Abstract: The Transformer is one of the vital component and expensive asset which constitute a high principle investment within the Power Generation, Transmission, and Distribution sectors. With the high escalating cost of substitution, it is crucial to consider methods of life extension of transformer. Transformer with moisture has great influence on the life anticipation of it. The phenomenon of the thermal decomposition of the insulating paper inside the transformer is directly proportional to the water content found in the transformer. Most other components can be replaced or repaired, but once the insulating paper of transformer has lost its mechanical integrity, the core must be re-wound, or the transformer has to be scrapped. So we must remove the water not only from the oil, but also from the paper insulation, to maximize the life of the transformer.

The core, insulation paper etc. absorbs more than 97% of water present in transformer, only 3 % is left behind in oil. Oil filtration systems or drying systems will absorb moisture from oil and moisture from paper will to maintain nature equilibrium. Also these systems will remove moisture from the insulation paper during on-load condition & will help to extend the life of transformer. So this online drying system helps in continuous processing of oil to keep transformer in normal state and removes the moisture from oil as well as insulation paper inside transformer so that it increases life expectancy of the transformer.

The presence of moisture in the transformer, to whatever degree, does actual harm to the insulation, which is, in fact permanent damage. Drying methods only substantially reduce that deterioration. So the on-line drying system helps us to remove moisture not only from the oil but also from the insulation paper.

Keywords: Transformer, Insulation Paper, Moisture, Oil Filtration, Degree of polymerization

1. Introduction

New methods for assessing the condition of transformers and other components in electrical power plant are becoming of increasing importance in the power industry. The degraded condition of the insulation is a significant contributor to decrease in performance and possible component failure and condition assessment could benefit from new and improved on-line and non-destructive off-line methods. In particular, the use of spectroscopy, already established in the analysis of insulating oil which has also been shown to be a promising technique for measuring solid electrical insulation non-destructively.

Power transformer conductor windings are insulated by paper impregnated with insulating oil, which is expected to last the life of the transformer. It is 25 years minimum at an operating temperature of 65-95°C. A typical transformer contains 10-12 t of paper, 30-120 pm thick i.e. density 0.7-0.8 kg/m3 and 45 t of oil. Heat, water and oxygen degrade the cellulose, reducing the polymer molecular chain length and with it the mechanical strength of the material.

Power transformers are typically insulated with some 12 tons (12,192 kg) of paper and 40 tons (40,642 kg) of mineral oil, and the life of a transformer is ultimately determined by that of the solid insulation, although other factors may cause it to fail early. Transformers are currently monitored by sampling the oil at regular but infrequent intervals and analyzing for dissolved gases, such as hydrogen and hydrocarbons like methane, ethane, acetylene and carbon monoxide (often referred to as dissolved gas analysis, or DGA). Changes in the relative ratios of certain critical gases provide empirical information about the state of the transformer through the widely used Rodger’s ratios. Unfortunately, the major source of these gases is the hydrocarbon oil, and the results are therefore not specific to the paper condition. Insulation life expectancy has been estimated by accelerated laboratory studies of paper ageing, from the
relationship of the change in the degree of polymerization (DP) of cellulose in the paper with time.

Nowadays, there is an increasing interest in using transformer monitoring systems. Some monitoring systems use models to predict the value of certain variables. One of the key variables to be monitored is moisture content in oil, as moisture has a high influence on transformer exploitation.

Water has a detrimental effect on transformer insulation life. According to Fabre, the rate of thermal ageing of paper, is proportional to its water content. According to Clark, if the water content of paper is doubled, its life in terms of mechanical strength is halved. The increase of water content in zones of high electrical stress can lead to a reduction in partial discharge inception level and to an increase of its intensity. The migration of small amounts of water from paper to oil has been associated with the phenomenon of static electrification appearing when there is a charge accumulation on the interfaces between dry and humid zones. Water in transformer oil can also lead to bubble formation, when high temperatures are attained in the winding and an abrupt desorption of water takes place from the paper toward the oil.

All those reasons, moisture in paper-oil insulation has been considered since 1920 to be one of the functional conditions that must be controlled during transformer operation. With the recent development of sensors to measure moisture dissolved in transformer oil, the measurement of this variable is becoming a habitual practice in transformer monitoring systems.

2. Literature Review

Current research into paper ageing, such as that being carried out at the University of Surrey, UK and a number of other centers throughout the world, is aimed at developing condition monitoring and life prediction techniques. Measurement of the concentration and distribution of degradation products, such as 2-furaldehyde in the oil provides data that can complement traditional DGA analyses, because they apply specifically to paper ageing. The long-term objective is to generate a model that can be used to assess the current condition of Kraft insulating paper in power transformers and then predict its remaining life. In order to relate the standing concentrations of such products to paper condition, it is necessary to understand the chemistry of the degradation of cellulose and to derive chemical and physical models of the breakdown process. To this end, established methods of studying polymer ageing processes are being adapted to study cellulose degradation in paper insulation.

