Study of Transformer Oil Purification

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Abstract

Transformer is one of the main assets in the electrical power industry which needs to be maintained for guaranteed uninterrupted power transmission in order to get assured revenue benefits. Transformer's life mainly depends on the quality of its insulating oil i.e. transformer oil. Since transformer oil serves as a dielectric material and as an effective coolant in transformer, to perform these functions effectively the transformer oil must be purified regularly. In this paper, we will discuss about the contamination of transformer oil, why transformer oil needs to be purified and which equipment purifies the transformer oil.

Keywords — *Contaminants, Insulating oil, Purification, Transformer.*

I. INTRODUCTION

Transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current. To overcome losses, the electricity from a generator is passed through a step up transformer, which increases the voltage. Throughout the distribution system, the voltages are changed using step-down transformers to voltages suitable to the applications at industries and homes. Transformers are generally housed in tightly fitted sheet metal tanks filed with special insulating oil, also known as transformer oil. Due to contamination of transformer oil, the original chemical properties of transformer oil changes, rendering it ineffective for its intended purpose for many years. Hence transformer oil needs to be purified regularly. To purify transformer oil, transformer oil filtration machine is used.

II. TRANSFORMER OIL

Insulating oil in an electrical power transformer is commonly known as transformer oil. It is normally obtained by fractional distillation and subsequent treatment of crude petroleum. That is why this oil is also known as mineral insulating oil. Transformer oil is highly refined mineral oil that is stable at high temperatures and has excellent electrical insulating properties. Transformer oil serves mainly two purposes, one it is liquid insulation in electrical power transformer and the other is it dissipates heat of the transformer i.e. it acts as a coolant. In addition to these, this oil serves other two purposes, it helps to preserve the core and winding as these are fully immersed inside oil and another important purpose of this oil is, it prevents direct contact of atmospheric oxygen with cellulose made paper insulation of windings, which is susceptible to oxidation.

A. Electrical Parameters of Transformer Oil

1) Break down voltage

Dielectric strength of transformer oil is also known as breakdown voltage of transformer oil or BDV of transformer oil. Break down voltage is measured by observing at what voltage, sparking strants between two electrodes immerged in the oil, separated by specific gap. Low value of BDV indicates presence of moisture content and conducting substances in the oil. For measuring BDV of transformer oil, portable BDV measuring kit is generally available. Dry and clean oil gives BDV results better than the oil with moisture content and other conducting impurities. Minimum breakdown voltage of transformer oil or dielectric strength of transformer oil at which this oil can safely be used in transformer, is considered as 30 KV.

2) Specific Resistance:

This is another important property of transformer oil. This is measure of DC resistance between two opposite sides of one cm^3 block of oil. Its unit is taken as ohm-cm at specific temperature. With increase in temperature the resistivity of oil decreases rapidly. Just after charging a transformer after long shut down, the temperature of the oil will be at ambient temperature and during full load the temperature will be very high and may go up to 90°C at over load condition. So resistivity of the insulating oil must be high at room temperature and also it should have good value at high temperature as well. That is why specific resistance or resistivity of transformer oil should be measured at 27°C as well as at 90°C. Minimum standard specific resistance of transformer oil at 90°C is 35×10^{12} ohm–cm and at 27°C it is 1500×10^{12} ohm–cm.

3) Dielectric Dissipation Factor or Tan Delta

Dielectric dissipation factor is also known as loss factor or tan delta of transformer oil. When an insulating material is placed between live part and grounded part of an electrical equipment, leakage current will flow. As insulating material is dielectric in nature and the current through the insulation ideally leads the voltage by 90^o. Here voltage means the instantaneous voltage between live part and ground of the equipment.

