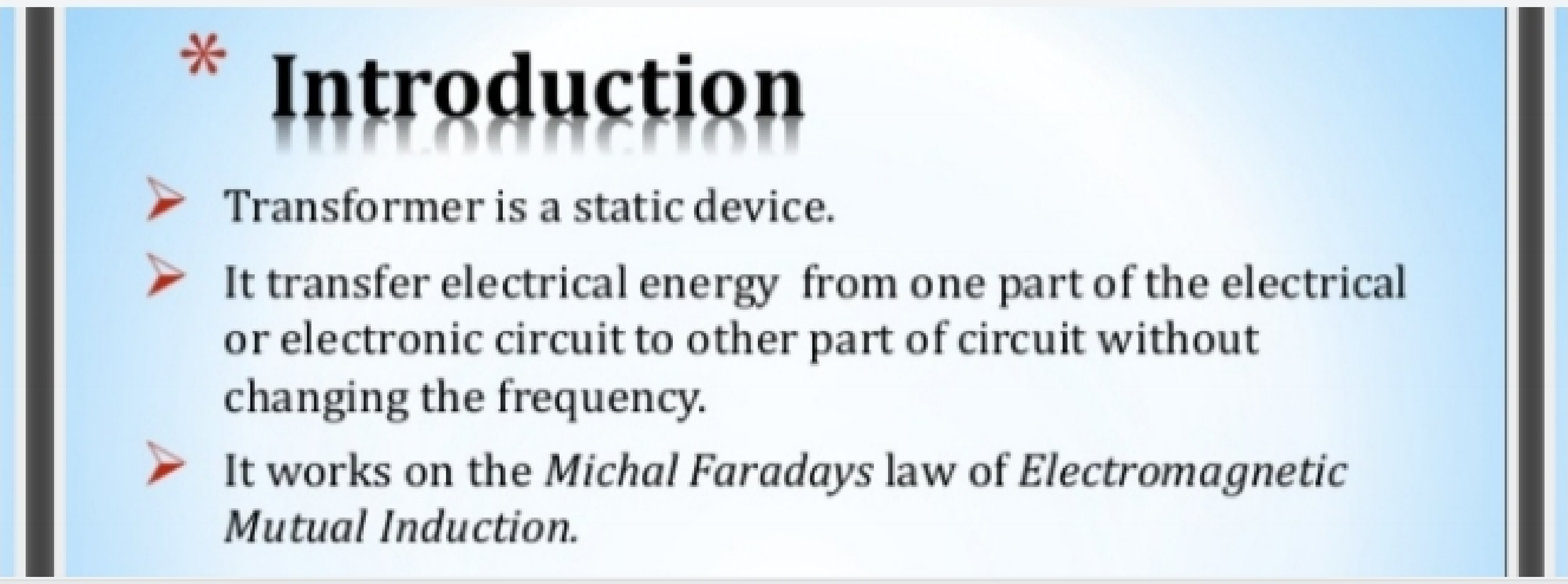
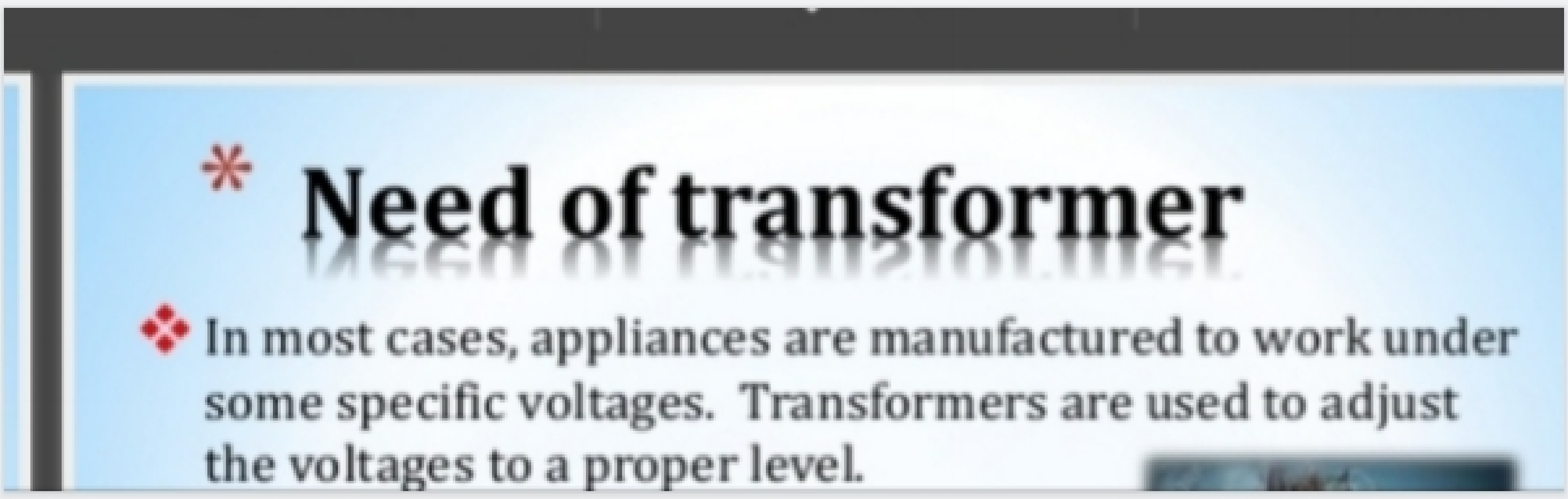




Transformer Parts And Construction

The three main parts of a transformer:

- Primary Winding of Transformer
- Magnetic Core of Transformer
- Secondary Winding of Transformer

Primary Winding of Transformer

Which produces magnetic flux when it is connected to an electrical source.

Magnetic Core of Transformer

The magnetic flux produced by the primary winding, that will pass through this low reluctance path linked with

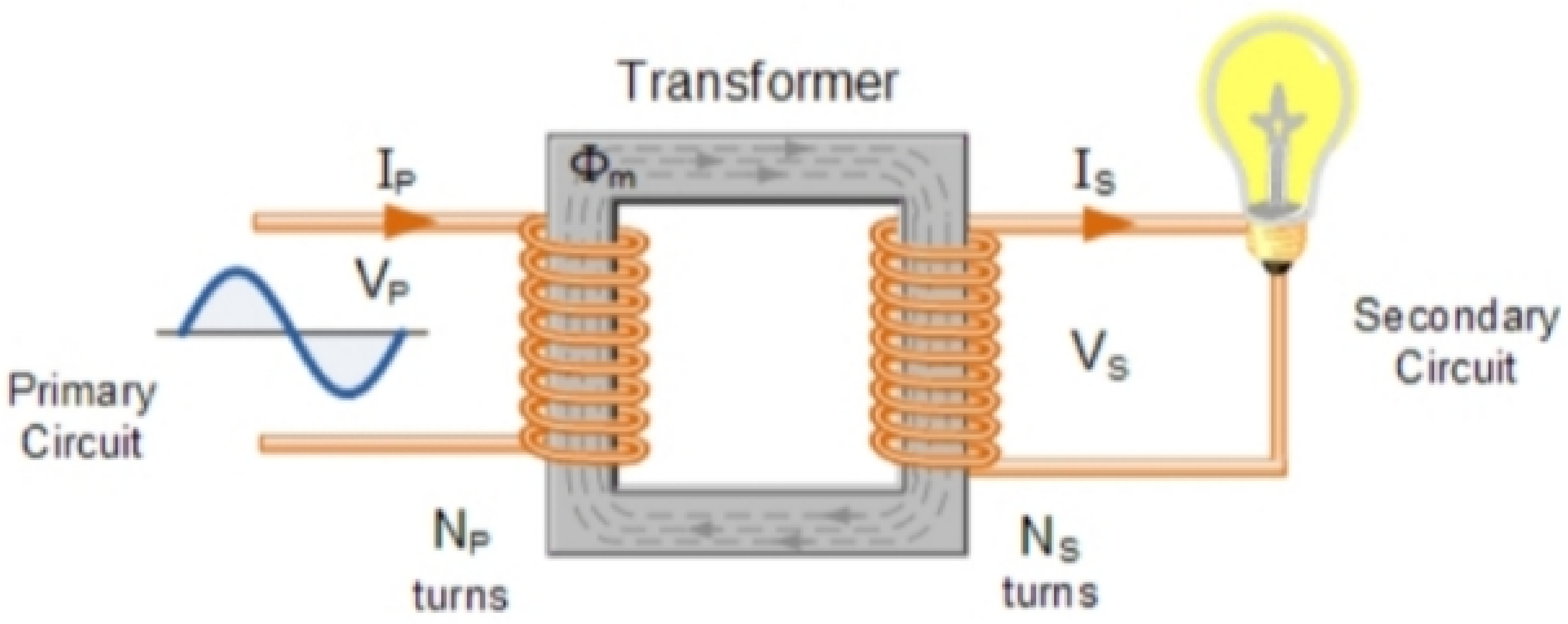
Magnetic Core of Transformer

The magnetic flux produced by the primary winding, that will pass through this low reluctance path linked with secondary winding and create a closed magnetic circuit.

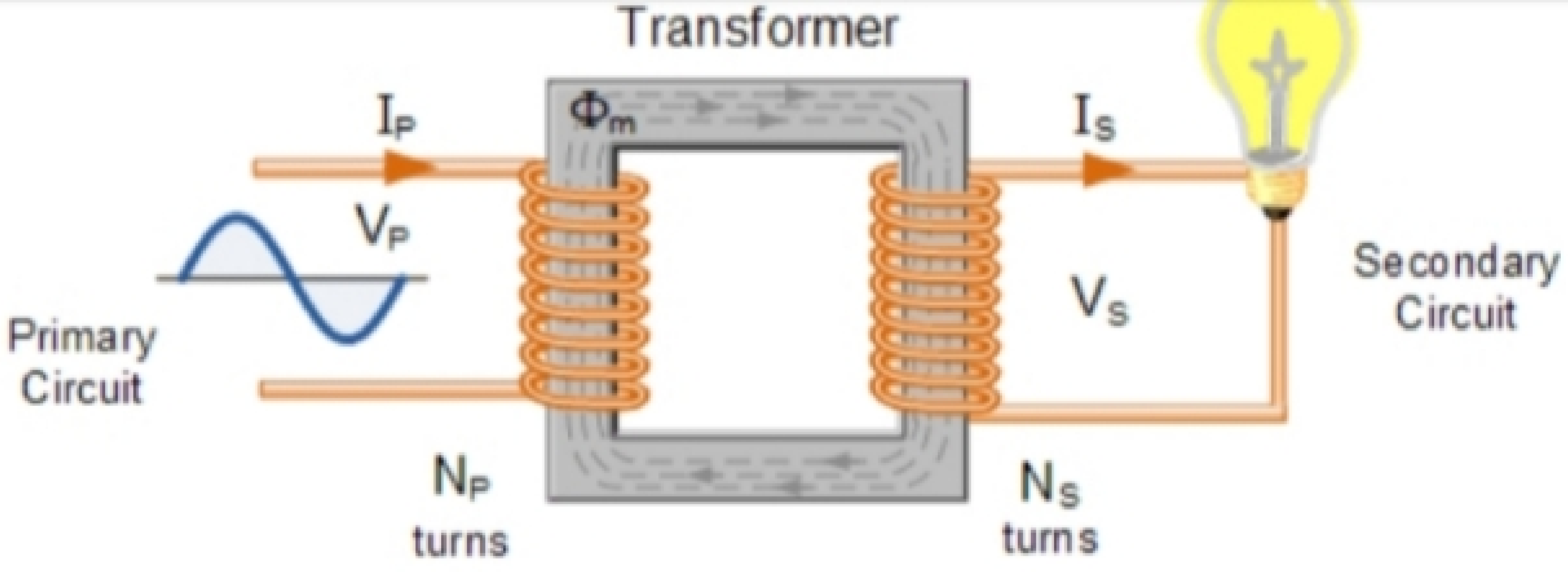
Secondary Winding of Transformer

The flux, produced by primary winding, passes through the core, will link with the secondary winding. This winding also wounds on the same core and gives the desired output of the **transformer**.

