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EVOLUTIONS IN TRANSFORMER TECHNOLOGY

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ABSTRACT

A variety of types of electrical transformer are made for different purposes. Despite their design differences, the various types employ the same basic principle as discovered in 1831 by Michael Faraday, and share several key functional parts.

Index Terms: Transformers, Faraday's Laws, Manufacturing Process, Assembly

Transformer development timeline:

1830s - Joseph Henry and Michael Faraday work with electromagnets and discover the property of induction independently on separate continents.

1836 - Rev. Nicholas Callan of Maynooth College, Ireland invents the induction coil

1876 - Pavel Yablochkov uses induction coils in his lighting system

1878 -1883 - The Ganz Company (Budapest, Hungary) uses induction coils in their lighting systems with AC incandescent systems. This is the first appearance and use of the toroidal shaped transformer.

1881 - Charles F. Brush of the Brush Electric Company in Cleveland, Ohio develops his own design of transformer (source: Brush Transformers Inc.)

1880-1882 - Sebastian Ziani de Ferranti (English born with an Italian parent) designs one of the earliest AC power systems with William Thomson (Lord Kelvin). He creates an early transformer. Gaulard and Gibbs later design a similar transformer and loose the patent suit in English court to

Ferranti.

1884 - In Hungary Ottó Bláthy had suggested the use of closed-cores, Károly Zipernowsky the use of shunt connections, andMiksa Déri had performed the experiments. They found the major flaw of the Gaulard-Gibbs system were successful in making a high voltage circuit work using transformers in parallel. There design was a toroidal shape which made it expensive to make. Wires could not be easily wrapped around it by machine during the manufacturing process.

1884 - Use of Lucien Gaulard's transformer system (a series system) in the first large exposition of AC power in Turin, Italy. This event caught the eye of William Stanley, working for Westinghouse. Westinghouse bought rights to the Gaulard and Gibbs Transformer design. The 25 mile long transmission line illuminated arc lights, incandescent lights, and powered a railway. Gaulard won an award from the Italian government of 10,000 francs.

1885 - George Westinghouse orders a Siemens alternator (AC generator) and a Gaulard and Gibbs transformer. Stanley begin experimenting with this system.

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1885 - William Stanley makes the transformer more practical due to some design changes: "Stanley's first patented design was for induction coils with single cores of soft iron and adjustable gaps to regulate the EMF present in the secondary winding. This design was first used commercially in the USA in 1886". William Stanley explains to Franklin L. Pope (advisor to Westinghouse and patent lawyer) that is design was salable and a great improvement. Pope disagrees but Westinghouse decides to trust Stanley anyway.

1886 - William Stanley uses his transformers in the electrification of downtown Great Barrington, MA.This was the first demonstration of a full AC power distribution system using step and step down transformers.

Later 1880s - Later on Albert Schmid improved Stanley's design, extending the E shaped plates to meet a central projection.

1889 -Russian-born engineer Mikhail Dolivo-Dobrovolsky developed the first three-phase transformer.

Some of the popularly known transformers are as follows:

Dry Isolation Auto Transformer:

An isolation transformer is a special type of impedance matching transformer that is used to couple telephone equipment to electronic equipment. It is made with a primary winding that may or may not have a DC voltage impressed upon it.

Cast Resin Transformer:

Cast-resin power transformers encase the windings in epoxy resin. These transformers simplify installation since they are dry, without cooling oil, and so require no fire-proof vault for indoor installations.

K- Factor Transformer:

These specialized transformers feature conductors capable of carrying the harmonic currents of non-linear loads without exceeding the temperature rating of the insulation system.

Rectifier Transformer:

Rectifier Transformers are combined with a diode or thyristor rectifier. The applications range from very large aluminum electrolyses to various medium-size operations.

Ferroresonant transformer:

Ferroresonant transformers are a special type of laminated transformer which provides a regulated output. These are sometimes known simply as "ferros", or "CVTs" (constant voltage transformers).

