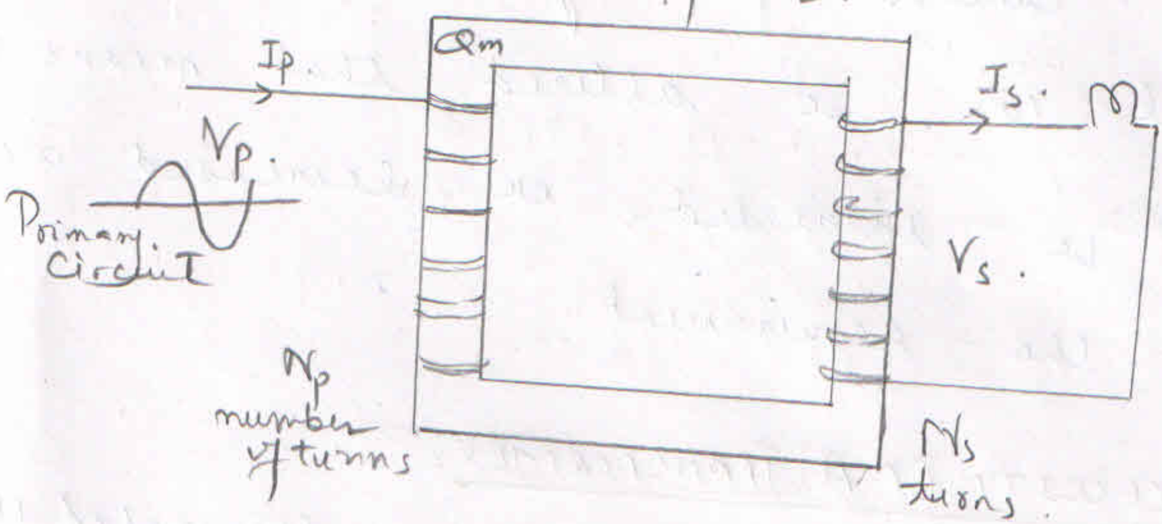
TRANSFORMER

A transformer is a static electrical machine which transfers AC electrical power from one circuit to the other circuit at the constant frequency, but the voltage level can be altered that means voltage can be increased or decreased according to the requirement

NECESSITY OF A TRANSFORMER:

Usually, electrical power is generated 11KV. for economic reasons. AC power is transmitted at very high voltages say 220KV or 440KV. over long distances. Therefore, a step-up transform-er is applied at the generating stations- Now for safety reasons the voltage is stepped down to different levels by step down transformer at various substations. to feed the power to the different location and thus utilization of power is done at 400/230V.

Transformer.



WORKING PRINCIPLE OF TRANSFORMER:

It works on the principle of mutual induction of two coils or Faraday's law of electromagnetic induction, which states that whenever a conductor is placed in a varying magnetic or or electric field conductor is rotated, magnetic field lines are induced.

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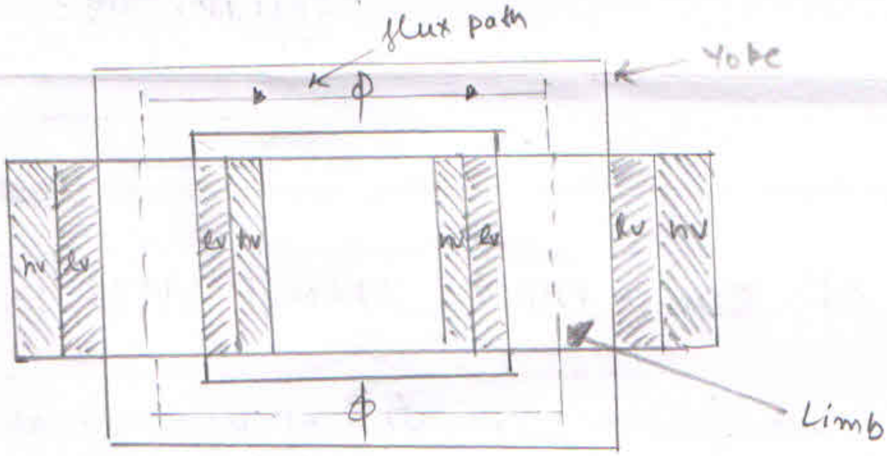
CONSTRUCTION OF SINGE PHASE TRANSFORMER :-

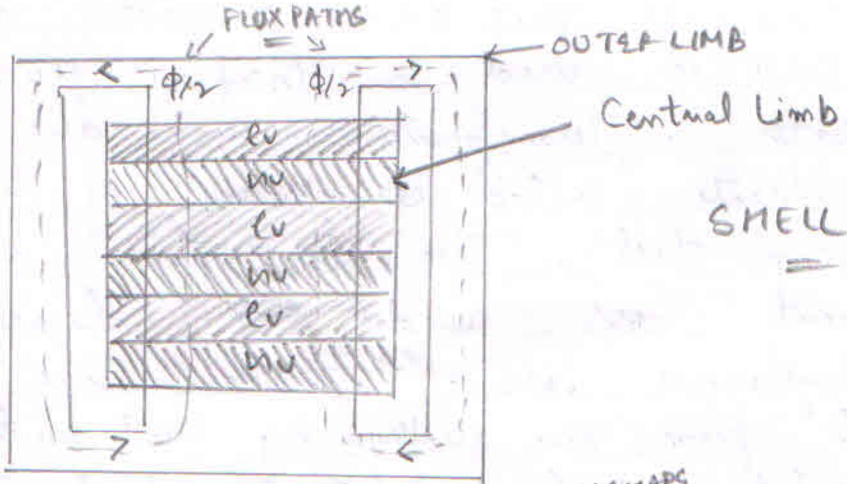
A single phase transformer consists of primary and secondary windings put on a magnetic core. Magnetic core is used to confine flux to a define path. Transformer cores are made from thin sheets (called laminations) of high grade silicon steel. The laminations reduce eddy current loss and the silicon steel reduces hysteresis loss. The laminations ~~reduce~~ are insulated from one another by heat resistant enamel insulation coating. L-type and E-type laminations are used. The ~~laminated~~ laminations are built up into stack and joints in the laminations are staggered to minimize airgaps (which require large exciting currents). The laminations are tightly clamped.