Single Phase Voltage Transformer



In other words, for a transformer there is no direct electrical connection between the two coil windings, thereby giving it the name also of an **Isolation Transformer**. Generally, the primary winding of a transformer is connected to the input voltage supply and converts or transforms the electrical power into a magnetic field. While the job of the secondary winding is to convert this alternating magnetic field



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A Transformers Turns Ratio

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = n = \text{Turns Ratio}$$

$$\therefore E_{rms} = 4.44 f N \Phi_{max}$$

Where:

f – is the flux frequency in Hertz, $= \omega/2\pi$

N – is the number of coil windings.

Φ – is the amount of flux in webers

This is known as the **Transformer EMF Equation**. For the primary winding emf, N will be the number of primary turns, (N_P) and for the secondary winding emf, N will be the number of secondary turns, (N_S).

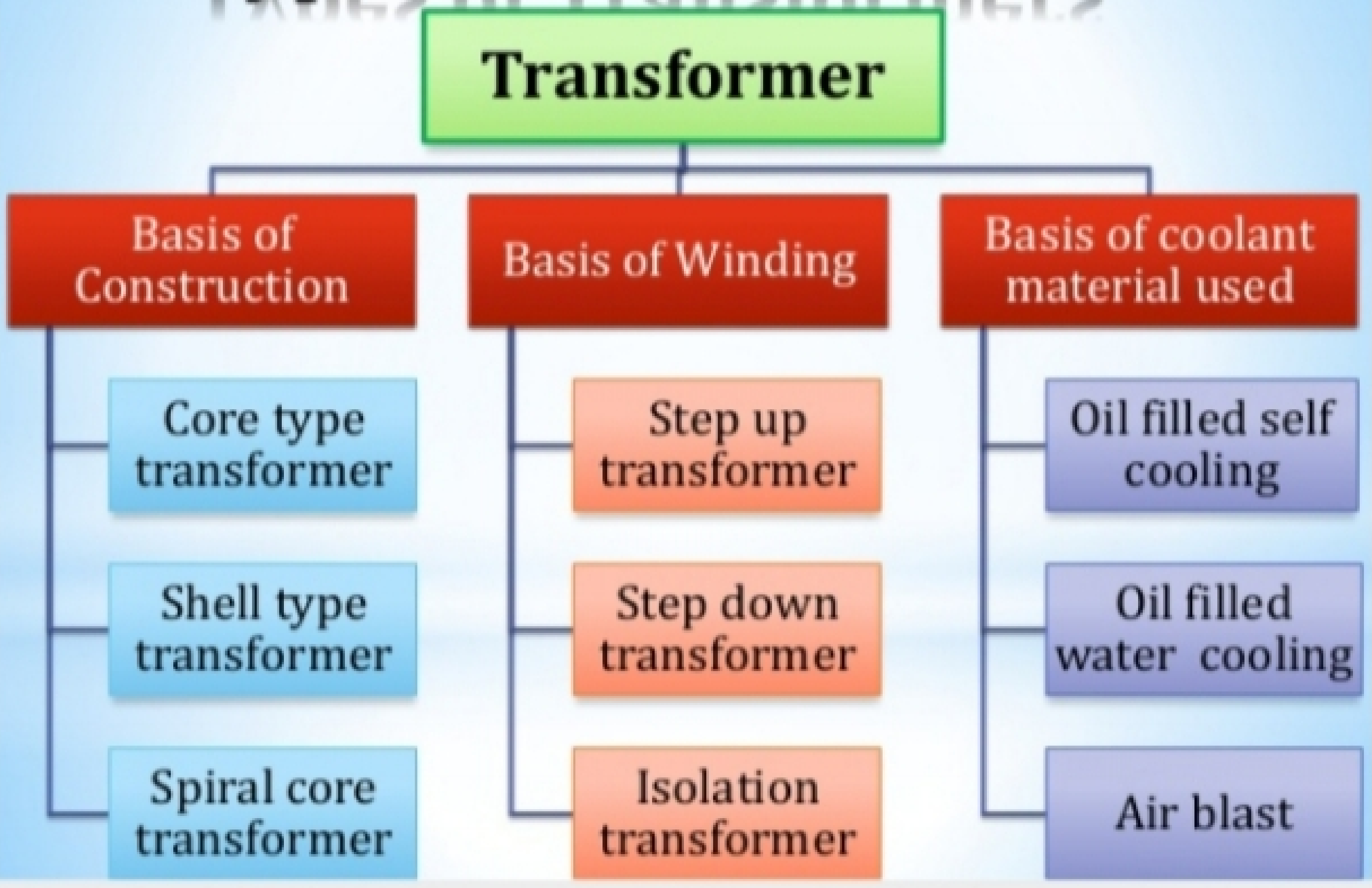
Transformer Efficiency

Transformer Efficiency

$$\text{efficiency}, \eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

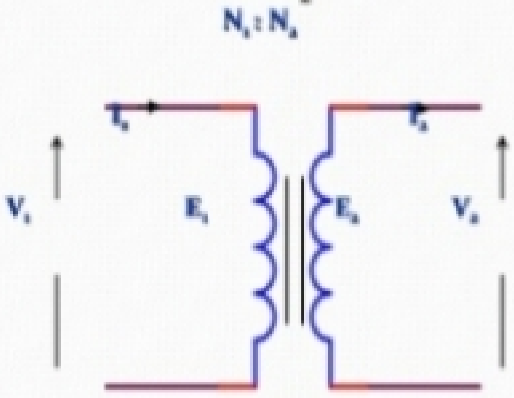
$$= \frac{\text{Input Power - Losses}}{\text{Input Power}} \times 100\%$$

* Types of Transformers



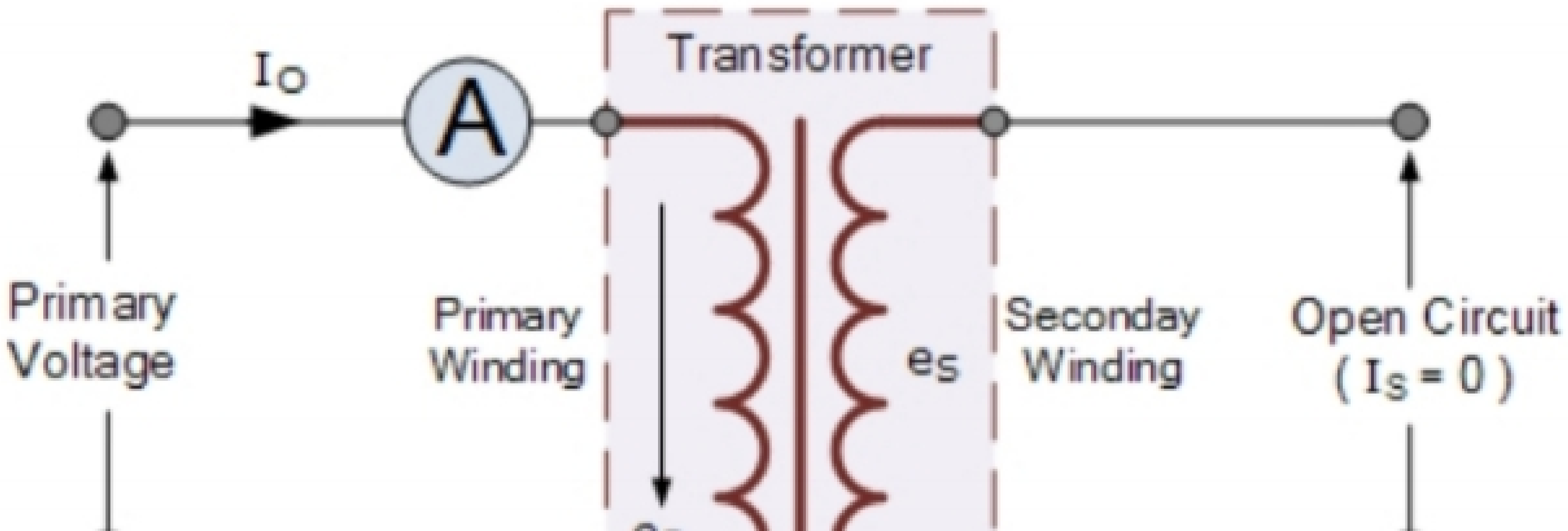
Ideal transformer

- An ideal transformer is a transformer **which has no loses**, i.e. it's winding has no ohmic resistance, no magnetic leakage, and therefore no I^2R and core loses.
- However, it is **impossible** to realize such a transformer in practice.
- Yet, the **approximate characteristic of ideal transformer will be used in characterized the practical transformer.**



V_1 – Primary Voltage
V_2 – Secondary Voltage
E_1 – Primary induced Voltage
E_2 – secondary induced Voltage
$N_1:N_2$ – Transformer ratio

Transformer "No-load" Condition



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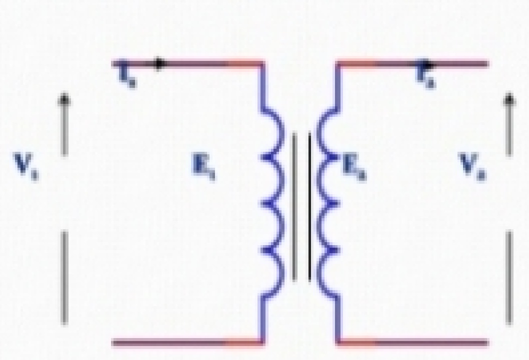

V_1 – Primary Voltage
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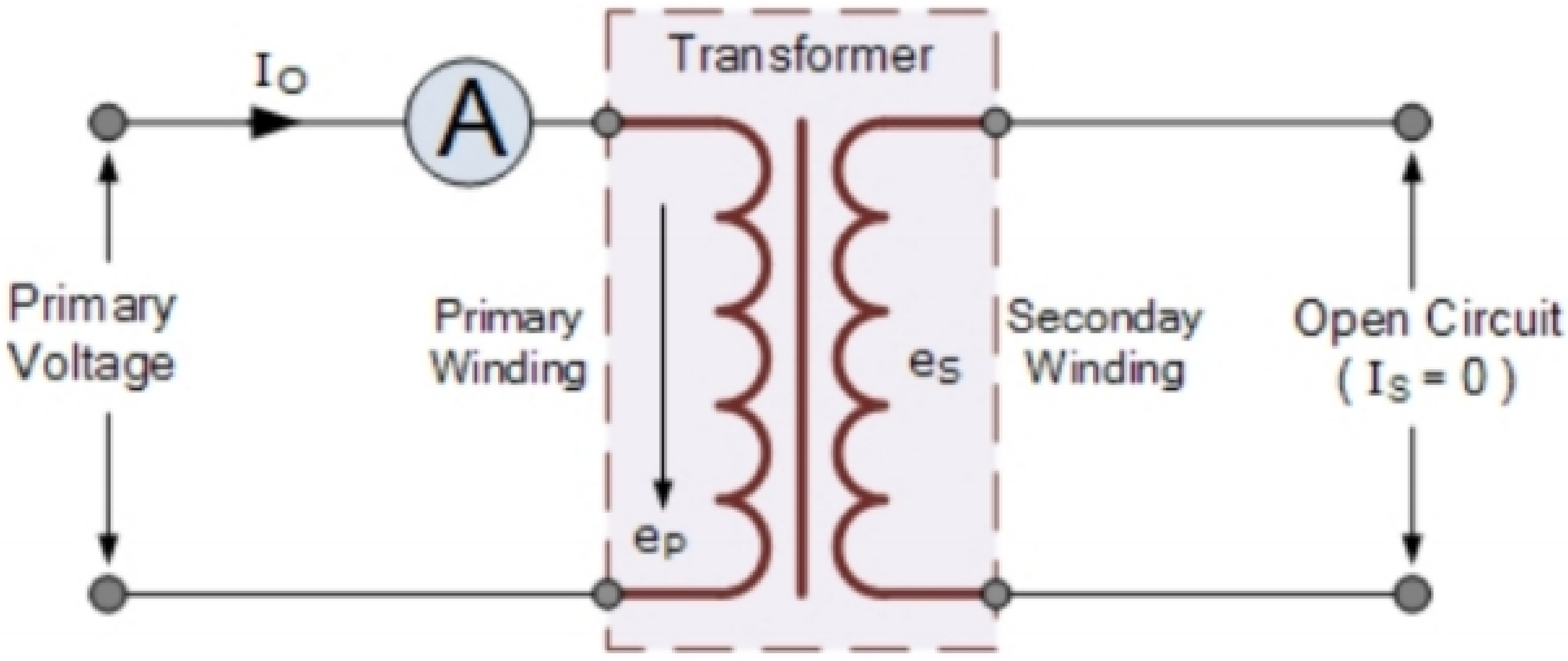
E_2 – secondary induced Voltage
N_1:N_2 – Transformer ratio

Transformer "No-load" Condition



The ammeter above will indicate a small current flowing through the primary winding even though the secondary circuit is open circuited. This no-load primary current is made up of the following two components:

- ✓ An in-phase current, I_E which supplies the core losses (eddy current and hysteresis).
- ✓ A small current, I_M at 90° to the voltage which sets up the magnetic flux.

