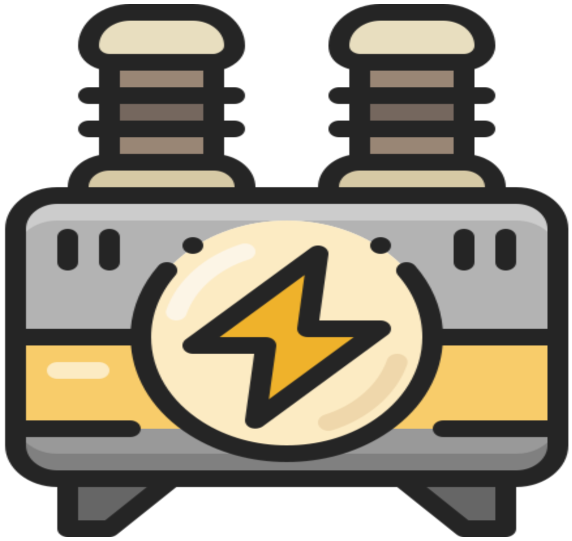

Making a Transformer

Course No: EEE 206
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Objectives:

- To learn how to build a step-down transformer.
  Transformer rating : 100 VA
  Primary voltage : 220 V
  Secondary voltage : 160 V
- To study the voltage and current ratios of a transformer.
- To learn about transformer parameters.
- To perform open circuit and short circuit test.

Transformer Theory:

Transformer is a device that transfers electrical energy from one alternating-current circuit to at least one or a lot of alternative circuits, either increasing or reducing the voltage. In general, a transformer is a n-port AC device that converts time varying voltage and current from one amplitude at an input port to other values at the output ports. This device only performs transformation for time varying signals. Transformers are used for wide varied purposes. For example, to cut back the voltage of typical power circuits to control low-tension devices, appreciate doorbells and toy electric trains, and to boost the voltage from electric generators in order that electrical power will be transmitted over long distances.

Working principle of transformer:

The basic principle on which the transformer works is **Faraday's Law of Electromagnetic Induction** or mutual induction between the two coils. Transformers amendment voltage through magnetic force induction. The magnetic lines of force (flux lines) build up and collapse with the changes in current passing through the primary coil, current is induced in another coil, referred to as the secondary. The secondary voltage is calculated by multiplying the first voltage by the quantitative relation of the amount of turns within the secondary to the number of turns in the primary coil, a quantity called the turns ratio. The working of transformer is explained below.

Here we explain two-port transformer. One is primary-port and another is secondary port. The transformer consists of two separate windings placed over the laminated silicon steel core.

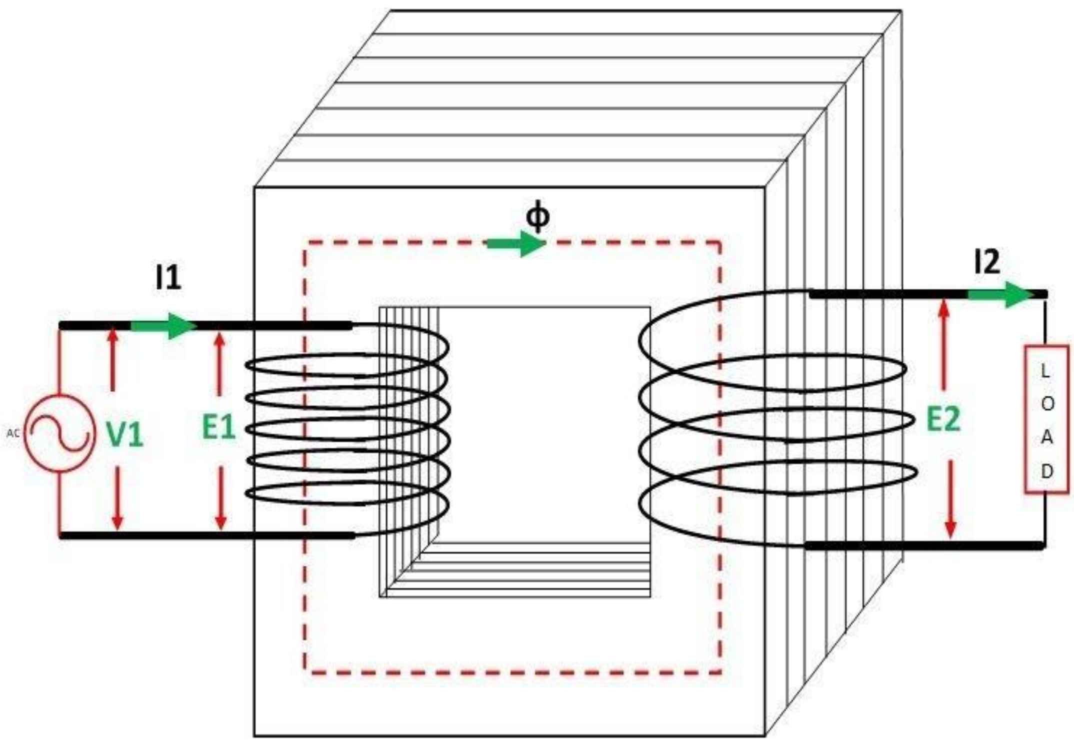

Figure 1: Transformer

The winding to which AC supply is connected is called primary winding and to which load is connected is called secondary winding as shown in the figure. It works on the alternating current only because an alternating flux is required for mutual induction between the two windings.

