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Prediction of the Characteristics of Transformer Oil under Different Operation Conditions

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***Abstract*—**Power systems and transformer are intrinsic apparatus, therefore its reliability and safe operation is important to determine their operation conditions, and the industry uses quality control tests in the insulation design of oil filled transformers. Hence the service period effect on AC dielectric strength is significant. The effect of aging on transformer oil physical, chemical and electrical properties was studied using the international testing methods for the evaluation of transformer oil quality. The study was carried out on six transformers operate in the field and for monitoring periods over twenty years. The properties which are strongly time dependent were specified and those which have a great impact on the transformer oil acidity, breakdown voltage and dissolved gas analysis were defined**.** Several tests on the transformers oil were studied to know the time of purifying or changing it, moreover prediction of the characteristics of it under different operation conditions.

***Keywords*—**Dissolved Gas Analysis, Prediction, Purifying and Changing.

I. Introduction

POWER transformers are high cost important equipment used in the transmission and distribution of the electric energy. Its right performance is important for the electric systems operation, since the loss of a critical unit can generate great impact in safety, reliability and cost of the electric energy supply.

Electrical power transformers are used to step up or step down voltage and are an integral component of any efficient power distribution network. A typical transformer incorporates coils of conducting wire wrapped around a core and covered with a paper-based insulator. Essential to the operation of these units are transformer oils that serve both functions: electrical insulation and heat dissipation. Regrettably, there are instances of transformers failing whilst in service, creating significant cost implications for the power supplier and, in extreme cases, explosion with a consequent threat of workers for severe injury or death and significant environmental impacts.

Power transformers are among the most valuable and important assets in electrical power systems. Insulation system ageing reduces both the mechanical and dielectrics withstand strength of the transformer. An ageing transformer is subject to faults that result in high radial and compressive forces. In an aged transformer failure, the conductor insulation has typically deteriorated to the point where it cannot longer sustain the mechanical stresses caused by a fault.

Transformer life/aging is mainly related to the degradation of the insulation, caused mainly by the thermal stress of the insulating paper, together with the electrochemical decomposition of the paper.

Transformer life known to us is based on the designed parameter with respect to normal operation and climate conditions [1].

Aging depends not just on loading, but is also influenced significantly by the type of paper, pulp composition, humidity and oxygen contents, as well as the acidity level of the insulating liquid.

Insulation is the major component, which plays an important role in the life expectancy of the transformer.

Oil suffers continuous deterioration and degradation due to the sustained application of the electric and cyclic thermal stresses because of loading and climatic conditions. This may be hazardous to the electric equipment and installation. Continuous monitoring of oil insulation characteristics has become an important task [2] to avoid deterioration of oil characteristics under working conditions. Several efforts have been made over the past years to study the electrical, physical and chemical properties of insulating oils. The preventive maintenance for transformer oil daily recording of oil level readings and temperature readings, half yearly take oil sampling to test the chemical, physical and electrical properties. Oil testing including specific gravity, kinematics viscosity, flash point, total acidity, humidity, breakdown voltage and dissolved gases. That is the monitoring for condition of transformer oil.

Among those efforts there is a property of natural fresh and aged oils. This area is still open to study the effect of service period on the properties of the transformers oil. The several tests on the transformers oil studied to know when it purifier or change and prediction of the aging in the different operation conditions

II. Experimentation

The reliable performance of mineral insulating oil in an insulation system depends upon certain basic oil characteristics which can affect the overall performance of the electrical equipment. In order to accomplish its multiple roles of

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dielectric, heat- transfer agent and arc-quencher the oil must possess creation basic properties. Oil in service will vary widely in the extent of degradation and the degree of contamination. Mineral oil in service is subject to deterioration due to the conditions of use. In many applications, insulating oil is in contact with air and therefore subject to oxidation reactions accelerated by elevated temperature and the presence of metals, organo–metallic compounds or both acting as oxidation promoters.

There are a large number of tests that can be applied to oil delivered in equipment or oil from equipment in service but the following tests are believed to be sufficient to determine whether the oil condition is adequate for continued operation and to suggest the type of corrective action required. In general no one test can be used as the sole criterion of the condition of the oil sample.

Evaluation of condition should preferably be based upon the composite evaluation of significant characteristics determined in properly equipped laboratories.