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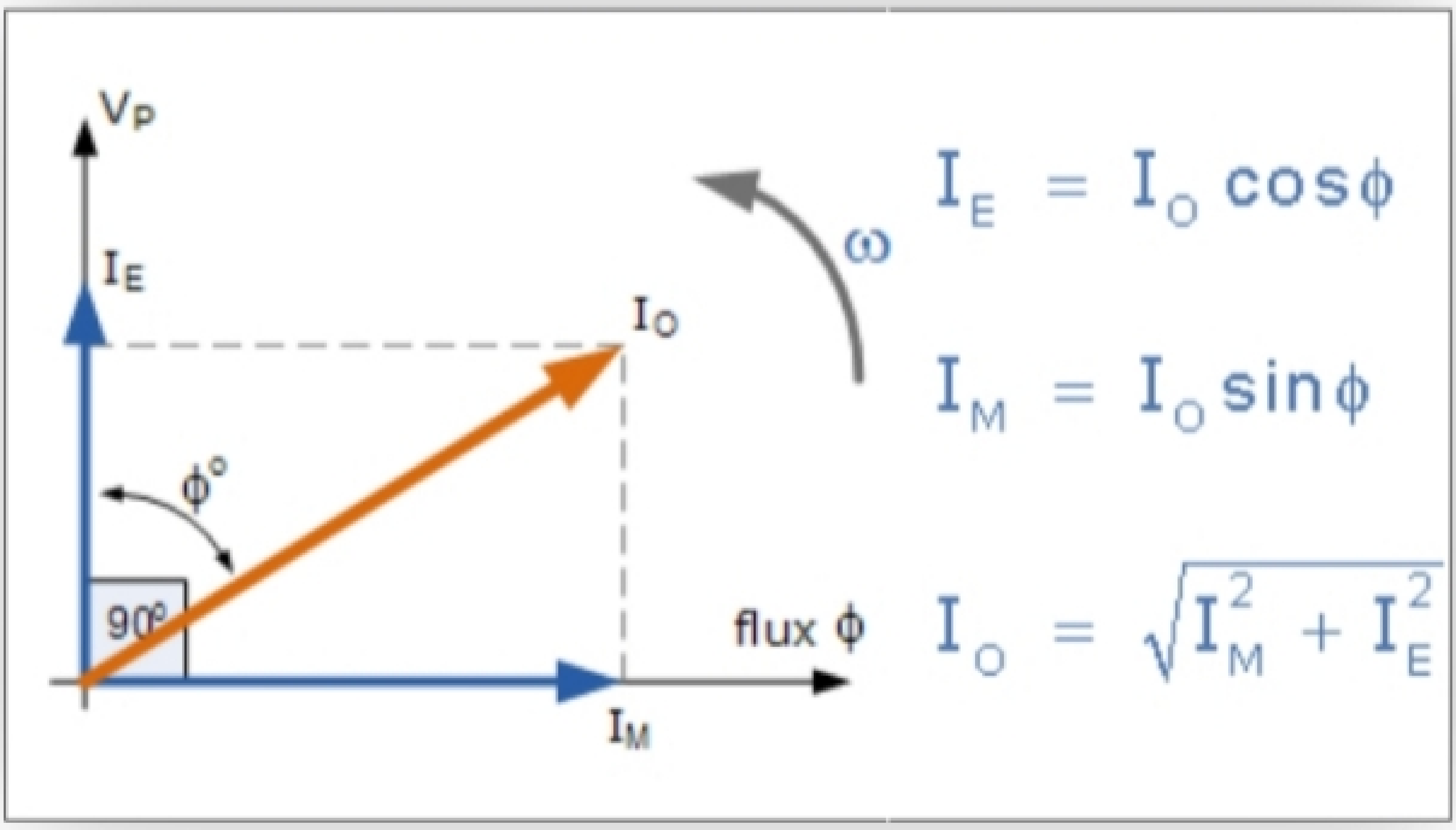


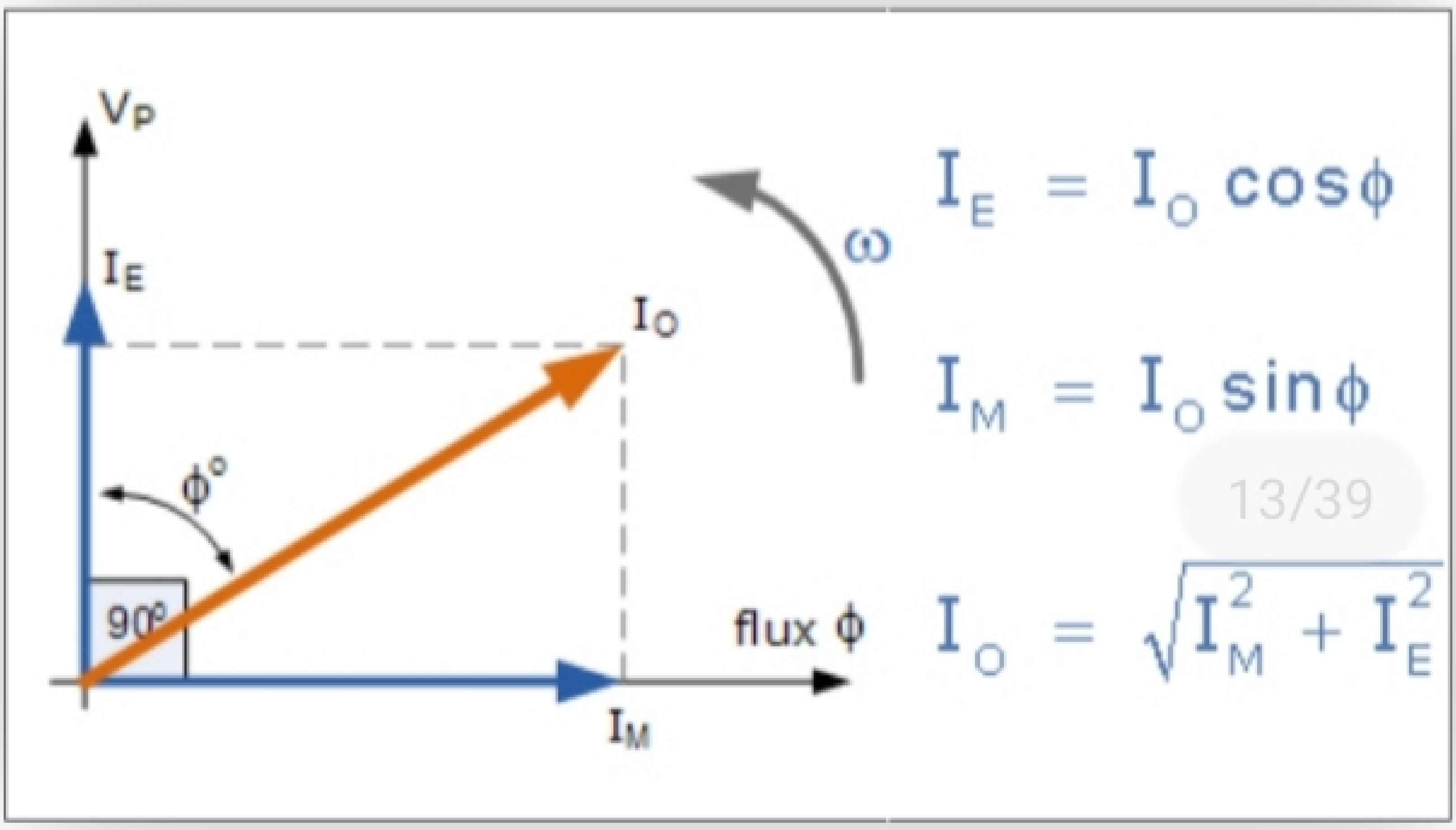
Type of Transformer Testing

Tests done at factory

1. Type tests
2. Routine tests
3. Special tests

Tests done at site

- An in-phase current, I_E which supplies the core losses (eddy current and hysteresis).
- A small current, I_M at 90° to the voltage which sets up the magnetic flux.



Type of Transformer Testing

Tests done at factory

1. Type tests
2. Routine tests
3. Special tests

Tests done at site

1. Pre-commissioning tests
2. Periodic/condition monitoring tests
3. Emergency tests

Power in a Transformer

$$\text{Power}_{\text{Primary}} = \text{Power}_{\text{Secondary}}$$

$$P_{(PRI)} = P_{(SEC)} = V_P I_P \cos\Phi_P = V_S I_S \cos\Phi_S$$

Where: Φ_P is the primary phase angle and Φ_S is the secondary phase angle.

Note that since power loss is proportional to the square of the current being transmitted, that is: I^2R, increasing the voltage, let's say doubling (×2) the voltage would decrease the current by the same amount, (÷2) while delivering the same amount of power to the load and therefore reducing losses by factor of 4. If the voltage was increased by a factor of 10, the current would decrease by the same factor reducing overall losses by factor of 100.

Transformer Basics Example No3

A single phase transformer has 480 turns on the primary winding and 90 turns on the secondary winding. The maximum value of the magnetic flux density is 1.1T when 2200 volts, 50Hz is applied to the transformer primary winding. Calculate:

a). The maximum flux in the core.

$$E_{rms} = \frac{N\omega}{\sqrt{2}}\Phi_{max}$$

$$\Phi_{max} = \frac{E_{rms}}{N\omega} \times \sqrt{2} = \frac{2200}{480 \times 2\pi \times 50} \times \sqrt{2}$$

$$\therefore \Phi_{max} = 0.0206\,\text{Wb or } 20.6\,\text{mWb}$$

b). The cross-sectional area of the core.

