Parameters Affecting the Lifetime of Transformer Oil in Distribution Transformers: Parameter Monitoring of 50 Transformers from the Athens Area

M.G. Danikas, E. Rapti, I. Liapis, A.B.B.Abd. Ghani *

Department of Electrical and Computer Engineering,
Democritus University of Thrace, Xanthi, Greece [1, 2]
Public Electricity Corporation, Athens, Greece [3]
High Voltage Cable Diagnostics, Distribution Unit TNB
Research Sdn. Bhd. Selangor, Malaysia [4]

Abstract

The aim of this paper is the study of various parameters affecting the ageing of transformer oil in distribution transformers of 20/0.4 kV. Fifty (50) samples of oil were taken from such transformers. The transformers function in the major Athens area, Greece. Parameters, such as breakdown strength, oil color, humidity, interfacial tension and tanδ were taken into account. Transformer ageing and lifetime are strictly related to the rate of ageing of the whole insulating system, and mainly of the oil.

Absence of transpiring system with silica gel has as a result the increase of oil humidity. The lengthy use of transformers under heavy load, and consequently under high temperatures, is a main factor for oil ageing and oxidation. Especially in the last few years, the increased loads required by the transformers which have to do also with the climatic changes, have as a result the additional stressing of the oil. Various arcs, resulting from short circuits in the network, have as a consequence the production of gases and sludge. Such gases and sludge influence in a negative way the insulating properties of the oil as well as its rate of ageing. The role of silica gel is stressed.

Keywords

Transformer oil, distribution transformer, diagnostic methods, breakdown voltage, dielectric strength

Introduction

Transformer oil is a most important component in transformers [1]. Transformer oil ageing has been studied as well as the parameters and factors influencing its behavior under a variety of stresses (electrical, thermal, etc.) [2]-[5]. Faults in power and distribution transformers are rare (of the order of 1% - 2% per year), but when they occur, they have very serious technical and economic consequences. They may even lead to dangerous situations for human life and the environment. Main factors affecting the acceleration of ageing of the insulation of a transformer are humidity, high temperature, oxidation and the acidity of its oil. The role of chemical byproducts of the transformer insulation is also very important for its ageing. There is no single measurement able to give a whole picture of the state of a transformer. It must be noted that the variety of the diagnostic methods used, does not have as an aim the prediction of the useful remaining lifetime of the insulation, but it tries to reveal the increasing probability of faults and the corresponding decrease of the insulation reliability. Needless to say, that reduced reliability implies also reduced remaining insulation lifetime.

With this in mind, in the context of the present paper, diagnostic methods were used in order to study the state of distribution transformers of the major Athens area. The transformers investigated were 20/0.4 kV. The whole work was carried with the aid of Public Power Company (PPC) of Greece, and more specifically with the aid of PPC Transformer Division. Oil was taken from 50 distribution transformers.

Diagnostic Methods

Warning signs about the state of a transformer are, among others, a big increase of partial discharges (>> 2500 pC), a visible deterioration because of foreign metallic and carbon particles, the presence of humidity in the solid insulation about 3-4 % and the presence of sludge.

Several diagnostic methods were used in order to see the quality of the transformers in question. The characterization of the oil color (DIN 51517 – ASTM D155) was performed through a device (chromometer) including standard glass disks and two glass jars with lid. The control of dielectric strength was measured by a typical Foster test cell, according to IEC 156/95 (Fig. 1).

The control of humidity in the oil was measured by a Metrohm – 684 KF Coulometer, which consisted of a glass container with a stirrer titration in which the reagent from container storage is added. The device is fully automated and once the experimenter gives the settings, it measures the moisture content of the oil. The measurements were performed according to IEC 814. The control of interfacial tension (ASTM D971 – 91) was performed via a tensimeter, which gives the value in dynes per centimeter in a direct reading (Fig. 2).

Fig. 1: Device for the measurement of dielectric strength

The device that performed measurements of tanδ and of resistivity, is the BAUR-DTL fully automated device for measuring dielectric losses of oils. Such a system has a fully automated process for measuring dielectric loss, relative dielectric constant and resistivity. The measurements were performed with a system counting tanδ values with maximum accuracy from 0.00001 to 4.0, measured according to IEC 247.

It is true that no single diagnostic method can give full information as to the state of a transformer. The aforementioned methods may give a better picture of its state.

Fig. 2: Tensimeter Cenco du Nouy

Experimental Results

The sampling was performed with due care, and according to general standard practice, i.e. during sampling there must not be any dust and humidity in the nearby space, the sampling cells must be clean and dry and they must be washed with oil from the transformer which is to be checked, the samples must be protected from light and they must be taken while the oil is hot but due time should pass before the various particles settle down. Sampling was done from the bottom of the transformers. The glass cells used for oil sampling were big enough so that they contained enough oil volume for additional measurements, if needed. No measurement was performed based on only one value or sample. All results must be verified with additional samples and measurements. Color measurements of the oil sam-ples were based on specifi-cation DIN 51517 – ASTM D155 (Fig. 3). Dielectric strength measurements were based on specification IEC 156/95. Humidity measurements were based on specification IEC 814. Interfacial tension measurements were based on specification ASTM D971-91. Loss factor measurements were based on specification IEC 247.

