ABSTRACT

Power transformers are key elements of a high voltage electrical transmission grid, which adapt voltage levels to the different needs of electric power users at constant power (disregarding the losses). This electrical machine is classically constructed out of copper, steel, paper and insulating oil. All those materials are made into different components. The main ones are the windings, tap changing system, core, tank and bushings. The components are assembled together to produce a power transformer. Power transformers are developed worldwide using a few basic designs established almost a century ago, that can be largely adapted for many special applications [1].

Keywords:

Basics, Components, Power Transformers

Basics of Power Transformers

What are the basic transformation principles and essential transformer parts?

Introduction

Nowadays, electric energy is available almost everywhere, and we do not even think how it was produced. Production of the electric energy is possible by application of the power transformers.

Power transformer is a complex assembly of elements based on decades-long, worldwide proven technologies. Those electrical machines are essential for power grids to transmit electrical power by minimising Joules effect losses using high voltage over long distances.

Transformers have been used worldwide for many years and their availability and reliability is a major concern for all electricity users and the assets owners.

Basics of power transformers

The basic facts and the main parts and components of power transformers are presented in this article to understand which diagnoses can be applied accordingly.

Electromagnetic basis

A single-phase transformer is basically made out of two separate windings that are inserted into each other into a closed loop of magnetic core. The voltage ratio (V_1/V_2, where $V_1>V_2$) of the transformer is equal to the ratio of the number of turns of the two windings (N_1/N_2, where $N_1>N_2$) in a first approximation. It should be noted that a classic power transformer requires alternative voltage.

In a rough approximation, if the transformer losses are disregarded, the power (Voltage x Current) transmitted through the windings has a lower current on the high voltage (HV) side than on the low voltage (LV) side. Moreover the Joules heat effect is proportional to the square of the current transmitted into any ordinary conductor like transformer windings or transmission lines.

Both these effects combined at constant power of elevating voltage reduce heat dissipation accordingly by the square of the current, and enable the transmission of power of alternating current and voltage over very long distances from the energy producer to the energy consumer while limiting the power losses in the grid. This is possible due to a key grid component - the power transformer. Most of them are the three-phase transformers or the three single-phase transformers.

Three points could be noted from these electromagnetic principles. First, with the voltage increase of an electrical network, the Joule losses are reduced. The trend in countries like Canada, Brazil, Russia, China, South Africa, South Korea, USA, and Venezuela is the development of the 800 kV electrical networks, or the 1000 kV to 1200 kV ones in China and India, respectively. Secondly, the two main constraints of power transformers are high voltage and high current, depending on whether the HV or LV is observed. Those constraints are taken into account when studying the transformer limits, like overvoltage (lightning) and overcurrent (short circuits). The reader interested in finding out more about the theory and the practice regarding power transformers could read [2], a book last updated almost a century ago!

The theoretical and practical principles of power transformers have remained the same since more than a century ago.

Active part

The active part of a transformer is made of the elements that are in contact with the voltage and the current, and are mainly composed of windings, core, tap changer bushings. The other components are ancillary components not mentioned here.

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Windings

The windings of a power transformer are its main element, like the heart in a human. The windings are handmade out of copper, or sometimes out of aluminium coils insulated mainly with several layers of paper between the turns. The two main winding designs and technologies have been developed over time with many variations: the core type and the shell type windings. The electromagnetic basis remains the same in both cases but the mechanical construction is different. In the core type design, the winding is “enclosing” the magnetic core legs, while in the shell type the core is “enclosing” (and running through) the windings. Every transformer manufacturer has its own experience with these technologies, neither of which is automated.

The manufacturing of windings involves a lot of human labour and requires significant experience as well as application of the highest quality standards. This is

