Diagnostic Techniques in Transformer Oils: Factors Affecting the Lifetime of Transformer Oil in Transformers of 150/20 kV and the Problem of Relating Diagnostics Data with their Pre-history

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Abstract

The aim of this paper is the study of various parameters affecting the lifetime of transformer oil in transformers of 150/20 kV. Fifty (50) samples of oil were taken from such transformers in the major Athens area, Greece. The parameters investigated – according to international standards – were breakdown strength, oil color, humidity, interfacial tension and tanδ. Thermal and mechanical stresses have as result the oxidation of transformer oil and the deterioration of its insulating properties. Humidity and foreign particles also consist factors contributing to the lowering of the breakdown strength of transformer oil. In most examined samples the breakdown strength and tanδ were satisfactory. It is shown that the slightest contact with the atmospheric air may affect humidity. A color index of 3 does not necessarily mean that the oil is bad. Foreign particle presence combined with humidity may decrease the interfacial tension. Generally speaking, the 50 investigated transformers were in a satisfactory state and none of them was required to have its oil replaced. A main conclusion of this work is that we should not base our judgment about the oil quality on only one or two parameters but on a combination of more parameters.

Keywords

Transformer oil, partial discharges, diagnostic tools, breakdown voltage, dielectric strength

Introduction

Transformer oil is a very important component of a transformer. It must have good thermal and insulating properties [1]. The insulating oil is used for providing insulation between the live parts of the transformer and the grounded parts as well as for carrying out the heat from the transformer to the atmosphere [2]. Faults in transformers are rare (1%-2% per year in power transmission and distribution systems), but they can be very costly in terms of economic and technical consequences. Faults can due, among others, to lightning and switching overvoltages, insulation failure, humidity, foreign particles and bad maintenance. The latter is a significant factor for the lifetime of a transformer [3], [4]. The main factors which may accelerate the ageing of the oil are humidity, temperature variations, oxidation and foreign particles. Various factors affecting the breakdown strength of transformer oils have been discussed and analyzed [5], [6]. There is no single measurement which can deliver enough information as to the ageing and/or deterioration of transformer oil, mainly because transformer insulation is a dynamic system, in which e.g. humidity may migrate from the oil to paper insulation and from paper insulation back to the oil [3], [7]. With this in mind, a variety of diagnostic methods were employed in order to study the state of fifty transformers of 150/20 kV. The whole work was carried out with the aid of the Public Power Corporation (PPC) Transformer Division in Athens, Greece. The fifty investigated transformers were from the major Athens area.

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. The latter is the last visible state of deterioration. Experience indicates that the breakdown behavior and breakdown voltage are determined much more from the above mentioned factors than that of pure insulating liquids [4], [8], [9].

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 155) was performed through a device (chromometer) including standard glass disks and two glass jars with lid. The control of breakdown voltage 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.

Fig. 1: The test cell for breakdown voltage measurements

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.

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 (Fig. 2). The measurements were performed according to IEC 247. The density of oil was performed according to DIN 51517, with the aid of a pipe of 250 ml, an electronic thermometer and a glass cylinder.

Fig.2: Device for measurement of tanδ and resistivity

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

Results

The sampling was done according to specification ASTM D 923. Sampling should take place in clean conditions (absence of humidity and pollution), suitable glass vessels should be used and the latter should be kept clean and hermetically closed. Every sample should be kept away from light according to VDE 0370/ 9.61. Every sample should be taken while the oil is warm.

In Tab. 1 a classification of values of the various investigated parameters of insulating oil is given. An oil can be classified as good, acceptable or bad according to Tab. 1 [10].

Tab. 1: Classification of insulating oils

Oil Parameters	Good	Acceptable	Poor
Color	< 2	—	> 2
Breakdown Voltage (kV)	> 40	30 — 40	< 30
Humidity [ppm]	< 10	10 — 25	> 25
Interfacial Tension (mN/m)	> 28	22 — 28	< 22
$\tan\delta$	< 0.1	0.1 — 0.5	> 0.5
Resistivity (ρ) (GΩ·m)	> 3	0.2 — 3.0	< 0.2

The sampling of oil from the fifty transformers 150/20 kV was done with due care and according to the standard practice. In Figures 3-7, the results of the measurements are shown, regarding $\tan\delta$, color, humidity and interfacial tension respectively. Green color symbolizes the good samples, yellow color the acceptable samples whereas the red color shows the bad samples. From Figs. 3 and 4, it is clear that the breakdown voltage and $\tan\delta$ values of most of the samples are very good. This is due to systematic control of the oil and the good maintenance. Figs. 3 and 4 indicate that these two factors, which are related to ageing and oxidation, are relatively stable.

In Fig. 5, humidity is in relatively acceptable levels. Only a small percentage of the transformers (4%) seems to have high humidity. Most of the samples are within the limits prescribed by the international standards. It must be emphasized that the humidity level is a parameter which changes easily, since the slightest contact of the oil with the atmosphere may change its characteristics. In Figs. 6 and 7 the results regarding the color as well as the interfacial tension are shown.