Transformer oil is characterized as good, if its color is not dark, its breakdown voltage more than 40 kV, its humidity less than 10 ppm, its resistivity more than 3 GΩ·m, its loss factor 0.1, its interfacial tension more than 28 mN/m. It is acceptable if its breakdown voltage is between 30 to 40 kV, its humidity between 10 and 25 ppm, its resistivity between 0.2 and 3 GΩ·m, its loss factor between 0.1 and 0.5, its interfacial tension between 22 and 28 mN/m. In the case of an acceptable oil, samplings should be carried out more frequently, and the content in foreign particles and contained water should be controlled. If the breakdown voltage and humidity are near the limit values, then the oil should be filtered and cleaned. An oil is poor when its color is dark (the dark color is an indication of pollution or ageing), its breakdown voltage less than 30 kV (in this case the oil should be replaced or thoroughly cleaned), its humidity more than 25 ppm (in such a case the oil should be replaced or thoroughly cleaned), its resistivity less than 0.2 GΩ·m, its loss factor more than 0.5, its interfacial tension less than 22 mN/m (in this case a check should be carried out for the presence of sludge).

Generally it is suggested that in case one of the parameters mentioned (color, dielectric strength, humidity, interfacial tension, loss factor, resistivity) is acceptable, a more frequent sampling should be done in order to better monitor the oil quality. In the case any of the mentioned parameters is poor, cleaning or replacement of the oil is suggested. In any case, it is good to control all parameters concerned in order to have a clear picture of the state of the oil.

From the 50 oil samples investigated (taken from 50 distribution transformers), 3 of them showed breakdown voltage lower than 30 kV (i.e. percentage of 6%), 45 samples indicated humidity higher than 25 ppm (i.e. percentage 90%), 28 samples presented interfacial tension lower than 15 dynes/cm (percentage 56%), whereas 44 samples showed a color higher than 1 1/2 (percentage 88%) (Fig. 4). It was evident from the data – mentioned in detail in [6] – that the more the number of years in service, the more the number of samples with lower dielectric strength. This is due to the fact that with the years there is also an increase of humidity in oil as well as an increase of the oxidation byproducts. Trans formers which are in cities or in urban localities do not usually suffer lightning strokes, consequently the only stresses come from switching overvoltages and/or some high currents.

Fig. 3: Chromometer Hellige Comparator

Fig. 4: Typical glass colored disc

As the years pass by, humidity increases because fluctuations in temperature cause an increase of humidity entering the main oil volume. In distribution transformers having silica gel, the latter looses its absorbing property with an increasing number of years in service. Consequently silica gel should be replaced at regular intervals. The increasing number of years in service infuences also the oil oxidation. Oxidation byproducts in turn affect tanδ. The loss factor, however, is not influenced from the existence of humidity in the samples and for this reason is not a criterion for its existence. Interfacial tension is reduced with the years in service. This is due to the increasing quantity of humidity as well as to the byproducts of oxidation. There is, however, a number of samples with rather reduced interfacial tension although the number of years in service was not that big. This may be due to the quality of the oil used or to the fact that it contained only a small quantity of anti-oxidants. Finally, the oil color changes with the years in service. A change of color may also be due to the overcharging of a transformer.

Discussion

In this work, sampling from 50 transformers of 20/0.4 kV was carried out. Sampling and measurements were performed as suggested by the various international specifications [7]. All transformers were in the major Athens area. It should be noted that the transformers were not all from the same manufacturer. There were transformers from various manufacturers, both from Greece and abroad. This is one of the complications of the Greek Electricity System and certainly, this fact hinders any thought for a statistical approach. In case of poor oil color, this may be a symptom of humidity. Poor oil dielectric strength may imply that the oil should be cleaned or replaced. If the humidity level is high, the oil has to be again either cleaned or replaced. If the interfacial tension of oil is acceptable, this means that a control for the possible presence of byproducts may be performed. Acceptable values of oil resistivity may be tolerated. In most cases, tanδ was good. The parameters which changed most were the color, the oil dielectric strength, the levels of humidity and the oil interfacial tension. From the above, it is evident that one cannot pronounce any verdict on the quality of a transformer oil based on only one parameter.