CORE - TYPE CONSTRUCTION :-

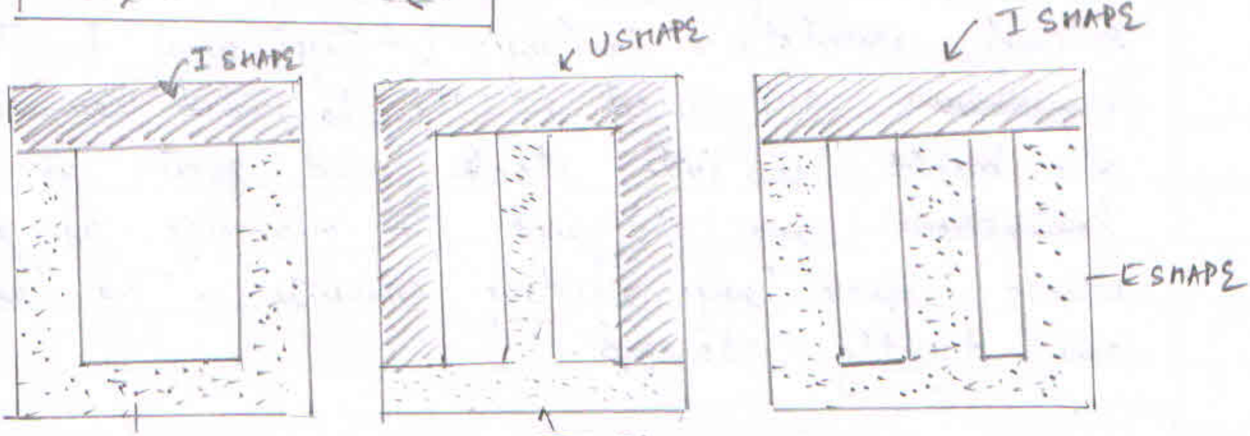
In core type transformer, the magnetic circuit consists of two vertical legs or limbs with two horizontal sections, called yokes. To keep the leakage flux to minimum, half of each winding is placed on each leg of the core as shown in fig. The low



CORE TYPE



SHELL TYPE



U SHAPE
(a)
for core type

T SHAPE
(b) for shell type

(c) for shell type

CORE LAMINATIONS

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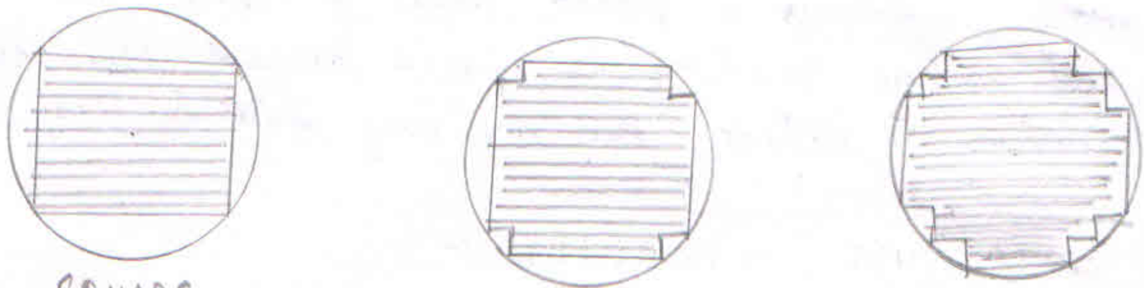
voltage windings is placed next to core and the high voltage winding is placed around the low voltage winding to reduce the insulating material required.

SHELL TYPE TRANSFORMER :-

In shell type transformer, both primary and secondary windings are wound on central limb, and the two outer limbs complete the low reluctance flux paths. Each winding is subdivided into sections. Low voltage (LV) and high voltage subsections put in the form of a sandwich known as sandwich or disc winding.
Core must be made up of atleast two types of laminations.
Various types of laminations are shown in fig.

Small core transformers are made of rectangular section core lims with rectangular coils as shown in fig.
For economy, stepped core arrangement is used.
The core-type transformer is easier to dismantle for repair. The shell-type transformer gives better support against electromagnetic forces b/w the current carrying conductors.



SQUARE (a)

CRUCIFORM TWO SLIPPED (b)

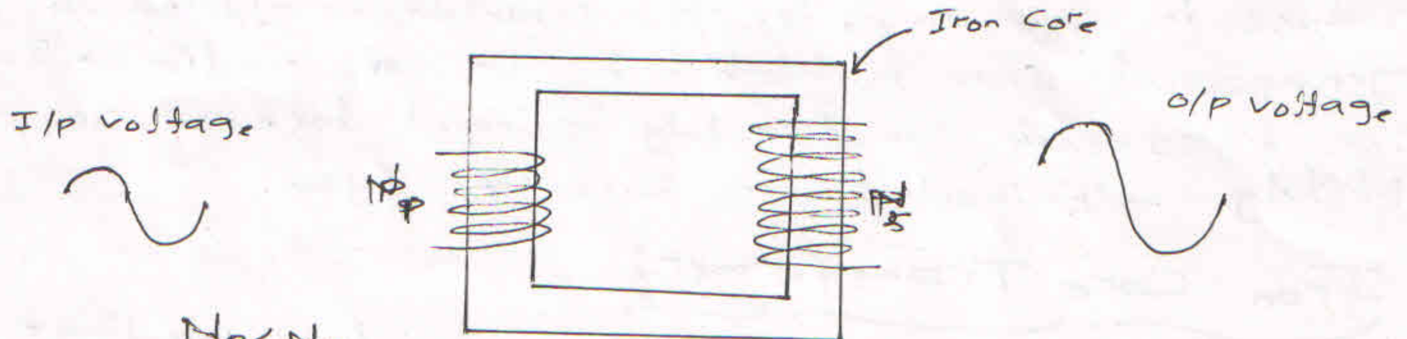
THREE STEPPED (C)

SQUARE AND STEPPED CROSS-SECTIONS

Classification of transformers on the basis of voltage:

