UNIT - 2

TRANSFORMER

2.1 TRANSFORMER - INTRODUCTION

A transformer is an electrical device, having no moving parts, which by mutual induction, it transfers electrical energy from one circuit to another at the same frequency, usually with changed values of voltage and current.

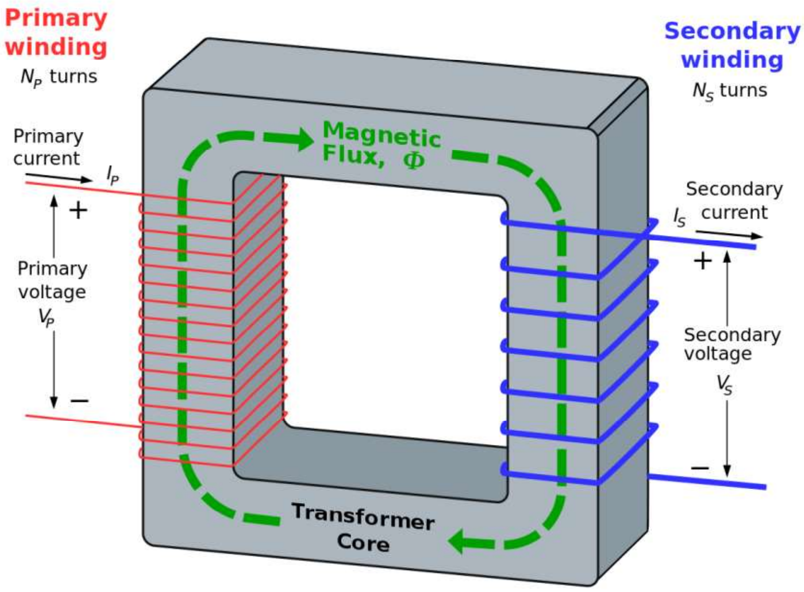
2.2 CONSTRUCTION OF TRANSFORMER

The main components of transformer are,

1. Magnetic core
2. Windings
3. Insulation
4. Insulating oil
5. Expansion tank
6. Temperature gauge
7. Oil gauge
8. Buchholz relay
9. Breather
10. Bushings
11. Cooling arrangements

Magnetic core

Magnetic circuit consists of an iron core. The transformer core is generally laminated and is made out of a good magnetic material like silicon steel. The laminations are insulated from each other by coating then with a thin coat of varnish.

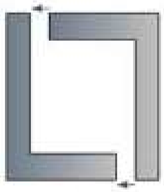


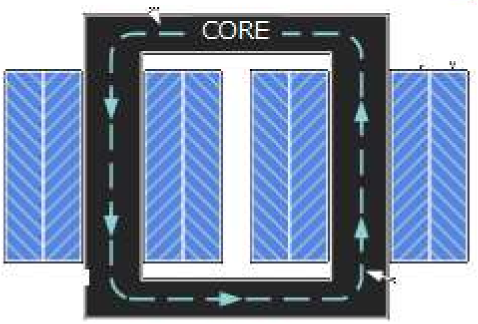
The two types of transformer cores are,

1. Core type
2. Shell type

Core type transformer

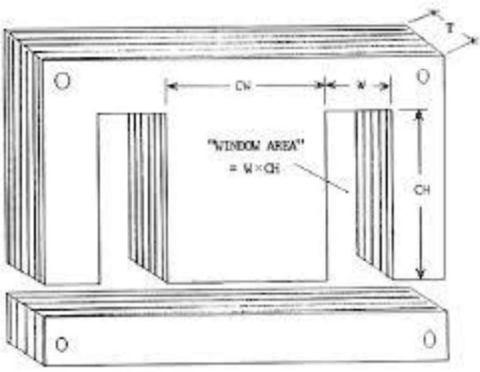
- It has only one magnetic path
- It has two limbs for the two windings
- It is made up of two L – type stampings
- The coils are usually are of cylindrical type. For transformers of higher rating stepped core with circular cylindrical coils are used. For transformers of smaller rating, rectangular coils with core of square or rectangular cross section is used.

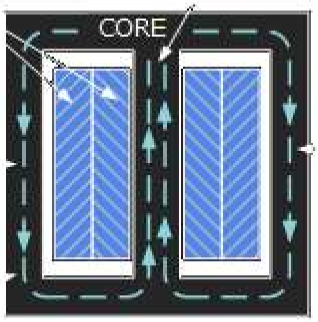




Shell type transformer

- It has two parallel paths for magnetic flux
- It has three limbs. The two windings are carried by the central limb.
- It is made up of E and I type stampings
- The coils used are of multilayer disc type.





Windings

Windings are made up of copper. There are two types of windings in a transformer. They are,

1. Primary windings
2. Secondary windings

Insulation

Paper is still used as the basic conductor insulation. Enamel insulation is used as the inter-turn insulation of low voltage transformers. For power transformers enamelled copper with paper insulation is used.

Insulating oil

The oil used in a transformer protects the paper from dirt and moisture and removes the heat produced in the core and coils. It also acts as a insulating medium.

Expansion tank or conservator

A small auxiliary oil tank may be mounted above the transformer and connected to main tank by a pipe. Its function is to keep the transformer tank full of oil.

Temperature gauge

Every transformer is provided with a temperature gauge to indicate hot oil. It is self contained weather proof unit made of alarm contacts.

Oil gauge

Every transformer is fitted with an oil gauge to indicate the oil level present inside the tank. The oil gauge may be provided with an alarm contact which gives an alarm when the oil level has dropped beyond permissible height due to oil leak or due to any other reason.