As time passes by, the oxidation products change the oil color. Most of the samples had a rather acceptable color. Even a color index of 3 does not necessarily consist an objective indication of the oil quality. For this reason, color measurements should in fact be accompanied by other parameter measurements. In fact, although 36% of the samples showed a rather dark color (Fig. 6) other parameter measurements indicated that these samples were good or acceptable. The presence of foreign particles in combination with humidity may reduce the interfacial tension of the oil. In the investigated samples, a percentage of 28% (Fig. 7) is characterized as poor. This, however, is not particularly annoying, if we take into account for these samples also the other parameter measurements.

The density of the investigated oil samples was measured in the generally acceptable values, i.e. between 0.85 and 0.92 gr/ml (with the lowest recorded being 0.85 gr/ml, whereas the highest was 0.91 gr/ml). Although the oil density does not consist per se an individual characteristic of the examined sample, its increase may imply an increase of degradation by-products. In the context of the present work the oil density was used for the calculation of the interfacial tension [11], [12].

It can be said that, in general, the state of the investigated transformer oil samples was more or less satisfactory. In a few cases, there is a need of further filtering and possibly a second sampling it should be carried out. Whereas no transformer functioned with a particularly bad oil, it is true that, with transformer ageing, the oil suffers from solid impurities, free and dissolved water particles and dissolved air. Frequent sampling is necessary in order to ensure the good functioning of such transformers. The results reported here are in line with those published before [11]. Although a statistical approach of the whole subject is desirable (i.e. to try to correlate the data collected here as well as from previous published work with the pre-history of each individual transformer), it is difficult to be realized since the Greek Electricity System has transformers from a variety of manufacturers. This inhomogeneity of suppliers certainly renders the relation between the data collected with the pre-history of transformers very difficult. It also should be noted that with the term "pre-history" we mean the detailed registration of all faults, faulty conditions, lightning strokes, switching overvoltages etc. which have occurred in a transformer. Previous work done in this direction was only partially successful since at that time, pre-history of transformers was only related to one parameter, namely that of breakdown strength [13], [14], [15].

