

Chapter Two

Transformer

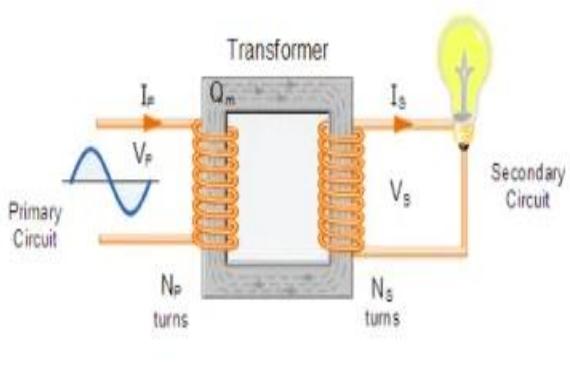
Learning Outcomes:

After the ending of the lesson, students will be able to know

- ✚ About the definition and operating principle of a transformer.
- ✚ Classification and characteristics of a transformer.
- ✚ Emf equation of a transformer
- ✚ Transformer behavior for dc supply voltage, load and no-load conditions
- ✚ Rating of a transformer
- ✚ Equivalent circuit diagram of a transformer

Transformer

A transformer is defined as a passive electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. It is most commonly used to increase ('step up') or decrease ('step down') voltage levels between circuits.



Where,

V_s = Secondary Voltage

V_p = Primary Voltage

N_s = Number of windings in secondary coil

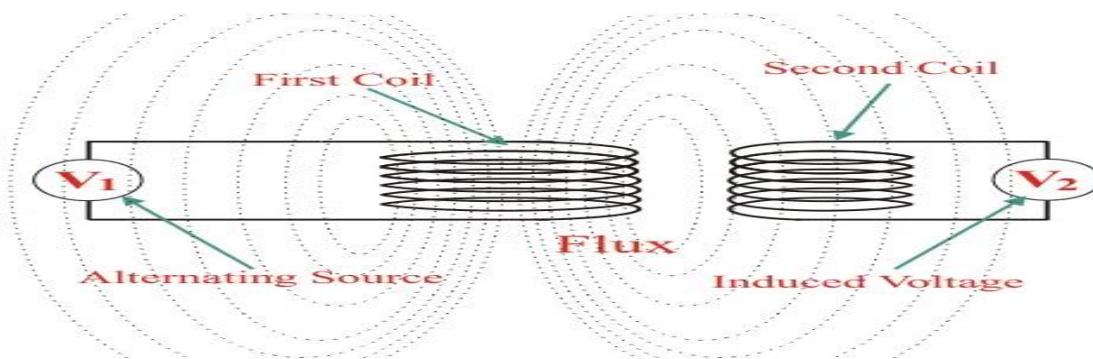
N_p = Number of windings in primary coil

Fig. 1. Transformer.

Operating Principle of Transformer

Say you have one winding (also known as a coil) which is supplied by an alternating electrical source. The alternating current through the winding produces a continually changing and alternating flux that surrounds the winding. If another winding is brought close to this winding, some portion of this alternating flux will link with the second winding. As this flux is continually changing in its amplitude and direction, there must be a changing flux linkage in the second winding or coil.

According to Faraday's law of electromagnetic induction, there will be an EMF induced in the second winding. If the circuit of this secondary winding is closed, then a current will flow through it. This is the basic working principle of a transformer.



Let us use electrical symbols to help visualize this. The winding which receives electrical power from the source is known as the 'primary winding'. In the diagram below this is the 'First Coil'. The winding which gives the desired output voltage due to mutual induction is commonly known as the 'secondary winding'. This is the 'Second Coil' in the diagram above.

Based on Voltage Levels:

Commonly used transformer type, depending upon voltage they are classified as:

Step-up Transformer: They are used between the power generator and the power grid. The secondary output voltage is higher than the input voltage.

Step down Transformer: These transformers are used to convert high voltage primary supply to low voltage secondary output.

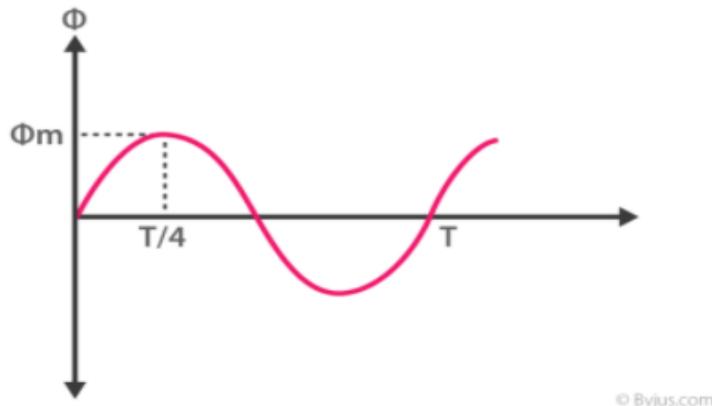
The magnetic Leakage flux: The flux which is generated in primary but not cut the secondary winding is known as leakage flux. It is denoted by inductance in transformer equivalent circuit diagram.