Buchholz relay

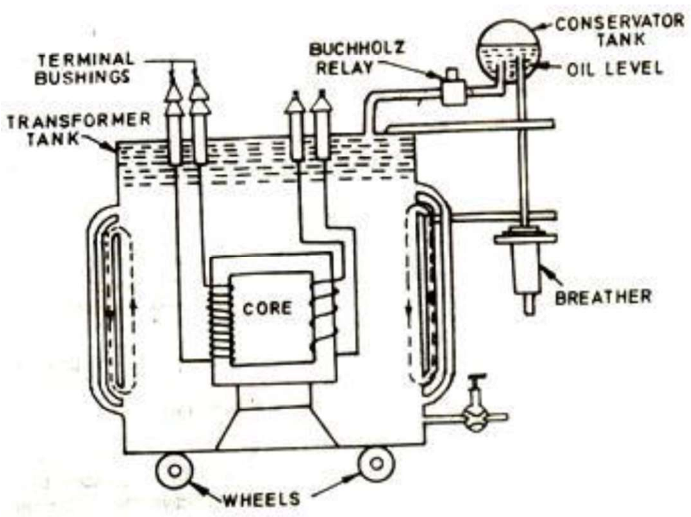
The first warning that a fault is presented may be given by the presence of bubbles in the oil. The gas operated relay gives an alarm in case of minor fault and to disconnect the transformer from the supply mains in case of severe faults.

Breather

The simplest method to prevent the entry of the moisture inside the transformer tank is to provide chambers known as breather. The breather is filled with some drying agents, such as calcium chloride or silica gel. This drying agents absorbs moisture and allow dry air to enter the transformer tank. The drying agent is replaced periodically as routine maintenance.

Bushings

Connections from the transformer windings are brought out by means of bushings. Bushings are fixed on the transformer tank.



Cooling arrangements

The various methods of cooling employed in a transformer are,

1. Oil immersed natural cooled transformers
2. Oil immersed forced air cooled transformers
3. Oil immersed water cooled transformers
4. Oil immersed forced oil cooled transformers
5. Air blast transformers

1. Oil immersed natural cooled transformers

In this type, the core and coils are immersed in insulating oil contained in an iron tank. The heat produced in the core and windings is conduct by the circulation of oil to the surface which dissipates heat to surroundings. In transformers of larger output, the dissipation surface is increased by providing large number of tubes on its sides. The oil not only keeps the windings cool but also provides additional insulation.

2. Oil immersed forced air cooled transformers

In this type, the core and windings are immersed in oil and cooling is increased by forced air over the cooling surfaces. The air is forced over external surfaces such as tank, tubes and radiators by means of fan mounted external to the transformer.

3. Oil immersed water cooled transformers

In this type, the core and windings are immersed in oil and cooling is increased by circulation of cold water through the tubes immersed in oil.

4. Oil immersed forced oil cooled transformers

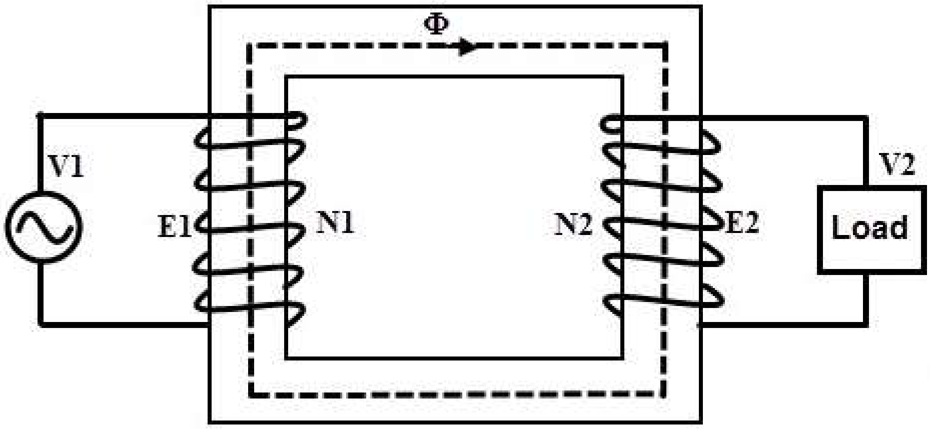
In this type, the core and windings are immersed in oil and cooling is achieved by forced oil circulation. In this method of cooling forced oil circulation is obtained by a centrifugal pump which is located at either the oil inlet or outlet. The pump motor used for cooling is designed to operate totally immersed in the cooling oil being circulated.

5. Air blast transformers

Here the transformer is cooled by a forced circulation of air through core and windings. It is used in substations located in thickly populated places where oil is considered a fire hazard. The air supplied is filtered to avoid dust entering the ventilating ducts.

2.3 OPERATION OF TRANSFORMER

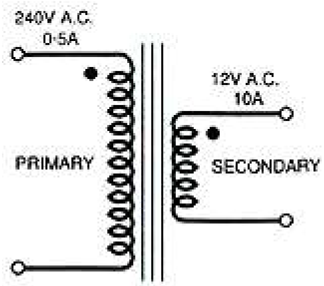
The transformer works on the principle of electromagnetic induction.

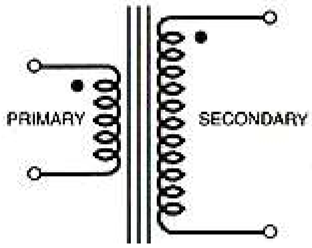


When the primary winding is connected to an AC source, an exciting current flows through the winding. As the current is alternating, it will produce an alternating flux in the core which will be linked by both the primary and secondary windings. The induced emf in the primary winding (E_1) is almost equal to the applied voltage V1 and will oppose the applied voltage. The induced emf in the secondary winding (E_2) can be utilized to deliver power to any load connected across the secondary. Thus power is transferred from the primary to the secondary circuit by electromagnetic induction.

The flux in the core will alternate at the same frequency as the same frequency of the supply voltage. The frequency of induced emf in secondary is the same as that of the supply voltage. The magnitude of the emf induced in the secondary winding will depend upon its number of turns.

In a transformer, if the number of turns in the secondary winding is less than those in the primary winding, it is called a step down transformer, when the number of turns in the secondary winding is higher than the primary winding, it is called a step up transformer.