$$\Phi_{max} = \beta \times A$$

$$\therefore A = \frac{\Phi_{max}}{\beta} = \frac{0.0206}{1.1} = 0.0187\text{m}^2$$

$$E_{S(rms)} = 4.44 \times 50 \times 90 \times 20.6 \times 10^{-3}$$

$$\therefore E_{S(rms)} = 412 \text{ Volts}$$

Since the secondary voltage rating is equal to the secondary induced emf, another easier way to calulate the secondary voltage from the turns ratio is given as:

$$\text{T.R.} = \frac{V_P}{V_S} = \frac{N_P}{N_S}$$

$$\therefore V_S = \frac{V_P \times N_S}{N_P} = \frac{2200 \times 90}{480} = 412 \text{ Volts}$$

$$\text{efficiency}, \eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100\%$$

$$= \frac{\text{Input Power - Losses}}{\text{Input Power}} \times 100\%$$

$$= 1 - \frac{\text{Losses}}{\text{Input Power}} \times 100\%$$

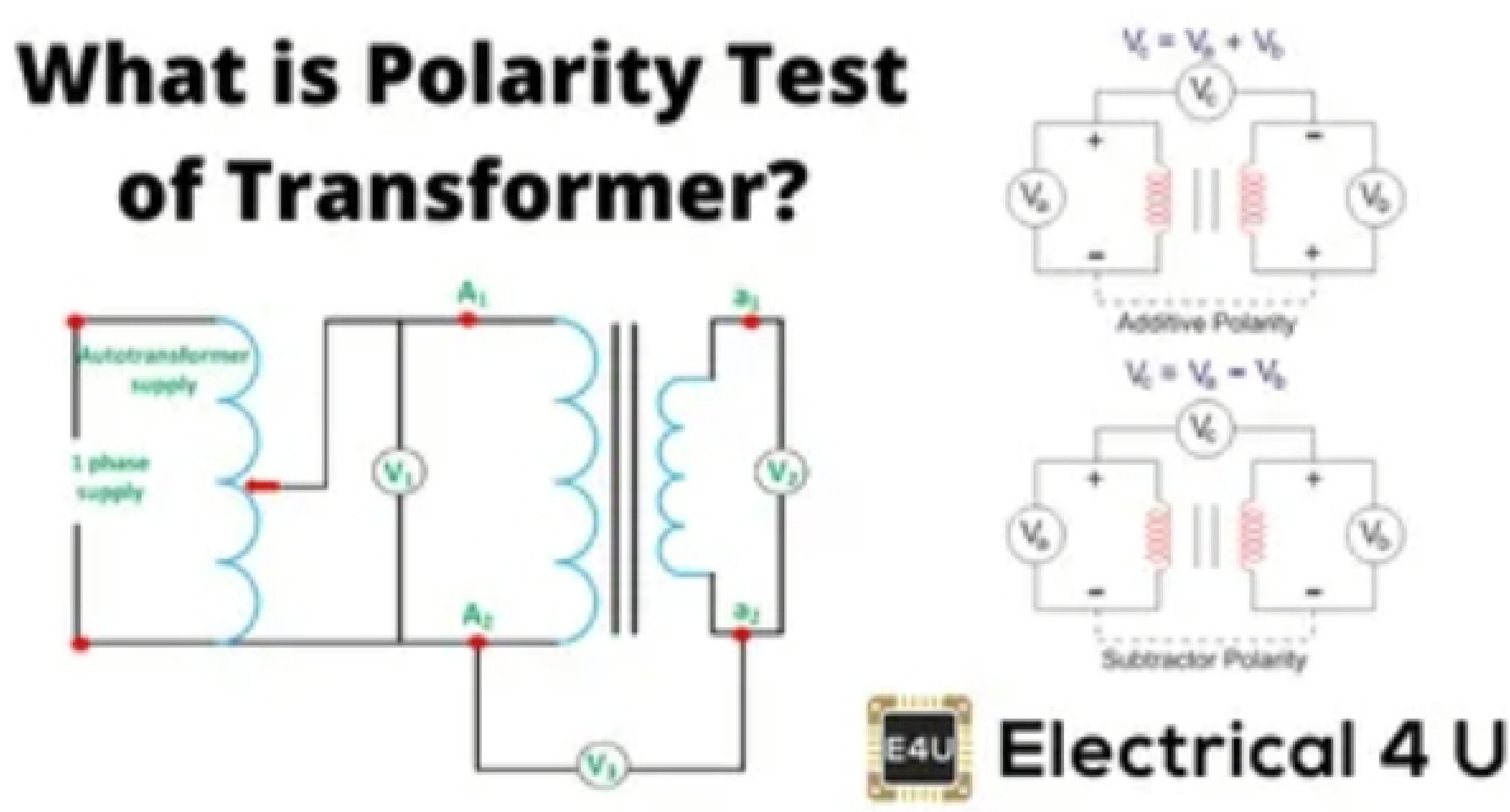
Where: Input, Output and Losses are all expressed in units of power.

Generally when dealing with transformers, the primary watts are called "volt-amps", **VA** to differentiate them from the secondary watts. Then the efficiency equation above can be modified to:

$$\text{Efficiency}, \eta = \frac{\text{Secondary Watts (Output)}}{\text{Primary VA (Input)}}$$

Polarity Test of Transformer (Explanation + Diagrams)

Last updated October 27, 2020 by Electrical4U



Current flows from high voltage point to low voltage point due to the potential difference between them. Here, electrical polarity comes into the picture. Electrical polarity simply describes the direction of the current flow. When we look into DC system, we find that one pole is always positive and difference between them. Here, electrical polarity comes into the picture. Electrical polarity simply describes the direction of the current flow. When we look into DC system, we find that one pole is always positive and the other one is always negative that imply that the current flows in one direction only. But when we look into an AC system, the terminals are changing their polarity periodically, and the direction of the current also changes accordingly.

Additive Polarity

In additive polarity, the voltage (V_c) between the primary side (V_a) and the secondary side (V_b) will be the sum of both high voltage and the low voltage, i.e. we will get $V_c = V_a + V_b$

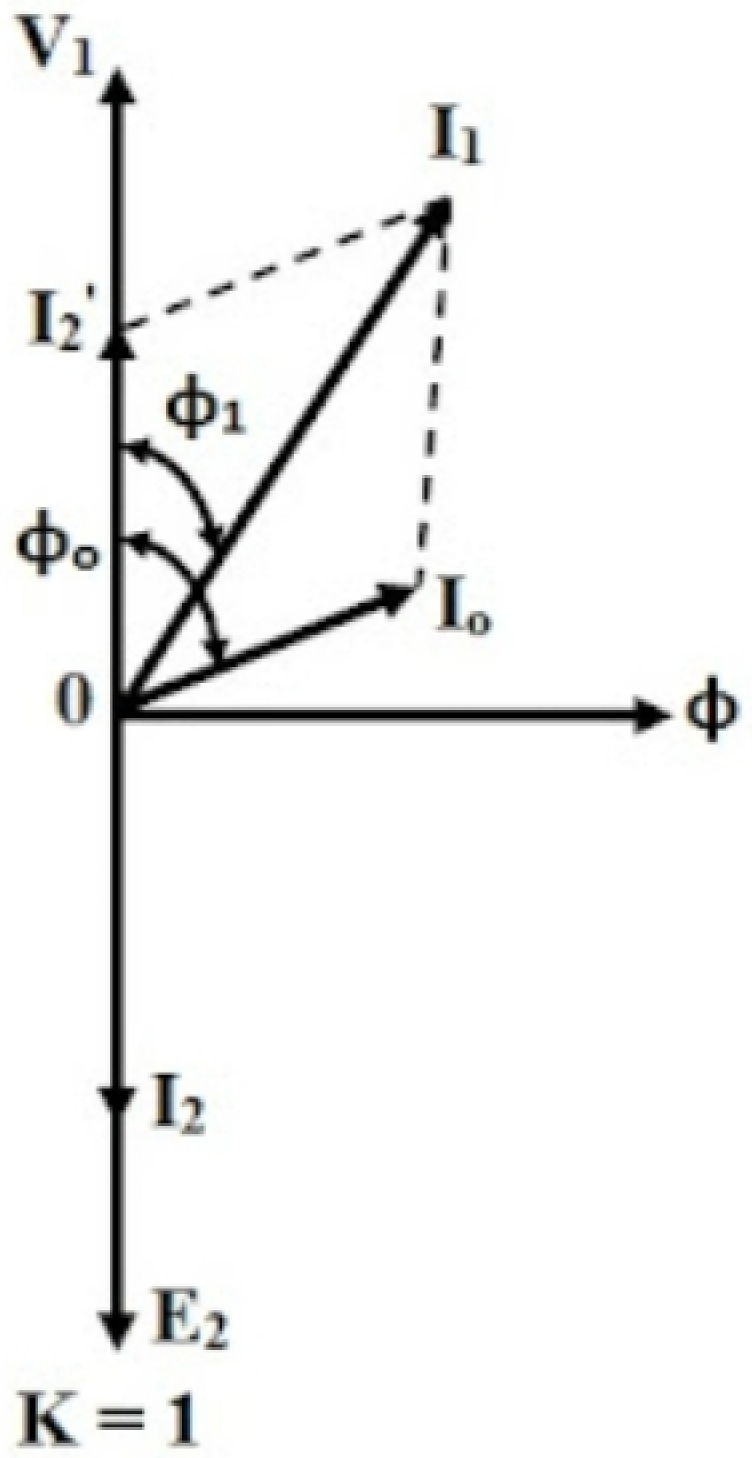
Subtractive Polarity

In subtractive polarity, the voltage (V_c) between the primary side (V_a) and the secondary side (V_b) will be the difference of both high voltage and the low voltage, i.e. we will get $V_c = V_a – V_b$

In subtractive polarity, if $V_c = V_a – V_b$, it is a step-down transformer and if $V_c = V_b – V_a$, it is a step-up transformer.

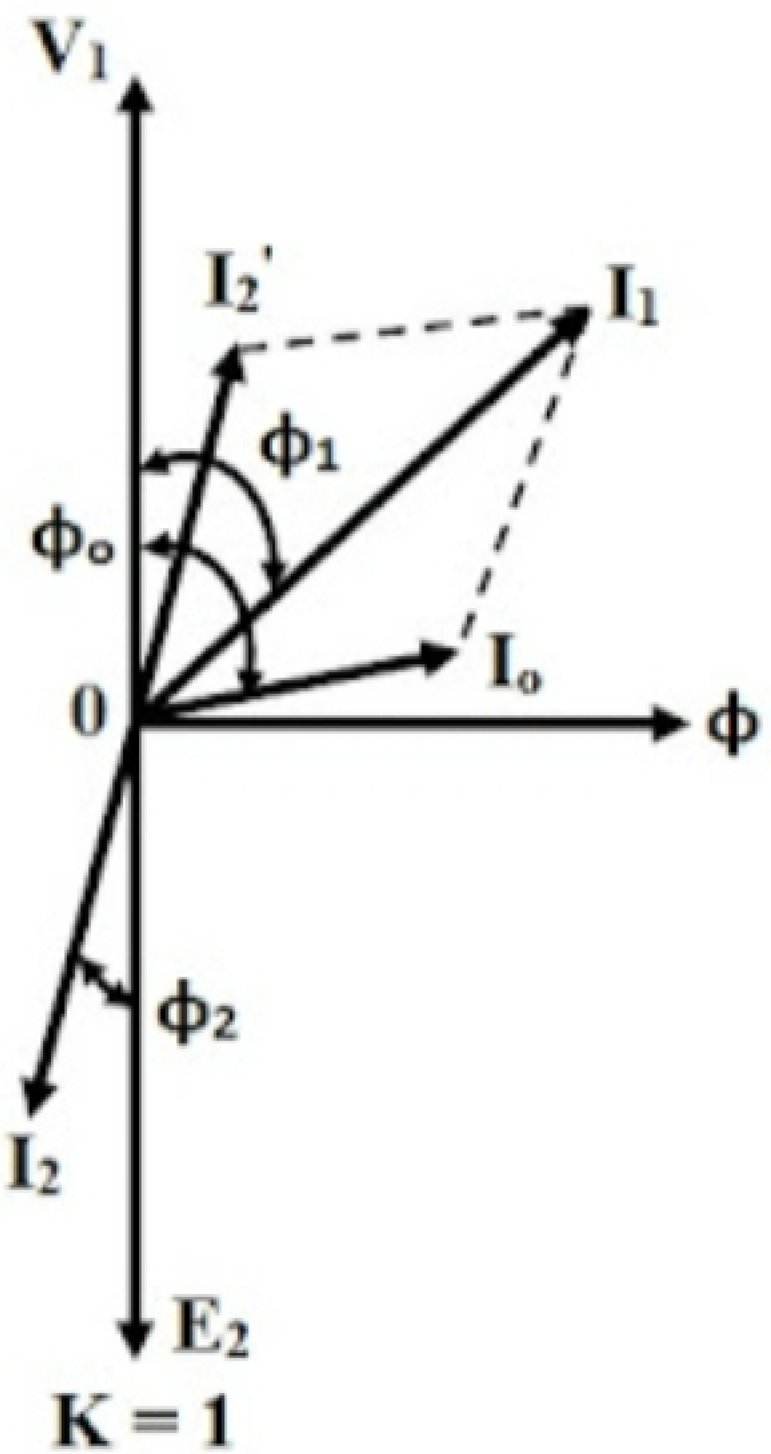
For Resistive (non-inductive) Load :

When the transformer secondary is connected to a resistive load, the current will be in-phase with the voltage.