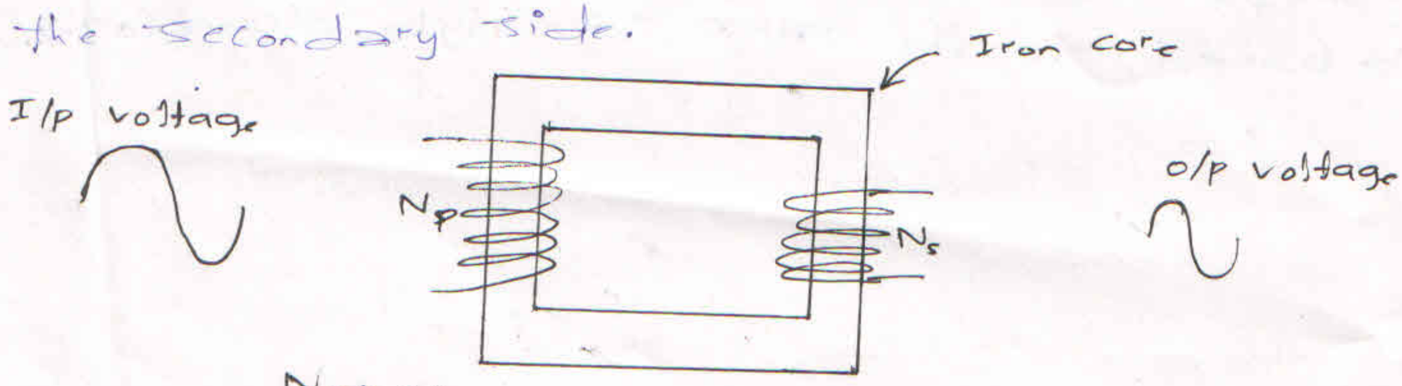
Depending upon the voltage ratios from primary to secondary windings these are:

Step-Up transformer: As the name states that, the secondary voltage is stepped up with a ratio compared to primary voltage. This can be achieved by increasing the number of windings in the secondary than the primary windings as shown in figure. In power plant, this transformer is used as connecting transformer of the generator to the grid.



$N_p < N_s$

Step-down transformer: It is used to step down the voltage level from lower to higher level at secondary side as shown below so that it is called as a step-down transformer. The winding turns more on the primary side than the secondary side.



$N_p > N_s$

In distribution networks, the step-down transformer is commonly used to convert the high grid voltage to low voltage that can be used for home appliances.

Classification based on Core medium used

Based on the medium placed between the primary and secondary winding the transformers are classified as Air core and Iron Core.

Air Core Transformer:

Both the primary and secondary windings are wound on a non-magnetic strip where the flux linkage b/w primary and secondary windings is through the air.

Compared to iron core the mutual inductance is less in air core, ie., the reluctance offered to the generated flux is high in the air medium. But the hysteresis and eddy current losses are completely eliminated in air-core type.

Iron Core Transformer:

Both the primary and secondary windings are wound on multiple iron plate bunch which provide a perfect linkage path to the generated flux. It offers less reluctance to the linkage flux due to the conductive and magnetic property of the iron. These are widely used transformers in which the efficiency in high compared to the air core type transformer.

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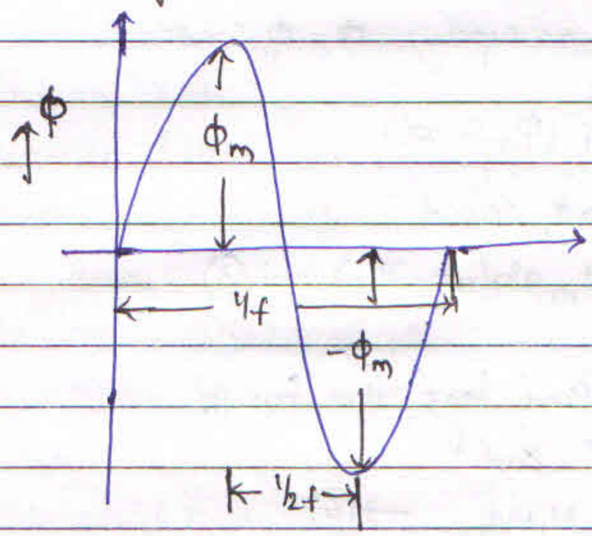
Emf Equation of a Transformer:

When a sinusoidal voltage is applied to the primary winding of a transformer, alternating flux 'ϕ_m' sets up in the iron core of the transformer. The sinusoidal flux links with both primary and secondary windings. The function of flux is a sine function. The rate of change of flux with respect to time is derived mathematically.



Where ϕ_m be the maximum value of flux in webers.
f be the supply frequency in Hertz
N_1 is the number of turns in the primary winding
N_2 is the number of turns in the secondary winding
ϕ is the flux per turn in weber.

As shown in the above figure that the flux changes from $+\phi_m$ to $-\phi_m$ in half a cycle of $1/2f$ seconds.

By faraday's law

Let E_1 is the emf induced in the primary winding

$$E_1 = -\frac{d\psi}{dt} \rightarrow (1)$$

where $\psi = N_1\phi$

$$\therefore E_1 = -N_1 \frac{d\phi}{dt} \longrightarrow (2)$$

Since ϕ is due to ac supply, $\phi = \phi_m \sin\omega t$

$$E_1 = -N_1 \frac{d}{dt}(\phi_m \sin\omega t)$$

$$E_1 = -N_1 \omega \phi_m \cos\omega t$$

$$E_1 = N_1 \omega\phi_m \sin(\omega t - \pi/2) \longrightarrow (3)$$

So the induced Emf lags flux by 90°.

Maximum value of Emf

$$E_{1max} = N_1\omega\phi_m \rightarrow (4)$$

but $\omega = 2\pi f$

$$E_{1max} = 2\pi f N_1 \phi_m \rightarrow (5)$$

Root mean square (Rms) value is $E_1 = \frac{E_{1max}}{\sqrt{2}} \rightarrow (6)$

putting the value of E_{1max} in equation(6), we get

$$E_1 = \sqrt{2}\pi f N_1 \phi_m \rightarrow (7)$$

putting the value of $\pi = 3.14$ in eqn (7), the value of E_1 as

$$E_1 = 4.44 f N_1 \phi_m \longrightarrow (8)$$

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Similarly,

$$E_2 = 4.44 f N_2 \phi_m \rightarrow (9)$$

Now, eqn(8)/eqn(9), we get

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

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = k.$$

The above equation is called the turn ratio where k is known as Transformation ratio.