Toroidal Transformer:

Toroidal transformers are passive electronic components, typically consisting of a circular ring-shaped magnetic core of high magnetic permeability material such as iron powder or ferrite, around which wire is coiled to make an inductor.

Oil Type Transformer:

Oil cooled Transformer is handling higher power, or having a high duty or high voltages and generate high heat. In order to cool the transformer, we use oil as the coolant.

TRANSFORMER

TRANSFORMER- is one of oldest innovations in Electrical Engineering. It is an essential device in every electrical network circuitry. A transformer is a static electrical device that transfers electrical energy between two or more circuits through electromagnetic induction. It transforms power from one circuit to another without changing its frequency but may be in different voltage level. A transformer consists of two electrically isolated coils and operates on the basic principle as discovered in 1831 by Michael Faraday, Faraday's principal of “mutual induction”, in which an EMF is induced in the transformers secondary coil by the magnetic flux generated by the voltages and currents flowing in the primary coil winding. The working principles of transformer are very simple. Mutual induction between two or more winding is responsible for transformation action in an electrical transformer.

Faraday's Laws of Electromagnetic Induction

According to these Faraday's laws, "Rate of change of flux linkage with respect to time is directly proportional to the induced EMF in a conductor or coil".

$E = N\, d\phi / dt$

Where

E = Induced EMF

N = the number of turns

$d\phi$ = Change in flux

dt = Change in time

Main Constructional Parts of Transformer

The three main parts of a transformer are:

Primary Winding of Transformer- Which produces magnetic flux when it is connected to electrical source.

Magnetic Core of Transformer- The magnetic flux produced by the primary winding, that will pass through this low reluctance path linked with secondary winding and create a closed magnetic circuit.

Secondary Winding of Transformer- The flux, produced by primary winding, passes through the core, will link with the secondary winding. This winding also wounds on the same core and gives the desired output of the transformer.

Types of Transformers

Transformers are constructed so that their characteristics match the application for which they are intended. There are several transformer types used in the electrical power system for different purposes, like in power generation, distribution and transmission and utilization of electrical power. The transformers are classified based on:

- voltage levels
- Core medium used
- winding arrangements
- usage
- installation place

Thus there are different types of transformers like the step up and step down Transformer, Distribution Transformer, Potential Transformer, Power Transformer, 1-ϕ and 3-ϕ transformer, Auto transformer, etc.

Transformers Based on Voltage Levels

These are the most commonly used transformer types for all the applications. Depends upon the voltage ratios from primary to secondary windings, the transformers are classified as step-up and step-down transformers.

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 as compared to primary windings as shown in the figure. In power plant, this transformer is used as connecting transformer of the generator to the grid.

Step-Down Transformer

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

Transformer Based on the 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 between primary and secondary windings is through the air. Compared to iron core the mutual inductance is less in air core, i.e. 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 transformer.

Iron Core Transformer

Both the primary and secondary windings are wound on multiple iron plate bunches 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 is high compared to the air core type transformer.

Transformers Based on Winding Arrangement

Auto-transformer

Standard transformers have primary and secondary windings placed in two different directions, but in autotransformer windings, the primary and the secondary windings are connected to each other in series both physically and magnetically as shown in the figure below. On a single common coil which forms both primary and secondary winding in which voltage is varied according to the position of secondary tapping on the body of the coil windings.

Transformers Based on Usage

According to the necessity, these are classified as the power transformer, distribution transformer measuring transformer, and protection transformer.

Power Transformer

The power transformers are big in size. They are suitable for high voltage (greater than 33KV) power transfer applications. It used in power generation stations and Transmission substation. It has high insulation level.

Distribution Transformer

In order to distribute the power generated from the power generation plant to remote locations, these transformers are used. Basically, it is used for the distribution of electrical energy at low voltage is less than 33KV in industrial purpose and 440v-220v in domestic purpose. It works at low efficiency at 50-70. Has a smaller size, easy installation, low magnetic losses. It is not always fully loaded.

