SINGLE PHASE TRANSFORMER (Theory)

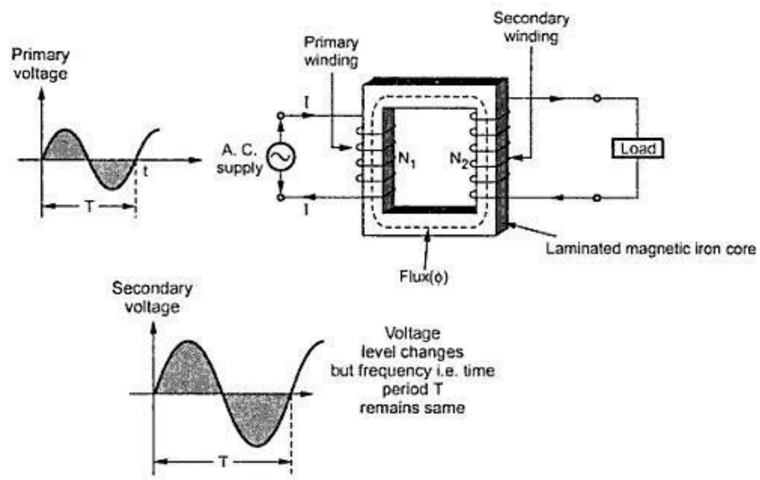
Transformer

A transformer can be defined as a static device which helps in the transfer of electric power in one circuit to other ckt without changing the frequency by raised or lowered the voltages, but with a proportional increase or decrease in the current at same time.

Transformer Working Principle

Thus produces the mutual induced electro-motive force. The so produced electro-motive force can be explained with the help of Faraday's laws of Electromagnetic Induction as

$e = -N\, d\phi/dt$ where N is the No of Turn of a coil and ϕ mutual flux
or $e = -M * dI/dt$



If the second coil circuit is closed, a current flows in it and thus electrical energy is transferred magnetically from the first to the second coil.
The alternating current supply is given to the first coil and hence it can be called as the primary winding.
The energy is drawn out from the second coil and thus can be called as the secondary winding.
In short, a transformer carries the operations shown below:

1. Transfer of electric power from one circuit to another.
2. Transfer of electric power without any change in frequency.
3. Transfer with the principle of statically induced emf of the electromagnetic induction.
4. The two electrical circuits are linked by mutual induction or magnetic ckt.

Losses in Practical Transformers:

There are two main types of losses in practical transformers.

1. Copper losses (Variable loss depend upon the load)
2. Iron Losses (Constant loss depends upon Voltage and frequency of supply which is constant)
   a) Eddy current losses
   b) Hysteresis losses

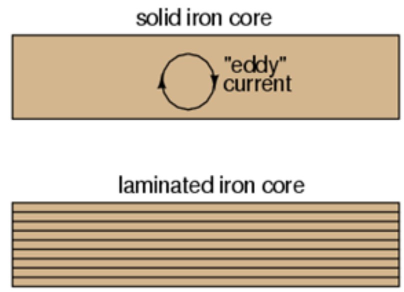
Copper losses

This Loss can be calculated practically by Short Circuit Test. Copper loss is I^2R loss, in primary side it is $I_1^2R_1$ and in secondary side it is $I_2^2R_2$ loss, where I_1 & I_2 are primary & secondary current of transformer and R_1 & R_2 are resistances of primary & secondary winding. As the both primary & secondary currents depend upon load of transformer, **copper loss in transformer vary with load**. Thus copper losses are called variable losses. Copper loss can simply be denoted as,

$$\text{Total copper losses} = I_1^2R_1 + I_2^2R_2 = I_1^2R_{eq1} = I_2^2R_{eq2} \propto I^2 \propto (KVA)^2$$

Where, $I_L = I_2$ = load Current, and R_{eq1} is the total resistance of transformer referred to Primary. R_{eq2} is the total resistance of transformer referred to secondary.

Eddy current losses



Transformer core lamination

This Loss can be calculated practically by open Circuit Test. Due to ac voltage supply, currents are produced in core and can cause losses. To limit the flow of these currents **laminated cores** are used. If there is large fluctuation of flux in the core of transformer then these losses become quite considerable and if not controlled then they can waste lot of power.

Eddy current loss per unit volume in transformer is

$$W_e = K_e f^2 t^2 B_m^2 \ watts$$

or $W_e = K_e t^2 V^2 \ watts$ where t is the thickness of core and V is the supply voltage

Hysteresis losses

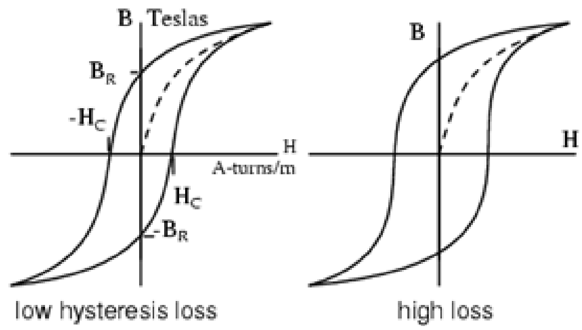


Fig. Hysteresis loop

This Loss can be calculated practically by open Circuit Test. When flux in the core is in one direction the domains of the core align themselves in one direction and when flux changes its direction domains also change their direction. Due to this change in direction of magnetic domains energy is loss this loss is called hysteresis loss.