The equations (8) & (9) can also be written as shown below using the relationship. $(\phi_m = B_m \times A)$

where A = area

B_m = Maximum value of flux density.

$$E_1 = 4.44 N_1 f B_m A_i \text{ volts}$$

$$E_2 = 4.44 N_2 f B_m A_i \text{ volts}$$

for a sinusoidal wave

$$\frac{\text{R.M.S Value}}{\text{Average Value}} = \text{Form factor} = 1.11$$

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Transformer "No-load" Condition:

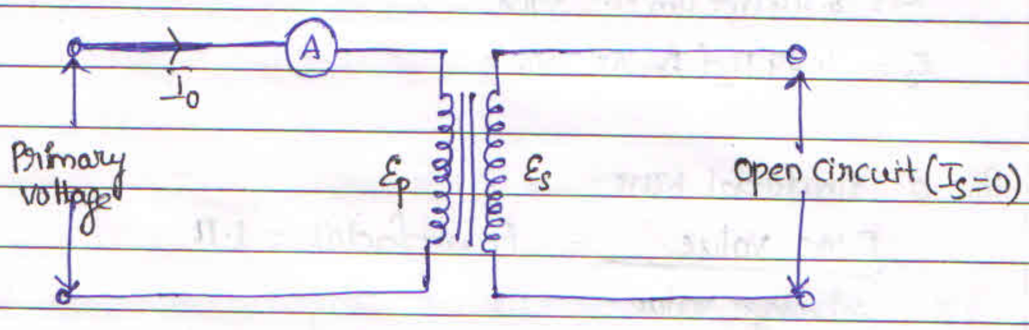
When transformer is on "no-load" condition, that is with no electrical load connected to its secondary winding and therefore no secondary current flowing.

Transformer is said to be on "no-load" when its secondary side winding is open circuited.

When an Ac sinusoidal supply is connected to the primary winding of a transformer, a small current I_{open} will flow through the primary coil winding due to the presence of the primary supply voltage.

With secondary circuit open, nothing connected, a back emf along with the primary winding resistance acts to limit the flow of this primary current.

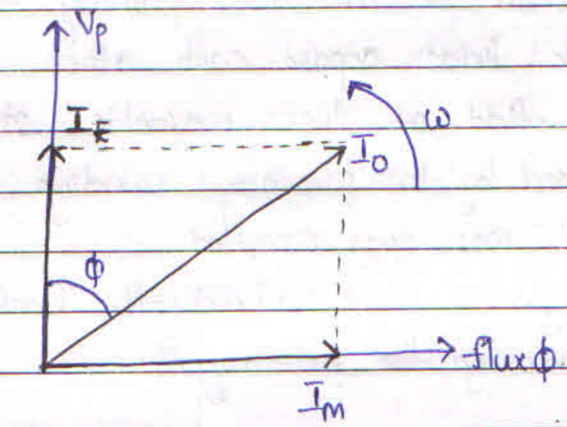
No-load primary current (I_0) must be sufficient to maintain enough magnetic field to produce the required back emf.



The armature 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.

As in-phase current, I_E which supplies the core losses.
A small current I_m at 90° to the voltage which sets up the magnetic flux.



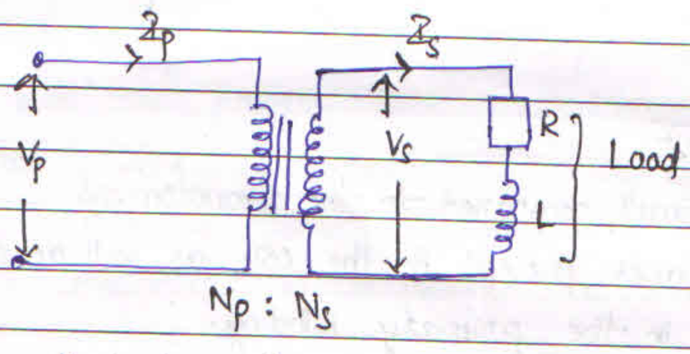
$I_E = I_0 \cos\phi$
$I_M = I_0 \sin\phi$
$I_0 = \sqrt{I_m^2 + I_E^2}$

I_0 is very small compared to the transformers
Due to iron losses present in the core as well as a small amount of copper losses in the primary winding.
I_0 does not lag behind the supply voltage, V_p by exactly 90° ($\cos\phi = 0$) there will be some small phase angle difference.

Transformer "on-load".

When an electrical load is connected to the secondary wdg of a transformer & the transformer loading is therefore greater than zero, a current flows in the secondary winding & out to the load. This secondary current is due to the induced secondary voltage, set up by the magnetic flux created in the core from the primary current.

The secondary current I_s creates a self-induced secondary magnetic field, ϕ_s in the transformer core which flows in the exact opposite direction to the main primary field, ϕ_p.
These two magnetic fields oppose each other resulting in a combined magnetic field of less magnetic strength than the single field produced by the primary winding alone when the secondary circuit was open circuited.
The combined magnetic field reduces the back Emf of the primary winding causing the primary current I_p to increase slightly.