2.4 TYPES OF TRANSFORMERS

Transformers are classified on the basis of

Construction

1. Core type transformer
2. Shell type transformer
3. Berry type transformer

Duty they perform

1. Power transformer - for transmission and distribution purposes
2. Current transformer - Instrument transformers
3. Potential transformer - Instrument transformers

Input supply

1. Single phase transformer
2. Three phase transformer
    a. Star – Star
    b. Star – Delta
    c. Delta – Delta
    d. Delta – Star

e. Open delta

f. Scott connection

Voltage output

1. Step down transformer (higher to lower)
2. Step up transformer (lower to higher)
3. Auto transformer (variable from 0 to rated value)

Cooling

1. Duct type transformer (Air natural or Air blast)
2. Oil immersed
   a. Self cooled
   b. Forced air cooled
   c. Water cooled
   d. Forced oil cooled

Application

1. Welding transformer
2. Furnace transformer

2.5 EMF EQUATION OF TRANSFORMER

Let

N_1 – Number of primary turns

N_2 - Number of secondary turns

Φ_m – Maximum value of the flux in the core in wb

B_m - Maximum value of the flux density in the core in wb/m^2

A – Area of the core in m^2

F – Frequency of the AC supply in Hz

V_1 – Supply voltage across primary in volts

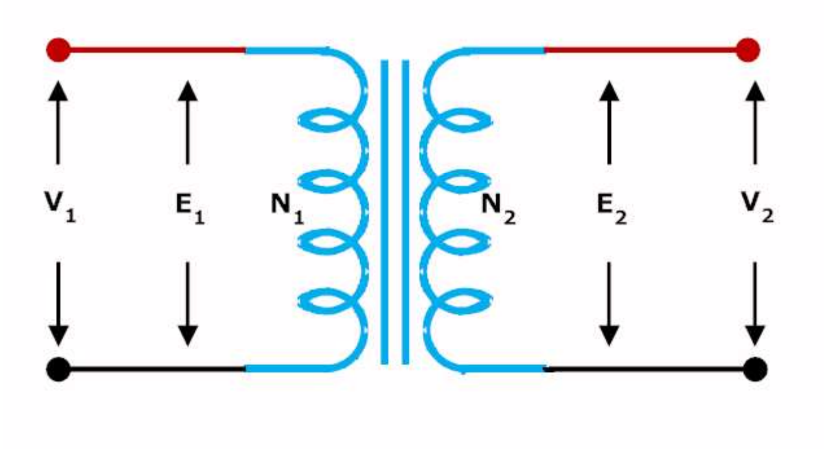
V_2 – Terminal voltage across secondary in volts

I_1 – Full load primary current in amperes

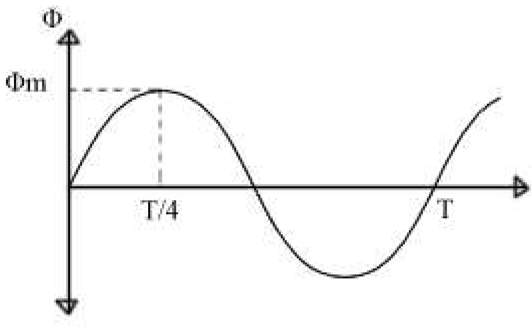
I_2– Full load secondary current in amperes

E_1 – EMF induced in the primary in volts

E_2 - EMF induced in the secondary in volts



Since supply voltage is alternating in nature, the flux established is also an alternating one. The flux is attaining its maximum value in one quarter of the cycle i.e., T/4 sec where 'T' is the time period in second.



We know that, $T = \frac{1}{f}$, where 'f' is the frequency in Hz.

According to Faraday's law,

$$e \; \alpha \; \frac{d\phi}{dt} = \frac{\phi_m}{1/4f}$$

The average value of induced emf / turn = $4f\Phi_m$

Form factor = Rms value / Average value = 1.11 (Since Φ_m is sinusoidal)

Rms value = Form factor × Average value

Rms value of induced emf / turn = 1.11 × $4f\Phi_m$ = $4.44f\Phi_m$

Rms value of induced emf in the entire primary winding,

$$E_1 = 4.44f\Phi_m \times N_1$$

or

$$\boxed{E_1 = 4.44fB_m A N_1}$$

Similarly, Rms value of induced emf in the entire secondary winding,

$$E_2 = 4.44f\Phi_m \times N_2$$

or

$$\boxed{E_2 = 4.44fB_m A N_2}$$

2.6 TRANSFORMATION RATIO

For an ideal transformer,

$V_1 = E_1$; $V_2 = E_2$ and $V_1 I_1 = V_2 I_2$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} \; ; \; \frac{E_2}{E_1} = \frac{I_1}{I_2}$$

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

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

Note:

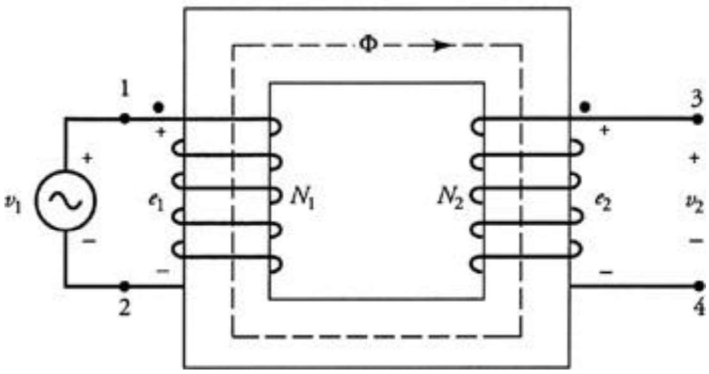
- If N2 >N1, i.e., K>1, then transformer is a step up transformer.
- If N2<N1, i.e., K<1, then transformer is a step down transformer.

Voltage ratio $= \frac{E_2}{E_1} = K$

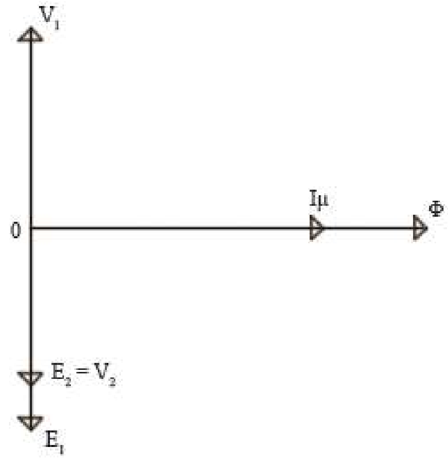
Current ratio $= \frac{I_2}{I_1} = \frac{1}{K}$

2.7 IDEAL TRANSFORMER

100% efficient or no loss transformer is called ideal transformer. It consists of purely inductive coil and loss free core. Windings are wound on a core.

