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Theory and Application of Transformer in Electrical & Electronics circuits

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Abstract:

A transformer is a device that transfers electrical energy from one circuit to another by magnetic coupling without requiring relative motion between its parts. It usually comprises two or more coupled windings, and, in most cases, a core to concentrate magnetic flux. An alternating voltage applied to one winding creates a time-varying magnetic flux in the core, which induces a voltage in the other windings. Varying the relative number of turns between primary and secondary windings determines the ratio of the input and output voltages, thus transforming the voltage by stepping it up or down between circuits.in this paper we studies how transformer working and various application in Electrical and Electronics circuits

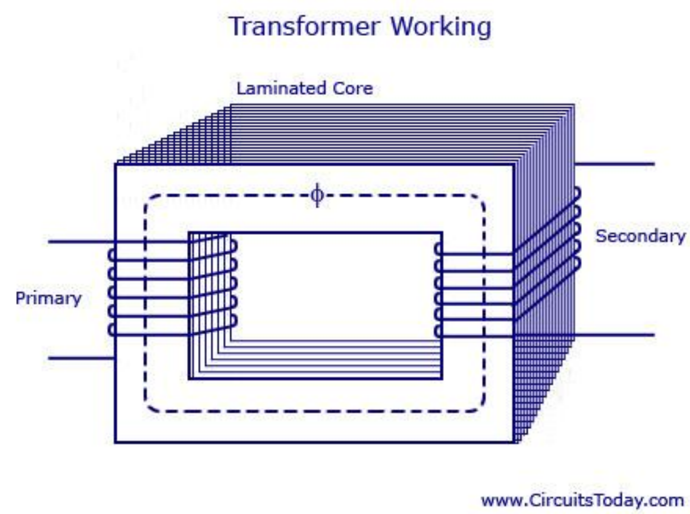
Introduction

Most of the electronic circuits used in Circuitstoday.com have different applications of the transformer. Therefore, it is important to know the working principle, construction and types of transformers used in different analog circuits.1

Transformer – Working Principle

A transformer can be defined as a static device which helps in the transformation of electric power in one circuit to electric power of the same frequency in another circuit. The voltage can be raised or lowered in a circuit, but with a proportional increase or decrease in the current ratings. In this article we will be learning about Transformer basics and working principle

The main principle of operation of a transformer is mutual inductance between two circuits which is linked by a common magnetic flux. A basic transformer consists of two coils that are electrically separate and inductive, but are magnetically linked through a path of reluctance. The working principle of the transformer can be understood from the figure below.



Transformer Working

As shown above the electrical transformer has primary and secondary windings. The core laminations are joined in the form of strips in between the strips you can see that there are some narrow gaps right through the cross-section of the core. These staggered joints are said to be 'imbricated'. Both the coils have high mutual inductance. A mutual electro-motive force is

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induced in the transformer from the alternating flux that is set up in the laminated core, due to the coil that is connected to a source of alternating voltage. Most of the alternating flux developed by this coil is linked with the other coil and 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

$e=M*dI/dt$

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 electromagnetic induction.
4. The two electrical circuits are linked by mutual induction.

Transformer Construction

For the simple construction of a transformer, you must need two coils having mutual inducta1nce and a laminated steel core. The two coils are insulated from each other and from the steel core. The device will also need some suitable container for the assembled core and windings, a medium with which the core and its windings from its container can be insulated.

In order to insulate and to bring out the terminals of the winding from the tank, apt bushings that are made from either porcelain or capacitor type must be used.

In all transformers that are used commercially, the core is made out of transformer sheet steel laminations assembled to provide a continuous magnetic path with minimum of air-gap included. The steel should have high permeability and low hysteresis loss. For this to happen, the steel should be made of high silicon content and must also be heat treated. By effectively laminating the core, the eddy-current losses can be reduced. The lamination can be done with the help of a light coat of core plate varnish or lay an oxide layer on the surface. For a frequency of 50 Hertz, the thickness of the lamination varies from 0.35mm to 0.5mm for a frequency of 25 Hertz.