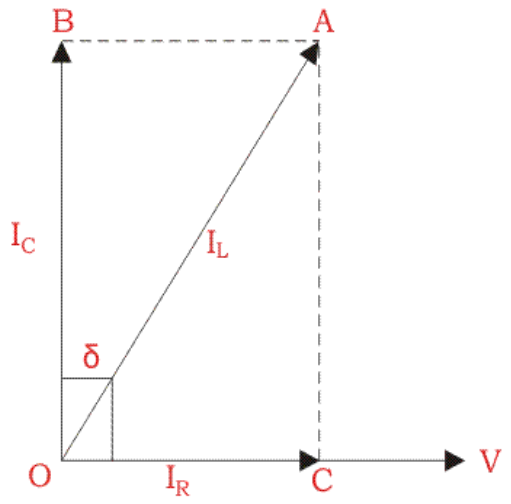

Fig 1: Loss Angle

But in reality no insulating materials are perfect dielectric in nature. Hence current through the insulator will lead the voltage with an angle little bit shorter than 90°. Tangent of the angle by which it is short of 90° is called dielectric dissipation factor or simply tan delta of transformer oil. More clearly, the leakage current through an insulation does have two components, one is capacitive or reactive and the other one is resistive or active. Again it is clear in Fig 1, the value of ′δ′ which is also known as loss angle, is smaller, means resistive component of the current I_R is smaller which indicates high resistive property of the insulating material. High resistive insulation is good insulator. Hence it is desirable to have loss angle as small as possible. So we should try to keep the value of tanδ as small as possible. High value of this tanδ is an indication of presence of contaminants in transformer oil. Hence there is a clear relationship between tanδ and resistivity of insulating oil. If resistivity of the insulating oil is decreased, the value of tan-delta increases and vice versa. So both resistivity test and tan delta test of transformer oil are not normally required for same piece of insulator or insulating oil. In one sentence it can be said that, tanδ is measure of imperfection of dielectric nature of insulation materials like oil.

III. CONTAMINANTS OF TRANSFORMER OIL

The power transformer insulation gets degraded under a combination of thermal, electrical, chemical, mechanical, environmental stresses, etc. during its operation. These stresses reduce the dielectric capability of a transformer and increase the probability of failure. Principal causes of oil contamination are electrical disturbance and thermal decomposition. Contaminants commonly found in transformer oil are moisture, sludge contents, dissolved gases and acids.

A. Moisture

The presence of even an extremely small percentage of moisture in the oil is highly detrimental from the insulation viewpoint as it adversely affects the dielectric properties of oil and solid insulation of transformer. When transformer is filled with oil, the paper absorbs the moisture from oil (due to hygroscopic nature of paper) affecting its insulating property and thereby reduces its life. Even an addition of 8 parts of water in 10,00,000 reduces the insulating quality of the oil to a value generally recognized as below standard. Water can originate from two sources :

*1) **Atmospheric :***

- Via the silica gel breather (dry silica gel is always blue).
- Via leaks into the power equipment, i.e. bad gasketing, cracked insulation, a loose manhole cover, a ruptured explosion diaphragm etc.

*2) **Internal Sources :***

- Paper degradation produces water.
- Oil degradation produces water

Moisture content in transformer oil is a life shortening parameter and has following effect on the insulation system:

1. It can weaken the breakdown capacity of the insulation system.
2. It promotes local heating
3. It reduces the overload capability of transformer in emergency conditions.
4. It accelerates the insulating deterioration process.
5. It decreases the electrical and mechanical strength.
6. Electrical or partial discharges can occur in a high voltage region due to a disturbance of the moisture equilibrium.
7. It increases the electrical conductivity, tan δ, etc.

B. Acidity

Just like industrial oils, transformer oils are oxidized under the influence of excessive temperature and oxygen, particularly in the presence of small metal particles which act as catalysts, resulting in an increase in acid number, due to the formation of carboxylic acids. In the worst-case scenario, the oil canals become blocked and the transformer is not cooled well, which further exacerbates oil breakdown. Furthermore, an increase in the acidity has a damaging effect on the cellulose paper.

Oil degradation also produces charged by-products, such as acids and hydro peroxides, which tend to reduce the insulating properties of the oil. An increase in acid number often goes hand-in-hand with a decrease in dielectric strength and increased moisture content.

The acidity of oil in a transformer should never be allowed to exceed 0.25mg KOH/g oil. This is

the critical acid number and deterioration increases rapidly once this level is exceed.

C. Sludge Contents

Another thing to avoid in the transformer oil is the sludge which is simply the decomposition of oil with long and continued use. Sludge is formed principally by exposure to oxygen during heating and results in the formation of large deposits of dark and heavy matter that eventually clogs the cooling ducts in the transformer. Sludge attacks the cellulose of the transformer windings causing it to deteriorate. Sludge also forms a layer on the transformer winding and reduces the heat transfer. These lead to higher transformer winding temperatures. The early precursors of sludge are peroxides, organic acids, alcohols, aldehydes, ketones, lacquers, and other aromatic compounds, particularly those that have polar functional groups. As these materials attack other transformer components such as the paper, iron, and copper, they form intermediate by-products in the oil that then polymerize together to form a solid type material which is called sludge. This is the terminal stage of this degradation process. Sludge tends to precipitate out in the coldest and hottest regions of the transformer.

D. Dissolved Gases

The electrical windings in a power transformer consist of paper insulation immersed in insulating oil, hence transformer oil and paper insulation are essential sources to detect incipient faults, fast developing faults, insulation trending and generally reflects the health condition of the transformer. During faults and due to electrical and thermal stresses, oil and paper decomposition occurs. As a result of this decomposition some gases are evolved. These gases decrease the heat dissipation capability and the dielectric strength of the transformer oil. Gases produced due to oil decompositions are hydrogen (H2), methane (CH4), acetylene (C2H2), ethylene (C2H4) and ethane (C2H6). On the other hand paper decomposition produces carbon monoxide (CO) and carbon dioxide (CO2). The gases listed above are considered key gases and are generally considered combustible (note that CO2 is not a combustible gas). The total of all combustible gases may indicate the existence of any one or a combination of thermal, electrical, or corona faults.