When the AC supply is given to the primary winding with a voltage of V_1, an alternating flux φ sets up in the core of the transformer, which links with the secondary winding and as a result of it, an Emf is induced in it called **Mutually Induced Emf**. The direction of this induced Emf is opposite to the applied voltage V_1, this is because of the Lenz's law shown in the figure below:

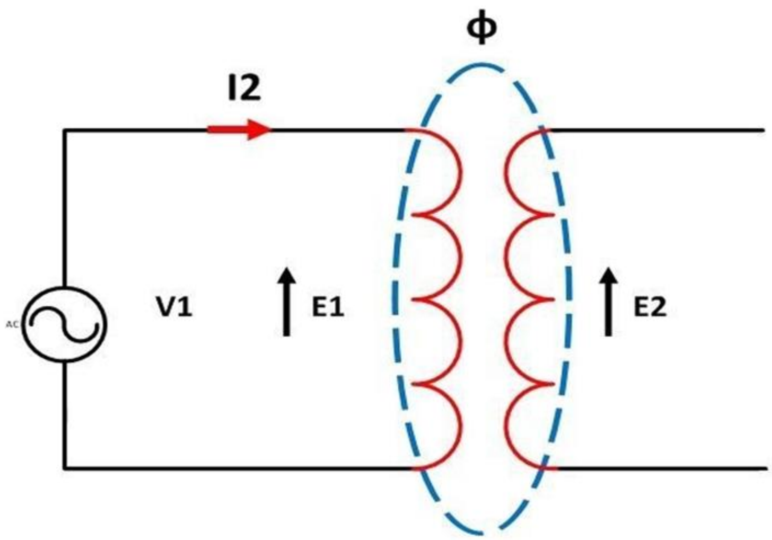

Figure 2: Opposite flux (Lenz's law)

Here, induced voltage E2 in opposite direction to the applied voltage E1.

Physically, there is no electrical connection between the two windings, but they are magnetically connected. Therefore, the electrical power is transferred from the primary circuit to the secondary circuit through mutual inductance.

The induced emf in the primary and secondary windings depends upon the rate of change of flux linkage that is $N\frac{d\phi}{dt}$

dφ/dt is the change of flux and is same for both the primary and secondary windings. The induced emf E_1 in the primary winding is proportional to the number of turns N_1 of the primary windings ($E_1 \propto N_1$). Similarly induced emf in the secondary winding is proportional to the number of turns on the secondary side. ($E_2 \propto N_2$).

Turn ratio, a = $\frac{N1}{N2}$

If N2 > N1 the transformer is called step up

And if N1 >N2 the transformer is called step down.

Equivalent Circuit of transformer:

Equivalent Circuit of transformer is an electrical circuit explanation of equations representing the behavior of that Transformer. In fact, an equivalent circuit of any electric instrument is important for the analysis of its performance and to discover any scope of further modification of modeling. The equivalent circuit of transformer includes a setup of inductance, resistance, voltage, capacitance, etc. These circuits can then be analyzed and explored by applying the principles of the diagram's theory.

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.