Characteristics of Ideal Transformer:

- No winding resistance.

- No leakage flux i.e., the same flux links both the windings
- no iron losses (i.e., eddy current and hysteresis losses) in the core

EMF Equation of Transformer:



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N_1 – number of turns in primary.

N_2 – number of turns in secondary.

Φ_m – maximum flux in weber (Wb).

T – time period. Time is taken for 1 cycle.

The flux formed is a sinusoidal wave. It rises to a maximum value Φ_m and decreases to negative maximum Φ_m . So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to $T/4$.

Average rate of change of flux = $\Phi_m/(T/4) = 4f\Phi_m$

Where f = frequency

Hence, $T = 1/f$

Induced emf per turn = rate of change of flux per turn

We know that, Form factor = rms value / average value

Rms value = $1.11 * (4f\Phi_m) = 4.44 f\Phi_m$ [form factor of sine wave is 1.11]

RMS value of emf induced in winding = RMS value of emf per turn * no of turns

Primary Winding

Rms value of induced emf = $E_1 = 4.44 f\Phi_m * N_1$

Secondary winding:

Rms value of induced emf = $E_2 = 4.44 f\Phi_m * N_2$

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 f \Phi_m$$

This is the emf equation of the transformer.

For an ideal transformer at no load condition,

E_1 = supply voltage on the primary winding.

E_2 = terminal voltage (theoretical or calculated) on the secondary winding.

Applications Of Transformer

- The transformer transmits electrical energy through wires over long distances.
- Transformers with multiple secondary's are used in radio and TV receivers which require several different voltages.
- Transformers are used as voltage regulators.

Voltage Transformation Ratio

$$E_1 = 4.44 f\Phi_m * N_1 \quad (1)$$

$$E_2 = 4.44 f\Phi_m * N_2 \quad (2)$$

From equation (i) and (ii), we get

$$\therefore E_1 / N_1 = E_2 / N_2 = 4.44 f \Phi_m = K$$

Constant K is known as voltage transformation ratio.

- i) If $N_2 > N_1$ i.e $K > 1$, then transformer is called step-up transformer.
- ii) If $N_2 < N_1$ i.e $K < 1$, then transformer is called step-down transformer.

Transformer with DC supply

If the primary of a transformer is connected to dc supply, the primary will draw steady current and hence produce constant flux. Consequently, no back e.m.f will be produced. The primary winding will draw excessive current due to the low resistance of the primary.

The result is that the primary will overheat and burn out or the fuses will blow. Care must be taken not to connect the primary of a transformer across the d.c. supply. Thus, dc supply should not be connected to the transformers.

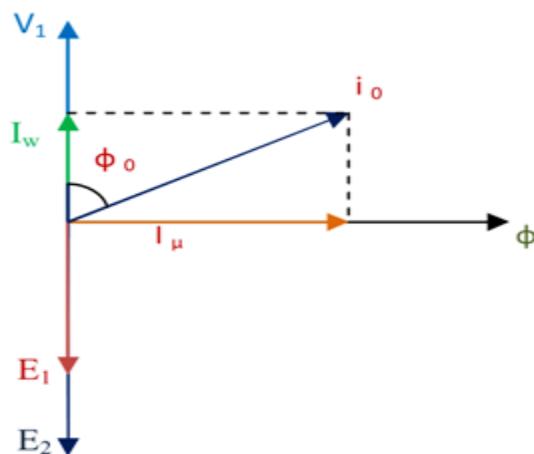
Transformer with No Load

No load Transformer means a transformer which has no load connection at secondary winding only normal voltage is applied at the primary winding. Let V_1 is applied at the primary winding. After applying A.C voltage V_1 , it is seen that small amount of current I_0 flows through the primary winding. In case of Ideal Transformer, no load primary current (I_0) will be equal to magnetizing current (I_μ) of the transformer. We assumed there is no core losses and copper loss, So, $I_0 = I_\mu$. But, in case of actual transformer, there is two losses, i.e i) Iron Losses in the core i.e hysteresis loss and eddy current loss , ii) and a very small amount copper loss in the primary winding.

So, the primary current I_0 has two components:

I_w = Iron loss component which is same ph of applied voltage V_1 .

I_μ = magnetizing component which is 90° behind V_1 .