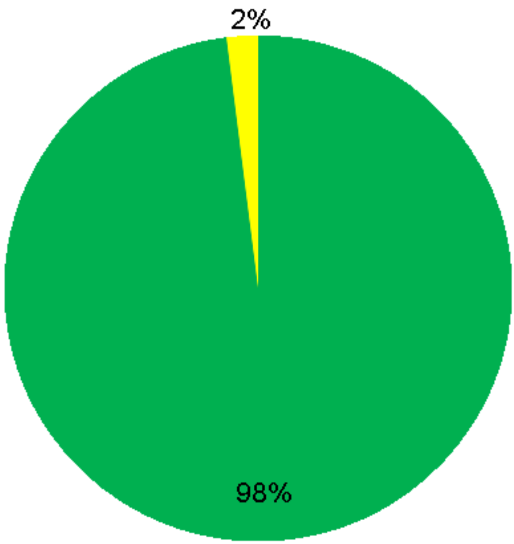

Fig.3: Graph of breakdown voltage results

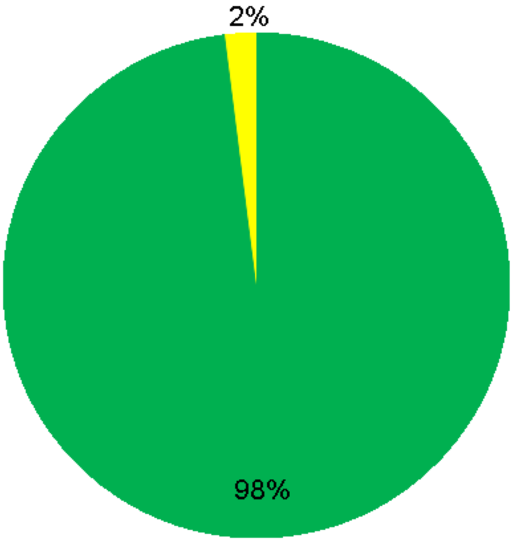

Fig.4: Graph of tanδ results

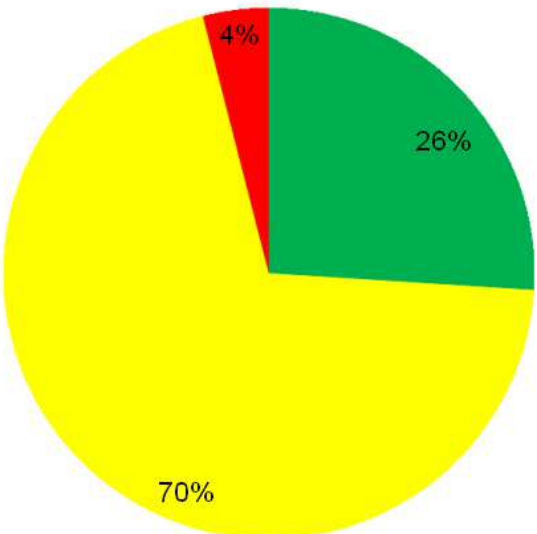

Fig.5: Graph of humidity results

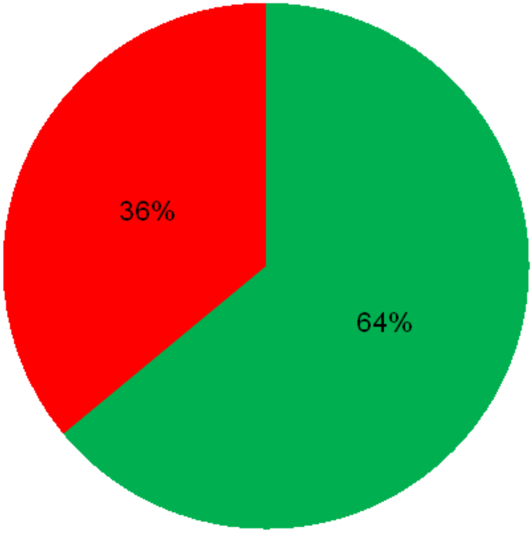

Fig.6: Graph of color results

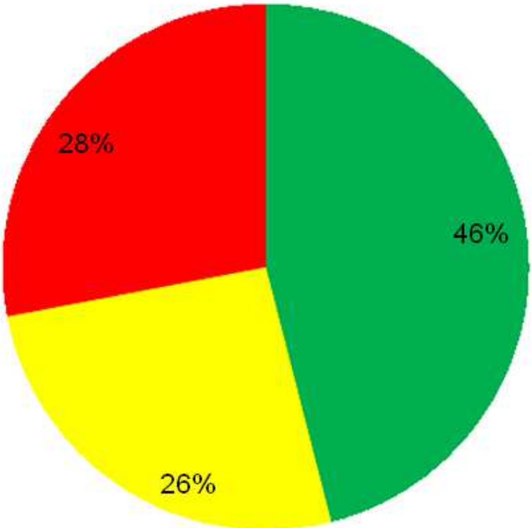

Fig.7: Graph of interfacial tension results

It can be said that this piece of work here does not consist per se an original piece of research. This paper does not claim to have explored new inroads regarding the mechanisms of breakdown of dielectric liquids, as for example in [16], or novel directions regarding new diagnostic methods, as for example in [17]. The whole purpose of this paper is, however, to show that monitoring work is necessary – not to say essential – for the correct maintenance of transformer oil in bigger transformers. An attempt to also relate the present state of transformer oil in the above mentioned transformers with their previous history will follow.

Some Further Remarks

One may ask which from the parameters investigated, are the most important. It is a difficult question to answer. However, if one has to choose between the aforementioned parameters, he would most probably select two of them, namely humidity and breakdown strength. If one looks carefully Fig. 3 (referring to breakdown voltage results) and Fig. 5 (regarding humidity results), one may see that 98% of the investigated transformers had good oil breakdown strength and 96% of the investigated transformers had good or acceptable levels of humidity. This means that Fig. 3 and Fig. 5 are in more or less good agreement. Humidity plays a critical role, since it can contribute to a dramatic lowering of breakdown strength, as was also indicated in some older but nevertheless classical publications [18], [19], [20]. Generally speaking, inclusions of humidity more than about 10 ppm (at normal temperature) cause a lowering of breakdown strength. A low oil breakdown strength may imply that there are foreign particles and/or admixtures in the oil. On the other hand, a high breakdown strength does not necessarily mean that the oil is good. It may be possible that the quantity of foreign particles may not be sufficiently large, so that it can influence the breakdown voltage [21].

The interfacial tension, although it gives an idea of the concentration of oxidation by-products in a transformer oil, is not necessarily an indicator for definite conclusions about the oil under investigation. This is because in warmer periods of the year, the oil temperature increases and humidity may affect the oil more than in cooler periods [22].

Change of the oil color

may mean the existence of by-products or the presence of foreign particles. Although such a change may imply a certain degree of pollution of the oil under investigation, the color by itself may not be considered as a very reliable indicator of the oil quality, as was shown in this paper and was also reported in [23].

Tanδ results (Fig. 4) match very well with Fig. 3 results of breakdown strength. Tanδ changes as the oil degrades. Although tanδ measurements cannot be taken as a sole criterion of oil quality, its results match extremely well with the breakdown strength data, in the context of the present paper. The low value of tanδ depends on the nature of the oil as well as on its processing [22], [24].

A last remark should be made concerning the monitoring of both transformers of 150/20 kV and of distribution transformers (both kinds of transformers in the major Athens area): it seems that the former have a larger percentage of good/acceptable oil than the latter [25]. To validate, however, this point, more work has to be done with transformers of both kinds from the major Athens area.

Conclusion

Insulating oil samples from transformers of 150/20 kV have been investigated. In the context of this work, several parameters – through the appropriate diagnostic techniques – affecting the state and lifetime of transformer oil have been studied. No single parameter can fully describe the state of the oil of a transformer. The variety of parameters investigated here may give a more complete picture. In the context of this work, the majority of the investigated transformer oil samples were found to be good or acceptable. This points out to the further continuing sampling at regular intervals.

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