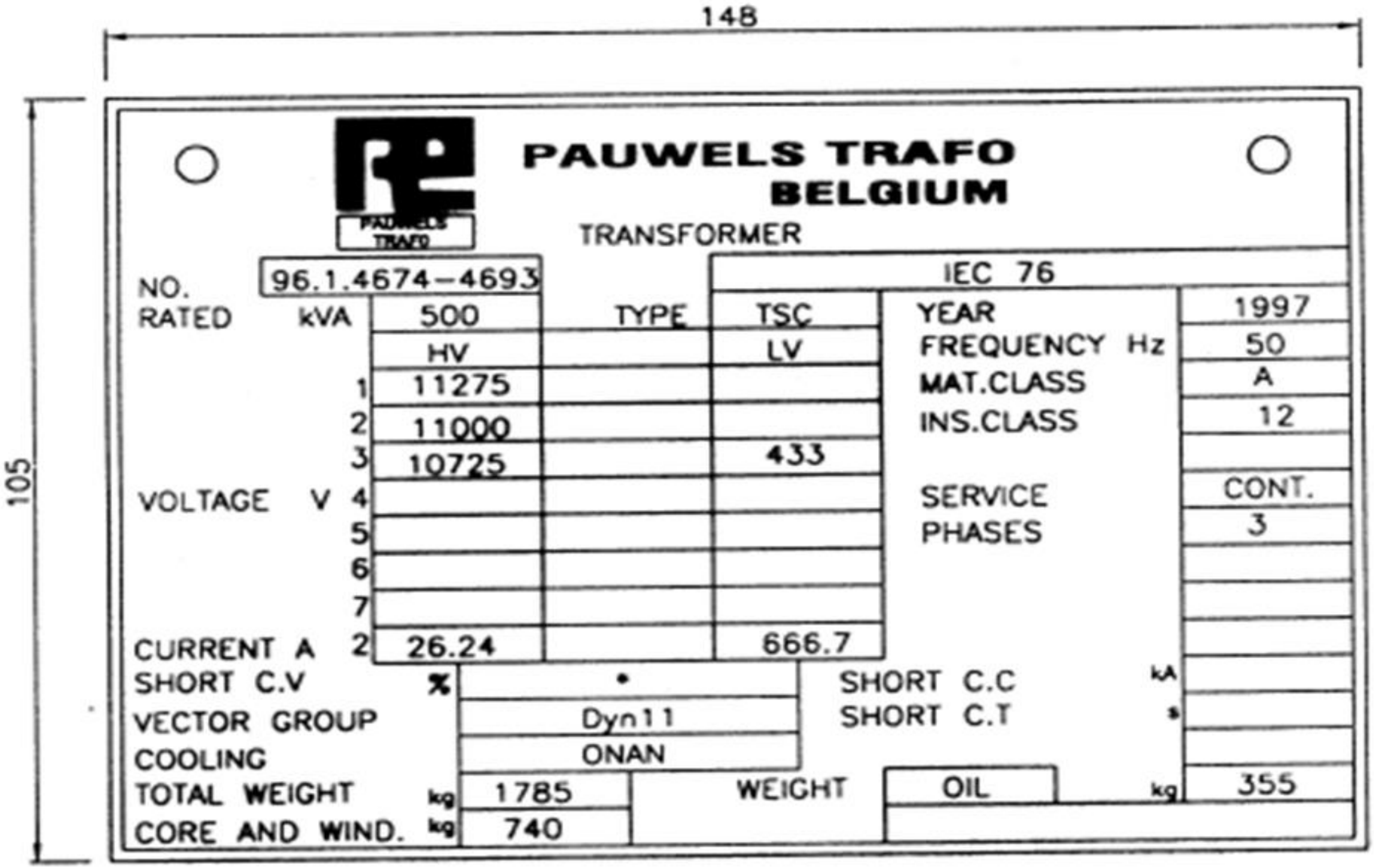


Example #1 schematic with all values.

