The Evaluation of quality of transformer oil by measuring capacitance

Thesis Report Submitted

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Declaration:

We declare that this pre thesis is fully based on research type. We also ensure that all the information such as formula, table, have given is trustworthy and their sources have mentioned in reference part. In this thesis we concern about transformer oil testing technique, based on regular sampling and testing of insulation oil taken from transformer. In this report we also partially analyze previous approaches like different method of oil analysis and oil gas analysis and also our future working plan to test the quality of transformer oil by measuring the capacitance.

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Abstract:

Transformer oil plays an important role to keep transformer active and operate efficiently. It keeps transformer cool and works as an insulator between transformer windings and body. Due to arcing, corona discharge, low-energy sparking, severe overloading, pump motor failure and overheating in the insulating system are some of the possible mechanisms of degradation of transformer oil. This problems can increase water content, decrease dielectric strength, increase acidity or neutralization number(NN), increase or decrease interfacial tension (IFT) out of a specific range(40 to 50 dyne/cm), decrease quality index system (QQIN), and rapid increase in the amount of combustible gases, which can decrease the transformer life time and quality of service to consumer. There are several methods to identify and solve this problem. If this problem go in severe condition, it is not possible to solve without replacing by new one. May be there are different methods to check this problem but no specific method to check without taking oil outside the transformer. These methods are very expensive and time consuming. That's why; our objective is to identify this problems as well as transformer condition without taking the oil outside by measuring the capacitance of the transformer.

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1. Introduction:

The fault free operation of power transformers is a factor of major economic importance and safety in power supply utilities and industrial consumers of electricity.

In the current economic climate, Industries/Supply Utilities tighten their control on capital spending and make cutbacks in maintenance; an increased awareness is placed on the reliability of the existing electric power supply. Down time is at a premium. Often, the loading is increase on present units, as this will defer purchasing additional plant capacity. Thus the stress on the transformer increases. The net total effect of the thermal, electrical and mechanical stress brought on by increased service needs to be monitored to ensure reliability.

Regular sampling and testing of insulation oil taken from transformers is a valuable technique in a preventative maintenance program. If a proactive approach is adopted based on the condition of the transformer oil, the life of the transformer can be extended.

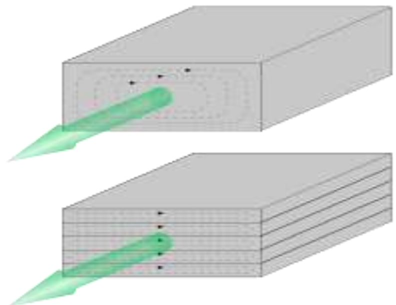
This pre thesis paper reviews some of the transformer oil tests and their significance and our working plan toward testing transformer oils quality through measuring the capacitance.

2. Transformer:

2.1. Construction:

Laminated steel cores:

Cores made of high permeability silicon steel are being used in transformer. The steel has a permeability many times that of free space and the cores reduce the magnetizing current, and confine the flux to a path which closely couples the windings. Early transformer developers soon realized that cores constructed from solid iron resulted in prohibitive eddy-current losses, and their designs mitigated this effect with cores consisting of bundles of insulated iron wires. Later designs constructed the core by stacking layers of thin steel laminations, a principle that has remained in use. Each lamination is insulated from its neighbors by a thin non-conducting layer of insulation. The universal transformer equation indicates a minimum cross-sectional area for the core to avoid saturation. The effect of laminations is to confine eddy currents to highly elliptical paths that enclose little flux, and so reduce their magnitude. Thinner laminations reduce losses, but are more laborious and expensive to construct. Thin laminations are generally used on high frequency transformers, with some types of very thin steel laminations able to operate up to 10 kHz.



One common design of laminated core is made from interleaved stacks of E-shaped steel sheets capped with I-shaped pieces, leading to its name of "E-I transformer". Such a design tends to exhibit more losses, but is very economical to manufacture. The cut-core or C-core type is made by winding a steel strip around a rectangular form and then bonding the layers together. It is then cut in two, forming two C shapes, and the core assembled by binding the two C halves together with a steel strap. They have the advantage that the flux is always oriented parallel to the metal grains, reducing reluctance.