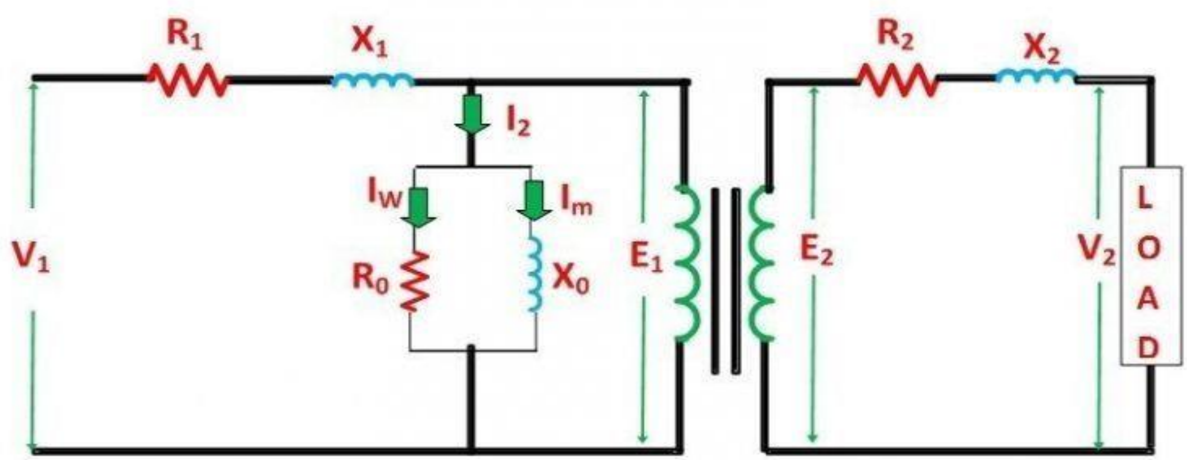

Figure 3: Main Equivalent Circuit

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

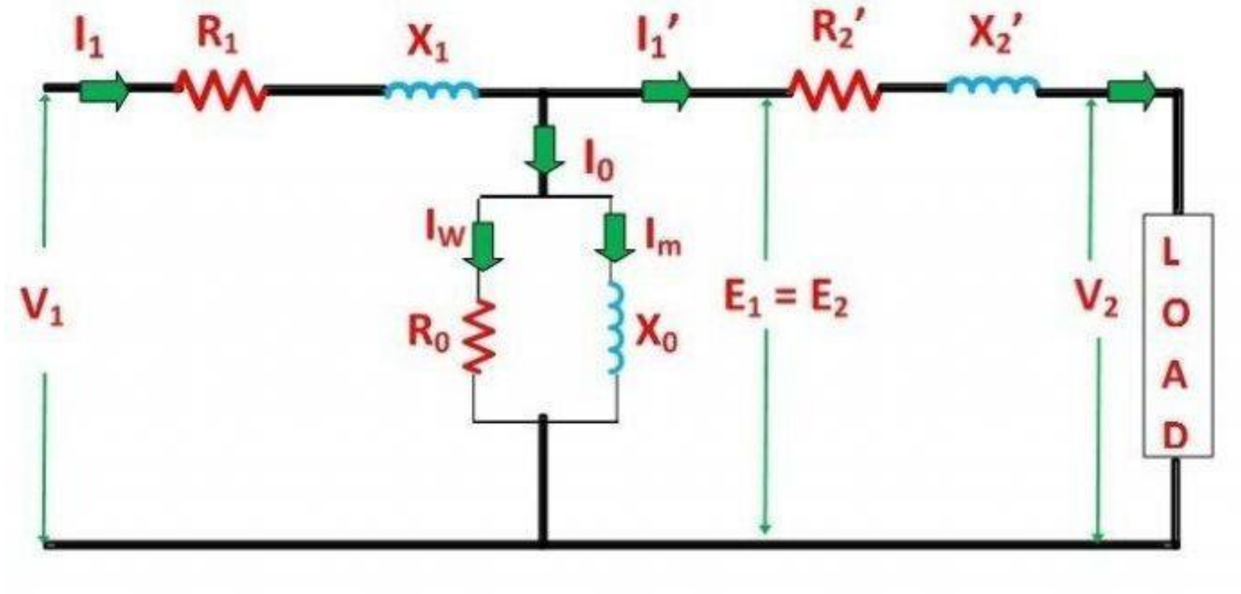

Figure 4: Equivalent Circuit referred to primary

Here,

Resistance of secondary referred to primary

$R_2' = a^2R_2$

Equivalent resistance at primary side

$R_{ep} = R_1 + R_2'$

Again, reactance of secondary referred to primary

$X_2' = a^2X_2$

Equivalent resistance at primary side

$X_{ep} = X_1 + X_2'$

If we ignore core loss component and magnetizing component

$Z_{load,p} = R_{ep} + X_{ep}$

Types of transformer:

Transformers are versatile. There are different kind of transformers which are constructed particularly to meet the respective applications. The transformers are classified based on voltage levels, Core medium used, winding arrangements, use and installation place.