Early studies, reported in the literature, include the work of Shroff and Stannett, who measured changes in the DP of paper with time, and in conjunction with Burton and others empirically related the Log (DP) to the furfural concentration in the oil. More recently, Unsworth and Mitchell and Darveniza and others have developed furfural analysis techniques and have investigated the use of size exclusion chromatography to assess the ageing of the paper in a transformer. Unsworth and Mitchell also investigated the stability of the furan products of degradation and attempted to correlate their concentration in the oil to the tensile strength of the paper, since it is ultimately loss of tensile strength that determines the life expectancy of the insulation. The whole area of insulation ageing, monitoring, and life prediction has recently been reviewed by Emsley and Stevens.

DP has been used in numerous studies of the degradation of cellulose under a variety of conditions, and simple, mathematical models have been developed to describe the kinetics of the reaction. The simplest of these was derived by Ekamstam from early statistical studies of Kuhn and co-workers. According to his analysis, the reciprocal DP should be directly proportional to the degradation time. Emsley and Stevens have re-analyzed a wide range of results reported in the literature and have shown that cellulose degradation fits this model, at least for the majority of the reaction, until the DP approaches a limiting value of about 200.

3. Transformer Insulation Ageing Factors

Ageing is an irreversible deleterious change to the serviceability of an insulation system. Transformer insulation is subjected to several types of stresses that produce ageing are called ageing factors.
insulation paper gradually decreases from an initial value of about 950. Below about 500 DP units the tensile strength starts to decrease in an approximately linear fashion with respect to DP. Below a DP of about 200, when only about 50% or less of the original tensile strength of the paper remains, the paper becomes brittle and may start to disintegrate. The mechanical failure of the insulation resulting from this degradation can block oil cooling ducts resulting in overheating and faster decomposition. Eventually a stage can be reached where electrical breakdown and transformer failure occur.

4. Factors Affecting Transformer Paper

Below are the factors influencing performance and degradation of transformer oil paper insulation and resulting breakdown mechanisms.

Effects of temperature: It was recognized long ago that the degradation process is a chemical reaction and as such should obey the Arrhenius theory of reaction kinetics. Values for the activation energy of degradation of cellulose in oil, quoted in the literature, range from of the order of 85 kJ/mole (which is close to the values quoted for the thermal degradation reaction) to 120 kJ/mole (close to those quoted for the hydrolytic degradation reaction). Above about 140°C,

Effects of oxygen: According to Fabre and Pichon, oxygen increases the rate of degradation of paper containing 0.3 to 5% moisture in oil by a factor of 2.5. The effects on predicted insulation life. Fallou pointed out that, in an actual transformer, restricted oxygen access reduces the true value of the oxygen factor closer to 1.6. In a model transformer experiment, it was found that the oxygen level in the oil increased initially, as the paper outgassed, but then fell slowly as it was consumed by reaction with the paper and oil. If the dissolved oxygen level is maintained below 2000 ppm, the rate of oxidation of the oil is reduced substantially.

Effects of water: Early studies indicated that the rate of degradation of paper increased in direct proportion to the water content and predicted insulation life estimates. However, more detailed studies later concluded that, during the later stages of degradation the logarithm of the rate is proportional to the moisture level. Water is a product of degradation and so the moisture level in the paper increases with ageing by 0.5% every time the DP of the cellulose is halved by degradation, resulting in a decrease in electrical strength.

Life prediction from DP measurements: The advantages of using DP measurements to predict insulation life are: measurements are relatively easy to make; DP can be empirically related to insulation condition. However, using DP values for life prediction presents a number of problems. The mechanisms and kinetics of the process are ill defined, because a number of different reactions could be operating simultaneously. The strength of paper is not linearly dependent on its DP except over a limited range of about 200 to 500. It is worth noting that paper strength has been shown to bear a linear relationship to the total volume of carbon monoxide plus some workers have suggested that the rate of degradation increases significantly implying either a change in the activation energy or in the pre-exponential factor. The correlation between DP and strength is also independent of ageing conditions.

5. Conclusion

This paper describes an accelerated ageing factors of transformer oil/paper insulation. The humidity content of the cellulose paper has a decisive role in the degradation rate of the paper, as higher initial humidity greatly accelerates degradation. The ageing rate of cellulose is therefore directly proportional to moisture content. The existence of oxygen, however, markedly increases the rate. The influence of oxygen itself on the ageing process of the solid insulation seems to be in the same order of dimension order as moisture itself. The catalysts, that represent the metallic components in the transformer, accelerate the ageing process of the cellulose papers, while they seem to have no influence on the ageing process. Oil ageing without a solid partner is insignificantly influenced by water, but accelerated by air-oxygen, via the moisture and acid formation, and oxidation processes. A direct influence increase the loss factor and the decrease the electric strength particularly at low temperatures is to be noted.
6. References


