

# Dry-Type disc wound transformers in medium voltage applications

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Medium voltage, dry-type transformers may have their high voltage windings constructed using either the layer winding technique or the disc winding technique. Both winding techniques provide the same result in terms of electrical performance parameters, i.e. turns ratio, impedance etc. However, the use of transformers employing disc wound high voltage windings can result in increased reliability and therefore reduced downtime.

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## Introduction

The basic purpose of a transformer is to convert electricity at one voltage to electricity at another voltage, either of higher or lower value. In order to achieve this voltage conversion, coils are wound on a laminated silicon steel core which provides a path for the magnetic flux. The coils comprise a number of turns of conductor, either copper or aluminum, wound as two electrically separate windings, called the primary winding and the secondary winding. The primary winding is connected to the source of voltage while the secondary winding is connected to the load. The ratio of primary to secondary turns is the same as the required ratio of primary to secondary voltages. The turns of conductor forming the primary and secondary windings must be insulated from one another, while the primary winding must be insulated from the secondary winding and both the primary and secondary windings must be insulated from ground. The insulation of turns and windings is collectively called the insulation system of the transformer.

The insulation system must be designed to withstand the effects of lightning strikes and switching surges to which the transformer is subjected, in addition to the normal operating voltages. A further requirement of the insulation system is that it must withstand the environmental conditions to which it is exposed, such as moisture, dust etc. A variety of techniques and materials are employed to achieve the necessary performance characteristics of the insulation system.

## Layer winding

For low voltage, i.e. 600 Volt class windings, the winding technique used almost exclusively is the layer winding technique, also sometimes called helical winding or barrel winding.

In this technique, the turns required for the winding are wound in one or more concentric layers connected in series, with the turns of each layer being wound side by side along the axial length of the coil until the layer is full. The conductors of the winding are insulated and so between turns there will be a minimum of two thicknesses of insulation. Between each pair of layers there will be layers of insulation material and/or an air duct.

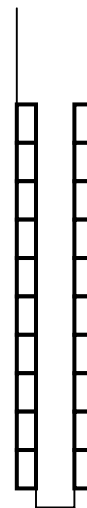


Fig.1  
Layer winding

Low voltage windings will generally be wound top to bottom, bottom to top etc. using a continuous conductor, until all layers are complete. High voltage windings, i.e. above 600 Volt class, may be wound in the same way, provided the voltage between layers is not too great. To reduce the voltage stress between layers, high voltage windings are often wound in only one direction, for example, top to bottom. When the first layer of winding is complete, the winding conductor is laid across the completed layer from bottom to top and then the next layer is wound, again from top to bottom. In this way, the voltage stress between layers is halved. The conductor must, of course, have additional insulation where it crosses the winding from bottom to top.



Fig.2 Transformer with layer wound coils

### Disc winding

In the disc winding, the required number of turns are wound in a number of horizontal discs spaced along the axial length of the coil. The conductor is usually rectangular in cross-section and the turns are wound in a radial direction, one on top of the other i.e. one turn per layer, until the required number of turns per disc has been wound. The conductor is then moved to the next disc and the process repeated until all turns have been wound. There is an air space, or duct, between each pair of discs. The disc winding requires insulation only on the conductor itself, no additional insulation is required between layers, as in the layer winding.

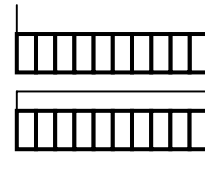


Fig.3  
Disc winding

The disc wound high voltage winding is usually wound in two halves, in order that the required voltage adjustment taps may be positioned at the electrical center of the winding. In this way the magnetic, or effective length of the winding is maintained, irrespective of which tap is used, and therefore the magnetic balance between primary and secondary windings is always close to its optimum. This is essential to maintain the short circuit strength of the winding, and reduces the axial electromagnetic forces which arise when the windings are not perfectly balanced.



Fig.4 Transformer with disc wound coils

### Characteristics of Layer wound coils

As stated previously, the layer wound coil requires insulation between layers, in addition to the conductor insulation. The thickness of insulation required will depend upon the voltage stress between layers, and comprises one or more thicknesses of the appropriate insulation material. In practice, due to the nature of the construction of a layer wound coil, the finished coil will have several unavoidable small air pockets between turns and between layers. Many of these air pockets will become filled with

resin during vacuum pressure impregnation of the coil. However, it sometimes happens that some air pockets remain and it is in these air pockets that partial discharges can occur, greatly increasing the possibility of premature aging of the insulation and eventual failure. Catastrophic failure can occur within a few months of energization. Under short circuit conditions, the electromagnetic forces developed cause transformer windings to attempt to telescope. At the same time the coil end blocking is trying to prevent movement. The result is often that the turns of the winding have a tendency to slip over one another, causing turn-to turn failure, due to abrasion of the insulation as the turns rub together. A further disadvantage of the layer wound coil is its poor impulse voltage distribution between the first few turns of the winding, due to the high ground capacitance and the low series capacitance.