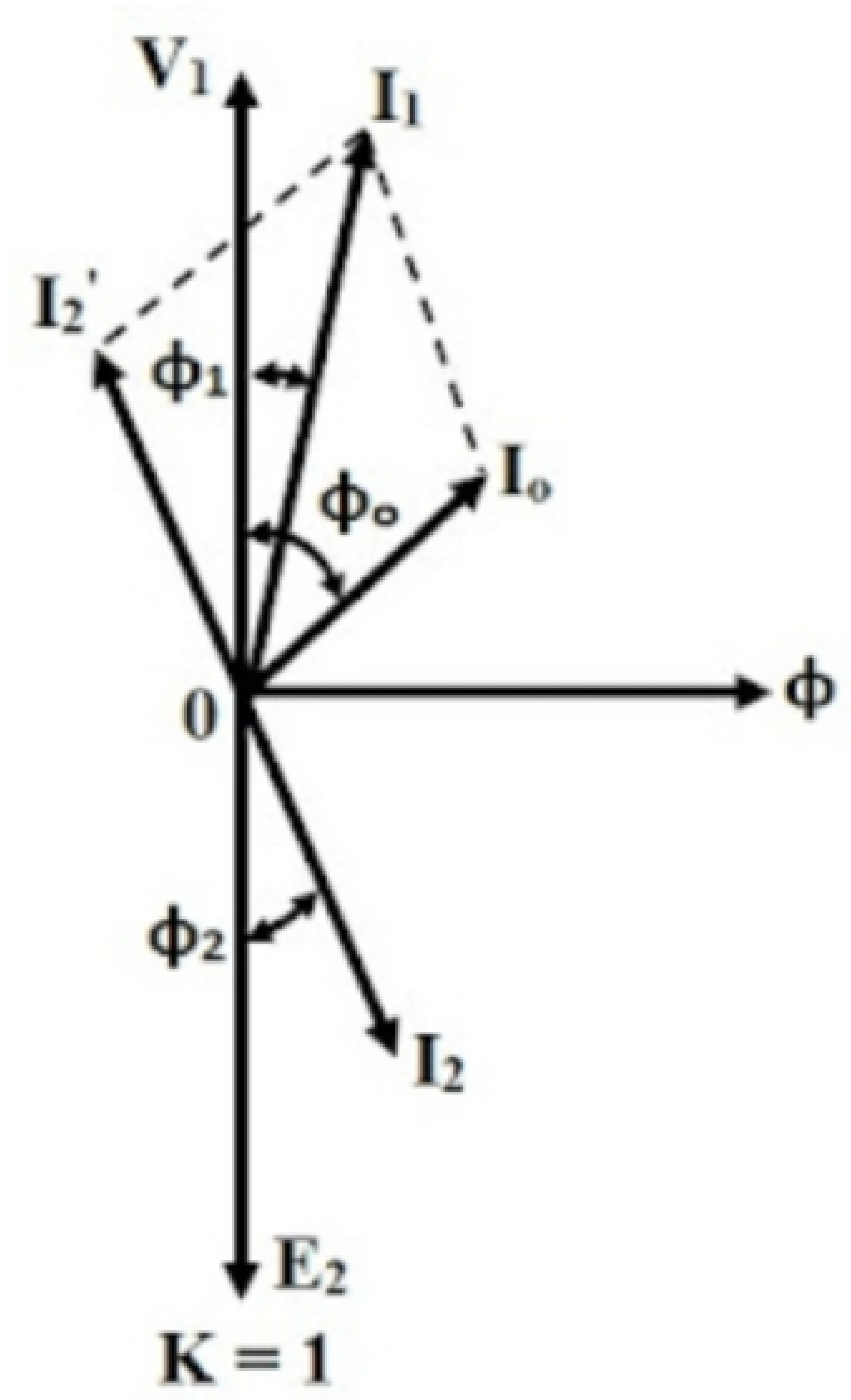
For Inductive Load :

When the transformer secondary is connected to an inductive load, the current flowing will lags with respect to the voltage as shown below.



For Capacitive Load :

Similarly, when the transformer secondary is connected to a capacitive load, the current flowing will leads the respective voltage as shown below.



Short Circuit Test or Impedance Test of Transformer

November 28, 2020

The performance or parameters of a transformer can be well determined by testing the transformer. In order to calculate the efficiency, regulation of the transformer various parameters like equivalent resistance and reactance, losses in the transformer at no-load as well as full-load must be calculated. To determine this the transformer testing must be done. They are,

- Open-circuit test, and
- Short-circuit test.

In the last article, we have determined the iron loss (core losses) by doing a no-load test or open-circuit test of the transformer as these losses are constant throughout the operation irrespective of the load. Now let us determine the power loss in the winding resistance, i.e., I^2 R loss (copper loss or variable loss) with the help of a short-circuit test.

Short-circuit Test of Transformer :

The purpose of this test is to determine the following :

1. The equivalent resistance and reactance referred to the metering side (used to find the regulation).
2. The copper loss at full load (used to calculate the efficiency).

In the short-circuit test of transformer one winding, mostly low voltage L.V. side (secondary winding) is short-circuited by a thick conductor, so that full-load current flows in the H.V. side (primary winding) or we can connect an ammeter in the short-circuit path, which serves to read the load current at the secondary side as shown in the figure.

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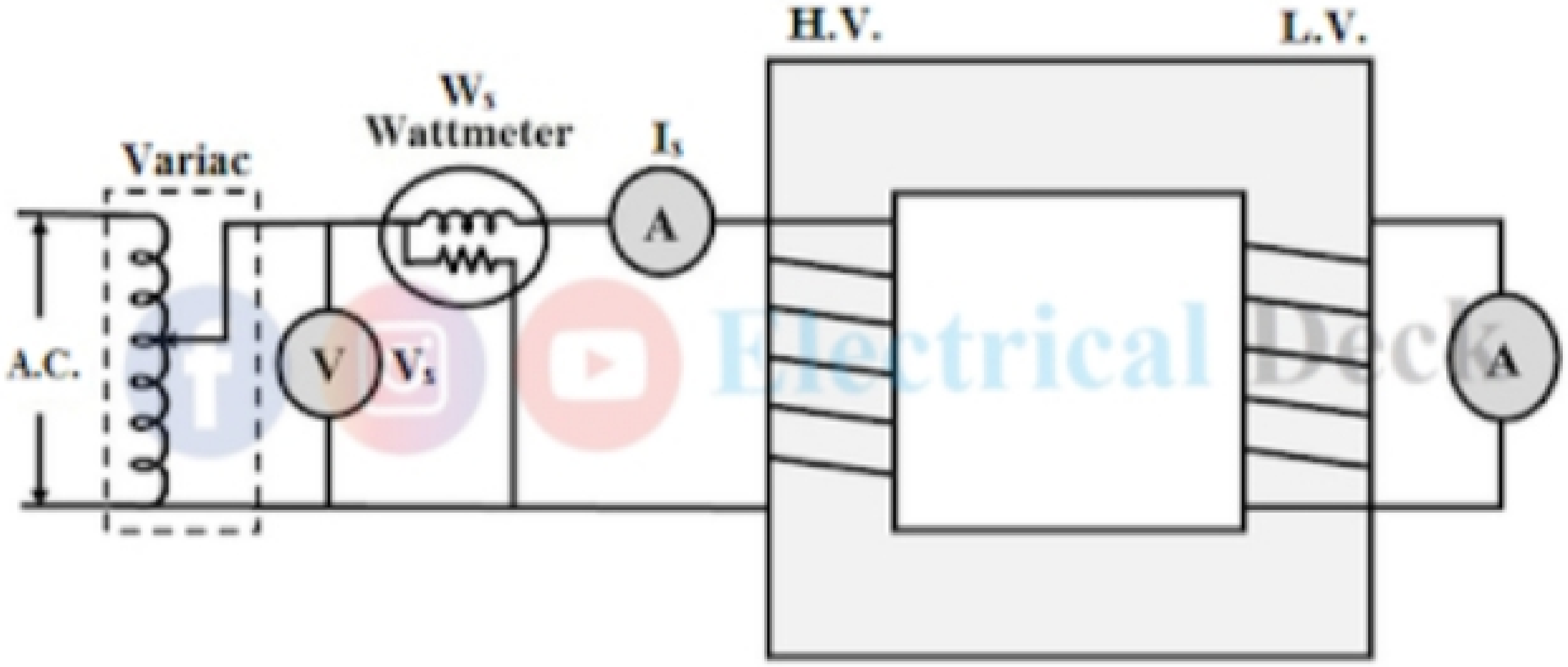


The testing of the transformer is performed on the high voltage H.V. side of the transformer. The supply is given to the transformer through a variac (autotransformer), voltmeter, wattmeter, and ammeter as shown in the above connection diagram.

Let W_S, I_S, and V_S are the short-circuit test wattmeter, ammeter, and voltmeter readings respectively. Then the full-load copper loss ($I^2 R$) which is equal to wattmeter reading would become,

$$W_s = I_s^2 R_{01}$$

From the wattmeter reading W_S, the equivalent resistance of the transformer referred to the primary side is given as,

$$R_{01} = \frac{W_s}{I_s^2}$$

From the wattmeter reading W_S, the equivalent resistance of the transformer referred to the primary side is given as,

$$R_{01} = \frac{W_s}{I_s^2}$$

The equivalent impedance of the transformer referred to the primary side is,

$$Z_{01} = \frac{V_s}{I_s}$$

Therefore, from the equation of resistance and impedance, equivalent reactance referred to the primary side is expressed as,

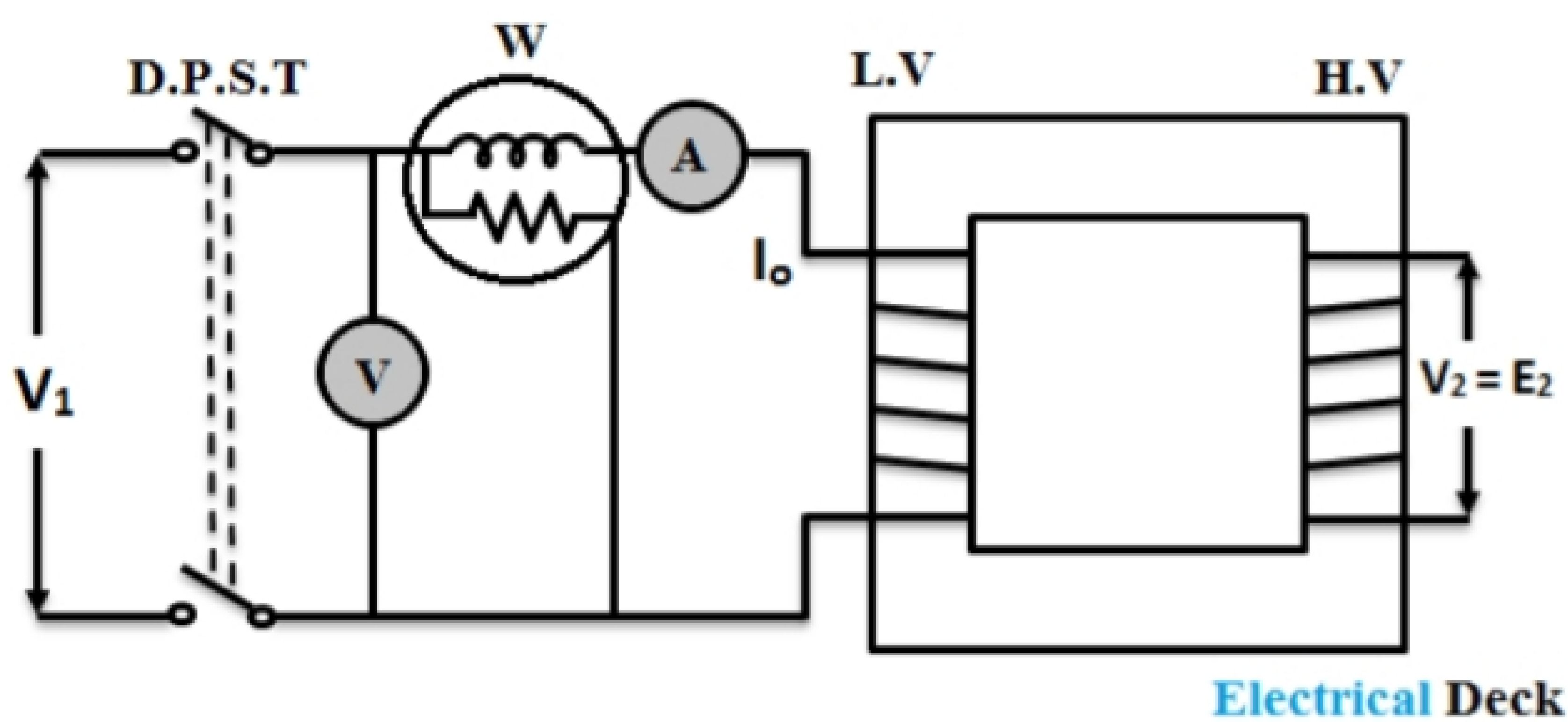
$$X_{01} = \sqrt{(Z_{01} - R_{01})^2}$$

Open Circuit Test :

The aim of the test is to determine the iron-loss or core-loss and no-load current I_o which is helpful in finding R_o and X_o. The amount of power wasted in the core of a transformer can be obtained by this test.

