Classic power transformer windings

ABSTRACT

The main function of any transformer is to adapt two or more different voltage levels, one being the high voltage (HV), the other being the low voltage (LV). Sometimes a medium voltage (MV) is needed in between, then one winding for every voltage level and every phase are manufactured.
Most of the inner parts of the transformer can be named the "active part", and on it, the "heart" of the transformers is composed of the windings which work on the principle of mutual induction.
The main power transformer winding technologies principles will be presented in this paper.

Keywords:

winding, power transformer

1. Introduction

The separate windings of every phase and every voltage level are assembled together onto a magnetic core. This core is typically made of cold rolled grain oriented steel, which is a highly magnetically permeable material, and highly facilitates mutual induction. The flux generated by the primary windings, which are connected to an electrical source, links with the secondary windings, which are connected to the load. [1]

The main flux for the no-load state passes through the core, the flux generated by the load is mainly passing into the space between the HV and the LV winding of every phase. This space between HV and LV (and MV if existing) windings is the main parameter for the short circuit impedance, which is main characteristic of any power transformer. [2]

Each winding, having a given number of turns, the voltage ratio at no-load condition of the transformer (> 1), is directly proportional to the turns ratio (number of HV turns on number of LV turns).

To minimise eddy current losses in the windings the conductors are wound almost always in parallel to build one electrical turn.

The line lead could be mostly taken out at the centre or the top of the coil, according to manufacturer experience.

Power transformer windings, mainly in contrast with distribution transformers, are still manually manufactured, as they can be quite massive, complex and should withstand very high stresses of over-voltage [3] and short-circuit current [4], and evacuate some important amount of energy losses.

Consequently over decades, only a few types of windings have remained used by most of the power transformer manufacturers, and those general power transformer windings are presented in this paper.

It should be understood and remembered that every power transformer manufacturer and almost every transformer factory has its own experience on winding design and manufacturing, which could be detailed infinitely. Those details are generally not communicated by the manufacturer as any one of those details should basically lead to an improvement of withstand capability of over-voltage, over-current, heat transfer capability or ease of manufacturing. The winding details could be quite strategic and make a technically significant difference between the manufacturers.

In the figures presented in this paper, the numbers are in a continuous sequence of turns. Those turns can be interleaved for design purpose, mainly to better withstand impulse test by increasing some internal capacitance.

Windings are the heart of transformers which works on the principle of mutual induction.

2. Continuous disc windings

Continuous disc winding might be the most used power transformer winding design worldwide as it is a robust winding suitable for most of the transformers. It could be seen as multiple “radial stages” of turns. When one stage is completed, a crossover is made to start the next axial stage (as shown in the Figure 1.), and so on, along the height of the winding.

This design is relatively easy to wind because of straight discs and it can be used for high or low voltage winding of many power ratings. Its limitation is the number of conductors in parallel used for one electrical turn. The discs are separated by radial spacers, the thickness of which depends on the voltage class of the winding. The rated voltage of the winding is distributed along the height of the winding.

This design offers good area of cooling and can withstand temperature rise and short-circuit current quite well.

The advantage of continuous winding is that it can basically be used for all voltage classes and up to a reasonably high current. Above around 100 kV some variations of this technology shall be used to get higher capacitance between the turns, which will lead to a better voltage distribution during impulse tests. Those designs are the interleaved and inter-shielded windings that are presented next.

3. Interleaved windings

This winding is a variation of continuous disc winding separated into a pair of discs, connecting the conductors in such a way that the series capacitance of the winding is increased. An example of such conductor organisation onto two discs is detailed in the figure below.

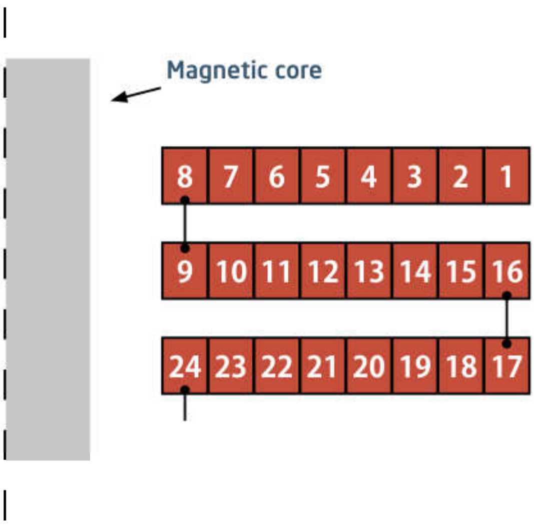

Figure 1: Continuous disc winding

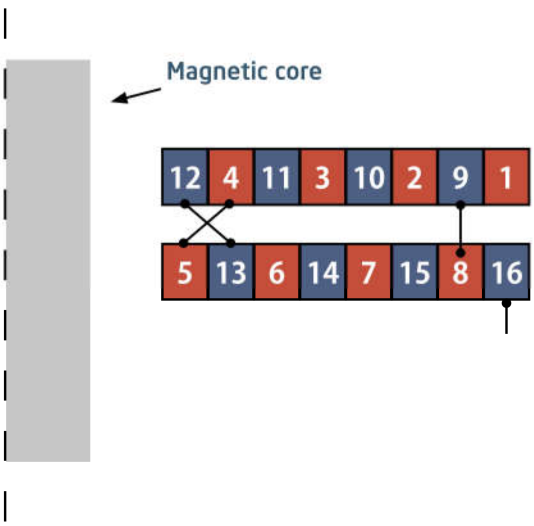

Figure 2: Interleaved winding

The construction of the winding is very similar to the continuous disc winding with specific focus on conductor crossover onto a couple of "interleaved" discs.