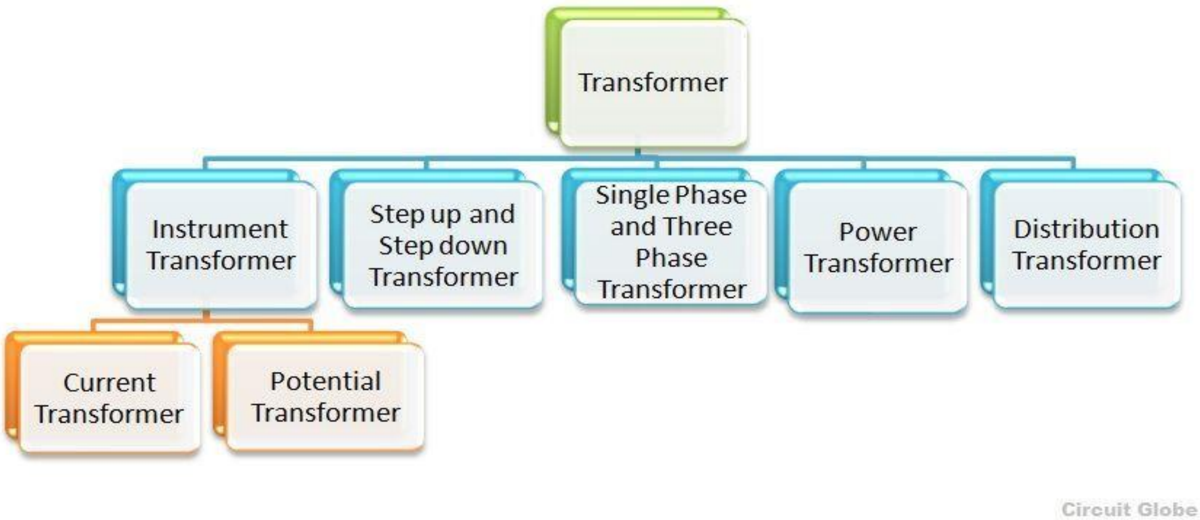

Figure 5: Various types of transformer

Based on transformer construction:

1.Core Type:

In core type transformers, winding is positioned on two limbs of the core and there is only one flux path and windings are circumventing the core. These transformers are quite favorite in High voltage practical applications like Distribution, Power, and Auto-Transformers.

2.Shell Type:

The shell type transformer is a simple rectangular form and the core surrounds the considerable portion of the windings. Both the primary and secondary windings are placed in the one limb. And the coils are wound in from of multi-layer disc type. The different layers of the multi-layer disc are insulated from each other by paper.

The transformer that we made here is a shell type transformer. E type and I type core has been used. The layers have been insulated from each other by insulating paper.

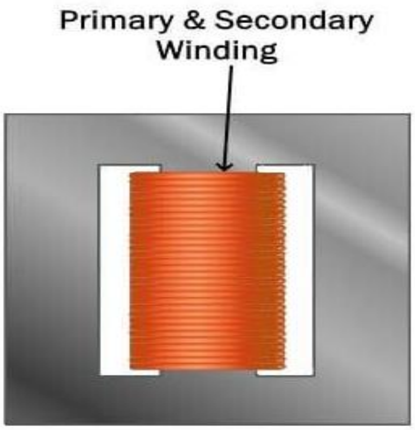

Figure 6: Shell type transformer and the transformer we made

Based on Voltage Conversion:

1) Step Down Transformer:

Step down transformer’s secondary voltage is less than the primary voltage. So, the transformer is designed to convert high-voltage, low-current power into a low-voltage, high current power**.**

The transformer we made here is a step-down transformer. It’s primary voltage is 220 v and secondary voltage is 162 v. Primary winding has 557 turns and secondary winding has 405 turns.

2) Step Up Transformer:

In step-up transformers there are more turns on the secondary winding than in the primary winding. So, the voltage supplied in the secondary transformer is greater than the one supplied across the primary winding.

Based on Purpose

1. **Power Transformer :**

The Power transformer is one type of transformer that is used to transmit electrical energy in any component of the electronic or electrical circuit between the distribution primary circuits and the generator. These transformers are utilized in distribution networks to interface step down and step up voltages.

2. **Distribution Transformer :**

A distribution transformer or service transformer is a transformer that provides the final voltage transformation in the electric power distribution system, stepping down the voltage used in the distribution lines to the level used by the customer

3. **Isolation Transformer :**

An isolation transformer is a transformer used to transfer electrical power from a source of alternating current power to some equipment or device while isolating the powered device from the power source, usually for safety reasons.

4. **Instrument Transformers :**

A transformer that is used to measure electrical quantities like current, voltage, power, frequency and power factor is known as an instrument transformer. These transformers are mainly used with relays to protect the power system

Instrument transformers are classified into two types such as,

I. **Current Transformer**

This type of transformer can be used in power systems to step down the voltage from a high level to a low level with the help of a 5A ammeter.

II. Potential Transformer

This type of transformer can be used in power systems to step down the voltage from a high level to a lower level with the help of a small rating voltmeter which ranges from 110 Volts to 120 Volts.

Based on Windings:

1) Two winding transformer:

In two-winding transformer two windings are linked by a common time-varying magnetic flux. One of these windings, known as the primary, receives power at a given voltage from a source; the other winding, known as the secondary, delivers power, usually at a value of voltage different from that of the source, to the load.