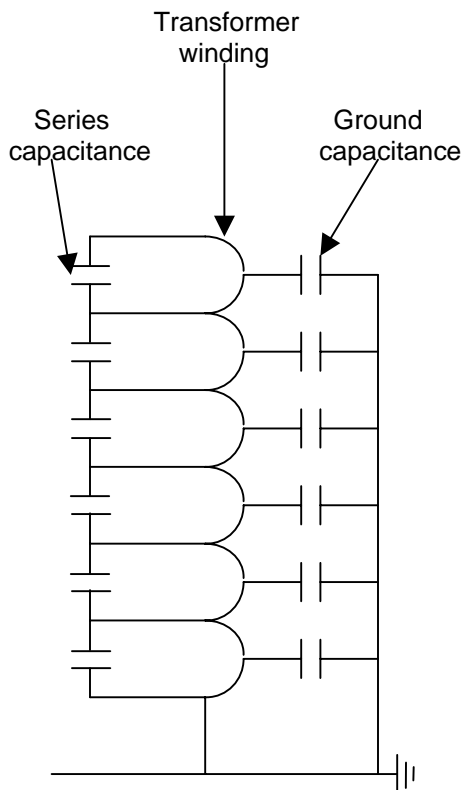


Fig. 5  
Equivalent circuit for  
Impulse voltage distribution

A transformer winding forms a complex network of resistance, inductance and capacitance. As far as the impulse voltage distribution is concerned, the resistance can be ignored and at the instant of application of the impulse wave, when very high frequencies are predominant, the inductive elements become effectively infinite impedances. The whole structure therefore reduces to a capacitive network (see fig.5). Each turn of a transformer winding is insulated with a dielectric material and can be thought of as one plate of a multiple plate capacitor. In addition, the combination of dielectric material and air between each turn and ground forms further capacitive elements.

### Characteristics of Disc wound coils

The major advantage of the disc wound coil lies in its open construction and relative lack of insulation. For a 15kV class transformer employing a disc wound primary winding, the number of discs will typically be in the range 36 to 48, resulting in a relatively low voltage per disc. Since each disc is separated from the next by an air space, the voltage stress between discs can easily be handled by the combination of conductor insulation and air, no additional insulation being necessary. Each disc comprises a number of turns with each turn occupying one layer, i.e. one turn per layer: the voltage stress between layers is therefore the same as the voltage stress between turns and again, can easily be handled by the conductor insulation. The turns of each disc, being wound tightly together provide almost no possibility of air pockets being present within the disc. Due to the open construction of the discs, any small air pockets which may be present are readily filled with resin during vacuum pressure impregnation of the coil. A properly designed and manufactured dry-type transformer disc winding therefore displays very low values of partial discharge, typically in the range 10 to 20 picocoulombs. Unlike the layer wound coil, the disc wound coil provides good impulse voltage distribution, due to its inherently low value of ground capacitance and high series capacitance.

The disc wound coil also displays excellent short circuit strength. Each disc by itself is mechanically very strong and the complete assembly of discs are held very securely in

place. While the electromagnetic forces resulting from a short circuit result in a tendency, for the windings to telescope, the high voltage turns usually remain intact relative to each other. Instead, the complete disc has a tendency to distort as an assembly, with all the turns distorting by the same amount. The transformer can often continue to function, despite the distortion, until a convenient time arises for repair.

#### **Losses/heat**

The flow of electric current through the turns of a transformer winding causes power losses which manifest themselves in the form of heat. These losses are called "load losses" and are proportional to the square of the current. Obviously, it is necessary to dissipate this heat, to prevent overheating of the transformer, and in a dry-type transformer, this is achieved by the use of air spaces, or ducts, within the winding. The layer wound coil relies on vertical air ducts between layers and between windings, for cooling. Cool air enters the air ducts at the bottom of the coil and by natural convection, rises through the ducts, collecting heat on its way, then exits the coil at the top. It is essential for proper operation of the transformer that these air ducts are kept clear at all times. The insulation required between the layers of a layer wound coil has a tendency to thermally lag the winding, impeding the dissipation of heat. The greater the operating voltage of the winding, the greater is the amount of insulation required and the greater is the lagging effect of the insulation. Some radiation also takes place from the outer surfaces of the coils.

The open nature of the disc wound coil greatly improves the transfer of heat from the winding to the surrounding air. The thermal lagging effect of insulation is removed and the multiple horizontal air spaces between discs provide a large surface area for cooling by both radiation and convection.

#### **Conclusions**

The combination of layer wound low voltage winding, disc wound high voltage winding, NOMEX insulation and vacuum pressure impregnation of the windings with a solventless epoxy resin, results in a very reliable transformer with a long life expectancy. Transformers constructed in this way will be relatively free from partial discharge and will provide excellent impulse strength and short circuit strength, vital requirements for reliable operation in the most demanding of applications.

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