Types of Transformers

The types of transformers differ in the manner in which the primary and secondary coils are provided around the laminated steel core. According to the design, transformers can be classified into two:

1. Core- Type Transformer

In core-type transformer, the windings are given to a considerable part of the core. The coils used for this transformer are form-wound and are of cylindrical type. Such a type of transformer can be applicable for small sized and large sized transformers. In the small sized type, the core will be rectangular in shape and the coils used are cylindrical. The figure below shows the large sized type. You can see that the round or

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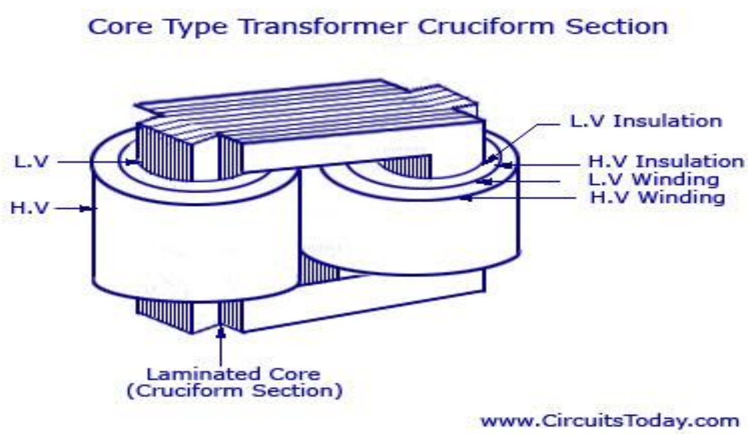
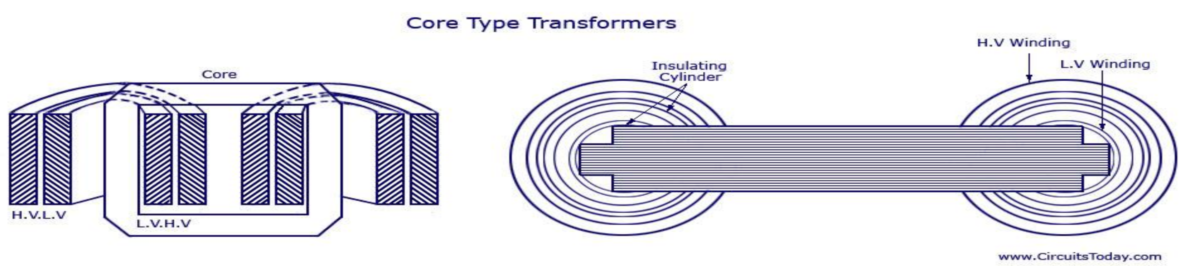
cylindrical coils are wound in such a way as to fit over a cruciform core section. In the case of circular cylindrical coils, they have a fair advantage of having good mechanical strength. The cylindrical coils will have different layers and each layer will be insulated from the other with the help of materials like paper, cloth, micarta board and so on. The general arrangement of the core-type transformer with respect to the core is shown below. Both low-voltage (LV) and high voltage (HV) windings are shown.



Core Type Transformer Cruciform Section



Core Type Transformers

The low voltage windings are placed nearer to the core as it is the easiest to insulate. The effective core area of the transformer can be reduced with the use of laminations and insulation.

2. Shell-Type Transformer

In shell-type transformers the core surrounds a considerable portion of the windings. The comparison is shown in the figure below.