In this test one winding usually, high voltage winding is left open and the other (LV side) is connected to normal voltage supply as shown in the figure. Since normal voltage is applied to the primary, the normal flux will be set up in the core hence normal core-loss will occur which are measured by the wattmeter.

As no current flows in the open secondary, the no-load primary current I_o is small (usually 3 to 10 of full-load current), the primary copper loss is negligibly small and nil in secondary. Hence, the OC test gives core loss alone practically (i.e., wattmeter reading) and is the same for all loads.



Sometimes, a high resistance voltmeter is connected across secondary to read secondary induced emf which helps to find the transformation ratio K.

The transformer vector diagram is the same as the no-load condition of a transformer as shown in the figure. If W_o is the wattmeter reading. Therefore,

$$W_o = V_1 I_o \cos\phi_o$$

$$\cos\phi_o = \frac{W_o}{V_1 I_o}$$

$$I_W = I_o \cos\phi_o$$

$$I_m = I_o \sin\phi_o = \sqrt{I_o^2 - I_W^2}$$

$$R_o = \frac{V_1}{I_W}$$

$$X_o = \frac{V_1}{I_\mu}$$

Separation of Hysteresis and Eddy Current Loss :

The core loss or iron loss consists of two parts

i. Hysteresis loss :

$$W_h = P\, B_m^{1.6}\, f \text{ watt} / m^3$$

ii. Eddy current loss :

$$W_e = Q\, B_m^{2}\, f^2 \text{ watt} / m^3$$

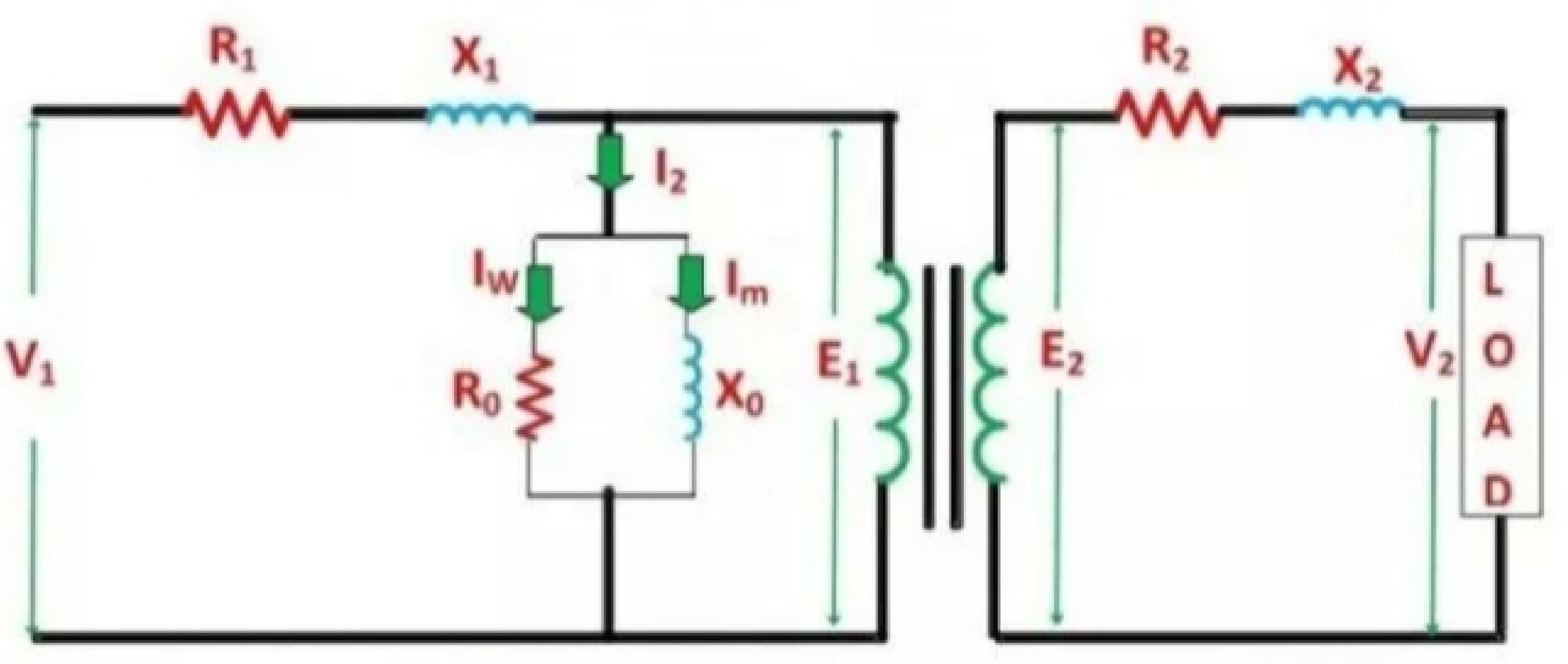
Where P, Q are two constants,

- B_m = maximum flux density (T)
- f = frequency (Hz)

The total iron loss is given by,

$$W_i = W_h + W_e$$

The simplified equivalent circuit of a transformer is presented by considering all the properties of the transformer either on the primary or secondary side. The main equivalent circuit of the transformer is shown below in the diagram:

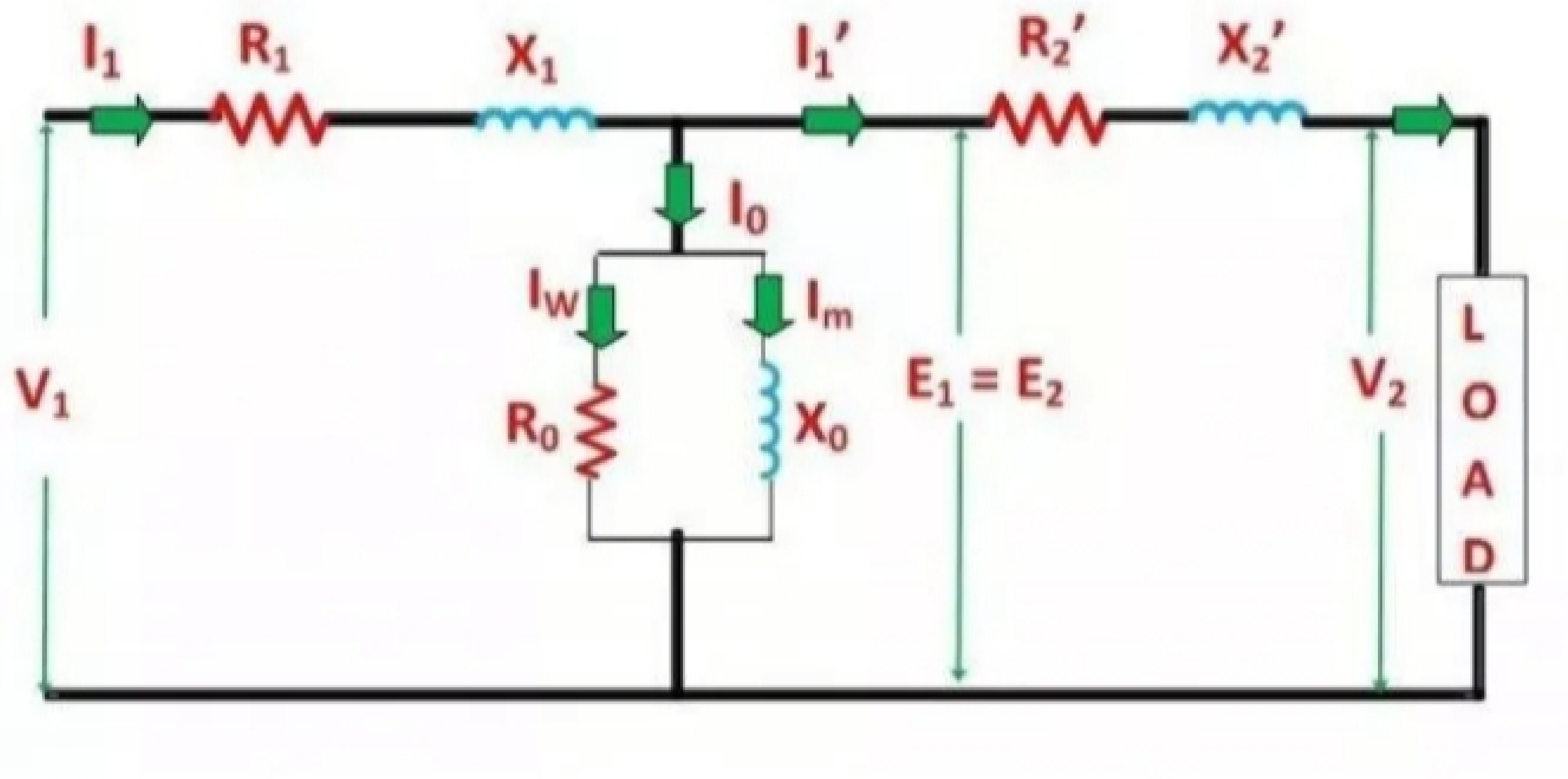


Equivalent Circuit of Transformer (Reference: ***circuitglobe.com****)*

A high percentage of consideration is to be given to this feature for the installation of a transformer in an existing system of electrical power. The relative impedance of various power transformers must be completely matched based on the parallel configuration of power systems. The relative impedance can be extracted from the equivalent value of the transformer's impedance so, it can be noticed that the equivalent circuit of transformer is also important during the estimation of the relative impedance.