Measurement Transformer

This kind of transformers is used to measure the electrical quantity like voltage, current, power, etc. These are classified as potential transformers, current transformers etc.

Protection Transformers

This type of transformers is used in component protection purpose. The major difference between measuring transformers and protection transformers is the accuracy that means that the protection transformers should be accurate as compared to measuring transformers.

Transformers Based on the Place of Use

These are classified as indoor and outdoor transformers. Indoor transformers are covered with a proper roof like as in the process industry. The outdoor transformers are nothing but distribution type transformers

Requirements of various divisions in transformer Manufacturing Company

Warehouse:

All the inventories should be stored in warehouse facility with systematic-controlled measures to maintain incoming and outgoing of material as per the ISO Norms.

Design Potential:

Manufacturer should be committed to meet the customer's requirements, and so design of each and every product is given individually proper attention to the specification given by the client.

Engineering Section:

This section should be dedicated towards achieving target production with full accuracy and quality; the engineering sections have got all modern machines in the workshop.

Windings:

The windings are manufactured from electrolytic high conductivity copper/aluminum conductors covering with suitable insulation and normally consist of one or a combination of the three main types of coils viz.

Quality Assurance:

Quality has been the paramount objective since our inception and hence we maintain a stringent quality policy for protecting customer's integrity with us.

Quality Assurance Test:

Manufacturer should conduct various tests like: Measurement of Winding Resistance, Measurement of Core Resistance Test, Measurement of Voltage Ratio, Impedance Voltage/short-circuit Impedance, High voltage Flash Test, Insulation resistance Test.

MANUFACTURING PROCESS OF TRANSFORMER

Windings:

L.V and H.V windings of the coil are made.

- Raw Material

A. L. winding

i. Paper insulated flat copper wire (For 10KVA to 50KVA)

ii. Copper foil (For 100KVA and above)

B. for H.V. winding

i. Enamel copper wire (For 10KVA to 200KVA)

ii. Paper insulated flat copper wire (400KVA and above)

- Type of Insulation Material

iii. Diamond dotted paper (For insulation between layers of windings)

iv. Press pan sheet (For end collars)

v. Creep paper pipe (For insulation of terminal of tap changer)

vi. Craft paper (Used for insulation in disc winding) thermo ducts

- Types of Windings

vii. Disc winding

viii. Packet winding

ix. Layer winding

Foil winding File and layer winding are used in L. V. File, packet and disc winding is used in H. V. Disc and packet winding are easy to repair.

- Machines Used

i. Slitting machine is used for the cutting of bundles of insulation material.

ii. H.V P.I copper winders are used for the winding of P.I copper wire for transformers of the rating 400KVA and above.

iii. H.V enamel copper winders are used for the winding of enamel copper wire for the transformer of the rating 10KVA to 400KVA.

- Standard Ratings of WAPDA

Standard ratings of WAPDA are 10KVA, 15KVA, 25KVA, 50KVA, 100KVA, 200KVA, 400KVA, 630KVA.

HV winding is done over L. V. winding; both are insulated from each other. Connections are made from start and end in LV and HV winding. But in HV we give taping connection at different places according to design. On HV winding we used DDP paper to insulate it from tank. Oil is also used for this purpose. Winding turns are according to design. At the end of this section testing of winding is done using transformer turns ratio (TTR) meter which gives no. of turns. We check it according to design.

Core Section

In the core section upper, side and yoke limbs of the core are made.

- Raw Material

Raw material used for the making of core is M4 grade silicone steel sheet which is an alloy of Iron and Silicon. Silicon is used to increase the permeability of iron.

- Machines:

i. Slitting machine is used to cut the big roll of silicon steel sheet in required sizes (widths) according to the rating of transformer. Power press machines are used to make limbs.

ii. They are operated manually. After cutting of limbs V punching is done on the yoke limb which is called yoke notching.

iii. PLC cutting machines are also used to make limbs. There are two PLC machines.

iv. SDRI machine has a capacity of 40,000 limbs per day. L.A.E machine has a capacity of 60,000 limbs per day. In CNC machines length, width and angle are given as input.

v. L.A.E measuring table is used to check errors in angle, width and length.

