Use of Ester Oil in Power Transformer & It's Various Characteristics Analysis with Convectional Mineral Oil

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Abstract— I have planned to investigate the various characteristics like Dielectric, Overloading, Partial Discharge (PD) etc. of mineral oil and Ester oil filled power transformer. Mineral oil is the most commonly used insulating liquid for transformer applications, and an extensive database of knowledge has been accumulated over the years. Increased environmental, safety performance and economic have led to the consideration of other oils for use as transformer insulating fluids. Esters have been used as dielectric liquids since the invention of oil filled transformers in the late 1980s. Both types of oils tested are commercial products and commonly used in transformers. A Partial discharge (PD) is localized dielectric breakdown of a small portion of a solid or fluid electrical insulation (EI) system under high voltage (HV) stress. The discharge may occur at any point in the insulation system that the electric field strength exceeds the breakdown strength of that portion of the insulation system. In transformers, the insulation system is comprised of the winding insulation material as well as the dielectric fluid. PD can occur in a gaseous (i.e.SF6), liquid (Mineral Oil –Ester Oil) or solid insulating medium (Press board, Craft Paper, Insulation etc). Insulation failures begin with and are characterized by small but detectable releases of energy or Partial Discharge. That means partial discharges are the first indication of insulation breakdown. PD measurements can also provide information about ageing condition of transformers and thus enable conclusions about their lifetime. One of the main factory tests which used for assessing the insulation quality of power transformers is Partial Discharge test. The certainty of Partial Discharge (PD) measurement results can be affected by different factors such as materials used inside the transformer, Dielectric fluid, workmen ship during manufacturing process. The overload capability of Ester fluid is also remarkably higher compare to the mineral oil .An experimental study carried out on a real three phase Power Transformers at manufacturer high-tech test laboratory using modern test equipment . Dielectric tests were carried out on Power Transformer to understand Electrical Properties of Mineral oil and Ester Oil.

Keywords: Transformer insulating oil, Mineral oil, Ester oil, Breakdown voltage, Dielectric losses (tan δ), Relative permittivity (εr), Dielectric characteristics

I. INTRODUCTION

As we know today in the fast growing world in the electrical field and transformers are the indispensable equipment for the voltage level management or maintaining the floe of the power. Transformers are very necessary equipment from generation to distribution. First of all transformers generated the power at the power generation plant and increase the level of the voltage. After that as per our requirement we change the level of the voltage may be increase or decrease then for the distributing we decrease the level of the voltage as per the consumer's requirement at industry, commercial or consumers home.

Transformers are the very expensive equipment so it needed more protection in the system. Several conditions like overload conditions, insulation failure, cooling factor or acceleration factor might lead the chances of the failure of the transformer and it is affected the life of the transformer. Low quality raw material, design of the transformer, oil leakage, over load condition, fire or explosion, line surges, improper maintenance, loose connection, lightning, moisture are the several thing which may occur the failure of the insulation system of the transformer.

Transformer have two types of the insulation system:

1) Solid insulation: In the solid insulation system, there is kraft paper are used widely as the insulating material and the other solid insulating materials are paper, wood, pressboard.
2) Liquid insulation: In the liquid insulation type, it has mainly two purpose of the liquid insulating in the transformer are as the insulating material and as cooling material.

Now we know the purpose of the solid and liquid insulating system. But in the liquid insulation system it has two purpose in transformer as a cooling material and as a insulating material. So liquid insulating system required some requirements as below

1) If it is use as the coolant, it's work is absorb the moisture from inside and outside of the transformer.
2) It has low pour point so we can observe the oil at any observable time required.
3) It will good at insulation so that will come in to the wound insulation layer and fill the space between the layers.
4) Oil volatility should be low so the temperature is remain low. If the temperature is low then it is maintaining the flash point and evaporation losses.