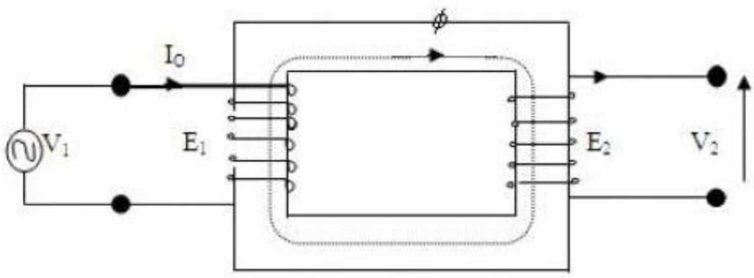


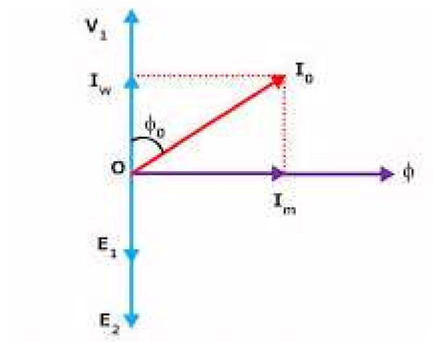
Here the ideal transformer secondary is open. The AC supply is connected to the primary winding. A current flows through the primary winding. This current is called magnetizing current. It is denoted as I_μ. This current is mainly used to magnetise the core. The value of magnetizing current is small. It is lagging V_1 by 90^o. the current I_μ produces an alternating flux Φ. I_μ and Φ are inphase. This changing flux is linking with primary and secondary windings. Due to the alternating flux, a self induced emf is produced in the primary winding. It is denoted as E_1 and equal to and in opposition to V_1. It is known as counter emf or back emf of the primary winding. Similarly, an induced emf E_2 is produced in the secondary winding, because the alternating flux is linking with secondary winding. This emf is known as mutually induced emf. This emf E_2 is in opposition to V_1 and its magnitude is proportional to the rate of change of flux and number of secondary turns.



2.8 PRACTICAL TRANSFORMER ON NO-LOAD

If the primary winding is connected to an alternating voltage and secondary winding is left open, then the transformer is said to be on no load.





Let the supply be V_1 volts. This causes an alternating current to flow through the primary. Since secondary is open, this current is called no load primary current (I_o). This I_o establishes a flux 'Φ' weber in the core. Thus I_o is not at 90^o behind V_1, but lags it by an angle $\Phi_o<90^o$. No load input power, $P_o = V_1 I_o \cos\Phi_o$. I_o has two components.

1. Active or working or iron loss or wattfull component (I_w), which is inphase with V_1.

$$I_w = I_o \cos\Phi_o$$

Where, $\cos\Phi_o$ – no load power factor

2. Reactive or magnetizing or wattles component (I_μ), which is in quadrature with V_1.

$$I_\mu = I_o \sin\Phi_o$$

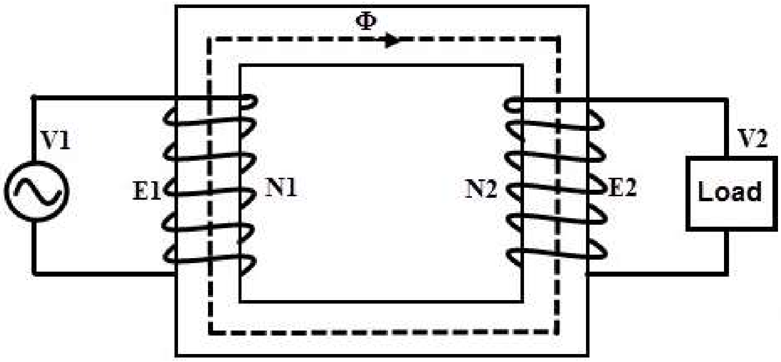
$$I_o = \sqrt{I_w^{\ 2} + I_\mu^{\ 2}}$$

From the above discussion, the following points are noted.

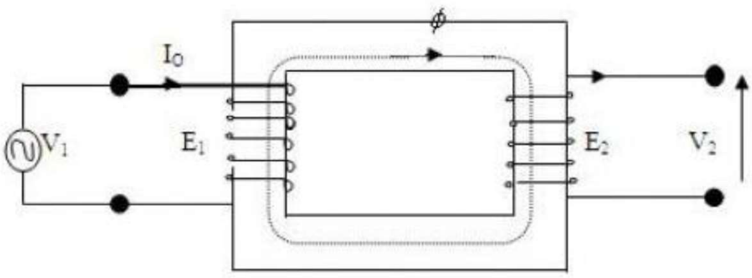
1. The no load primary current Io is very small as compared to the full load primary current.
2. As Io is very small, the no load primary copper loss is negligible this no load input power is practically equal to the iron or core loss of the transformer.

2.9 TRANSFORMER ON LOAD

When the secondary winding is connected to a load, then the transformer is said to be on load. Due to this load condition, the secondary current I_2 is flowing through the load.



The phase angle between V_2 and I_2 depends on the type of load. When the load is resistive I_2 will be inphase with V_2. When the load is inductive I_2 will be lagging V_2 and when the load is capacitive I_2 will be leading V_2. Here the primary winding draws no-load current I_o. This I_o sets up flux Φ.



The secondary current I_2 produces flux Φ_2. This flux Φ_2 opposes the no load flux Φ and decreases the no load flux. Due to this, induced emf E_1 is reduced and V_1 dominates over E_1 and thus causes additional current I_2' to flow through the primary. I_2' is also known as load component of primary current. This current is in antiphase with I_2. I_2' establishes a flux Φ_2'. This flux Φ_2' is equal in magnitude but in opposite direction of Φ_2. Hence Φ_2' and Φ_2 cancel each other.

Thus when the transformer is loaded,

1. The flux passing through the core is same as that at no load i.e., flux is constant at no load as well as loaded condition. That is why transformer is also called a constant flux apparatus.