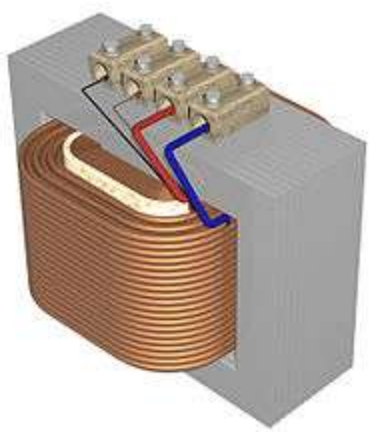
A steel core's remanence means that it retains a static magnetic field when power is removed. When power is then reapplied, the residual field will cause a high inrush current until the effect of the remaining magnetism is reduced, usually after a few cycles of the applied alternating current. Over current protection devices such as fuses must be selected to allow this harmless inrush to pass. On transformers connected to long, overhead power transmission lines, induced currents due to geomagnetic disturbances during solar storms can cause saturation of the core and operation of transformer protection devices.

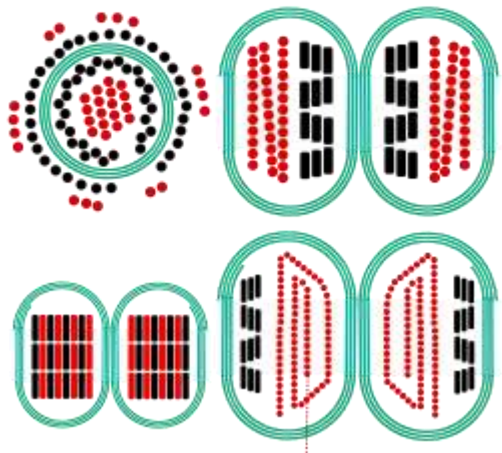
Distribution transformers can achieve low no-load losses by using cores made with low-loss high-permeability silicon steel or amorphous (non-crystalline) metal alloy. The higher initial cost of the core material is offset over the life of the transformer by its lower losses at light load.

Solid :

Powdered iron cores are used in circuits (such as switch-mode power supplies) that operate above main frequencies and up to a few tens of kilohertz. These materials combine high magnetic permeability with high bulk electrical resistivity. For frequencies extending beyond the VHF band, cores made from non-conductive magnetic ceramic materials called ferrites are common. Some radio-frequency transformers also have movable cores (sometimes called 'slugs') which allow adjustment of the coupling coefficient (and bandwidth) of tuned radio-frequency circuits.

Windings:





Windings are usually arranged concentrically to minimize flux leakage. Cut view through transformer windings. White: insulator. Green spiral: Grain oriented silicon steel. Black: Primary winding made of oxygen-free copper. Red: Secondary winding. Top left: Toroidal transformer. Right: C-core, but E-core would be similar. The black windings are made of film. Top: Equally low capacitance between all ends of both windings. Since most cores are at least moderately conductive they also need insulation. Bottom: Lowest capacitance for one end of the secondary winding needed for low-power high-voltage transformers. Bottom left: Reduction of leakage inductance would lead to increase of capacitance.

The conducting material used for the windings depends upon the application, but in all cases the individual turns must be electrically insulated from each other to ensure that the current travels throughout every turn. For small power and signal transformers, in which currents are low and the potential difference between adjacent turns is small, the coils are often wound from enamelled magnet wire, such as Formvar wire. Larger power transformers operating at high voltages may be wound with copper rectangular strip conductors insulated by oil-impregnated paper and blocks of pressboard.

High-frequency transformers operating in the tens to hundreds of kilohertz often have windings made of braided Litz wire to minimize the skin-effect and proximity effect losses.[Large power transformers use multiple-stranded conductors as well, since even at low power frequencies non-uniform distribution of current would otherwise exist in high-current windings. Each strand is individually insulated, and the strands are arranged so that at certain points in the winding, or throughout the whole winding, each portion occupies different relative positions in the complete conductor. The transposition equalizes the current flowing in each strand of the conductor, and reduces eddy current losses in the winding itself. The stranded conductor is also more flexible than a solid conductor of similar size, aiding manufacture.

For signal transformers, the windings may be arranged in a way to minimize leakage inductance and stray capacitance to improve high-frequency response. This can be done by splitting up each coil into sections, and those sections placed in layers between the sections of the other winding. This is known as a stacked type or interleaved winding.

Both the primary and secondary windings on power transformers may have external connections, called taps, to intermediate points on the winding to allow selection of the voltage ratio. In distribution transformers the taps may be connected to an automatic on-load tap changer for voltage regulation of distribution circuits. Audio-frequency transformers, used for the distribution of audio to public address loudspeakers, have taps to allow adjustment of impedance to each speaker. A center-tapped transformer is often used in the output stage of an audio power amplifier in a push-pull circuit. Modulation transformers in AM transmitters are very similar.