2) Autotransformer:

An autotransformer is an electrical transformer with only one winding. The "auto" prefix refers to the single coil acting alone, not to any kind of automatic mechanism. In an autotransformer, portions of the same winding act as both the primary winding and secondary winding sides of the transformer**.**

Based on the Insulation Used:

1) Dry Type Transformer: The dry type transformer never uses any insulating liquid where its winding or core are immerged in liquid.The windings and core are kept within a sealed tank that is pressurized with air.

2) Liquid Immersed Transformer: The liquid-immersed transformer consists of a magnetic core and coil assembly immersed in a fluid, normally mineral oil. The fluid must possess both good heat transfer characteristics and electrical insulating characteristics.

Based on the Number of Phases:

1) Single Phase Transformer:

The single-phase transformer is an electrical device that accepts single-phase AC power and outputs single-phase AC. It works on the principle of Faraday's Law of Electromagnetic Induction. Typically, mutual induction between primary and secondary windings is responsible for the transformer operation in an electrical transformer.

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. Single-phase and three-phase transformers differ in wiring configurations.

Basic parts of a real transformer:

Some basic components of a transformer:

Laminated core:

Laminated core is the most important parts of transformer, used to support the windings of transformer. It is made up of laminated soft iron material to reduce eddy current loss and hysteresis loss.

Windings:

In a transformer always two sets of windings are placed on laminated core and these are insulated from each other.

- **Primary winding**: the winding at which the input supply is connected is known as the primary winding.
- **Secondary winding**: the winding from which output is taken to the load is known as the secondary winding.

Insulating materials:

Insulating paper and cardboard are used in transformers to isolate primary and secondary winding from each other and from the transformer core.

Main Tank:

Main tank is the robust part of transformer that serves mainly two purposes:

- It protects core and windings from the external environment and provide housing for them.
- It is used as a container for transformer oil and provides support for all other external accessories of the transformer.

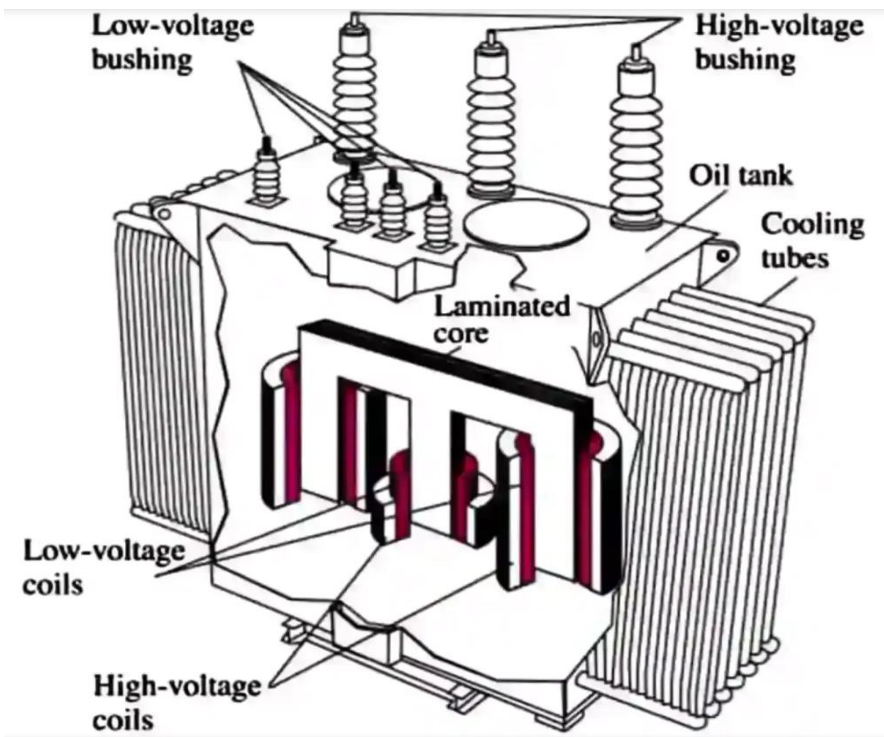

Figure 7: different parts of a transformer

Transformer oil:

Transformer oil may be another insulating material. transformer oil performs 2 necessary functions: additionally, to insulating function, it may also cool the core and coil assembly. Normally, hydrocarbon mineral oils are used as transformer oil.

Terminals and bushings:

Terminals and bushings are also important parts of the transformer that are used to connecting incoming and outgoing cables of supply and load. These are connected with the ends of the winding’s conductor.

Bushings are mainly an insulator made up of porcelain or epoxy resins. They are mounted over the tank and forms a barrier between terminals and tank. They provide safe passage for the conductor connecting terminals to the windings.