Experimental tests are carried out on transformers oil to determine experimentally their electrical, physical and chemical properties. The explained tests were carried out in the Central Laboratories, Egyptian Electricity Holding Company, Ministry of Electricity and Energy. Six transformer oil samples tested to study the characteristics of transformers oil as a function of the life time of it. Oil was sampled from different transformers. These transformers operate in Cairo south power station. The samples were taken from transformers operate for long years, different loads and operation condition.

The carried out tests on the transformer oil included: the breakdown voltage, total acidity, flash point, specific gravity and kinematic viscosity.

Different cases of transformer oil used in tests are:

- Transformer oil of transformers (1 & 5) is new (fresh).
- Transformer oil of transformers (3 & 6) is purified.
- Transformer oil of transformers (2 & 4) is change

The classifications of these transformers as shown in table (1). The effects of physical, chemical and electrical properties on transformer oil were studied using the international testing methods for the evaluation of transformer oil quality. Determination of breakdown voltage of each transformer oil sample was carried out according to the IEC 156 testing procedure [3]. Total acidity for a given oil sample in (mg KOH/g of oil) was determined according to the procedure given in IP 139/64 [4]. Flash point of the transformer oil sample was determined by ASTM D92 [5]. The testing procedure to determine transformer oil viscosity (mm^2/s) is given in Reference [6] as ASTM D445**.** The specific gravity determined by ASTM 1298. Several methods of interpretation of dissolved gas analysis (DGA) in transformers in service are provided in IEC Standard 60599[6], the IEEE Guide C57.104[8].

III. Experimental Result and Discussion

Transformer oil will age rapidly at high temperatures and moisture acts as a catalyst for its aging. There are also other catalysts present in a transformer that are responsible for oil degradation. These include copper, paint, varnish and oxygen. The principal mechanism of transformer oil aging is oxidation, which results in acids and other polar compounds being formed. These oxidation products will have a deleterious effect on the study degradation processes. Transformer oil, when subjected to thermal and electrical stresses in an oxidizing atmosphere, gradually loses its stability and becomes decomposed and oxidized, its acidity increases and finally begins to produce mud. This is the degradation mechanism of the oil. In fact the aging mechanisms of oil are complicated.

In general oxygen reacts with certain hydrocarbons by a free radical process, which generates hydro-peroxides. Hydro-peroxides are not stable and decompose to form ketones and water. Ketones can be oxidized further to form carboxylic acids or cleaved to make aldehydes. The presence of hydroxyl groups will result in the production of alcohols and phenols. Most oxidation products will have a negative effect on the electrical properties of the oil. The carboxylic acids that are produced will either dissolve in the oil or volatilize into the headspace. Dissolved acids may cause damage to the paper and copper windings, while volatile acids corrode the top of the unit. As a result, all of the necessary conditions exist properly in a power transformer for the degradation of the oil. An important part of the oil degradation is caused by air in contact with the heated oil in the apparatus, which by oxidation results in the oil degradation. Hot cellulose is also a source of oxygen.

Experimental tests are carried out on transformer oil to clarify experimentally their electrical, physical and chemical properties. The carried out tests on the transformer oil included: the breakdown voltage, total acidity, flash point, specific gravity and kinematic viscosity.

The breakdown voltage increases in the first period and then decrease with long periods as shown in Fig. 1. Under normal operating conditions, a minimal breakdown voltage will occur from oxidization and contamination. Contamination commonly found in transformer oil includes water and particulate, these contaminants will reduce the insulating qualities of transformer oil.

The decreasing in the breakdown voltage because of the long periods in service increases some particulate impurities, this will increase the moisture and the oil will become non homogeneous, consequently it will decrease the transformer oil resistance, which will decrease the maximum value of the breakdown voltage of the transformer oil.

Silent discharges and concentrated conduction current lead to the formation of water, acids and growing of hydrogen. Arc discharge and intensive localized of the liquid produce particles of carbon, wax and gases such as carbon monoxide, carbon dioxide, acetylene and the acidic products due to oxidation and discharges attack the solid insulation, iron and copper in the liquid, which lead to lowering electric strength.

If the transformer oil purified or changed, the breakdown voltage would be increased firstly and then decreased with long periods.