Hysteresis loss per unit volume in transformer is

$$W_h = K_h f (B_m)^{1.6} \ watts$$

or $W_h = K_h f^{-0.6} V^{1.6} \ watts$ where f is the frequency and V is the supply voltage

To reduced hysteresis loss, used **high grade of silicon steel core material**.

Transformer Basics – Efficiency

A transformer does not require any moving parts to transfer energy. This means that there are no friction or windage losses associated with other electrical machines. However, transformers do suffer from other types of losses called “copper losses” and “iron losses” but generally these are quite small.

An ideal transformer is 100% efficient because it delivers all the energy it receives. Real transformers on the other hand are not 100% efficient and at full load, the efficiency of a transformer is between 94% to 96% which is quiet good. For a transformer operating with a constant voltage and frequency with a very high capacity, the efficiency may be as high as 98%. The efficiency, η of a transformer is given as:

Transformer Efficiency

Efficiency = η= (Output / Input)*100
Efficiency = η= [Output Power (in kW)/ {Output (in kW) + Losses (in kW)}] *100
As Input = Output +Losses

Efficiency = η= {Output / (Output +Copper Losses + Iron Losses)}*100
Output power (in KW) = x*Transformer power Rating (in KVA)*pf
X = fraction of full-load in KVA
Copper Losses other than Full-load (kW) = $X^2 P_C$
which is variable and depend upon the loading of transformer
Full-load Copper Loss (kW) = P_C
Iron Loss (kW) = P_I which is constant and not depend upon the loading of transformer

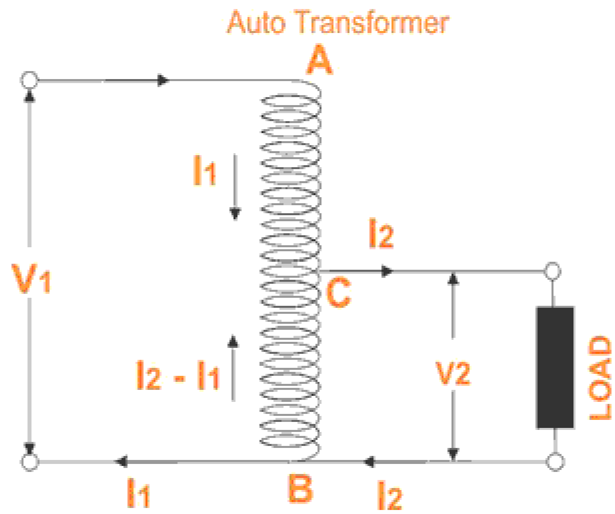
Proof of Maximum Efficiency Condition
We know that,

Copper Loss = $P_C = I_1^2 Req_1$ or $I_2^2 Req_2$
Iron Loss=P_i = Hysteresis Loss + Eddy Current Loss
$P_I = P_H + P_E$
Suppose to Primary Side…
Primary Input = $P_1 = V_1 I_1 \cos\theta_1$
Efficiency = η = (Input – Losses) / input ….. (As Output = Input – Losses)
Efficiency = η = (Input – Copper losses – Iron Losses)/Input
Efficiency = $\eta = (P_1 - P_C - P_I) / P_1$
Efficiency = $\eta = (V_1 I_1 \cos\theta_1 - I_1^2 Req_1 - P_I)/ V_1 I_1 \cos\theta_1$
Taking LCM
Efficiency = $\eta = 1 - (I_1^2 Req_1 / V_1 I_1 \cos\theta_1) - (P_I / V_1 I_1 \cos\theta_1)$
Or
Efficiency = $\eta = 1 - (I_1 . R_1 / V_1 \cos\theta_1) - (W_I / V_1 I_1 \cos\theta_1)$
Differentiate both sides with respect to I_1
$D\eta / dI_1 = 0 - (Req_1 / V_1 \cos\theta_1) + (P_I / V_1 I_1^2 \cos\theta_1)$
$D\eta / dI_1 = - (Req_1 / V_1 \cos\theta_1) + (P_I / V_1 I_1^2 \cos\theta_1)$

For Maximum Efficiency, the value of ($D\eta / dI_1$) should be Minimum i.e.
$D\eta / dI_1 = 0$