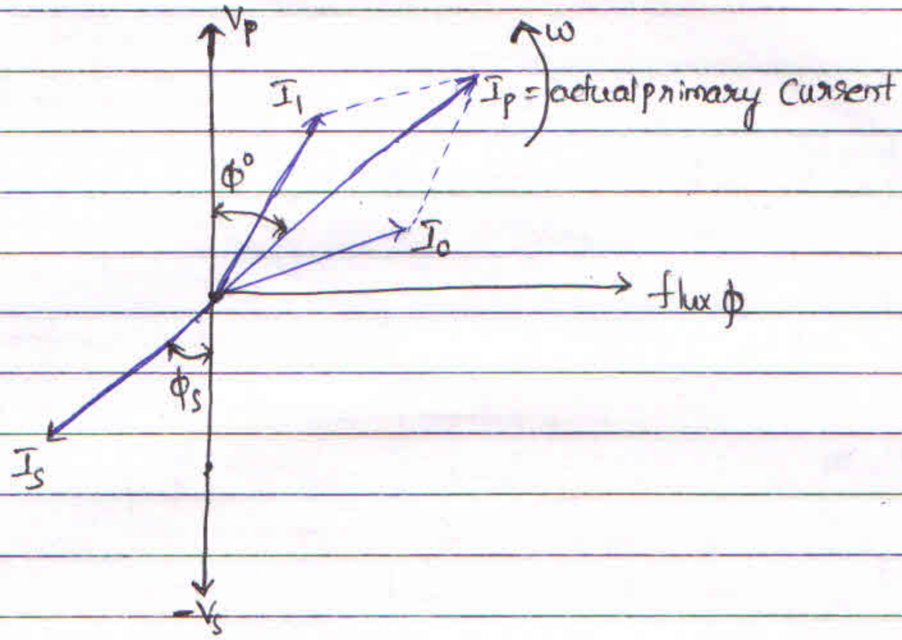
We know that the turns ratio of a transformer states that the total induced voltage in each winding is proportional to the number of turns in that winding & also that the power output & power input of a transformer is equal to the volts times amperes. (V×I)

$$\frac{V_p}{V_s} = \frac{I_s}{I_p}$$

Transformer ratio:

$$n = \frac{N_p}{N_s} = \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

Transformer loading current.



Transformer Losses: There are mainly two kind of losses in transformer namely i) Core loss ii) ohmic loss

i) Core Loss: The core loss 'P_c' occuring in the transformer iron consists of two component hysteresis loss 'P_h' and eddy loss 'P_e'

$$\therefore \boxed{P_c = P_h + P_e}$$

$$P_h = K_h f B_m^x$$

$$P_e = K_e f^2 B_m^2$$

$$V = \sqrt{2}\pi f N \phi_m$$

$$B_m \times A_i = \phi_m$$

$$\boxed{\phi_m = \frac{V}{\sqrt{2}\pi f N}}$$

$K_h, K_e \rightarrow$ proportionality constant

$f \rightarrow$ frequency of alternating flux

$B_m =$ Maximum flux density in core

The value of exponential 'x' (called Steinmetz's constant) varies 1.5 to 2.5 depending upon the magnetic properties of core material.

$$\boxed{P_c = K_h f B_m^x + K_e f^2 B_m^2} \longrightarrow \text{Total Core Loss}$$

The procedure is given below

The applied voltage is almost equal to the induced emf

$$\boxed{V = \sqrt{2}\pi f N \phi_{max}} = \sqrt{2}\pi f N B_m A_i$$

where $A_i =$ net core area

$N =$ No of turns

$$B_m = \frac{V}{\sqrt{2}\pi f N A_i}$$

$$P_h = K_h f \left(\frac{1}{\sqrt{2}\pi N A_i}\right)^x \left(\frac{V}{f}\right)^x$$

For a transformer N and A_i are constant

$$\boxed{P_h = K_h V^x f^{1-x}}$$

Thus the hysteresis loss both depend upon applied voltage and its frequency

$$P_e = K_e f^2 \left(\frac{1}{\sqrt{2}\pi N A_i}\right)^2 \left(\frac{V}{\cancel{f}}\right)^2 = K_e V^2$$

$$\boxed{P_e = K_e V^2} \quad V = \text{Applied voltage}$$

Neglecting constant terms we get

The eddy current loss is therefore proportional to sq. of applied voltage and independent of freq

$$\boxed{V \propto B_m f}$$

The total core loss in terms of voltage and frequency

$$\boxed{P_c = K_h V^x f^{1-x} + K_e V^2}$$

Ohmic Loss When a transformer is loaded, ohmic loss (I^2R) occurs in both primary and secondary winding resistances. Since the standard operating temperature of electrical machine is 75°C the ohmic loss should be calculated at 75°C ②

iii) **Dielectric Loss** : This loss occurs in insulating material i.e. in the transformer oil and the solid insulation of H.V transformers

iv) **Stray Load Loss** : Leakage fields present in a transformer induce eddy currents in conductors tanks, channels bolt these eddy current give rise to stray load loss.

Transformer Efficiency : It is defined as the ratio of output power to the input power It is denoted by the symbol η

$$\boxed{\eta = \frac{\text{Output power}}{\text{Input power}}} = \frac{V_2 I_2 \cos\theta_2}{V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2}} \quad -①$$

P_c = Total core loss

$I_2^2 r_e^2$ = Total ohmic loss

$V_2 I_2$ = Output VA

$$\eta = \frac{\text{Input power} - \text{Losses}}{\text{Input power}} = 1 - \frac{\text{Losses}}{\text{Input power}}$$

$\cos\theta_2$ = Load p.f

Efficiency of a transformer can also be expressed in unit parameters

$$\eta = \frac{\text{load pf}}{\text{load pf} + \text{P.U core loss} + \text{P.U equivalent resistance}}$$

$$\eta = 1 - \frac{P.U.P_c + P.U.\,r_e}{\text{load pf} + P.U. + P.U.\,r_e}$$

Efficiency at load current I_2', different from rated load current I_2 is given by

$$\eta = 1 - \frac{P.U.P_c + \left(\frac{I_2'}{I_2}\right)^2 P.U\,r_e)}{\left(\frac{I_2'}{I_2}\right)^2 \text{load pf} + P.U P_c + \left(\frac{I_2'}{I_2}\right)^2 (P.U.\,r_e)}$$

Condition for maximum efficiency:

From Eq ① P_c is constant and the load voltage V_2 remains practically constant. At a specified value of load p.f. $\cos\theta_2$ the efficiency will be maximum when $\frac{d\eta}{dI_2} = 0$ Therefore $\frac{d\eta}{dI_2}$ for Eq ①

$$\frac{d\eta}{dI_2} = \frac{(V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2})(V_2\cos\theta_2) - V_2 I_2 \cos\theta_2 (V_2\cos\theta_2 + 2I_2 r_{e2})]}{[V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2}]^2} = 0$$