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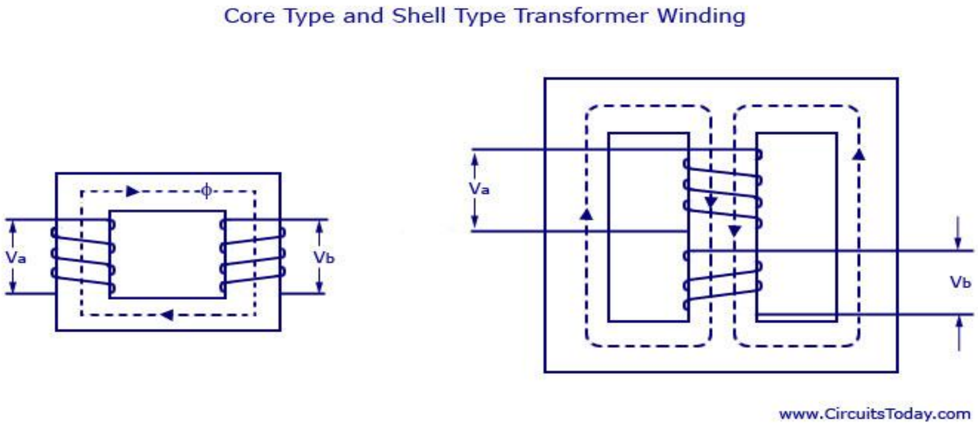
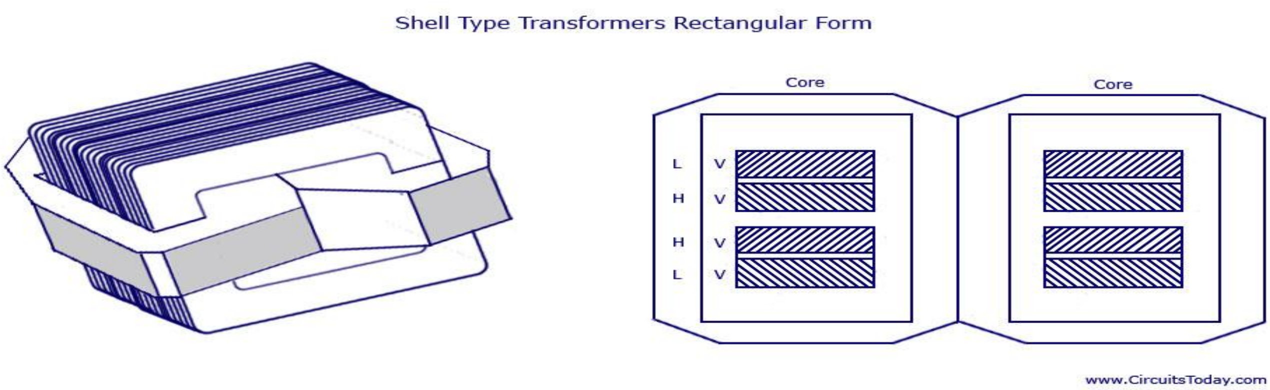
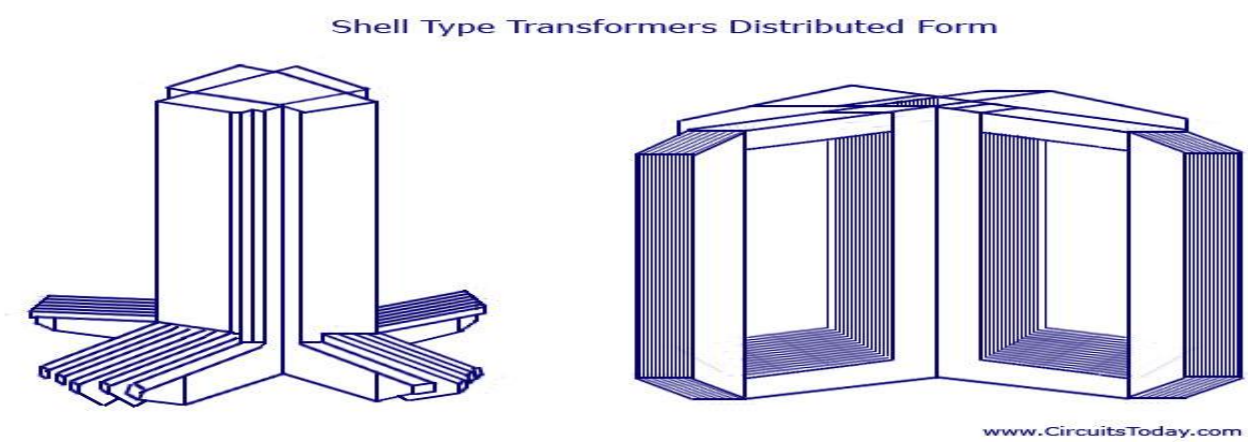


Core Type and Shell Type Transformer Winding

The coils are form-wound but are multi layer disc type usually wound in the form of pancakes. Paper is used to insulate the different layers of the multi-layer discs. The whole winding consists of discs stacked with insulation spaces between the coils. These insulation spaces form the horizontal cooling and insulating ducts. Such a transformer may have the shape of a simple rectangle or may also have a distributed form. Both designs are shown in the figure below:



Shell Type Transformers Rectangular Form



Shell Type Transformers Distributed Form

A strong rigid mechanical bracing must be given to the cores and coils of the transformers. This will help in minimizing the movement of the device and also prevents the device from getting any insulation damage. A transformer with good bracing will not produce any humming noise during its working and will also reduce vibration.