Figure 1: Three phase power transformer

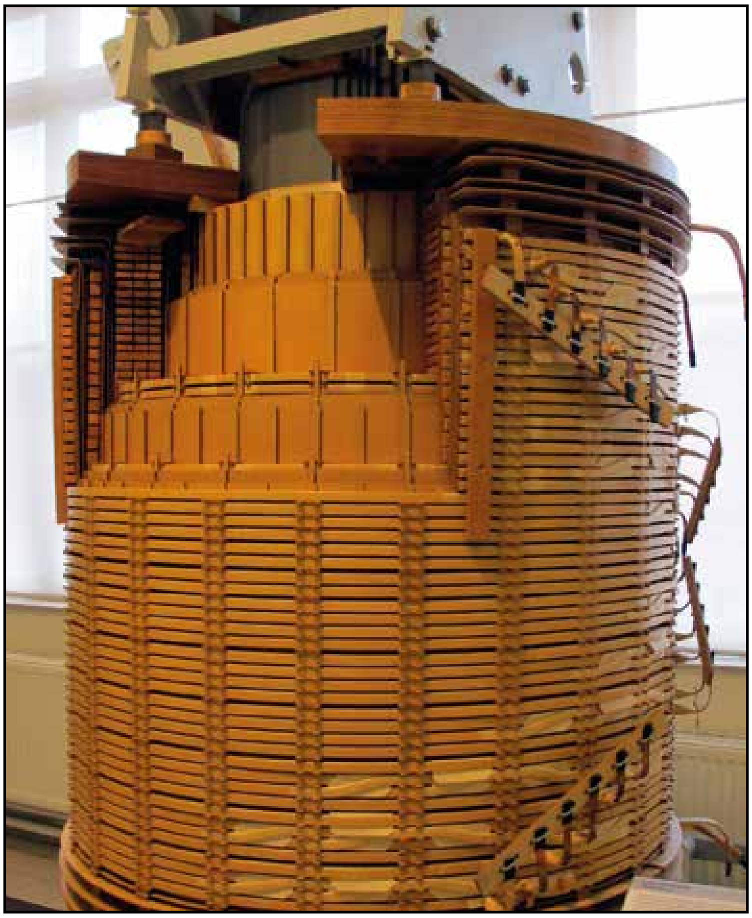

Figure 2: Insulation in power transformer

Figure 3: High voltage bushings of power transformer

because winding conductors are covered by a type of insulation such as varnish or insulating paper with a limited mechanical and thermal stability. Nevertheless, this insulation type provides protection from high overvoltages, high overcurrents, short-term overheating, and high mechanical stresses in order to prevent reduction of the insulation paper durability. It must be taken into account that the winding insulation cannot be easily repaired or replaced during the service life of a transformer and rewinding has to be performed only in a specialised workshop. A review of winding types used in power transformers is provided in the article [3].

Core

The core is an important part of a transformer and generally the heaviest one. Produced from steel, it has high magnetic permeability and provides low magnetic resistance to the magnetic flux. It is made from thin steel sheets with the thickness of a few tenths of a millimetre in order to reduce losses and magnetising current. The main way to produce a core is to stack the sheets, cut to desired size, onto the automatic machines, and then manually stack them to build a core. Wound cores provide much better productivity for single-phase small distribution transformers.

The main core parts are the legs (vertical parts), and yokes (horizontal parts). The legs are mainly situated in a same plain but the three-phase transformers can have so called triangular-spaced core legs. This

The manufacturing of core and windings - the heart of a transformer, involves a considerable amount of manual labour even to date.

type of transformer is called hexaformer. Small-size transformers, like distribution transformers, are sometimes produced as hexaformers but their market penetration is very low. Even transformers of up to 10 MVA have been produced in this form but the concept was cancelled due to complexity. They produce lower losses but their productivity is lower compared to transformers with a 'traditional' core.

Tap Changer

Most transformers have additional turns added to the HV windings and some of those turns are linked to a device called the "Tap Changer". It enables a specific range of the voltage variation during the transformer service life. The electric circuit of the windings and the tap changer have some movable contacts. The two main types of tap changers are the DE-energized Tap Changer (DETC) - mechanically quite simple type that changes the voltage while the transformer is not loaded; and the On Load Tap Changer (OLTC) - a more complex type [4] which operates when the transformer supplies the load.

Mostly used solid insulating materials, paper and pressboard, are organic and subject to aging. They cannot be repaired or replaced easily, therefore they limit the lifetime of a transformer.

It should be noted that the tap changers, the OLTCs in particular, are contributing to an increasing transformer failure rate, mainly due to the movable contacts wearing over the years (hot spots, aging mechanisms) [5].

Bushings

The bushings are the components that link the windings to a network through the grounded tank. High voltage bushings can be technically complex and, in some cases, their failure can lead to a transformer explosion quite rapidly. This is because one of the highest voltage gradients is between the HV bushing central part at full potential, and the grounded tank at the distance of just a few centimetres. The insulating oil just below is very flammable and if the bushing is sparking, it could generate a lot of energy, open the tank slightly and then ignite the oil, which could lead to an explosion. For this reason, the HV bushing is manufactured to withstand very high voltages within a small space filled with paper and oil between the bushing and transformer tank.

Insulating materials

The three most typical insulating materials for the power transformers are: mineral oil and paper and pressboard in different forms. The mineral insulating oil is weighted in tons within the tank and can be used to assess many essential points about the condition of a transformer and some critical incipient faults. The paper insulates the winding turns, while the pressboard strengthens the electrical insulation and provides dielectric distance at specific locations, for example in the main duct between the windings.

Insulating materials, such as paper, pressboard and mineral oil are organic materials subject to aging. As the solid insulation cannot be repaired or replaced easily like other transformer parts and components, it limits the transformer service lifetime. Therefore, the solid insulation lifetime is the lifetime of a transformer.

Conclusion

The basic facts about transformers and the main transformer parts and components are briefly described above. Power transformers can be seen as main components of any high voltage grid, which reduce the losses during the delivery of electrical energy to wide areas. More details on the topics above can be found in the literature cited, including [6] and [7].

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