Or $[V_2 I_2 \cos\theta_2 + P_c + I_2^2 r_{e2}]\, V_2 \cos\theta_2$

$$= V_2 I_2 \cos\theta_2 (V_2 \cos\theta_2 + 2 I_2 r_{e2}]$$

$$\boxed{I_2^2 r_{e2} = P_c}$$

is variable ohmic Loss $I_2^2 r_{e_2}$ = Constant core loss, P_c ③

Hence the maximum efficiency occurs when the variable ohmic loss $I_2^2 r_{e_2}$ is equal to the fixed core loss P_c

the load current I_2 at which maximum efficiency occurs is given by

$$I_2 = \sqrt{\frac{P_c}{r_{e_2}}} = I_{fl}\sqrt{\frac{P_c}{I_{fl}^2 r_{e_2}}}$$

If both sides of above eq are multiplied by $E_2/1000$ we get

$$\frac{E_2 I_2}{1000} = \frac{E_2 I_{fl}}{1000}\sqrt{\frac{P_c}{\text{Full load ohmic Losses}}}$$

$\therefore$ KVA load for maximum η = rated transformer (KVA) $\times \sqrt{\frac{\text{Core Loss}}{\text{ohmic losses at current}}}$

$$\boxed{(KVA)_{max\,\eta} = (KVA)\sqrt{\frac{P_c}{I_{Fl}^2 r_{e_2}}}}$$

:- VOLTAGE REGULATION :-

It is defined as the arithmetic difference in the secondary terminal voltage between no-load $(I_2=0)$ and full rated load $(I_2 = I_{2fl})$ at a given power factor with the same value of primary voltage for both rated load and no load.

$$\text{voltage regulation} = \left. \frac{V_{2nl} - V_{2fl}}{V_{2fl}} \right|_{V_1 \,=\, \text{constant}}$$

In terms of primary values, we have

$$V_{2nl} = \frac{V_1}{a}$$

$$\therefore V.R\,[P.U] = \frac{\left|\frac{V_1}{a}\right| - |V_{2fl}|}{|V_{2fl}|}$$

CALCULATIONS:

The approximate equivalent circuit of the transformer referred to the secondary is shown in fig 1.22.

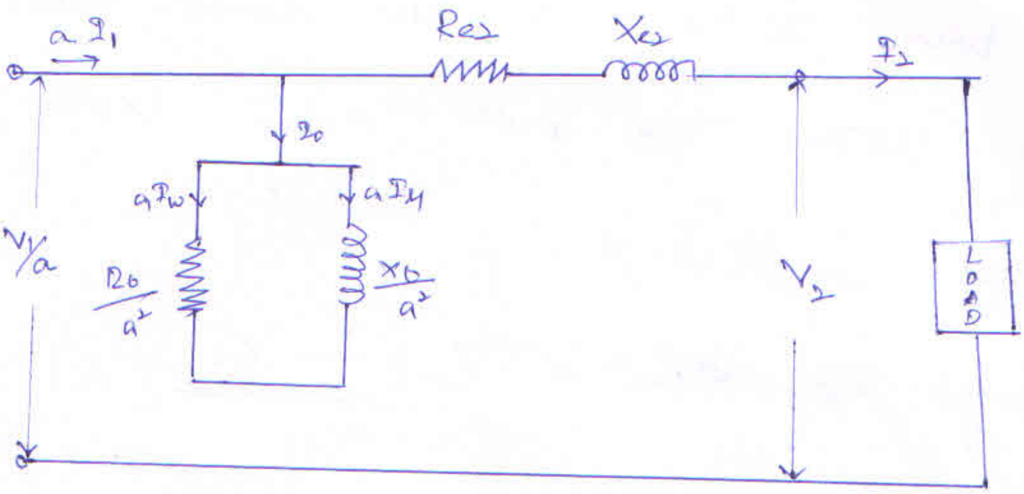


Fig 1.22:- Equivalent circuit reffered to the secondary.

where R_{e2} = equivalent resistance of the whole transformer refferred to secondary.

X_{e2} = equivalent reactance refferred to secondary.

Also. Z_{e2} = equivalent impedance reffered to secondary.

$$R_{e2} = R_2 + \frac{R_1}{a^2} \quad , \quad X_{e2} = X_2 + \frac{X_1}{a^2} \, ,$$

$$Z_{e2} = R_{e2} + jX_{e2}.$$

By KVL $\frac{V_1}{a} = V_2 + I_2 Z_{e2}$

* Procedure for calculating regulation:

1. Take V_2 as reference phasor
   i.e $V_2 = V_2 \angle 0^\circ = V_2 + j0$.

2. Write I_2 in phasor form

   For lagging power factor $\cos\phi_2$

   $I_2 = I_2 \angle -\phi_2 = I_2 \cos\phi_2 - j I_2 \sin\phi_2$

   For leading power factor $\cos\phi_2$

   $I_2 = I_2 \angle \phi_2 = I_2 \cos\phi_2 + j I_2 \sin\phi_2$

   For unity power factor

   $I_2 = I_2 \angle 0^\circ + I_2 + j0$

3. Calculate Z_{e2} i.e $Z_{e2} = R_{e2} + jX_{e2}$

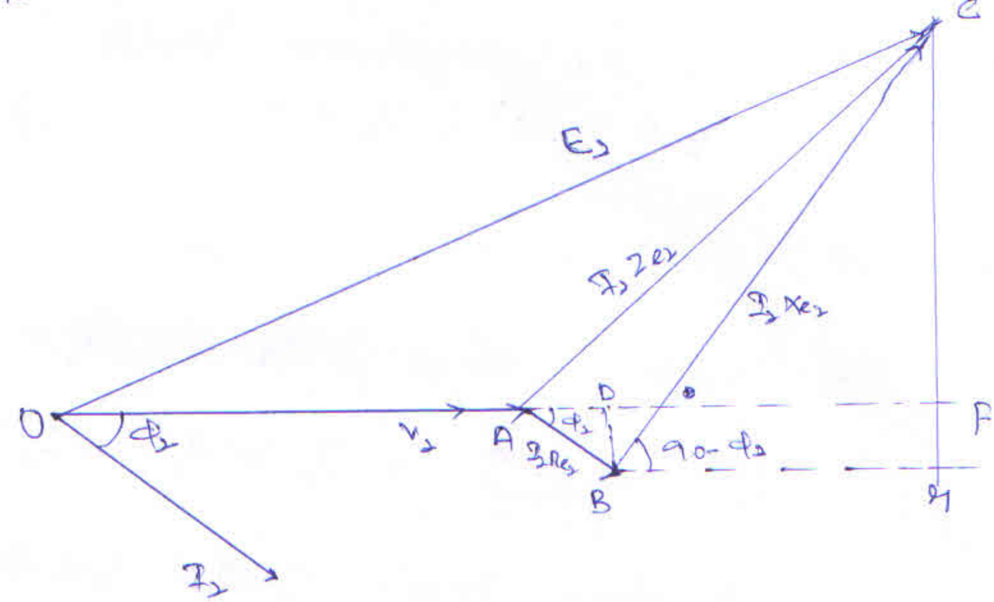
4. Calculate V_{2nl}, i.e $V_{2nl} = \frac{V_1}{a}$