Equivalent Circuit of Transformer when all the quantities are referred to Primary side

In this method, to derive the equivalent circuit of transformer, all the features are to be considered as the primary section as presented in the figure below:



Chapter 2: Three-phase Transformer

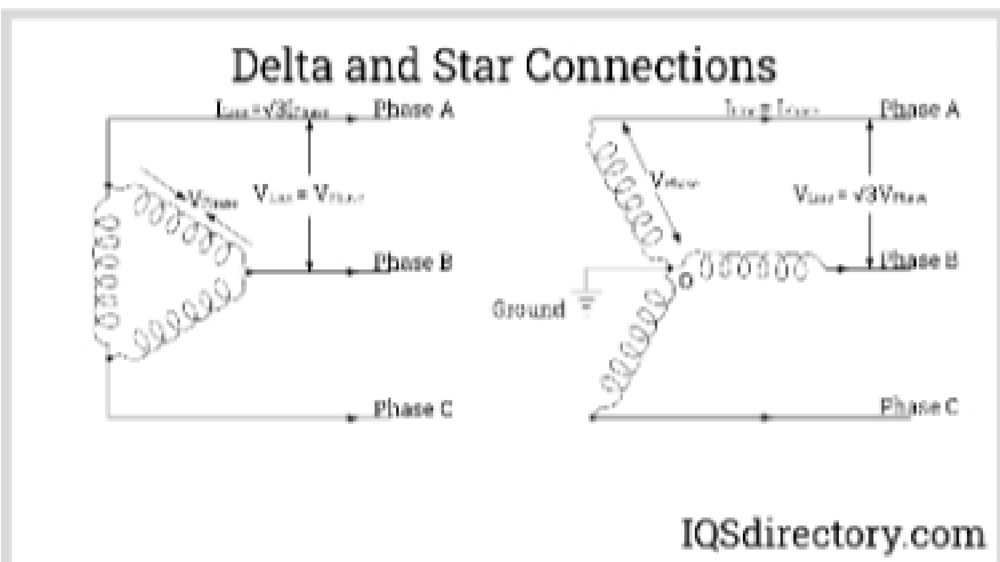
Three-phase transformers are transformers that operate with a three-phase electrical system. The type of transformer described in the previous chapter is a simple single-phase transformer. The working principle of three-phase transformers is the same, Faraday's Law of Induction. Single-phase and three-phase transformers differ in wiring configurations. To further understand, it is better to take a look at three-phase electrical systems.

Three-phase Electrical System

Single-phase and three-phase electrical systems use alternating current (AC). AC is a form of electricity that is constantly changing amplitude and direction, usually characterized by a sine wave. Though other waveforms can be created such as complex, triangular, and square waves. AC signals have three main properties: period, frequency, and amplitude. Period and

Three-phase Transformer Construction

A three-phase transformer consists of six windings, three for the primary and three for the secondary. The windings on each side (primary and secondary side) can be connected in either delta or star configurations. These windings can be viewed as separate single-phase windings. In theory, three single-phase transformers can be connected creating a three-phase transformer.



- **Star-Star Connection**

  This type has both star windings on the primary and secondary sides. Line voltages on each side are √3 times the voltage of a single phase. The main advantage of a star-star connection is the access to the neutral terminal on both sides of the transformer which can be grounded if desired. By connecting the star neutral to ground, distortion to the waveform is eliminated. Without grounding, this configuration's operation is satisfactory only if the loads on all the three phases are balanced.

- **Delta-Delta Connection**

  In this configuration, the line-to-line voltages on both the primary and secondary sides are equal to the phase voltage. The main advantage of this type is that even under unbalanced loads, the three-phase voltages remain equal. Also, since both sides have the same type of windings, there is no phase shift between them.

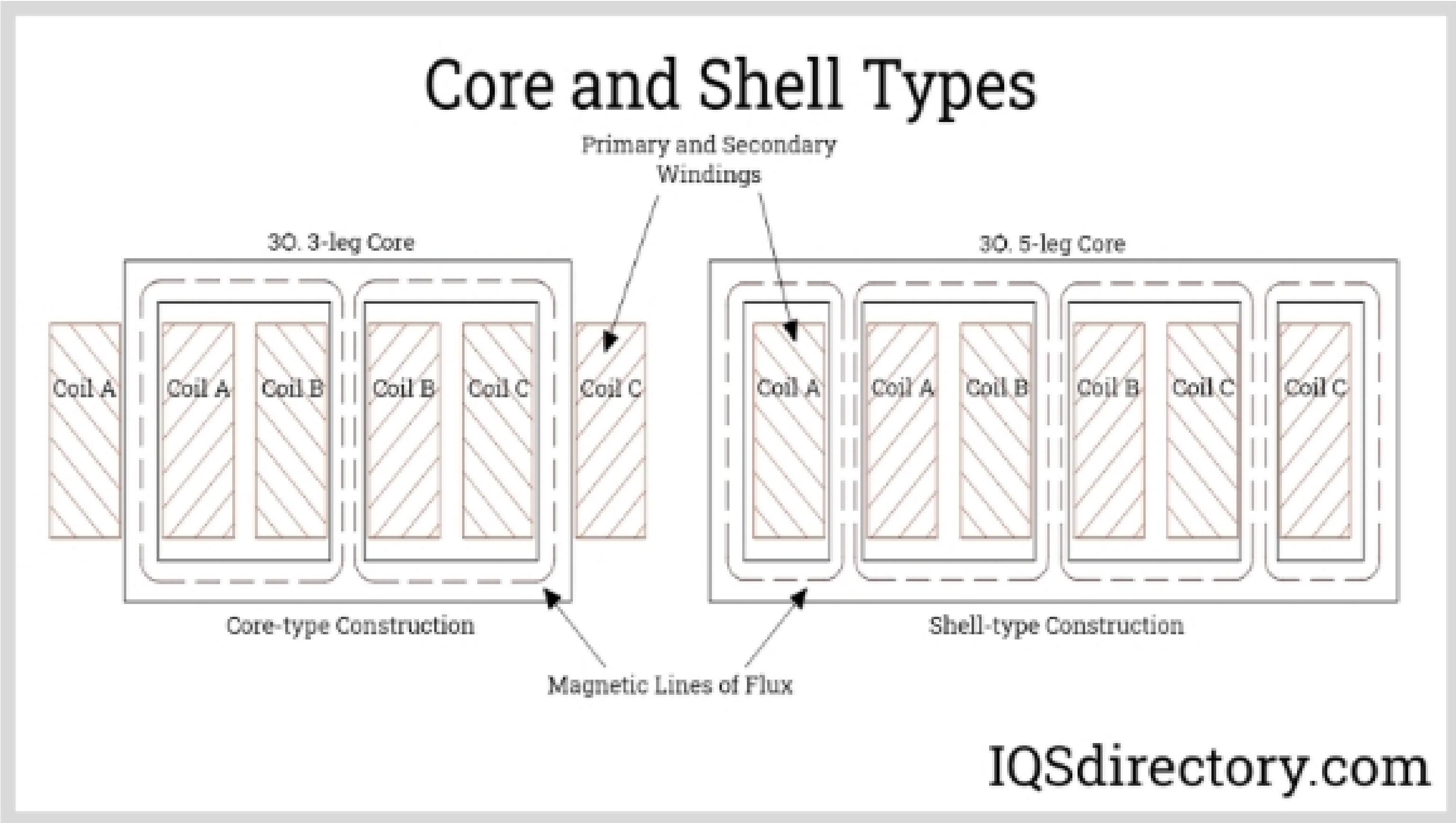
  The disadvantages of delta-delta connections are the absence of the neutral connection on both sides and the more expensive coils required. Delta connected transformers must be wound to the full line voltage. This makes this type useful for low voltage applications.

Chapter 4: Three-phase Transformer Construction

The previous chapter discussed the types of three-phase transformers according to its phase windings. Three-phase transformers can also be classified with respect to their construction. Construction of three-phase transformers can be done by creating a single core with the primary and secondary windings combined or by connecting three single-phase transformers.

- ## Core-type Transformer

  In a core-type transformer, the windings are evenly split and wound on the limbs of the core. The core consists of three limbs on the same plane. Each of these limbs contains both the primary and secondary windings. These windings may be better referred to as the high voltage and low voltage windings. The low voltage windings are wound closest to the core since it is easier to insulate. The high voltage coil is then wrapped around the low voltage winding with insulation between them. In this construction, the windings are


Core and Shell Types
Primary and Secondary Windings
3O. 3-leg Core
Coil A
Coil A
Coil B
Coil B
Coil C
Coil C
Core-type Construction
3O. 5-leg Core
Coil A
Coil A
Coil B
Coil B
Coil C
Coil C
Shell-type Construction
Magnetic Lines of Flux
IQSdirectory.com

- **Shell-type Transformer**

  The shell-type transformer can be viewed as three separate single-phase transformers since the magnetic fields of the three phases are almost independent of each other. This type of transformer has a core with five limbs. The high voltage and low voltage windings are wrapped around the three main limbs similar to the core-type where the low voltage is closest to the core. By having the two outer limbs, the magnetic flux has additional return paths. As the magnetic field comes to the yoke, the magnetic flux divides into two. Thus, the yoke and the outer limbs can be sized half of the main limbs. By decreasing the size of the yoke, the overall height of the transformer can also be decreased.

Parallel operations of transformers

When we connect the primary windings of two transformers to a common supply voltage and the secondary windings of both the transformers to a common load, this type of connection of transformer is said to be the **parallel operation of transformers**.

Reasons for parallel operation

The reasons for operating the transformers in parallel are as follows:

1. This is an economical method because a single large transformer is uneconomical for large load.
2. If the transformers are connected in parallel, we require extra load then we can expand the system by adding more transformers in the future.

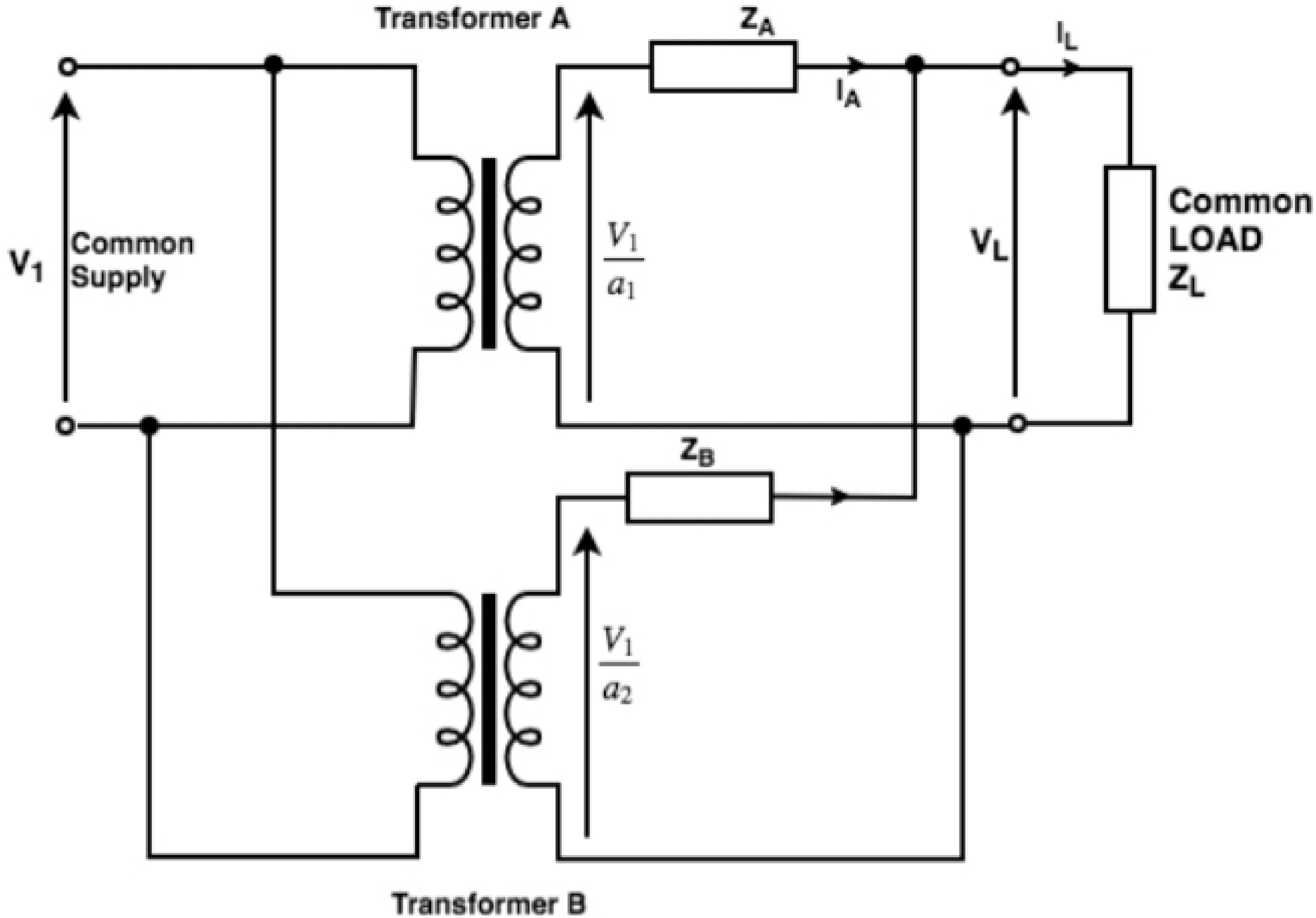


Fig: Two single-phase transformers in parallel.