The main advantage of interleaved windings is a better ability to withstand impulse conditions compared to continuous disc windings, especially for the highest voltage windings. Hence, this winding is used in high voltage transformer windings only although it takes more time to wind.

Today, interleaved windings are used for any high voltage class transformer.

4. Intershielded windings

Intershielded windings are used for high voltage coils of any high voltage class transformer (up to 800 kV).

To withstand impulse voltage tests, a different solution from interleaved windings are intershielded windings. Every company uses more or less specific winding designs depending on their experience and the past R&D results.

This winding construction is very similar to the continuous disc winding but shielding is added to specific discs to achieve the desired values of series capacitance. The "shield" piece is a small insulated conductor at a floating potential.

A detail of such conductor organisation is presented in the below figure.

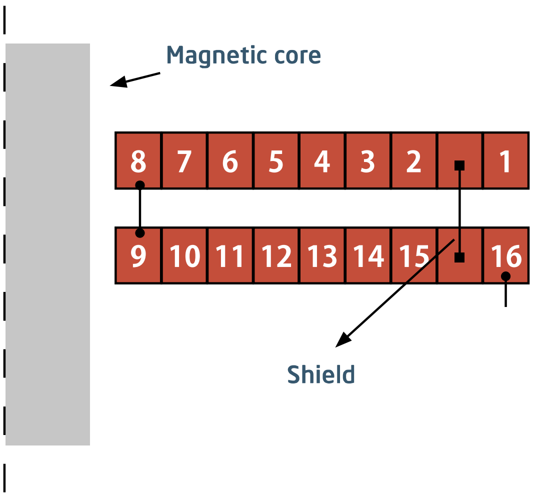

Figure 3: Intershielded winding

The advantage of intershielded windings is similar to that of the interleaved windings.

5. Layer type windings

Layer type windings are classically used up to around 100 kV, even if some manufacturers have specially developed this winding design up to 400 kV for high voltage windings to make them withstand impulse conditions. One layer is the continuation of the conductors

Many winding designs have been developed over the years by manufacturers.

axially wound up along the height of the winding, before starting a new axially wound layer, and so on, as presented in the figure below.

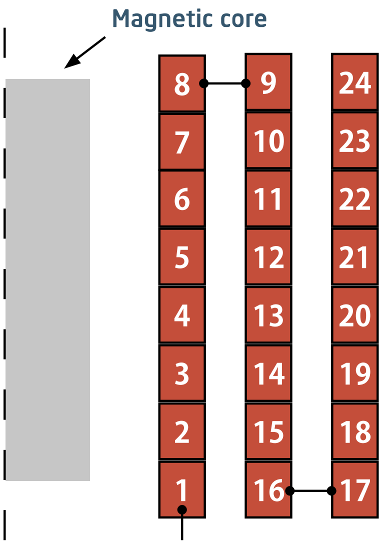

Figure 4: Layer type winding

Here the rated voltage is distributed along the width of the winding in comparison to the height of any disc windings technology. Hence the insulation between the layer needs to be important and adapted to the high voltage level.

Shields between windings could also be used so they withstand even better impulse voltages. The shield in layer type windings is generally composed of an insulated aluminium sheet installed in parallel of the conductor layers along the height of the winding.

The advantage of this type of winding is, in some way, the same as that of an interleaved winding.

Every winding type has its own advantages, from easy construction on „low voltage" transformers to impulse voltages and short-circuit withstand capability as the high voltage increases.

6. Helical winding

This type of winding is mostly used for low voltage windings (up to a few kV) and some high voltage tap windings, which are connected to a tap changer. With a small number of turns, the current could be very high. We can use a large number of parallel conductors in helical windings (as in the figure below).

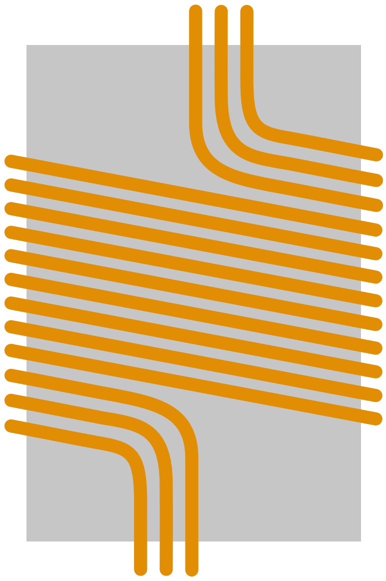

Figure 5: Helical winding

Helical windings are robust and can withstand temperature rise, impulse and short circuit conditions well. Helical windings can be used in large power transformers of hundreds of MVA, as well as smaller transformers where LV is around several tens kV.

The advantage of helical windings is that very high currents can be handled easily by using many conductors in parallel.

7. Pancake windings

This kind of winding is used for shell type transformers. It could be seen as very wide discs assembled together to form a "pancake" block. Each disc is mainly made of multiple conductors in parallel, shields could be inserted between discs or

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Very often winding design and construction is highly linked to experience of each manufacturer.

windings, and they can be used either for low voltage as well as high voltage windings. Shell type transformers are made at least up to 800 kV.

Some manufacturers worldwide are specialised in those shell type winding power transformers (JST in France, EFACEC in Portugal, ABB in Spain, Mitsubishi in Japan, etc.).

Conclusion

These few types of windings are the basics to withstand impulse test, short-circuit duty and heat evacuation for power transformers. Every manufacturer then adapts its winding design to the customer needs and mostly according to its own past experience.

References

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Jean SANCHEZ completed a Ph.D. degree on power transformers fault diagnosis in 2011 and worked in a French power transformer reparation factory. His work involved many transformer designs, tests, fault expertise, power ratings, and OLTC repairs. Today he is working on generator diagnosis in a major French utility. He also completed a Masters degree in Applied Physics.