In recent years, many researchers are investigating to find out the best suitable insulating oil for the transformer. may it can be natural or synthetic. Some basic properties required to choose the best insulating oil for transformers are as given below:

1) High impulse strength
2) High electric strength
3) High volume resistivity
4) High thermal conductivity
5) High specific heat
6) High flash point
7) Low viscosity
8) Low volatility
9) Low dielectric dissipation factor

10) Low flammability
11) Biodegradability
12) Low pour point
13) Non-Toxic
14) Recyclable and readily disposable.

II. HISTORY

In 1892, mineral oil is introduce as the dielectric coolant because of it has high flash point characteristics and availability of this oil is worldwide. Now a day mineral oil is main source of the insulating material in power transformer. But it has a big disadvantage of it's biodegradability. In the case of leakage during the operation it may be explose. paraffin based mineral oil is used in 1899 and production of this oil is in large quantity, but due to high pour point it is decrease the viscosity and reduce the heat transfer capacity.

In 1930 to 1970, askarel is used as the insulating material for the transformer, askarel is mixture of chrolobenzene and polychrolinated biphenyl (PCB). This material is choose because of non-flammable characteristics. But it is a hazardous material and dangerous for the environment so it was no longer use as insulating material. Because of its hazardous characteristic its banned in 1970.

Now researchers are investigating for the alternative source as insulating material. In 1962 we use the vegetable oil as capacitor insulation .it has a high dielectric constant. Today vegetable oil is also use as the insulating material because of its biodegradability. Vegetable oil is also known as the ester oil.

III. MINERAL OIL

The most commonly used insulating oil in the transformer is petroleum based mineral oil. Which is purified to transformer graded oil. Mineral oil is refined from the petroleum. Main source and production of mineral oil is from the process of petroleum refining.

It has two source as given below A) crude petroleum B) refined petroleum

A. Crude petroleum:

Crude petroleum is produce from the extraction process of the source. In the crude petroleum, there are hydrocarbons and small amount of sulphur and nitrogen. Due to the hydrocarbon chemical bonds its can be divided into the three parts:

1) Paraffin:

In paraffin, there are hydrocarbon molecules like Methane (CH4) is a gas, normal buthane (C4H10), and isobutene.

2) Naphthene:

In naphthene, it has ring structures with six carbon atoms (within six-member rings) or fourteen carbon atoms (within three-member rings)

3) Aromatics:

It has six-member ring structures, fall into two groups: mono-aromatics (single rings) and poly-aromatics (two or more rings).

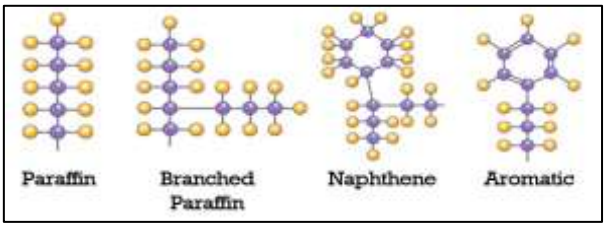

Fig. 1: chemical structure of the Paraffin, Naphthene, Aromatic.

Mineral oil is produce worldwide and available at the low cost. Mineral oil is used as insulating material worldwide because of its good electrical properties like low viscosity, aging factor, And Low Relative Permittivity. Mineral oil is poorly degradable which leads to environmental issues. Mineral oil is non-biodegradable and takes years to unravel because it is made from petroleum. Mineral oil can cause pollution when there is leak in the transformer. Other environmental aspects are toxicity, water pollution and waste treatment. A serious spill due to leakage and equipment failure will contaminate the soil and waterways.

Fig. 2: the mineral oil leakage afterv19kv transformer explosion.

B. Refining petroleum:

Crude petroleum refined and produce more useful petroleum products such as Gasoline, kerosene, liquid petroleum gas (LPG), lubricating oils etc.

IV. ESTER OIL

Ester oil is nothing but the synthetic compound group of alcohol and acid. Ester oil have mainly two types A) synthetic ester B) natural ester

A. Synthetic ester:

Synthetic ester oil is product of the polyol molecules with an acid group. Other three group of which made structure from the tetra-alcohol pentaerythritol (C5H12O4). from this chain, ester oil give the very stable chemical bonded structure. Ester oil has some characteristics like good oxidation, low pour point, low viscosity, thermal stability, less flammable, good biodegradability.