5. Calculate the voltage regulation as

   $$V.R = \frac{\left|\frac{V_1}{a}\right| - (V_{2fl})}{V_{2fl}}.$$

• Voltage Regulation At Lagging power factor

Fig 1.23 shows the phasor diagram for lagging power factor.



Here V_2 is taken as reference phasor. I_2 lags V_2 by ϕ_2. $I_2 R_{e2}$ is in phase with I_2 and $I_2 X_{e2}$ leads I_2 by 90^0.

Calculation :-

$$V_2 = V_2 \angle 0^0 ,$$

$$I_2 = I_2 \angle -\phi_2 = I_2 \cos\phi_2 - j I_2 \sin\phi_2$$

$$Z_{e2} = R_{e2} + j X_{e2} \quad , \quad E_2 = V_2 + I_2 Z_{e2}$$

$$\Rightarrow E_2 = V_2 + j0 + (I_2 \cos\phi_2 - j I_2 \sin\phi_2)(R_{e2} + j X_{e2})$$

$$E_2 = (V_2 + I_2 R_{e2} \cos\phi_2 + I_2 X_{e2} \sin\phi_2) + j[I_2 X_{e2} \cos\phi_2 - I_2 R_{e2} \sin\phi_2)$$

$$\therefore \text{ approx. reg.} = \frac{I_2 R_{e_2} \cos\phi_2 + I_2 X_{e_2} \sin\phi_2}{V_2}.$$

- Voltage regulation at Leading power factor -

$V_2 = V_2 \angle 0^\circ$

For leading power factor $\cos\phi_2$

$I_2 = I_2 \angle \phi_2 = I_2 \cos\phi_2 + j I_2 \sin\phi_2$

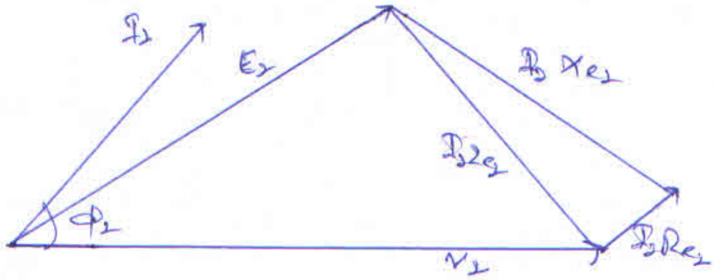
also $E_2 = \frac{V_1}{a} = V_2 + I_2 Z_{e_2}$

$E_2 = V_2 + (I_2 \cos\phi_2 + j I_2 \sin\phi_2)(R_{e_2} + j X_{e_2})$

$$|E_2| = \sqrt{(V_2 + I_2 R_{e_2} \cos\phi_2 - I_2 X_{e_2} \sin\phi_2)^2 + (I_2 X_{e_2} \cos\phi_2 + I_2 R_{e_2} \sin\phi_2)^2}$$

$$\therefore \text{ approx. regulation} = \frac{I_2 R_{e_2} \cos\phi_2 - I_2 X_{e_2} \sin\phi_2}{V_2}$$

Phasor Diagram.



- Voltage Regulation at Unity Power factor.

For unity power factor

$I_2 = I_2 \angle 0^\circ = I_2 + 0j$

$E_2 = V_2 + I_2 Z_{e2}$

$E_2 = V_2 + I_2 (R_{e2} + j X_{e2}) = V_2 + I_2 R_{e2} + j I_2 X_{e2}$

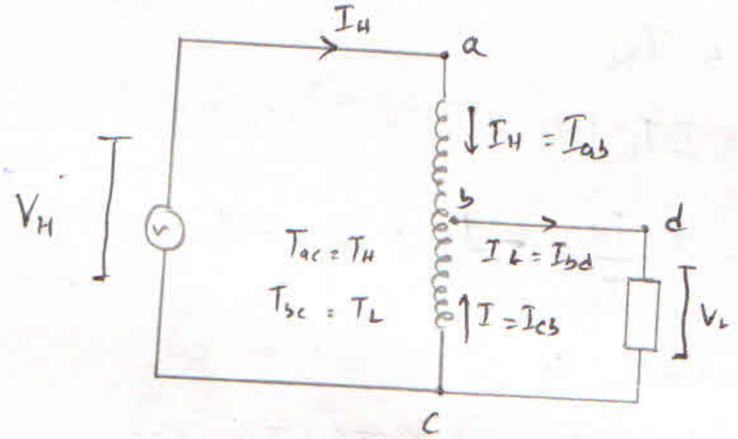
$|E_2| = \sqrt{(V_2 + I_2 R_{e2})^2 + (I_2 X_{e2})^2}$

$\Rightarrow \boxed{\text{voltage regulation} = \dfrac{I_2 R_{e2} + I_2 X_{e2}}{V_2}}$

AUTO TRANSFORMERS :

Single Phase Auto Transformer

It has one winding of Tf common to both highvoltage and lowvoltage sides.