The above Equation can be written as
$R_1 / (V_1 \cos\theta_1) = (P_I / V_1 I_1^2 \cos\theta_1)$
$P_I = I_1^2 Req_1$ or $I_2^2 Req_2$
Iron Loss (constant loss) = Copper Loss (variable loss)
The value of Output current (I_2) on which Maximum efficiency can be gained
I_2 (current at max. efficiency) = $\sqrt{(P_I / Req_2)}$
As we have
I_2 (current at max. efficiency) = $\sqrt{(P_I / Req_2)}$
Or $I_2 / I_{2\,RATED} = \{\sqrt{(P_I / Req_2)}\} / I_{2\,RATED}$
Or $V_{2\,RATED} I_2 / V_{2\,RATED} I_{2\,RATED} = \sqrt{(P_I / I_{2\,RATED}^2 Req_2)}$ or X (fraction of full-load) =$\sqrt{(P_I / Pc_{FULL\text{-}LOAD})}$
Or $V_2 I_2 = V_{2\,RATED} I_{2\,RATED} \sqrt{(P_I / Pc_{FULL\text{-}LOAD})}$
Or Load in KVA (at max. efficiency occur) **= Rated KVA $\sqrt{(P_I / Pc_{FULL\text{-}LOAD})}$**

Auto Transformer



Auto transformer is kind of electrical transformer where primary and secondary shares same common single winding.

Theory of Auto Transformer

In **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 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,

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

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

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

As BC portion of the winding is considered as secondary, it can easily be understood that value of constant 'k' is nothing but turns ratio or voltage ratio of that auto transformer.

When load is connected between secondary terminals i.e.between 'B' and 'C', load current I_2 starts flowing. The current in the secondary winding or common winding is the difference of I_2 & I_1.

Advantages of Autotransformers:

1. Its efficiency is more when compared with the conventional one.
2. Its size is relatively very smaller.
3. Voltage regulation of autotransformer is much better.
4. Lower cost

5. Low requirements of excitation current.
6. Less copper is used in its design and construction
7. In conventional transformer the voltage step up or step down value is fixed while in autotransformer, we can vary the output voltage as per out requirements and can smoothly increase or decrease its value as per our requirement.

Disadvantages of Using Auto Transformer

1. There is no isolation between the primary winding and the secondary winding. Therefore protection of the equipment is dependent on the supply devices.
2. As the primary and secondary share a common end, if the neutral side of the primary voltage is not grounded, the secondary side will not be either.
3. A failure of the winding insulation of the autotransformer will result in full input voltage applied to the output.

Applications:

1. Used in both Synchronous motors and induction motors to start.
2. Used in electrical apparatus testing labs since the voltage can be smoothly and continuously varied.
3. They find application as boosters in AC feeders to increase the voltage levels.

Comparison between Auto Transformers with Two Winding Transformers

S.No	**Two Winding Transformer**	**Auto Transformer**
1	Required more copper materials	Required less copper materials
2	Lower efficiency	Higher efficiency
3	Larger in size	Smaller in size
4	costlier	Cheaper
5	Two ckt are connected magnetically only	Two ckt are connected magnetically and electrically both.

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TRANSFORMERS

1) A 400 KVA transformer has a core loss of 400W and full load copper loss of 800W. If the pf of the load is 0.9 lagging then calculate i) The full load efficiency (Ans 99.67%) ii) Percentage of full load at which the maximum efficiency occur. (Ans 70.7%)

2) Find the efficiency of a 150KVA transformer at 25%, 33% and 100% of full load

   a) at unity power factor (Ans 96.15%; 96.91%; 98.03%)

   b) at 0.8 power factor lagging. (Ans 95.23%; 96.17%; 97.56%)

   If the copper loss is 1600W at full load and iron loss is 1400W.

3) In a 25 KVA, 2000/200 V transformer, the iron loss and copper loss are 350 W and 400 W, respectively. Calculate efficiency at half load and 0.6 pf. (Ans 94.34%)

   Determine also the maximum efficiency and the corresponding load. (Ans 95.23%; 23.38 KVA)

4) A transformer has full load of 500W at unity pf. At half load and full load its efficiency is 90%. Find the efficiency of transformer if transformer is running at 75% of full load. (Ans 90.5%)

5) The efficiency of a 400 kVA, Single phase transformer is 98.77% at full load 0.8 power factor and 99.13 % at half full load unity power factor. Find: i) Iron losses at full and half full loads (Ans same Pi=1012.0225 W) ii) Cu losses at full and half full loads (Ans Pcu=2972.99W; Pcu=743.25W)

6) The maximum efficiency of a 100KVA, 1100/440V, 50Hz transformer is 96%. This across at 75% of full load at o.8pf lagging. Find the efficiency of transformer at (1/2) of full load at 0.6 p.f leading. (Ans 94.74%)

7) A 100KVA single phase transformer operating at 0.9 p.f lagging has 90% maximum efficiency. Calculate iron loss and copper loss. (Ans Pi=Pc=5000 W)

8) A full load copper loss and Iron loss of a transformer are 6400 W and 5000 W respectively. . Calculate iron loss and copper loss at half load. (Ans Pi=5000 W & Pc=1600 W)

9) A 100 KVA, 1100/220V, 60Hz transformer has a high-voltage winding resistance of 0.1Ω and a leakage reactance of 0.3Ω. The low voltage winding resistance 0.004Ω and leakage reactance is 0.12Ω. The supply is applied to high voltage side. Find equivalent Resistance, equivalent Reactance & equivalent Impedance for High Voltage and Low Voltage Side.
   Find the total copper losses and voltage regulation at full load at 0.8 pf lagging.