Synthetic ester oil used in distribution transformer and where high temperature expected, where transformer are prime concern like fire safety and environmental protection, and where fire resistance is important like mobile transformer and specially applications.

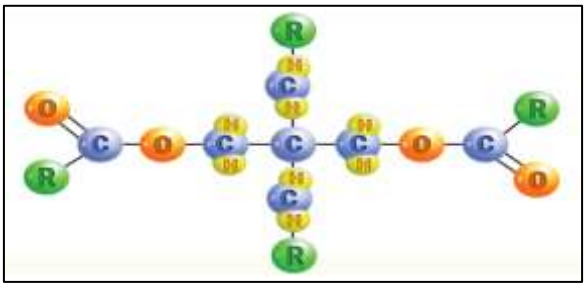

Fig. 3: chemical structure of synthetic ester oil

B. Natural ester oil:

In 1990, where the environmental concern increasing, researchers are more focus on the vegetable oil as insulation oil. The structure of natural ester is based on glycerol which is occurring fatty acid group and bonded it. Plants produce ester oil in seeds and provide us valuable high calorific oil.

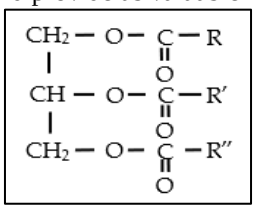

Fig. 4: chemical structure of natural ester oil

Natural ester has high fire point, good biodegradability, but its not more stable in oxidation with compare of other insulating oils.

Natural ester is produce from the edible seed based vegetable oil like soya, rapeseed, sunflower oil as shown in figure below.

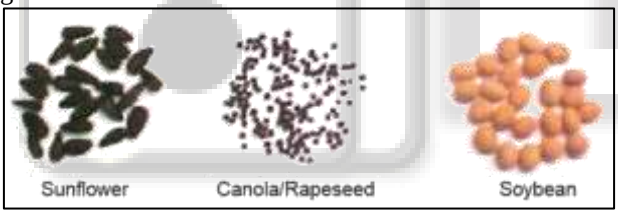

Fig. 5: oil seeds

V. EXPERIMENTAL CASE STUDY

A. MOISTURE SATURATION

The purpose of the moisture is provide the electrical insulation to the active parts of the transformer. while the moisture enter in the transformer, it will affected the dielectric strength and after a time it will also affected the life of the transformer.

Inside the transformer, moisture is exchange with the exchange of temperature of the transformer between the solid and liquid insulation material. If the temperature is high in transformer there will more amount of moisture and its dissolved in to the liquid insulating material (insulating oil)and dry out the solid insulation (mostly kraft paper is used as solid insulation). While the temperature is low, moisture is reduce and dissolved in to the liquid insulating material in small amount. Where transformer reaches the saturation level of the moisture, transformer is going to de-energized slowly.

All insulating fluids have different level of the relative saturation (RS). Relative saturation is ratio of the actual water to the maximum water content at certain level of temperature. Water content is in parts per million (PPM) reaches the maximum level of the water content in to the fluid, water is formed in to the transformer, which is called the "free water".

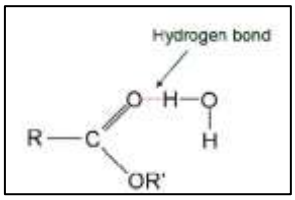

Fig. 6: ester oil fluid hydrogen bond with water.

If the insulation material is mineral oil, then this free water and mineral oil are un-mixable, so mineral oil has low PPM, while the insulating material is ester oil, then this free water is forming a weak bond with ester oil, which is called hydrogen bond. So PPM is high in the ester oil.