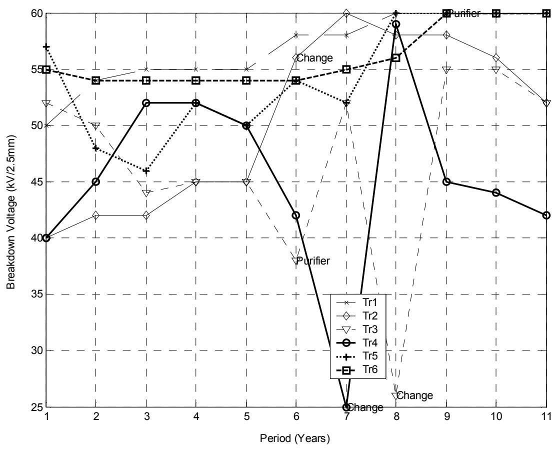

Fig. 1 Effect of service period on the breakdown voltage of the transformer oil

The total acidity of transformer oil increase very slowly with the service period and increase high when the transformer oil is aging as shown in Fig. 2.

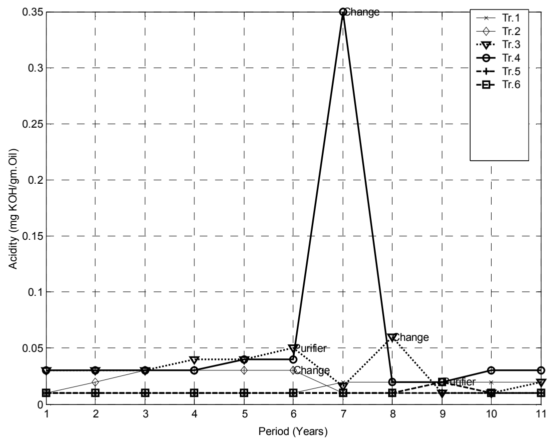

Fig. 2 Effect of service period on the total acidity of the transformer oil

The flash point decreases with long periods and if purified or changed the oil, it increases and then decreases with long period as shown in Fig. 3. This phenomenon occurs due to the increasing in temperature and aging in the transformer oil. Prolonged exposure of the oil to very high temperature under fault conditions may produce sufficient quantities of low molecular weight hydrocarbon to cause a lowering of flash point value. Low values of flash point temperature cause flashing throw transformer oil, which was an indication of the presence of volatile combustible products in the oil.

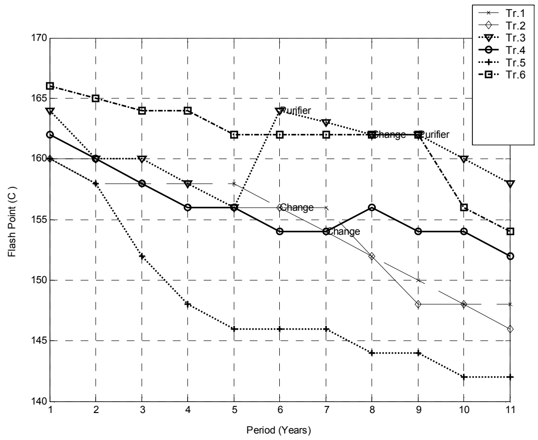

Fig. 3 Effect of service period on the flash point of the transformer oil

The specific gravity decreases with long periods of time. This phenomenon occurs due to heat transfer of the transformer oil. This test is not important to decide if transformer oil should be purifiered or changed because of the small change in reading of the tests for the long periods as shown in Fig. 4. Oils of different specific gravity may not readily mix when added to each other and precautions should be taken to ensure mixing.

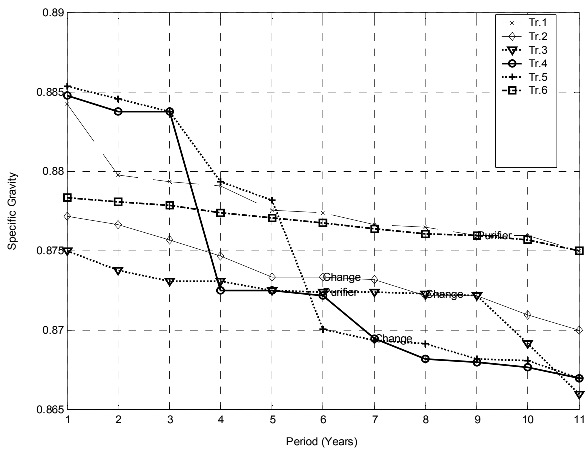

Fig. 4 Effect of service period on the specific gravity of the transformer oil

The kinematic viscosity increases with long periods and if the oil purified or changed, it decreases and then increases with long periods. This phenomenon occurs due to the increasing in temperature and aging in the transformer oil as shown in Fig. 5.