As windings are of two types and so bushings are also of two types as named below:

1. High-voltage bushing
2. Low-voltage bushing

Tap changer:

The output voltage of transformers varies depending on their input voltage and the load. Under load conditions, the voltage at the output terminal decreases, while under discharge conditions, the output voltage increases. Tap changers are used to compensate for voltage fluctuations.

Buchholz relay:

Buchholz relay is the most important part of a power transformer rated more than 500kVA. It is a gas-actuated relay mounted on the pipe connecting the main tank and conservator tank.

Oil conservator:

The function of the oil conservator tank is to provide adequate space for expansion and contraction of transformer oil according to the variation in the ambient temperature of transformer oil inside the main tank.

Cooling tube:

Cooling tubes are used to cool transformer oil. The transformer oil circulates through the cooling tubes. Oil circulation can be natural or forced. As the temperature of the oil rises in the natural cycle, the hot oil naturally rises and the cold oil sinks. Thus, the oil circulates naturally through the pipes. With forced circulation, the oil is circulated by an external pump.

Radiator and fans:

Since power losses in the transformer are dissipated in the form of heat. So a cooling arrangement is required for the power transformer.

Application of transformer:

A Transformer is an electrical device that can be used to transfer the power from one circuit and another circuit without physical contact and without changing its characteristics like frequency, phase. It is an essential device in every electrical network circuitry. It consists of majorly two circuits, namely primary circuits and one or more secondary circuits. All transformers have one basic function: increasing or decreasing alternating current within the electrical system. By regulating the flow of current, the transformer allows for increased energy efficiency, which regulates and ultimately lowers electricity bills.

Various specific electrical application designs require a variety of transformer types. Although they all share the basic characteristic transformer principles, they are customized in construction or electrical properties for certain installation requirements or circuit conditions.

In electric power transmission, transformers allow transmission of electric power at high voltages, which reduces the loss due to heating of the wires. This allows generating plants to be located economically at a distance from electrical consumers. All but a tiny fraction of the world's electrical power has passed through a series of transformers by the time it reaches the consumer.

In many electronic devices, a transformer is used to convert voltage from the distribution wiring to convenient values for the circuit requirements, either directly at the power line frequency or through a switch mode power supply.

Signal and audio transformers are used to couple stages of amplifiers and to match devices such as microphones and record players to the input of amplifiers. Audio transformers allowed telephone circuits to carry on a two-way conversation over a single pair of wires. A balun transformer converts a signal that is referenced to ground to a signal that has balanced voltages to ground, such as between external cables and internal circuits. Isolation transformers prevent leakage of current into the secondary circuit and are used in medical equipment and at construction sites. Resonant transformers are used for coupling between stages of radio receivers, or in high-voltage Tesla coils.

Instruments & Components:

The components we needed to design the transformer are given below along with the cost. It is given in the table below:

<table>
<tr><th colspan="2">Description</th><th>Amount</th></tr>
<tr><td colspan="2">Bobbin</td><td>1</td></tr>
<tr><td rowspan="2">Wire (SWG)</td><td>23 gauge</td><td rowspan="2">500 gm total</td></tr>
<tr><td>24 gauge</td></tr>
<tr><td colspan="2">Core (E & I type)</td><td>2.48 Kg</td></tr>
<tr><td colspan="2">Burnish</td><td>1</td></tr>
<tr><td colspan="2">Insulation paper</td><td>1</td></tr>
<tr><td colspan="2">Masking tape</td><td>1</td></tr>
<tr><td colspan="2">Flexible wire</td><td>-</td></tr>
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Procedure:

The first step in the design procedure for the transformer is determining and assembling the design inputs. These normally consists of:

- Rated VA (100VA)
- Rated primary and secondary voltage rating (220V-160V)
- Transformation ratio

After buying all the required materials we started our work.

Step 1:
Wiring on the bobbin for primary winding using 24-gauge wire consisting of about 560 turns.

Step 2:
Inserting insulation paper along with masking tape to separate primary winding from secondary winding.

Step 3:
After proper insulation we used 23-gauge wire for secondary winding consisting of about 410 turns.

Step 4:
Again, we inserted insulating paper on the secondary winding.

Figure 8: Wiring primary winding

Figure 9: Inserting E & I type core

Step 5:

Insertion E & I type cores on bobbin.

Step 6:

Burnish & dry up the complete transformer to fill the airspace.

Figure 10: 23 & 24gauge wire

Figure 11: E & I type core

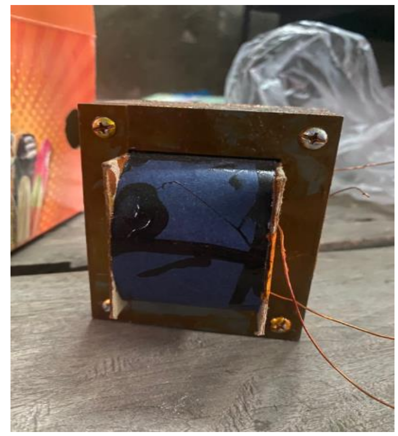

Figure 12: Final transformer

Step 7:

Finally, we assembled the transformer and got it characterized and via open circuit test and short circuit test.