Insulating fluid	Saturation limit at 20°C	Saturation limit at 60°C
Mineral oil	57	207
Natural ester oil	1200	1950
Synthetic ester oil	2750	4550

Table 1: Moisture saturation of M.O and E.O

B. Breakdown voltage test:-

According to standard IEC 60156 insulating liquid – determination of the breakdown voltage at power frequency, the procedures adopted in the measurement for determination of breakdown voltage of insulating oil are as outline:

By first initiating the voltage application approximately 5 minutes after completion of the filling, and making sure that air bubbles which are visible in the electrode gap is avoided. The applied voltage is increased uniformly from zero at the rate of 2 KV/s ± 0.2 KV/s until breakdown occurs.

There are total six numbers of measurements are carried out on the same cell. All measurements are taken within 1mm and 2mm and 2.5mm electrode gap. All the measurements are measured after the 5 minute and before measurement check the gas bubble presents in electrode gap in the cell.

The final result is mean value of all measurements in KV.

Fig. 7: Breakdown voltage test kit

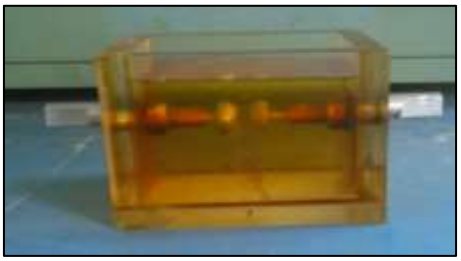

Fig. 8: Ester oil in cell

Fig. 9: Mineral oil in cell

Insulating fuel	Dielectric BDV at 1mm gap(KV)	Dielectric BDV at 2mm gap(KV)	Dielectric BDV at 2.5mm gap(KV)
Mineral oil	22	35	69
Natural ester oil	25	40	82
Synthetic ester oil	31	49	89

Table 2: Breakdown voltage test at 1MM, 2MM, 2.5 MM gap of M.O, N.E.O, S.E.O

C. The humidity in oil measurement:-

The humidity value in the oil sample is tested after the dielectric measurement to avoid contamination of the oil. The humidity tester should be turned on before placing the humidity probe inside the oil. The result is shown after sometime while it is take steady value of results in PPM. Operating temperature range of humidity tester is -40°C to 60°C and sensitivity of 1 PPM. To clean the probe after a measurement, two types of cleaning solvent (n-Heptaan) are used. The humidity tester can be used again at least 30 minutes after cleaning to get rid of any traces of the cleaning solvent.

Fig. 10: Humidity tester

Ageing hour	Mineral oil	Ester oil
0	11	4
46	11	5
96	15	5
190	15	5
286	13	4
430	13	4

Table 3: Humidity values of mineral oil and synthetic ester oil

D. Pour point

In insulating system, the thermal conductivity has a function to remove the heat from the active parts of transformer. To do this, insulating fluid is need a temperature which is increase the thermal conductivity between fluid and active parts. Make thermal conductivity stable so heat transfer capacity increase. In cold weather or winter season, insulating oil is increase and the viscosity increase and decrease the thermal conductivity.

Pour point is defined as the temperature below which oil is observed to flow when its cooled. As we know the, in the power transformer, the insulating fluid don't change immediately from solid to fluid. During de-energized, the power transformer take time for equilibrium condition with environment.

In no-load condition, internal losses occur in transformer and heat is prevent gelling of any fluid, because of this phenomenon viscosity of fluid and gel are increase. This concern two topic: dielectric strength and moving apparatuses.

Insulating fluid	Pour point (°C)
Mineral oil	-40° C
Natural ester oil	-10° C
Synthetic ester oil	-45° C

Table 4: Pour Point Temperatures of Liquid Insulation

As temperature is going down, and insulating oil is mineral oil, there is drop of water saturation level and increase chance of forming of "free water" in transformer. So mineral oil has low pour point because it has high moisture level in insulating fluid.

As we know, high RS level in ester oil, for ester oil dielectric strength don't reduce also when in cold weather.