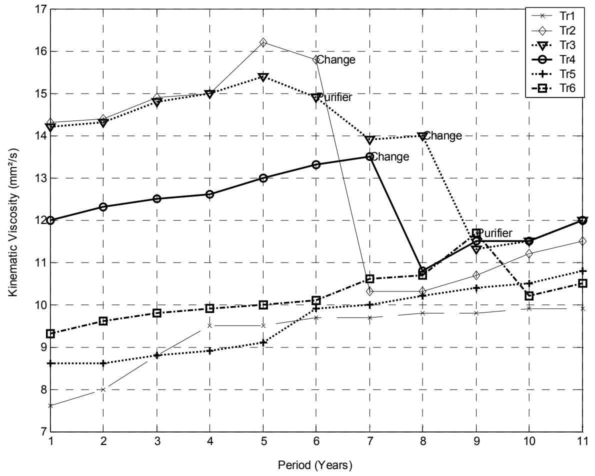

Fig. 5 Effect of service period on the kinematic viscosity of the transformer oil

Under conditions of normal transformer functioning, ageing can occur at a slow pace however this process tend to accelerate harmfully due to electrical and thermal faults. The transformer oil undergoes chemical reactions that result in generation of soluble gases of hydrocarbon composition. Thus, concentration and gas rate generation usually are dependent on fault characteristics, such as type and intensity. Fault gases dissolved in oil are known as a mixture of light hydrocarbons such as methane, ethane, ethylene, acetylene, propane and propane along with carbon monoxide, and carbon dioxide, hydrogen, oxygen and nitrogen [9]. From the results of tests, the important dissolved gases in transformer oil are hydrogen, acetylene, carbon monoxide and carbon dioxide.

It has been noticed that the reason of generation gases is not only the faults inside the transformer, but also the increasing in temperatures in transformer oil due to its cooling lack. The cooling system could be failed due to the fan failure or not operating automatically, which lead to the increasing in the total dissolved combustible gases.

IV. Conclusion

The study of the prediction of the transformer oil characteristics under different operation conditions investigated the effect of service period on the properties of naturally aged oil, and also show if it is need to be changed or purified. We can conclude the main results of this study as follows:

- The total acidity increases slowly with long periods and considered one of the main factors for changing or purifying the transformer oils.
- The chemical and electrical tests especially acidity and breakdown voltage are the most important tests in the transformer oil.
- The increasing in dissolved gas analysis (DGA) not only indicates to the fault inside the transformer, but also to insufficient cooling system.
- Normally the physical tests are slightly changed for long periods, consequently its limits in the allowable range for long years, so they can not be considered as good criterions to represent the oil degradation caused by ageing. If tests became beyond the allowable limits, the transformer oil must be changed due to the deterioration and ageing of it.
- The transformer oil can be changed in the following cases:

  a) Old transformer oil and high total combustible gases.

  b) Both of total acidity and breakdown voltage are out of allowable standard ranges.

  c) The physical tests are out of allowable ranges.
- The purification can be treated in the following cases:

  a) Replacement new transformer oil.

  b) Total combustible gases out of the standard ranges.

  c) Total acidity or breakdown voltage near to unallowable standard limits.

TABLE I
CLASSIFICATION OF TRANSFORMERS

Transformer	1	2	3	4	5	6
Unit	Main steam (1)	Auxiliary steam (3)	Auxiliary steam (7)	Auxiliary steam (9)	Main gas (1)	Main steam (combined)
Manufacturer	Germany	Germany	England	Germany	Mitsubishi	North American
Operating year	1999	1957	1965	1957	1989	1994
Rated capacity	80 MVA	9.4 MVA	9.4 MVA	2.5 MVA	125 MVA	58/77 MVA
Rated voltage	10.5/66 kV	66/6.6 kV	66/6.6 kV	6.6/0.4 kV	220/11.5 kV	220/11.5 kV
Rated current	4399/642.4 A	82.2/861.4 A	86.4/82.2 A	229/3608.4 A	6276/298 A	202/3866 A
Type of cooling	ONAF	ONAN	ONAN	ONAN	ONAF	ONAF
Oil weight	15.5 ton	7.9 ton	9.04 ton	3 ton	23000 Kg	13750 gal
Oil type	Shell Dialla (D)	Shell Dialla (D)	Shell Dialla (D)	Shell Dialla (D)	ASTM 3487	ASTM 3487

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