By KCL,

$I_A + I_B = I_L$

BY KVL,

$$V_L = \frac{V_1}{a_1} - I_A Z_A$$

$$V_L = \frac{V_1}{a_2} - I_B Z_B = \frac{V_1}{a_2} - (I_L - I_A) Z_B$$

By solving the above two equations, we get

$$I_A = \frac{Z_B I_L}{Z_A + Z_B} + \frac{V_1 (a_2 - a_1)}{a_1 a_2 (Z_A + Z_B)}$$

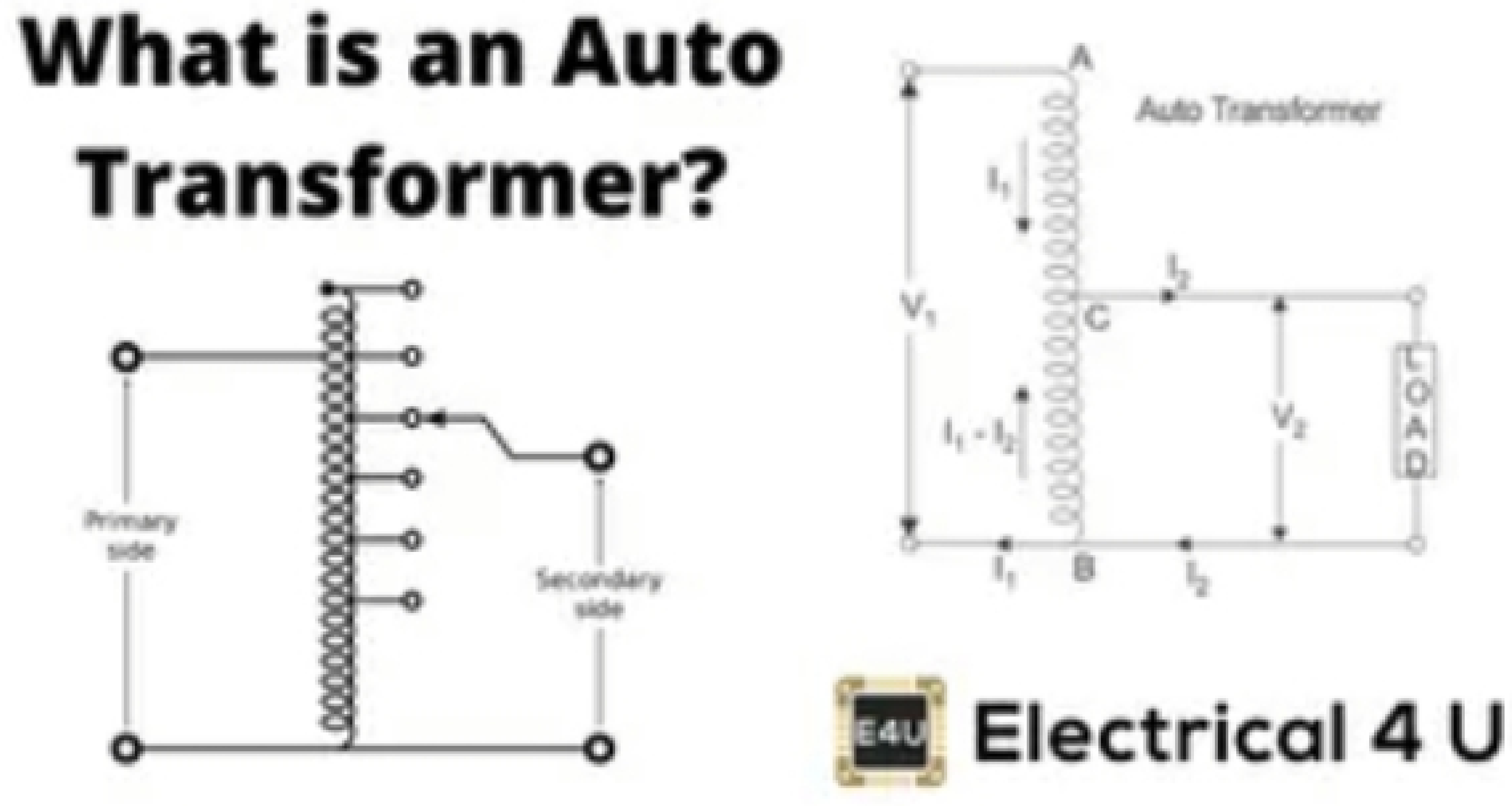
$$I_B = \frac{Z_A I_L}{Z_A + Z_B} - \frac{V_1 (a_2 - a_1)}{a_1 a_2 (Z_A + Z_B)}$$

Each of these currents has two components; the first component represents the transformer's share of the load current and the second component is a circulating current in the secondary windings.

Conditions for parallel operation of Single-Phase transformers:

Necessary conditions

1. The transformers must have the same polarities.
2. The transformers should have equal turn ratios.

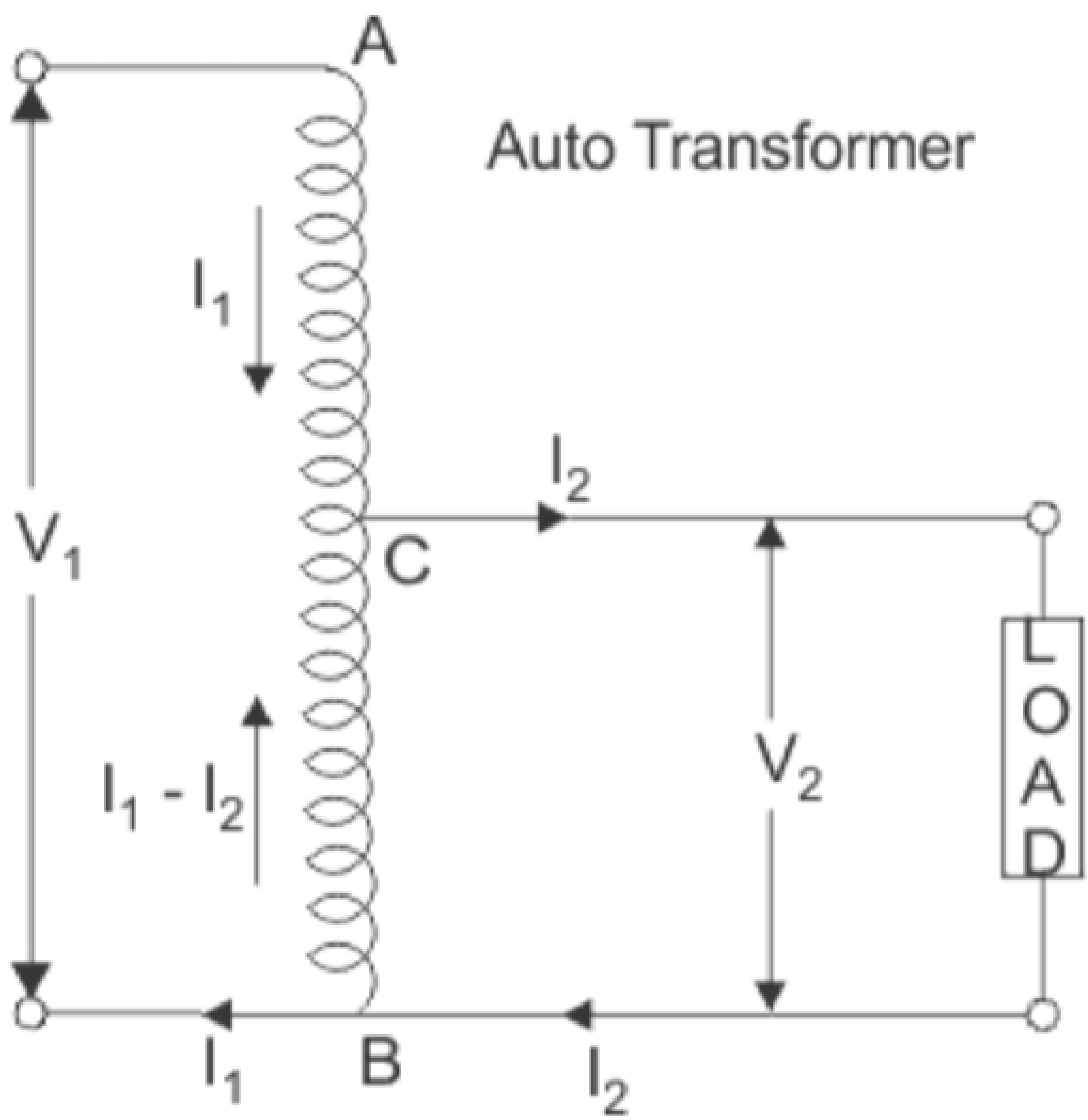


What is an Autotransformer?

An **autotransformer** (or **auto transformer**) is a type of electrical transformer with only one winding. The "auto" prefix refers to the single coil acting alone (Greek for "self") – not to any automatic mechanism. An auto transformer is similar to a two winding transformer but varies in the way the primary and secondary winding of the transformer are interrelated.

Autotransformer Theory

In an auto transformer, one single winding is used as primary winding as well as secondary winding. But in two windings transformer two different windings are used for primary and secondary purpose. A circuit diagram of auto transformer is shown below.



The winding AB of total turns N_1 is considered as primary winding. This winding is tapped from point 'C' and the portion BC is considered as secondary. Let's assume the number of turns in between points 'B' and 'C' is N_2.

If V_1 voltage is applied across the winding i.e. in between 'A' and 'C'.

$$So\ voltage\ per\ turn\ in\ this\ winding\ is\ \frac{V_1}{N_1}$$

Hence, the voltage across the portion BC of the winding, will be,

$$\frac{V_1}{N_1} X N_2\ and\ from\ the\ figure\ above,\ this\ voltage\ is\ V_2$$

$$Hence,\ \frac{V_1}{N_1} X N_2 = V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} = Constant = K$$

Copper Savings in Auto Transformer

Copper Savings in Auto Transformer

Now we will discuss the savings of copper in auto transformer compared to conventional two winding transformer.
We know that weight of copper of any winding depends upon its length and cross-sectional area. Again length of conductor in winding is proportional to its number of turns and cross-sectional area varies with rated current.
So weight of copper in winding is directly proportional to product of number of turns and rated current of the winding.

W_a = weight of copper in section AC + weight of copper in section CB

Therefore

$$W_a \propto I_1 (N_1 - N_2) + (I_2 - I_1)N_2$$

$$W_a \propto I_1 N_1 + I_2 N_2 - 2I_1 N_2$$

If the same duty is performed with an ordinary two winding transformer shown above in the figure (A), the total weight of the copper required in the ordinary transformer,

W_0 = weight of copper on its primary winding + weight of copper on its secondary winding

$$\frac{W_a}{W_o} = 1 - \frac{2\, I_1 N_2 / I_1 N_1}{I_1 N_1 / I_1 N_1 + I_2 N_2 / I_1 N_1} = 1 - K$$

OR

$$W_a = (1 - K) W_o$$

Saving of copper affected by using an auto transformer = weight of copper required in an ordinary transformer – weight of copper required in an auto transformer

Saving of copper = $W_0 - W_a = W_o - (1 - K) W_o = K W_0$

Therefore,

Saving of copper = K x weight of copper required for two windings of the

Advantages of Auto transformer

- Less costly
- Better regulation
- Low losses as compared to ordinary two winding transformer of the same rating.

Applications of Auto transformer

- It is used as a starter to give up to **50 to 60%** of full voltage to the stator of a squirrel cage induction motor during starting.
- It is used to give a small boost to a distribution cable, to correct the voltage drop.
- It is also used as a voltage regulator
- Used in power transmission and distribution system and also in the audio system and railways.