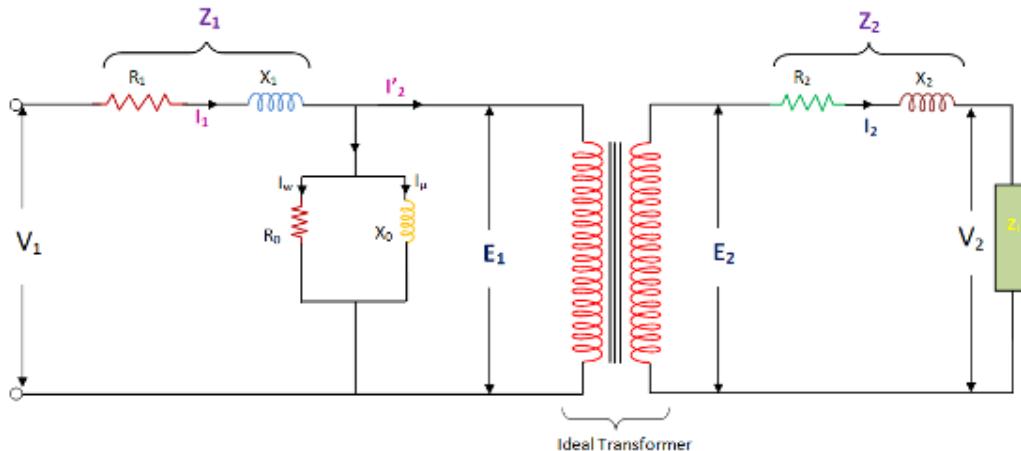
Hence, the primary current I_0 is vector summation of I_μ & I_w , So, we can write that $I_0 = (I_\mu^2 + I_w^2)^{1/2}$ and is not a 90° behind V_1 , but lags it by an angle $\phi < 90^\circ$ Which is shown in figure. And no-load input power, $W_0 = V_1 I_0 \cos \phi$. The magnitude of no load primary current is very small as compared to the full-load primary current. It is 1 percent of the full-load current. As, I_0 is very small, the no load primary Cu loss is negligible which means that no load primary input is practically equal to the iron loss in the transformer.

Transformer on load Condition:

When load is connected to the secondary winding of a transformer, I_2 (secondary current) is set up in the secondary winding. The magnitude and phase of I_2 with respect to V_2 (secondary voltage) depends upon the characteristics of the load. Secondary current I_2 is in phase with V_2 , if load is no inductive, lags if load is inductive and it leads if load is capacitive.

This secondary current sets up m.m.f ($=N_2 I_2$) and hence it produces magnetic flux Φ_2 which is in opposition to the main primary flux Φ . The secondary ampere-turns $N_2 I_2$ are known as demagnetizing amp-turns. The opposing secondary flux Φ_2 weakens the primary flux Φ momentarily, hence the primary winding back e.m.f E_1 tends to be reduced. For a moment $V_1 > E_1$ and hence more current to flow in the primary winding.

Equivalent Circuit diagram of single-phase Transformer



****Equivalent Circuit diagram of Transformer****

Where,

R_1 = Primary Winding Resistance.

R_2 = Secondary winding Resistance.

I_0 = No-load current.

I_μ = Magnetizing Component,

I_w = Working Component,

This I_μ & I_w are connected in parallel across the primary circuit. The value of E_1 (Primary e.m.f.) is obtained by subtracting vectorially $I_1 Z_1$ from V_1 . The value of $X_0 = E_1 / I_0$ and $R_0 = E_1 / I_w$. We know that the relation of E_1 and E_2 is $E_2 / E_1 = N_2 / N_1 = K$, (transformation Ratio)

From the equivalent circuit, we can easily calculate the total impedance of to transfer voltage, current, and impedance either to the primary or the secondary.

The secondary circuit is shown in fig-1. and its equivalent primary value is shown in fig- 2,

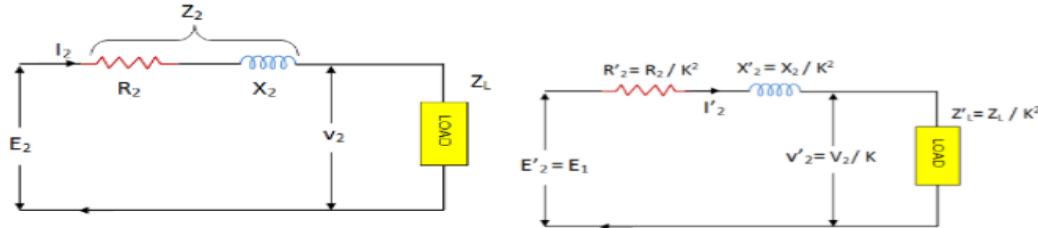


fig-1

fig-2

The total equivalent circuit of the transformer is obtained by adding in the primary impedance as shown in – Fig-3.