2. The total primary current, I_1 will be vector sum of I_o and I_2'.

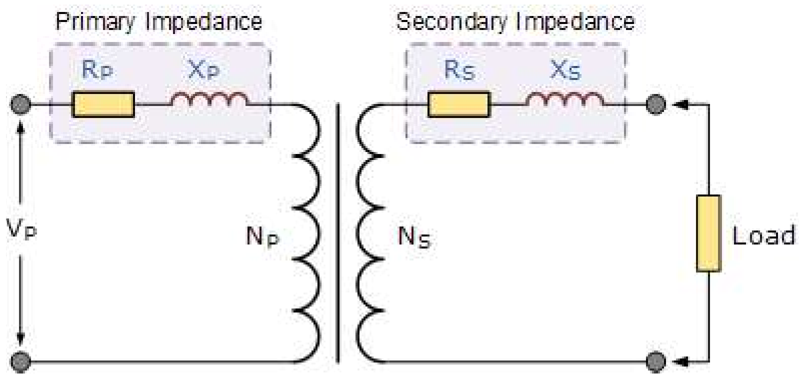
Transformer winding resistance

In the practical transformer, the windings have some resistances. The primary winding has primary resistance. It is denoted as R_1. Similarly the secondary winding has secondary resistance. It is denoted as R_2.

Transformer winding leakage reactance

In practice, all the flux generated by the primary winding does not link with the secondary winding. Some part of the flux passes through air rather than around the core. This flux is called the primary leakage flux. It is denoted as Φ_{L1}. The primary leakage reactance is denoted as X_1. Similarly, a leakage flux is set up in the secondary winding. This flux is called the secondary leakage flux. It is denoted as Φ_{L2}. The secondary leakage reactance is denoted as X_2.

Vector diagram of transformer on load



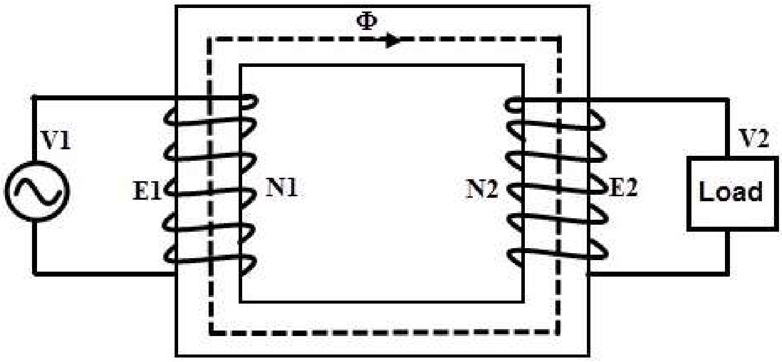
Consider two cases.

1. When such a transformer is assumed to have no winding resistances and leakage reactances.

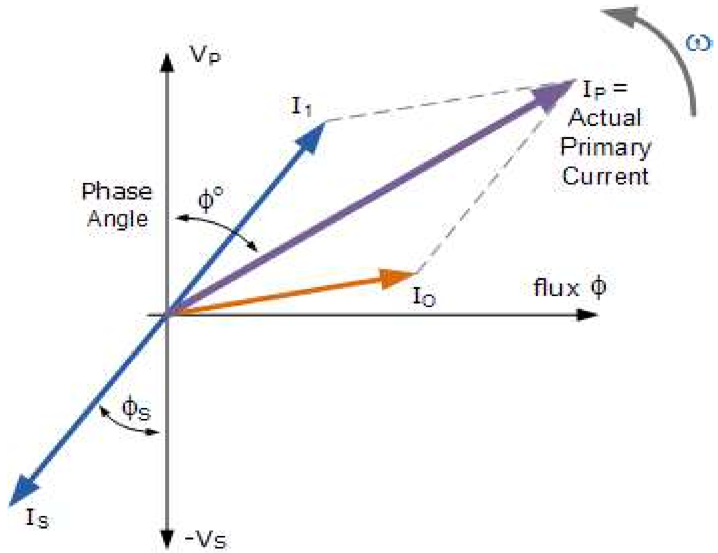
2. When the transformer has winding resistances and leakage reactances.

Case (i)

No winding resistances and leakage reactances (R_1, R_2, X_1, X_2 neglected)



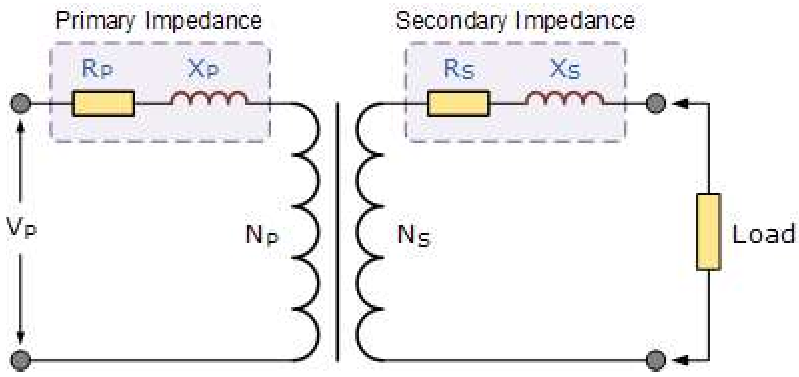
Vector diagram



Lagging power factor

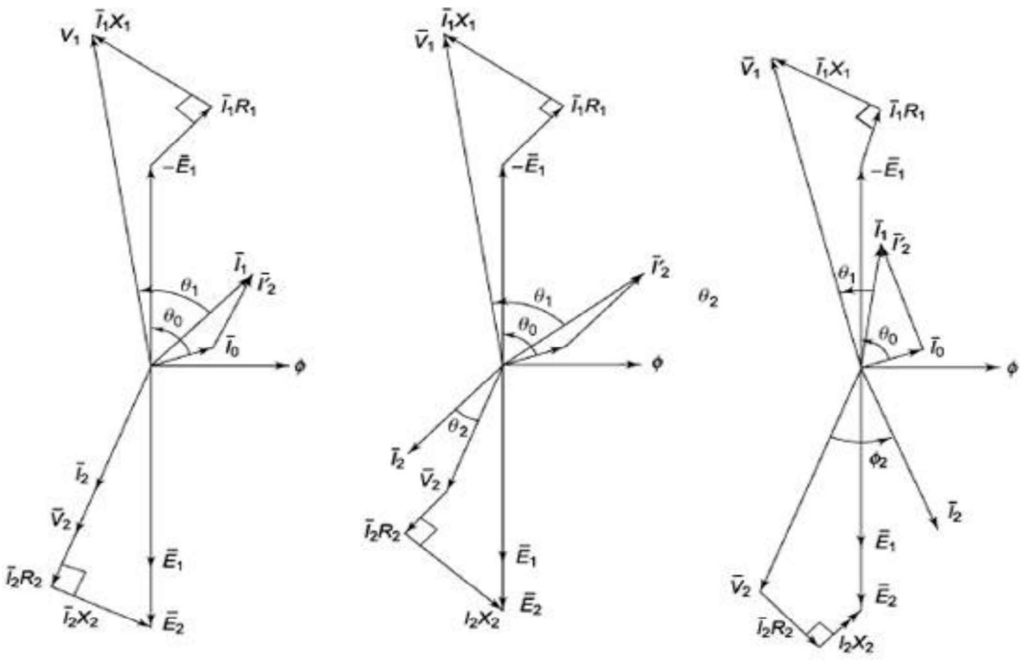
Case (ii)