Iron losses

Iron losses are the flux losses in core. Major factors in iron losses are:

i. Quality of material.

ii. Air gap.

iii. Bur

To reduce iron losses

i. Material should be of good quality.

ii. Limbs should be bur free.

iii. Limbs should be rust free.

iv. Weight of core should be according to Tr. Design

v. After cutting of the limbs, they are stacked in a way that there is no air gap between the limbs.

vi. All the limbs are joined except the upper yoke limb which is filled in the assembly section. Outer side of the core is varnished to avoid rusting. Core is tightened using upper and lower pressing beams. Then it goes to assembly section.

Assembly section

In the assembly section there are many processes in which all the components of the transformer are put together to form a transformer. Important processes in the assembly section are:

- Core Coil Assembly

In the core coil assembly coil is fitted in the core and upper yoke limb is inserted to complete the core, then core is tightened using upper and lower pressing beams. For coil to coil Insulation and core to coil insulation press pan sheet is used. For insulation between bottoms pressing beam and coil wooden base is used.

- Before Connection Test (BCT)

In the BCT area turns ratio of the coil is checked using TTR meter.

- H.T, L.T Connections

In this section Y-Delta connections are made. Tap changer is connected with the coil. Connections are made according to work order specifications given by the design department. Taping is done on these connections to avoid any short circuit.

- After Connection Test (ACT)

In the ACT area turns ratio of the transformer is checked using TTR meter.

- Furnace:

After ACT transformer is kept in the furnace for 48 to 72 hours according to its rating. It is done to evaporate all the moisture from core or coil. Temperature of the furnace is 120 to 130 degrees.

- Cover Plate Assembly

In this section H.T, L.T bushings, through bolts, eye bolts connectors, arcing horns and other parts are inserted in cover plate.

- Pre Tanking Section:

When transformer is unloaded from the furnace it is inserted in the tank as quickly as possible to avoid the getting of moisture in the live part. Live part of the transformer should be inserted in the tank in 50mins to 1 ½ hours.

- Oil Filling Section

In oil filling section oil is filled in the tank under vacuum. Amount of oil to be filled can be found from bill of quantity (BOQ). For 10kv to 200kv oil filling chambers are used and for transformers above 200kv oil is filled manually.

- Settling Area

After oil filling every transformer is kept for 12 hours in the settling area to check for oil leakage and oil level.

Tank Section

In the tanking section cover plate, tank, and other mechanical components of the transformer are made. Tank has following parts:

i. Frame
ii. Cover plate
iii. Bottom
iv. Side plate
v. Fin Walls
vi. Conservator

- Raw Material

  Raw material for tank and other components are

  i. MS sheet (Mild steel sheet)

  ii. MSCR sheet (Mild steel cold rolled sheet)

- Component Welding

  In this area lifting lugs, carrying beams and studs are welded using arc welding.

- Frame Punching and Welding Machine

  Frame is punched and then welded in this machine. MIG welding is used in this machine.

- Fin Welding

  After fin folding they are welded. MIG welding is used in this machine.

- Bottom Side Plate Welding

  In this section bottom and side plates are welded together.

- Tank Assembly

  Here all the parts of the tank are joint together.

- Tank Welding

  Tank is welded to stop leakage.

Inspection and quality Control:

Inspection and quality control department ensures, material purchased by the purchase department is according to the criteria suggested by IEC in their recommendations (Incoming), during the manufacturing of transformers all the components of transformer are according to transformer design(in processing),do all the quality tests so that transformer does not fail in real conditions (Testing). Inspection and quality control department is further divided into three sections:

i. Incoming

ii. In processing

iii. Testing

CONCLUSION

Power sector is the most important and developing sector in of the world currently. And transformer is one of the key elements of the system. Without transformer we cannot imagine power system. So, the manufacturing of the transformer is very important for our entire system and it also very important to compensate the losses of the power system.

Further readings

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