E. Insulation Power Factor and Insulation Resistance:

The Ester oil has a slightly more polar character compared to mineral oil. It also retains more moisture. This translates into lower resistivity and higher insulation power factor (Tan Delta) values as compared to mineral oil. Even with the increased tan delta value and lower resistivity of the ester oil, same dielectric performance of ester fluid is achieved. The Following result shows Comparison of Insulation Resistance and Capacitance and Tan-Delta of Power Transformer with Mineral oil and Ester oil.

Supply 5 KV	Seconds	Reading	Seconds	Readings
Connections	60 sec	Current	600 sec	Current
HV-LV	48.4	106	106	48.3
HV-E	21.3	240	36.3	141
LV-E	44.9	114	109	47.0

Table 5: Insulation Resistance Test (Mineral oil)

Supply 5 KV	Seconds	Reading	Seconds	Readings
Connections	60 sec	Current	600 sec	Current
HV-LV	680	7.40	1230	4.14
HV-E	280	18.3	343	14.9
LV-E	545	9.43	993	5.14

Table 6: Insulation Resistance Test (Ester oil)

	Test type	Capacitance (nF)	Tan-delta (% δ)
HV connection 10 KV (AC)	UST Y	5.2318	0.191
	GST G	2.8799	0.314
	GST YG	8.0948	0.235
LV connection 10 KV (AC)	UST Y	5.2336	0.188
	GST G	9.7794	0.230
	GST YG	15.046	0.215

Table 7: Capacitance & Tan-Delta Test (Mineral oil)

	Test type	Capacitance (nF)	Tan-delta (% δ)
HV connection 10 KV (AC)	UST Y	7.0205	0.688
	GST G	3.7577	0.650
	GST YG	10.761	0.676
LV connection 10 KV (AC)	UST Y	7.0216	0.687
	GST G	14.134	0.681
	GST YG	21.123	0.687

Table 8: Capacitance & Tan-Delta Test (Ester oil)

F. Impulse Breakdown Voltage Test:

Another breakdown test is impulse test, in which breakdown of insulating oil is not affected by the moisture so we access it as the insulating fluid due to its dielectric characteristics. The data and research paper results proved the impulse breakdown voltages of Ester fluids, showing lower breakdown strength than that of mineral oil. The following results shows Lightning and Chopping Impulse Voltage Test results of Power Transformer with Mineral oil and Natural ester oil.

	KVp	Impulse current(A)
HV (LI)	350	90.44
HV (CI)	385	32.90
LV (LI)	90	73.96
LV (CI)	99	39.13

Table 9: Impulse Test (Mineral oil)

	KVp	Impulse current(A)
HV (LI)	350	136.0
HV (CI)	385	243.9
LV (LI)	90	17.74
LV (CI)	99	60.30

Table 10: Impulse Test (Ester oil)

VI. CONCLUSION

In the research, all the experiments results are based on the dielectric properties of insulating material. How it's affected the other characteristics, what is the process, where the mineral and ester oil are used in different types of transformer. As the topic is given in this paper, conclusion are shown below

1) We conclude that, in future there will lack of the mineral oil worldwide. We have to find another source for the insulating material. it's applications, problems, source of production, avaibility, and its characteristics .
2) In the history, how we start the use of mineral and ester oil as the insulating material. Which insulating material banned and which are another alternative source of insulating material for the future.
3) Process of mineral oil production, its types and dielectric characteristics. For the transformer some characteristics are good but in biodegradability factor it's harmful and hazardous.
4) Ester oil has good biodegradability, with high flash point, low pour point and many other characteristics so we conclude it will better alternative source for the insulating material.
5) For moisture saturation, ester oil has better then mineral oil, as in the BDV test ester oil is much better in compare of mineral oil. As the distance between electrodes increase results may change for both oils gradually. Pour point is depends moisture saturation because of dielectric strength and moving apparatus.

For insulation resistance test, ester oil has higher rating values but for the dissipation factor (tan-delta) it looks weak for ester oil. The cost of ester oil filled transformer is high compare to mineral oil but, the specific merits of ester oil overcome this cost concept. So, more and more ester oil filled transformers to be set up in power system gradually to save environment as well as extend the human life.

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