Transformer with resistances and leakage reactances



Consider R_1, R_2, X_1 and X_2. Practical transformer having winding resistances and leakage reactances. Input voltage is applied to the primary winding. Current I_1 is flowing through the primary winding.

Vector diagram



(a) Unity pf (b) Lagging pf (c) Leading pf

2.10 SHIFTING IMPEDANCES IN A TRANSFORMER

The resistance and reactance of the winding can be transferred to the other side by appropriately using the factor K^2.

i) Referred to primary

When secondary resistance or reactance is transferred to the primary, it is divided by K^2. It is then called equivalent secondary resistance and reactance referred to primary and is denoted by R_2' and X_2'.

Equivalent resistance of transformer referred to primary

$$R_{o1} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

Equivalent reactance of transformer referred to primary

$$X_{o1} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$$

Equivalent impedance of transformer referred to primary

$$Z_{o1} = \sqrt{R_{o1}^2 + X_{o1}^2}$$

Figure shows the resistance and reactance of the secondary referred to the primary. Note that secondary now has no resistance and reactance

i) Referred to secondary

When primary resistance and reactance is transferred, it is multiplied by K^2. It is then called equivalent primary resistance and reactance referred to the secondary and is denoted by R_1' and X_1'.

Equivalent resistance of transformer referred to secondary

$$R_{o2} = R_2 + R_1' = R_2 + K^2R_1$$

Equivalent reactance of transformer referred to secondary

$$X_{o2} = X_2 + X_1' = X_2 + K^2X_1$$

Equivalent impedance of transformer referred to secondary

$$Z_{o2} = \sqrt{R_{o2}^{\ 2} + X_{o2}^{\ 2}}$$

Figure shows the resistance and reactance of the primary referred to the secondary. Note that primary now has no resistance and reactance.

2.11 EQUIVALENT CIRCUIT OF A TRANSFORMER

An equivalent circuit is merely a circuit interpretation of the equations which describe the behavior of the system.

Under no load condition, the primary of a transformer draws no load current I_o. It is mainly used to supply the iron loss and to produce the flux in the core. The effect of iron loss is represented by a non-inductive resistance R_o and the magnetizing current is represented by X_o. Both of them are connected in parallel with primary winding. This circuit is known as exciting branch or no-load branch (R_o and X_o). In this equivalent circuit,

R_1, X_1 – Primary winding resistance and reactance in Ω.

R_2, X_2 – Secondary winding resistance and reactance in Ω.

R_o – No-load resistance in Ω.

X_o – No-load reactance in Ω

I_o – No load primary current in A.

I_1 – Full load primary current in A.

I_2 – Full load secondary current in A.

I_2' – Load component of primary current in A.

I_w – Working component.

I_μ – Magnetising component.

E_1– Induced emf in primary winding in V.

E_2– Induced emf in secondary winding in V.

Z_L – Load impedance in Ω

K – Transformation ratio

Equivalent circuit of a transformer referred to primary

If all the secondary parameters are transferred to the primary side, we get the equivalent circuit of a transformer referred to primary. Note that when secondary parameters are referred to primary, resistances and reactances are divided by K^2, voltages are divided by K and currents are multiplied by K. this circuit is called the exact equivalent circuit of a transformer.

$$R_2' = \frac{R_2}{K^2}$$

$$X_2' = \frac{X_2}{K^2}$$

$$I_2' = KI_2$$

$$Z_L' = \frac{Z_L}{K^2}$$

$$V_2' = \frac{V_2}{K}$$

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

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

Approximate equivalent circuit

The no load current Io is only 1-3% of rated primary current. So I_2' is practically equal to I_1. Due to this, the equivalent circuit can be simplified by transferring the exciting branch (R_o and X_o) to the left position of the circuit. This circuit is known as approximate equivalent circuit of the transformer.

$$R_{o1} = R_1 + R_2'$$

$$X_{o1} = X_1 + X_2'$$

$$Z_{o1} = \sqrt{R_{o1}^2 + X_{o1}^2}$$

Similarly, the parameters referred to secondary are,

$R_{o2} = R_2 + R_1' = R_2 + K^2R_1$

$X_{o2} = X_2 + X_1' = X_2 + K^2X_1$

$Z_{o2} = \sqrt{R_{o2}^2 + X_{o2}^2}$

2.12 VOLTAGE REGULATION OF A TRANSFORMER

The regulation of a transformer is defined as reduction in magnitude of the terminal voltage due to load, with respect to the no load terminal voltage.

$$\% \text{ regulation} = \frac{|V2onnoload| - |V2whenloaded|}{|V2onnoload|} \times 100$$

For an ideal transformer, regulation is 0% since voltage drops, due to R_1, X_1, R_2, X_2 are negligible.

Lagging power factor

Voltage regulation is given by,

$$\% \text{ regulation} = \frac{I_1 R_{o1} \cos\phi + I_1 X_{o1} \sin\phi}{V_1} \times 100$$

Leading power factor

Voltage regulation is given by,

$$\% \text{ regulation} = \frac{I_1 R_{o1} \cos\phi - I_1 X_{o1} \sin\phi}{V_1} \times 100$$

Unity power factor

Voltage regulation is given by,

$$\% \text{ regulation} = \frac{I_1 R_{o1}}{V_1} \times 100$$

2.13 RATING OF A TRANSFORMER

The copper loss depends on current and iron loss depends upon voltage. Hence the total loss in a transformer depends upon volt-ampere (VA) only an not on the phase angle between voltage and current i.e., it is independent of load power factor. That is why the rating is given in KVA and not in KW.