It is evident from the results that there was absence of a transpiring system with silica gel in most investigated transformers. This absence has as a result that the humidity of the atmosphere is in contact with the oil. The functioning of a transformer under heavy load, and consequently its functioning at high temperatures, results in an acceleration of its ageing. High temperatures cause oxidation of the oil. In addition to that, in the last years, increased loads – as a consequence of climatic changes (such as increased temperature and humidity) – are required and they result in the stressing of the oil. Arcs, because of short circuits, create gaseous byproducts and sludge. The latter influence in a negative way the dielectric strength of the oil. Another point which should be considered is that, with the continuing effort from the side of the manufacturers for the reduction in the size of the transformers, the oil tends to be more easily thermally stressed. This results in an accelerated rate of rise in temperature and an accelerated rate in its ageing.

Generally speaking, the frequent oil sampling helps in pointing out potential trouble spots in the network. It goes without say that, as in this paper, a variety of measurements may give a better picture of the actual state of the transformers rather than isolated measurements or measurements confined only on a single quantity (e.g. dielectric strength). Ageing is a complex process and, as is well known, a variety of factors play a role. Ageing factors contribute not only to the ageing of the oil, but they may also interact among themselves, rendering thus the prediction of lifetime even more difficult [8], [9]. Breakdown of transformer oil is also a complex phenomenon determined mostly by the operating conditions [10].

As a way out of the various problems with transformer ageing, the construction of additional substations is proposed. This will reduce the load of each transformer. Needless to say that, the continuous checking of the whole distribution network and the requirement from the manufacturers to observe all the international norms and specifications, are necessary conditions for the good functioning of the whole system.

Special attention should be paid to the way one gets the oil samples. Sampling should be done with due care and care should be taken in order not for the sample to contain water. The samples should be taken from the transformers when the oil is still warm. Foreign particles should be allowed to settle at the bottom, so that no undue influence can be recorded in the various measurements.

In the case the results are contradictory, one has to repeat the sampling and the corresponding measurements. It is true that the manufacturers, try to reduce the production cost of the transformers and their respective materials by reducing the size of the transformers. This on one hand has as a result the possibly higher break-down strength of the oil, on the other hand, however, has as a result the faster increase of the oil temperature, and consequently the faster ageing and stressing of the mechanical parts of the transformer. Anyhow, a better maintenance of the distribution transformers should be followed as well as the placing of more transformers of larger power in localities with an increasing load demand.

The discussion as well as the conclusions of the present paper are in line with previously published work [11], [12]. Such work was carried out on transformers of 20/0.4 kV as well as of 150/20 kV. A statistical approach cannot be offered for the time being, as it was done before [13], for the reasons given above.

It is to be hoped that the next steps in our work will be a classification of the distribution transformers according to manufacturer, according to their power (kVA) and according to the previous history (which includes years in service, all faults, short -circuits, lightning strokes, switching operations etc.). Thereafter, an effort will be made in order to statistically analyze the data.

Concluding, it is fitting to note that the present paper does not claim any originality regarding any new diagnostic techniques. This paper is an application of already existing and well known specifications. It is a continuation of an effort started few years ago, as mentioned in [7], [11], [12]. In this respect, the present paper presents new results, although the methods used are the same as in [6], [7], [11], [12]. In other words, this paper presents the state of transformer oil in some distribution transformers of a given area at a given moment in time. Needless to say that continuous monitoring is necessary in order to check and confirm the transformer oil quality. Continuous monitoring, however, is often not enough. If possible, it should go together with fault detection, namely partial discharge (PD) detection. PD detection can help preventing a defect from developing into a fault, e.g. a short circuit [14],[15],[16]. Nevertheless, condition monitoring as presented here, should be done on a regular basis.

Conclusion

Transformers of 20/0.4 kV from the major Athens area were investigated. Various parameters (oil color, dielectric strength, humidity, interfacial tension, tanδ and resistivity) of the oil were studied with standard methods based on international specifications. No verdict on transformer oil quality can be based on only one parameter. A multitude of parameters is needed in order to pronounce a correct verdict on oil quality. The continuous control and monitoring of the distribution transformers is necessary in order to avoid problematic situations. The role of silica gel is emphasized.

Silica gel should be used in all transformers, so that humidity can be absorbed. The quantity of humidity increases with the number of years in service, consequently, distribution transformers should be checked at regular intervals.

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* About The Authors

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Elli Rapti, is a graduate of Democritus University of Thrace, Department of Electrical and Computer Engineering, Xanti, Greece. She is currently employed in a private-owned company. Her research interests are in transformer oil diagnostics.

Ioannis Liapis, is a graduate of Democritus University of Thrace, Department of Electrical and Computer Engineering, Xanthi, Greece, and is currently working with Public Power Corporation in Athens. His research interests are in transformer oil diagnostic techniques.
j-liapis@hotmail.com

Ahmad Basri Bin Abdul Ghani, Dr., is a researcher at TNB Research Institute in Selangor, Malaysia. His research interests include among other topics, power cable diagnostics, transformer oil diagnostics and partial discharge measurements.
abasri.aghani@tnbr.com.my