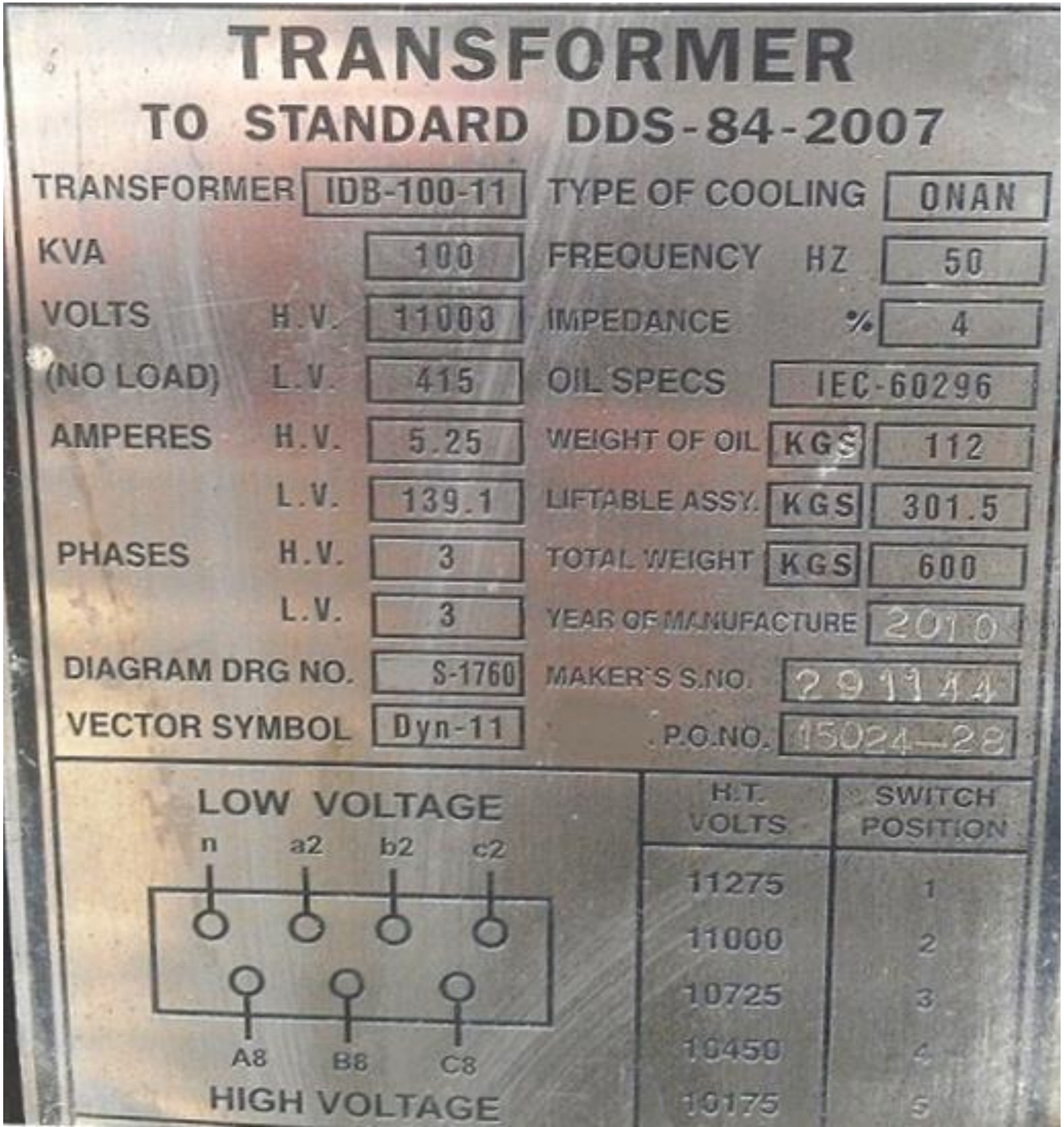
Three-Phase Transformers



Transformer Nameplate



https://www.youtube.com/watch?v=tGdr_XJcfOs


TRANSFORMER
TO STANDARD DDS-84-2007
TRANSFORMER IDB-100-11
TYPE OF COOLING ONAN
KVA 100
FREQUENCY HZ 50
VOLTS H.V. 11000
IMPEDANCE % 4
(NO LOAD) L.V. 415
OIL SPECS IEC-60296
AMPERES H.V. 5.25
WEIGHT OF OIL KGS 112
L.V. 139.1
LIFTABLE ASSY. KGS 301.5
PHASES H.V. 3
TOTAL WEIGHT KGS 600
L.V. 3
YEAR OF MANUFACTURE 2010
DIAGRAM DRG NO. S-1760
MAKER'S S.NO. 291144
VECTOR SYMBOL Dyn-11
P.O.NO. 15024-28
LOW VOLTAGE
n a2 b2 c2
A8 B8 C8
HIGH VOLTAGE
H.T. VOLTS
SWITCH POSITION
11275 1
11000 2
10725 3
10450 4
10175 5

Questions and Problems

1. Name the principal parts of a transformer.
2. Explain how a voltage is induced in the secondary winding of the transformer.
3. The secondary winding of a transformer has twice as many turns as the primary. Is the secondary voltage higher or lower than the primary voltage?
4. Which winding is connected to the load, the primary or the secondary?
5. State the voltage and current relationships between the primary and secondary windings of a transformer under load. The primary and secondary windings have N_1 and N_2 turns, respectively.
6. Name the losses produced in a transformer.
7. What purpose does the no load current of a transformer serve?
8. Name three conditions that must be meet in order to connect two transformers in parallel.
9. What are the purpose of taps on a transformer?
10. Name three methods to cool transformers.

Answers to Questions

1. The primary winding, secondary winding and the transformer core.
2. The voltage in induced according to Farady's law of Electromegnetic induction, $E = 4.44\, f\, N\, \varphi$
3. The secondary voltage will be two times higher than the primary voltage.
4. secondary winding is connected to the load.
5. $$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \frac{1}{n} \qquad \frac{I_1}{I_2} = \frac{N_2}{N_1} = n$$
6. The core or iron Losses and the copper or I^2R losses. The core losses are further divided into Eddy current and Hysteresis losses.
7. It creates the magnetic flux and supplies the core losses.
8. The primary voltages of the two transformers must be same. The secondary voltages must be same and the same per unit impedance.
9. Taps are provided on the primary winding of a distribution transformer to correct the under voltage problem. It enables us to change the turns ratio by 4.5%, 9%, 13.5%.
10. By natural circulation of Air. By forced air cooling with fan. By forced circulation of oil and air cooling.