2.14 APPLICATIONS OF TRANSFORMER

Transformers are used in,

- Transmission and distribution
- Radio and TV circuits, telephone circuits, control and instrumentation circuits.

2.15 LOSSES IN A TRANSFORMER

In any transformer, there are no friction or windage losses. The losses occuring are,

1. Core or iron loss
2. Copper loss

Core or iron loss

Iron loss is caused by the alternating flux in the core and consists of hysteresis and eddy current loss.

Hysteresis loss, $P_h = K_h \, B_{max}^{1.6} \, f$

Eddy current loss, $P_e = K_e \, B_{max}^{2} \, f^2$

Where,

K_h – Proportionality constant which depends upon the volume and quality of the core material

K_e - Proportionality constant which depends upon the volume and resistivity of the core material

B_{max} – Maximum flux density in the core

f – Frequency of the alternating flux

Both losses depends upon maximum flux density and supply frequency.

Hysteresis loss can be minimized by using steel of high silicon content for the core loss and eddy current loss can be minimized by using very thin laminations of transformer core.

Copper loss

This loss is due to ohmic resistance of the transformer winding. If I_1 and I_2 are the primary and secondary currents respectively and R_1 and R_2 are the respective resistances of the primary and secondary windings, the copper losses occurring in primary and secondary windings will be $I_1^2R_1$ and $I_2^2R_2$ respectively. So total copper losses will be $(I_1^2R_1 + I_2^2R_2)$. These losses vary as the square of the load current.

2.16 EFFICIENCY OF A TRANSFORMER

Transformer efficiency, $\eta = \frac{outputpower}{inputpower}$

$$\eta = \frac{outputpower}{outputpower + losses} = \frac{outputpower}{outputpower + ironlosses + copperlosses}$$

Output power = V_2 I_2 cosΦ

Where,

V_2 – secondary terminal voltage on load

I_2 - secondary current at load

cosΦ – power factor of the load

$$\eta = \frac{nV_2I_2\cos\phi}{nV_2I_2\cos\phi + P_i + n^2P_{cu}} = \frac{nKVA\cos\phi}{nKVA\cos\phi + P_i + n^2P_{cu}}$$

Where,

P_i – Iron loss

P_{cu} – Copper loss

Note:

At full load, n = 1

At half load, n = 1/2

2.17 CONDITION FOR MAXIMUM EFFICIENCY

Output power = V_2 I_2 $\cos\Phi_2$

If R_{o2} is the total resistance of the transformer referred to secondary, then,

Total copper los, $P_{cu} = I_2^2 R_{o2}$

Total losses = $P_i + P_{cu}$

$$\eta = \frac{outputpower}{inputpower} = \frac{outputpower}{outputpower + losses} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}}$$

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{o2}}$$

Dividing both numerator and denominator by I_2,

$$\text{We get, } \eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{o2}}$$

The condition for maximum efficiency is obtained by differentiating the denominator and equating it to zero.

$$\frac{d}{dI_2}(\text{denominator}) = 0$$

$$\frac{d}{dI_2}\left(V_2 I_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{o2} \right) = 0$$

$$\left(0 - \frac{P_i}{I_2^2} + R_{o2} \right) = 0$$

$P_i = I_2^2 R_{o2} = P_{cu}$

Iron loss = copper loss

Or

Constant loss = variable loss

Hence the efficiency of a transformer will be maximum when copper losses are equal to iron losses.

Load current corresponding to maximum efficiency is given by,

$$I_2 = \sqrt{\frac{P_i}{R_{o2}}}$$

Load corresponding to maximum efficiency is given by,

$$= \text{Full load KVA} \times \sqrt{\frac{Ironloss}{Fullloadco\,pperloss}}$$

2.18 ALL DAY (OR) ENERGY EFFICIENCY

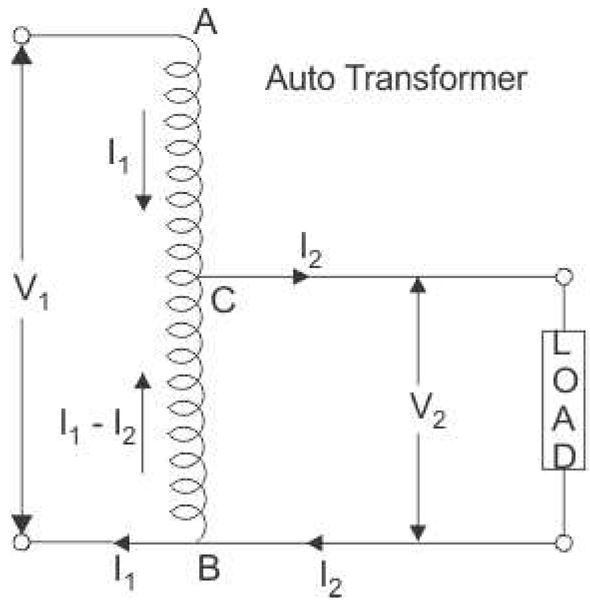
The ratio of the output in kwh to input in kwh of a transformer over a 24 hour period is known as all-day efficiency.

$$\eta_{all\text{-}day} = \frac{kwhoutputi\,n24hours}{kwhinputin\,24hours}$$

2.19 AUTOTRANSFORMER (OR) VARIAC

A transformer in which part of the winding is common to both the primary and secondary is known as an autotransformer.

The autotransformer differs from a conventional two winding transformer in the way in which the primary and secondary are irrealated. In the conventional transformer, the primary and secondary windings are completely insulated from each other but are magnetically linked by a common core. In the autotransformer, the primary and secondary windings are connected electrically as well as magnetically, infact a part of the single continuous winding is common to both primary and secondary.