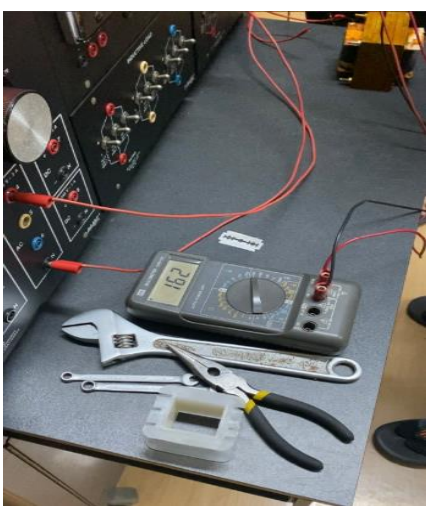

Figure 13: secondary winding voltage test

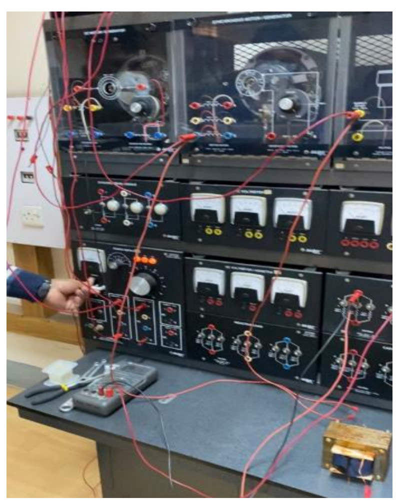

Figure 14: Open CKT test setup

Figure 15: Short CKT test setup

Calculation:

Length of bobbin, L = 4.9cm

Width of bobbin, W = 3.3cm

Frequency, f = 50Hz.

Magnetic flux density, B = 1.1 wb/m^2

Area of bobbin, A = 4.9*3.3

$=16.17cm^2$

$=.001617m^2$

Turns per voltage = $\frac{1}{4.44*f*B*A}$

$= \frac{1}{4.44*50*1.2*.001617}$

= 2.53 turns/volt

Turn number in primary windings, N_p = 220*2.53

= 557 turns

Turn number in secondary windings, N_S = 160*2.53

= 405 turns

Turn ratio, a = 1.375

Rated current in primary windings, I_p = 0.45 A

Rated current in secondary windings, I_s = 0.625 A

Test result:

Open circuit result:

Voltage in primary windings, V_p = 220 V

Voltage in secondary windings, V_s = 162 V

Error = $\frac{162-160}{160}$ X 100%

= 1.25%

Open circuit power loss, P_{OC} = 7 W

Open circuit voltage, V_{OC} = 220 V

Open circuit current, I_{OC} = 0.13 A

Total impedance, |Z| = $\frac{220}{.13}$

= 1692.307 Ω

Power factor, pf =$\frac{P}{v_I} = \frac{7}{220\times 0.13} = 0\cdot 245$

$$Y_E = \frac{I_0}{v_0}\angle - \cos^{-1} PF$$

= $5.909 \times 10^{-4}\angle - 75.818$

Z=$1692.3\angle 75.818$ = 414.615 + j 1640.73 Ω

Core resistance, R_C = 414.615 Ω

Magnetizing reactance, X_M = 1640.73 Ω

Short circuit test:

Short circuit current, I_{SC} = 0.6 A

Short circuit power loss, P_{SC} = 8 W

Short circuit voltage, V_{SC} = 18 V

Power factor, pf =$\frac{P}{v_I} = \frac{8}{18*0.6} = 0.7407$

Y =$Y_E = \frac{I_{SC}}{v_{SC}} \angle - \cos^{-1} PF$

=$3.33 \times 10^{-2} \angle - 42.21$

Total impedance, |Z| = $30\angle 42.21$ = 22.22 + j 20.15Ω

Equivalent resistance referred to high side, $R_{eq,H}$ = 22.22 Ω

Equivalent reactance referred to high side, $X_{eq,H}$ = 20.15 Ω

Equivalent resistance referred to low side, $R_{eq,L}$ = 22.22 / 1.375^2

= 11.753 Ω

Equivalent reactance referred to low side, $X_{eq,L}$ = 20.15 / 1.375^2

= 10.658 Ω

Result:

Input voltage, V_{IN} = 220 V

Output voltage, V_{out} = 162 V

Turn in primary side, N_P = 557

Turn in secondary side, N_S= 405

Turn ratio, a = 1.375

Core resistance, R_C = 414.615 Ω

Magnetizing reactance, X_M = 1640.73 Ω

Equivalent resistance referred to high side, $R_{eq,H}$ = 22.22 Ω

Equivalent reactance referred to high side, $X_{eq,H}$ = 20.15 Ω

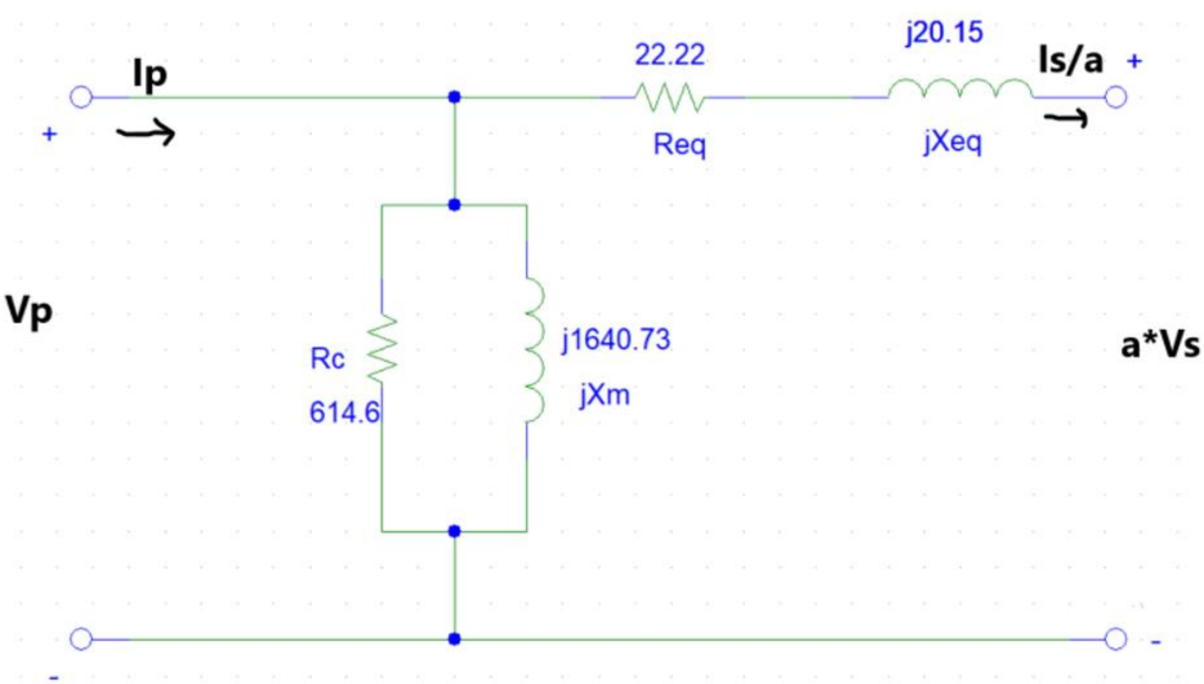

Figure 16: equivalent circuit of transformer

Discussion:

Due to a lack of experience and information, the choice of the wire was not optimum. We have used SWG 23 and SWG 24 wire. Whereas, SWG 29 and SWG 32 wire would have been standard with respect to the rated current of the transformer (0.5A on the high side and 0.7A on the low side). As the wire we choose had a greater diameter, we had to switch to a bobbin of bigger size which led to using of the extra core. So, the transformer can be operated at a higher rated voltage. The transformer might not be quite economical, but it is well suited for the operation.

If we notice the open circuit test, we performed the test applying voltage at the high side. But traditionally, voltage is applied on the low side. The main reason for this is that generally the high side voltage is huge, so it is difficult to supply rated voltage. As our transformer was small, the high side voltage (220V) was available, so the test could have been performed on either side.

The no-load voltage at the secondary side is 162V in response to 220V at primary winding, which is 2V more than the rated low side voltage. As there are many loops in the winding, there might be more loops on the low side or fewer loops in the primary winding which caused the voltage in the low side to be higher than estimated.

As we did not test it for a long time, we are uncertain about the transformer's longevity. So, it is not recommended to use it for a long time. Moreover, we didn't use fixable wire at the terminal, therefore during operation, we have to be careful so that any accident may not occurred.

Conclusion:

The main purpose of the project was to establish a connection between theoretical knowledge and practical knowledge of real transformer. The project helped us to know more about how transformers work, how it is made. We also got the opportunity to perform open circuit test and short circuit test practically, and designed the equivalent circuit of the transformer. So, it provided more clarification about the theoretical knowledge. Finally, the outcome was satisfying and the objectives of the project were fulfilled.