Stepdown Auto Tf:

$T_H = T_{ac}$ = no. of turns on hv side

$T_L = T_{bc}$ = no. of turns on lv side

$T_{ab} = T_H - T_L$ = no. of turns in serial winding ab

V_H = ip volt. on hv side

V_L = op volt. on lv side

I_H = ip current in hv side

I_L = op current in the lv side

Current in series winding $\cancel{bc} = I_{ab} = I_H$

Current in common windings = $\cancel{bc}\ I_{cb} = I$

Circuit voltage ratio $\dfrac{V_H}{V_L} = \dfrac{T_H}{T_L} = a_A$

a_A is always greater than 1

When the load is connected across the secondary terminals a current I flows in the common winding bc. It has a tendency to reduce the main flux but the primary current I_H increases to such a value that the mmf in winding ab neutralizes the mmf in winding bc.

ie $$I_a T_{ab} = I_{bc} T_{bc}$$

$$I_H (T_H - T_L) = I T_L$$

$$\frac{I}{I_H} = \frac{T_H - T_L}{T_L} = \frac{T_H}{T_L} - 1 = a_A - 1$$

The winding voltage ratio is

$$a = \frac{V_{ab}}{V_{bc}} = \frac{T_{ab}}{T_{bc}} = \frac{T_H - T_L}{T_L}$$

$$a = a_A - 1$$

By KCL at pt b

$$I_L = I_H + I$$

$$I = I_L - I_H$$

Since I_H & I are in phase

$$\frac{\bar{I}}{\bar{I}_H} = \frac{I}{I_H}$$

$$\therefore \quad \frac{I}{I_H} = a_A - 1$$

$$\frac{I_L - I_H}{I_H} = a_A - 1$$

$$\frac{I_L}{I_H} = a_A$$

$$I_H = \frac{I_L}{a_A}$$

$$\frac{I}{I_L} = \frac{a_A - 1}{a_A}$$

The Induced voltages in windings ab and bc are in time phase bez they are induced by the same flux

$$E_1 = E_{ac} = E_H$$

$$E_2 = E_{bc} = E_L$$

$$E_{ab} = E_{ac} - E_{bc}$$

$$\frac{E_{ab}}{E_{bc}} = \frac{E_{ac} - E_{bc}}{E_{bc}} = \frac{E_{ab}}{E_{bc}} - 1$$

$$= \frac{E_H}{E_L} - 1$$

$$\frac{E_{ab}}{E_{bc}} = a_A - 1$$

$$a_A = \frac{E_{ab}}{E_{bc}} + 1$$

$$a_A = a + 1$$

$a = \frac{E_{ab}}{E_{bc}}$ = two winding Tf Ratio

VOLTAMPERE RELATIONS:

volt amperes in winding ab = Voltamp in winding bc

$$E_{ab} I_{ab} = E_{bc} I_{bc} = S_{trans}.$$

Where S_{trans} is called transformed voltamperes.

$$S_{trans} = V_{ab} I_{ab} = V_{bc} I_{bc}$$

$$S_{in} = V_{ac} I_{ab}$$

$$= (V_{ab} + V_{bc}) I_{ab}$$

$$= V_{ab} I_{ab} + V_{bc} I_{ab}$$

$$S_{in} = S_{tran} + V_{bc} I_{ab}$$

The quantity $V_{bc} I_{ab}$ is called conducted volt Ampers S_{cond}.

$$S_{cond} = V_{bc} I_{ab}$$

$$\boxed{S_{in} = S_{tran} + S_{cond}}$$

$$S_{tran} = V_{bc} I_{bc} = V_L I$$

$$S_{cond} = V_L I_H$$

An autotransformer is rated on the basis of output VA rather than the Tf VA.

When used as an AutoTf its rating is

$$(VA)_{auto} = V_H I_H = V_L I_L$$

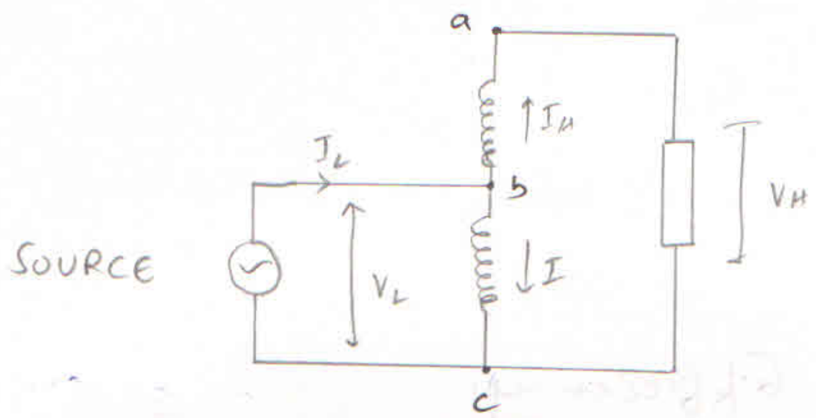
$$\frac{(VA)_{auto}}{(VA)_{TW}} = \frac{V_L I_L}{V_L I} = \frac{I_L}{I}$$

$$\frac{I}{I_L} = \frac{a_A - 1}{a_A}$$

$$\frac{(VA)_{auto}}{(VA)_{TW}} = \frac{a_A}{a_A - 1}$$

$$(VA)_{auto} > (VA)_{TW}$$

(St)ep up Autotransformer



Step up Auto Tf.

Applying the balanced mmf condition in windings ab & bc

$$I_H T_{ab} = I T_{bc}$$

$$a_A = \frac{T_{ac}}{T_{bc}} = \frac{V_H}{V_L} \qquad \text{Here } a_A > 1$$

$$\frac{I}{I_H} = \frac{T_{ab}}{T_{bc}} = \frac{T_{ac} - T_{bc}}{T_{bc}} = \frac{T_{ac}}{T_{bc}} - 1$$

$$\frac{I}{I_H} = a_A - 1$$

$$\frac{I + I_H}{I_H} = a_A$$

$$I + I_H = a_A I_L$$

$$\frac{I_L}{I_H} = a_A$$

$$\frac{I}{I_L} = \frac{a_A - 1}{a_A}$$

By KVL in the high voltage side

$$E_{ab} + E_{bc} = E_{ac}$$

$$E_{ab} = E_{ac} = E_{bc}$$
$$= a_A E_{bc} - E_{in}$$
$$= a_A E_L - E_L$$
$$E_{ab} = (a_A - 1) E_L$$

Auto Transformer Efficiency:

1) In an ordinary Tf the total electrical power is transferred from primary to secondary by transformation. Power Tf results in power loss
2) In an auto Tf electrical power is transferred from primary to secondary partly by the process of Tf and partly by direct electrical connection. Power conductively transferred produces no transformer loss.