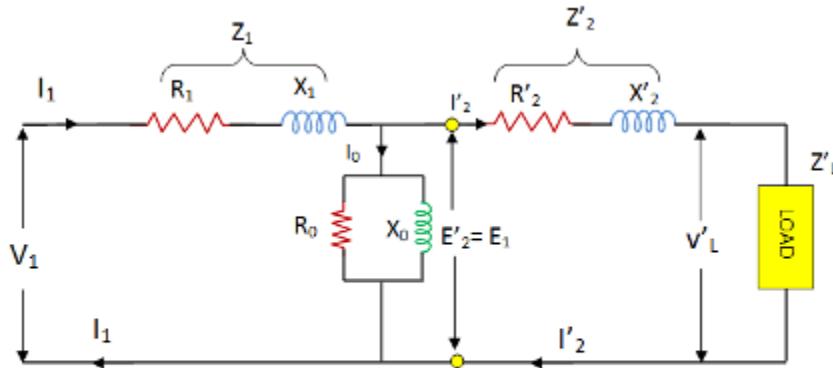


fig-3

Rating of a transformer

The copper and iron are the two types of losses that occur in the transformer. The copper loss depends on the current (ampere) flows through the windings of the transformer while the iron loss depends on the voltage (volts). i.e., the rating of the transformer is in kVA.

Math Problems

Q.1. Suppose you are Mr. X working as an assistant engineer of **DESCO**. One day you tested a transformer of rating 30KVA, 2400/120 V, 50Hz and had found the following data:

Low voltage winding resistance=0.1Ω

Low voltage leakage reactance=0.22 Ω

High voltage winding resistance=0.035 Ω

High voltage leakage reactance=0.012 Ω

Find the equivalent winding Resistance and leakage reactance referred to 1) H.V side; 2) L.V side.

Q.2. A 20 KVA, 250/2500 V, 50Hz, single phase transformer has the following test results

O.C. Test: 250 V, 1.4 A, 105 W (low voltage side)

S.C. Test: 104 V, 8 A, 320 W (high voltage side)

Develop an equivalent circuit with referred to low voltage side.

Q.3. A 20 KVA, 200/2000 V, 50Hz, single phase transformer has the following test results

O.C. Test: 200 V, 1.8 A, 109 W (low voltage side)

S.C. Test: 90 V, 8 A, 320 W (high voltage side)

Develop an equivalent circuit with referred to low voltage side.

Q.4. A 20 KVA, 200/400 V, 50Hz, single phase transformer has the following test results

O.C. Test: 200 V, 0.7 A, 70 W (low voltage side)

S.C. Test: 15 V, 10 A, 85 W (high voltage side)

Develop an equivalent circuit with referred to low voltage side.

OBE Based Questions (for practice)

Q.1. Rabby, a Computer Science Engineering student, wants to find out the characteristics of a transformer. For getting higher voltage at the secondary, he would like to apply low dc voltage at the primary side. What do you think will he get the desired voltage at secondary? Explain it.

Solution:

- ❖ If the primary of a transformer is connected to the dc supply, the primary will draw a steady current and hence produce constant flux.
- ❖ As a result, no back e.m.f will be produced across the primary winding.

- ❖ For this reason, the primary winding will draw excessive current due to the low resistance of the primary circuit.
- ❖ The primary circuit will overheat and burn out due to this excessive current.
- ❖ Therefore, Care must be taken not to connect the primary of a transformer across the d.c. supply.
- ❖ Thus, the dc supply should not be connected to the transformers.

Q.2. Jannat, a student of the CSE department, is testing the transformer under no-load and loaded conditions. She has gotten the following experimental data:

Primary Current (Ip) (A)	0.2	0.3	0.4	0.8	1
Load (w)	60	100	120	160	200

From the experimental results, it is observed that the primary current increases with increasing the load on secondary. Could you explain what is the reason behind it?

Solution:

- ✚ When a voltage is applied to the primary side of a transformer, a current will flow through the primary circuit. Due to this primary current, the flux will be generated across the primary winding.
- ✚ The primary flux cut the secondary winding by using a mutual induction process and generating a voltage across the secondary winding.
- ✚ Due to this secondary voltage, a current will also flow through the secondary circuit and create fluxes that will oppose the primary flux.
- ✚ Consequently, the resultant flux will be less, that's why the back emf of the primary winding will be reduced.
- ✚ As a result, the reduced back emf will increase primary current.

Q.3. Nisha, a student of the CSE department, is observing the nameplate of a transformer and has found out that the power rating is 50KVA. She wondered why the power rating is not in KW like generators and motors. Can explain what is the reason behind it?

Solution:

- ✚ Generally, Copper and iron are the two types of losses that occur in the transformer.
- ✚ The copper loss depends on the current (ampere) flows through the windings of the transformer while the iron loss depends on the voltage (volts).
- ✚ Since the total losses of the transformer don't depend on the power factor, for this reason, the transformer rating is in KVA, not KW.