Advantages

1. Higher efficiency
2. Small size
3. Smaller exciting current
4. Lower cost
5. Better voltage regulation
6. Required less copper

Disadvantages

1. If the ratio of transformation K differs from unity, the economic advantages of auto transformer over two winding transformer decrease.
2. The main disadvantage of an autotransformer is due to the direct electrical connection between low tension and high tension sides. If primary is supplied at high voltage, then an open circuit in the common winding BC, would result in the appearance of dangerously high voltage on the low voltage side. This high voltage may be detrimental to the load and the persons working there. Thus a suitable protection must be provided against such an occurance.

3. The short circuit current in an autotransformer is higher than that in a two winding transformer.

Applications

1. Autotransformers are used for starting of induction motors and synchronous motors.
2. Continuously variable autotransformer finds application in electrical testing laboratories.
3. Autotransformers are used as boosters to increase the voltage in AC feeder.
4. As furnace transformers for getting a convenient supply to suit th furnace winding from 230V AC supply.

PROBLEMS

1. A sinusoidal flux o.o2 wb links with 55 turns of a transformer secondary coil. Calculate the rms value of the induced emf in the secondary. The supply frequency is 50 Hz.
   Given data :

Supply frequency f =50 Hz, No. of secondary turns N_2= 55,

Flux ϕ = 0.02mwb

Maximum flux ϕ_m $= \sqrt{2 \times \phi}$

$= \sqrt{2 \times 0.02}$ = 0.028 wb

To find:

RMS value of induced emf in the secondary (E_2)

Solution:

$$E_2 = 4.44 f \phi_m N_2 = 4.44 \times 50 \times 0.028 \times 55$$

$$\boxed{E_2 = 341.8 \text{ V}}$$

2. The no load current of transformer is 15 A at a power factor of 0.2 when connected to a 460 V, 50 Hz supply. *F the primary winding has 550* turns, Calculate i) The magnetising component of no-load current, ii) The iron loss, iii) The maximum value of the flux on the core.

Given data :

The no-load current I_o = 15 A, Power factor = 0.2, V1 = 460 V

supply frequency f = 50 Hz Primary turns N_1 = 550,

Solution:

i) Magnetising component of no-load current I_μ

$$I_\mu = I_o \sin\phi_o = 15 \times 0.98 = 14.7A$$

ii) Iron loss (W_o) = $V_1 I_o \cos\phi_o = 460 \times 15 \times 0.2 = 1380\,W$

iii) Maximum value of the flux (ϕ_m)

$$E_1 = 4.44 f\phi_m N_1$$

$$\phi_m = \frac{E_1}{4.44 f\ N_1} = \frac{460}{4.44 \times 50 \times 550} - 3.77mwb$$

3. A 220/110 V, 10 kVA transformer has primary winding resistance of 0.25 Ω and a secondary resistance of 0.06 Ω .Determine the primary and secondary current at rated load, the total winding resistance referred to the primary and total winding resistance referred to the secondary.

Given data:

V1 = 220 V, V2 = 110 V, R1 = 0.25 Ω, R2 = 0.06 Ω, rating = 10 kVA

To find:

I_1, I_2, R_{o1}, R_{o2},

Solution:

Primary current at rated load $I_1 = \frac{Transformer\ rating}{V_1} = \frac{10\times10^3}{220} = 45.45\ A$

$I_1 = 45.45\ A$

Secondary current at rated load $I_2 = \frac{Transformer\ rating}{V_2} = \frac{10\times10^3}{110} = 90.90\ A$

$I_2 = 90.90\ A$

Transformation ratio $K = \frac{V_2}{V_1} = \frac{110}{220} = 0.5$

Total winding resistance referred to primary

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{k^2} = 0.25 + \frac{0.06}{0.5^2}$$

$R_{01} = 0.49\ \Omega$

Total winding resistance referred to secondary

$$R_{02} = R_2 + R_1'$$

$$= R_2 + R_1 k^2$$

$$= 0.06 + 0.25 \times 0.5^2$$

$R_{02} = 0.1225\ \Omega$

4. The required no load voltage ratio in a 150 kVA, 50 Hz single phase transformer is 5000/250 V. Find the efficiency at half rated kVA, Unity power factor and also efficiency at full load 0.8 pf lagging if the full load copper losses are 1800 W; core losses are 1500 W.

Given data:

Transformer rating = 150 kVA Supply Frequency = 50 Hz

Primary voltage = 5000 V, Secondary voltage = 5000 V, full load copper loss P_{cufl}= 1800 W core loss P_1 = 1500 W

Solution:

i)Efficiency at half rated kVA, UPF

$$n = 1/2 = 0.5,\ \cos\phi = 1$$

$$\%\eta = \frac{n\ kVA\cos\phi}{n\ kVA\cos\phi + P_1 + n^2 \times P_{cufL}}$$

$$= \frac{\frac{1}{2}\times 150\times 10^3 \times 1}{\frac{1}{2}\times 150\times 10^3 \times 1 + 1500 + \left(\frac{1}{2}\right)^2 \times 1800}$$

$$\%\eta = 97.46\%$$

ii)Full load kVA at $0.8pf, \cos\phi = 0.8$

$$\%\eta = \frac{kVA\cos\phi}{kVA\cos\phi + P_1 + P_{cufL}}$$

$$= \frac{150\times 10^3 \times 0.8}{150\times 10^3 \times 0.8 + 1500 + 1800}\times 100$$

$\%\eta = 97.33\%$

5. A 500 kVA transformer has an iron loss of 500 W and full load copper loss 700 W. Calculate the efficiency at 3/4th full load 0.8 power factor.

Given data:

Transformer rating = 500 kVA, Iron loss $P_1 = 500$ W

Full load copper loss $P_{cufL} = 700$ W, power factor $\cos\phi = 0.8$

Load = 3/4th full load

To find:

Efficiency at 3/4th full load and 0.8 pf

Solution:

$n = ¾ ; \cos\phi = 0.8$

$$\%\eta = \frac{n\, kVA \cos\phi}{n\, kVA \cos\phi + P_1 + n^2 \times P_{cufL}} \times 100$$

$$= \frac{\frac{3}{4}\times 500\times 10^3 \times 0.8}{\frac{3}{4}\times 500\times 10^3\times 0.8 + 500 + \left(\frac{3}{4}\right)^2 700}\times 100 = \frac{300000}{300000+500+393.75}\times 100$$

$\%\eta = 99.7\%$