A special housing platform must be provided for transformers. Usually, the device is placed in tightly-fitted sheet-metal tanks filled with special insulating oil. This oil is needed to circulate through the device and cool the coils. It is also responsible for providing the additional insulation for the device when it is left in the air.

There may be cases when the smooth tank surface will not be able to provide the needed cooling area. In such cases, the sides of the tank are corrugated or assembled with radiators on the sides of the device. The oil used for cooling purpose must be absolutely free from alkalis, sulphur and most importantly moisture. Even a small amount of moistures in the oil will cause a significant change in the insulating property of the device, as it lessens the dielectric strength of the oil to a great extent. Mathematically speaking, the presence of about 8 parts of water in 1 million reduces the insulating quality of the oil to a value that is not considered standard for use. Thus, the tanks are protected by sealing them air-tight in smaller units. When large transformers are used, the air tight method is practically difficult to implement. In such cases, chambers are provided for the oil to expand and contract as its temperature increases and decreases. These breathers form a barrier and resists the atmospheric moisture from contact with oil. Special care must also be taken to avoid sledging. Sledging occurs when oil decomposes due to over exposure to oxygen during heating. It results in the formation of large deposits of dark and heavy matter that clogs the cooling ducts in the transformer.

The quality, durability and handling of these insulating materials decide the life of the transformer. All the transformer leads are brought out of their cases through suitable bushings. There are many designs of these, their size and construction depending on the voltage of the leads. Porcelain bushings may be used to insulate the leads, for transformers that are used in moderate voltages. Oil-filled or capacitive-type bushings are used for high voltage transformers.

The selection between the core and shell type is made by comparing the cost because similar characteristics can be obtained from both types. Most manufacturers prefer to use shell-type transformers for high-voltage applications or for multi-winding design. When compared to a core type, the shell type has a longer mean length of coil turn. Other parameters that are compared for the selection of transformer type are voltage rating, kilo-volt ampere rating, weight, insulation stress, heat distribution and so on.

Transformers can also be classified according to the type of cooling employed. The different types according to these classifications are:

1. Oil Filled Self-Cooled Type

Oil filled self cooled type uses small and medium-sized distribution transformers. The assembled windings and core of such transformers are mounted in a welded, oil-tight steel tanks provided with a steel cover. The tank is filled with purified, high quality insulating oil as soon as the core is put back at its proper place. The oil helps in transferring the heat from the core and the windings to the case from where it is radiated out to the surroundings. For smaller sized transformers the tanks are usually smooth surfaced, but for large size transformers a greater heat radiation area is needed, and that too without disturbing the cubical capacity of the tank. This is achieved by frequently corrugating the cases. Still larger sizes are provided with radiation or pipes.

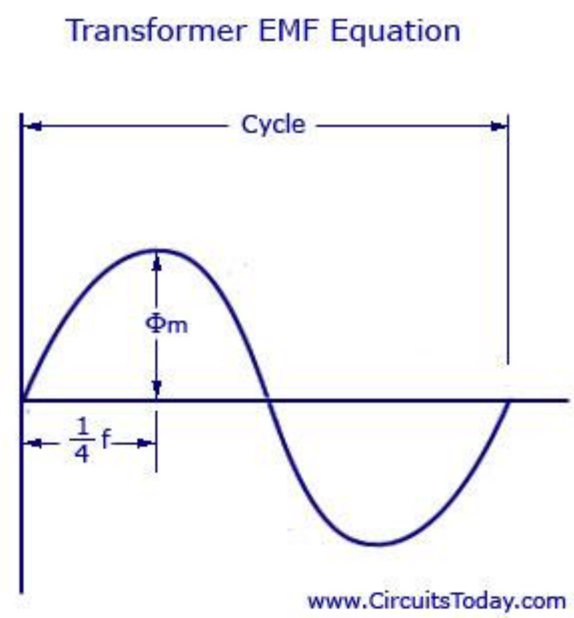
2. Oil Filled Water Cooled Type

This type is used for much more economic construction of large transformers, as the above told self cooled method is very expensive. The same method is used here as well- the windings and the core are immersed in the oil. The only difference is that a cooling coil is mounted near the surface of the oil, through which cold water keeps circulating. This water carries the heat from the device. This design is usually implemented on transformers that are used in high voltage transmission lines. The biggest advantage of such a design is that such transformers do not require housing other than their own. This reduces the costs by a huge amount. Another advantage is that the maintenance and inspection of this type is only needed once or twice in a year.