Considering all the adverse effects of the contaminants present in the transformer oil, it is cleared that transformer oil should be absolutely free from acids, sludge, dissolved gases and particularly from the moisture, to avoid catastrophic failure of transformer which leads to failure of power system network.

IV. PURIFICATION OF TRANSFORMER OIL

Transformer oil purification is a process to remove sludge, dissolved moisture, acidity and dissolved gases from the oil. Present and future transformer ratings require high quality and high purity insulating oils at the point of use. For effective maintenance of power transformer in service, maintenance of dielectric properties of insulation, whether, solid or liquid is most important. Better the insulation of transformer, longer the life of the transformer and lesser the breakdown of the transformer. Lesser breakdowns and failure of the transformer results in uninterrupted power supply.

A good oil purification system is able to deliver filtered oil with parameters as per the standard specification. To purify the transformer oil, transformer oil filtration machine is used. The revival of the transformer oil by oil filtration machine to standard oil parameters is based on the quality of unprocessed oil and its initial process. In case the unprocessed oil does not match the standard oil parameters, then the effort of transformer oil filtration is all in vain. Alternate method of regeneration of transformer oil should be adopted in this case.

A. Transformer oil filtration machine

Transformer oil filtration machine consists of inlet pump, filters, heaters, ionic reaction column, degassing and dehydration chamber, discharge pump, vacuum pumps etc. Inlet pump pumps the contaminated oil from transformer to oil filtration machine. Heaters heats the oil up to 60 to 70 degree Celsius. Oil is heated to make the purification process faster. An ionic reaction column is provided to reduce the acidity in the oil. Filters are provided for the removal of suspended particles, sludge content in the oil. The degassing and dehydration chamber is provided for removal of dissolved gases and moisture from the oil. Vacuum pumps are provided for evacuation of degassing and dehydration chamber. After three to five passes in transformer oil filtration machine the contaminated transformer oil is purified.

Fig 2: Transformer Oil Before and After Filtration

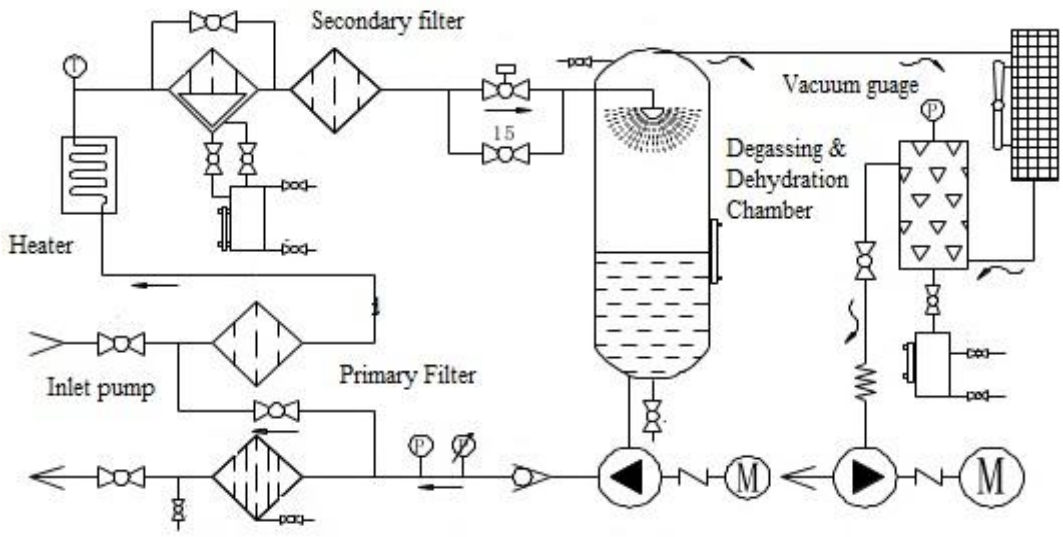

Fig 3: Circuit Diagram of Transformer oil filtration machine

Fig. 2 shows the transformer oil before and after filtration from transformer oil filtration machine. The brown coloured oil is unfiltered oil whereas pale yellow colored oil is filtered (or purified) oil. Fig. 3 shows the circuit diagram of transformer oil filtration machine.

V. CONCLUSIONS

In this paper, we have discussed about the transformer oil, the contaminants present in the transformer oil, why transformer oil needs to be purified and how transformer oil filtration machine purifies the transformer oil.

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