3. Air Blast Type

This type is used for transformers that use voltages below 25,000 volts. The transformer is housed in a thin sheet metal box open at both ends through which air is blown from the bottom to the top.

E.M.F Equation of a Transformer



Transformer EMF Equation

Let,

N_A = Number of turns in primary

N_B = Number of turns in secondary

$Ø_{max}$ = Maximum flux in the core in webers = B_{max} X A

f = Frequency of alternating current input in hertz (H_Z)

As shown in figure above, the core flux increases from its zero value to maximum value $Ø_{max}$ in one quarter of the cycle , that is in ¼ frequency second.

Therefore, average rate of change of flux = $Ø_{max}$/ ¼ f = 4f $Ø_{max}$Wb/s

Now, rate of change of flux per turn means induced electro motive force in volts.

Therefore, average electro-motive force induced/turn = 4f $Ø_{max}$volt

If flux Ø varies sinusoidally, then r.m.s value of induced e.m.f is obtained by multiplying the average value with form factor.1

Form Factor = r.m.s. value/average value = 1.11

Therefore, r.m.s value of e.m.f/turn = 1.11 X 4f $Ø_{max}$ = 4.44f $Ø_{max}$

Now, r.m.s value of induced e.m.f in the whole of primary winding

= (induced e.m.f./turn) X Number of primary turns

Therefore,

$E_A = 4.44f N_A Ø_{max} = 4.44f N_A B_m A$

Similarly, r.m.s value of induced e.m.f in secondary is

$E_B = 4.44f N_B Ø_{max} = 4.44f N_B B_m A$

In an ideal transformer on no load,

$V_A = E_A$ and $V_B = E_B$, where V_B is the terminal voltage

Voltage Transformation Ratio (K)

From the above equations we get

$E_B / E_A = V_B / V_A = N_B / N_A = K$

This constant K is known as voltage transformation ratio.

(1) If $N_B > N_A$, that is $K>1$, then transformer is called step-up transformer.

(2) If $N_B < 1$, that is $K<1$, then transformer is known as step-down transformer.

Again for an ideal transformer,

Input V_A = output V_A

$V_A I_A = V_B I_B$

Or, $I_B / I_A = V_A / V_B = 1/K$

Hence, currents are in the inverse ratio of the (voltage) transformation ratio.

Uses and Application of Transformer

The most important uses and application of Transformer are:

It can rise or lower the level of level of Voltage or Current (when voltage increases, current decreases and vice versa because P =V x I, and Power is same) in an AC Circuit.

It can increase or decrease the value of capacitor, an inductor or resistance in an AC circuit. It can thus act as an impedance transferring device.

It can be used to prevent DC from passing from one circuit to the other.

it can isolate two circuits electrically.

Transformer is the main reason to transmit and distribute power in AC instead of DC, because Transformer not work on DC so there are too difficulties to transmit power in DC. in the DC Transition and distribution, the level of voltage Step up by Buck and Boost Converter but it is too costly and not suitable economically.

The main application of Transformer is to Step up (Increase) or Step down (Decrease) the level of Voltage.

in other words, Increase or decries the level of Current, while Power must be same.

Other Uses and application of Transformer:

It step up the level of voltage at generation side before transmission and distribution.

in distribution side, for commercial or domestic use of electricity, transformer step down (decries) the level of voltage for example form 11kV to 220 V single phase and 440 V three phase.

The Current Transformer and Potential Transformer also used power system and in the industry. Also, it is used for impedance matching. So these were the simple uses and application of transformer.

Conclusions:

1. The output voltage of the transformer across the secondary coil dependence the ratio (Ns/Np) with respect to the input voltage

2. The output voltage of the transformer across the secondary coil depends upon the ratio Ns/Np) with respect to the input voltage

3. There is a loss of power input and output coil of transformer

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