Certain transformers have the windings protected by epoxy resin. By impregnating the transformer with epoxy under a vacuum, one can replace air spaces within the windings with epoxy, thus sealing the windings and helping to prevent the possible formation of corona and absorption of dirt or water. This produces transformers more suited to damp or dirty environments, but at increased manufacturing cost.

Terminals:

Very small transformers will have wire leads connected directly to the ends of the coils, and brought out to the base of the unit for circuit connections. Larger transformers may have heavy bolted terminals, bus bars or high-voltage insulated bushings made of polymers or porcelain. A large bushing can be a complex structure since it must provide careful control of the electric field gradient without letting the transformer leak oil.

2.2 Transformer Oil as Insulation:

Coolant:

Cut-away view of three-phase oil-cooled transformer. The oil reservoir is visible at the top. Radiative fins aid the dissipation of heat.

High temperatures will damage the winding insulation. Small transformers do not generate significant heat and are cooled by air circulation and radiation of heat. Power transformers rated up to several hundred kVA can be adequately cooled by natural convective air-cooling, sometimes assisted by fans. In larger transformers, part of the design problem is removal of heat. Some power transformers are immersed in transformer oil that both cools and insulates the windings. The oil is a highly refined mineral oil that remains stable at transformer operating temperature. Indoor liquid-filled transformers are required by building regulations in many jurisdictions to use a non-flammable liquid, or to be located in fire-resistant rooms. Air-cooled dry transformers are preferred for indoor applications even at capacity ratings where oil-cooled construction would be more economical, because their cost is offset by the reduced building construction cost.

The oil-filled tank often has radiators through which the oil circulates by natural convection; some large transformers employ forced circulation of the oil by electric pumps, aided by external fans or water-cooled heat exchangers. Oil-filled transformers undergo prolonged drying processes to ensure that the transformer is completely free of water vapor before the cooling oil is introduced. This helps prevent electrical breakdown under load. Oil-filled transformers may be equipped with Buchholz relays, which detect gas evolved during internal arcing and rapidly de-energize the transformer to avert catastrophic failure. Oil-filled transformers may fail, rupture, and burn, causing power outages and losses. Installations of oil-filled transformers usually includes fire protection measures such as walls, oil containment, and fire-suppression sprinkler systems.

Polychlorinated biphenyls have properties that once favored their use as a coolant, though concerns over their environmental persistence led to a widespread ban on their use. Today, non-toxic, stable silicone-based oils, or fluorinated hydrocarbons may be used where the expense of a fire-resistant liquid offsets additional building cost for a transformer vault. Before 1977, even transformers that were nominally filled only with mineral oils may also have been contaminated with polychlorinated biphenyls at 10-20 ppm. Since mineral oil and PCB fluid mix, maintenance equipment used for both PCB and oil-filled transformers could carry over small amounts of PCB, contaminating oil-filled transformers.

Some "dry" transformers (containing no liquid) are enclosed in sealed, pressurized tanks and cooled by nitrogen or sulfur hexafluoride gas.

Experimental power transformers in the 2 MVA range have been built with superconducting windings which eliminates the copper losses, but not the core steel loss. These are cooled by liquid nitrogen or helium.

<u>**Insulation drying**</u>:

Construction of oil-filled transformers requires that the insulation covering the windings be thoroughly dried before the oil is introduced. There are several different methods of drying. Common for all is that they are carried out in vacuum environment. The vacuum makes it difficult to transfer energy (heat) to the insulation. For this there are several different methods. The traditional drying is done by circulating hot air over the active part and cycle this with periods of vacuum (hot-air vacuum drying, HAV). More common for larger transformers is to use evaporated solvent which condenses on the colder active part. The benefit is that the entire process can be carried out at lower pressure and without influence of added oxygen. This process is commonly called vapour-phase drying (VPD).

For distribution transformers, which are smaller and have a smaller insulation weight, resistance heating can be used. This is a method where current is injected in the windings to heat the insulation. The benefit is that the heating can be controlled very well and it is energy efficient. The method is called low-frequency heating (LFH) since the current is injected at a much lower frequency than the nominal of the grid, which is normally 50 or 60 Hz. A lower frequency reduces the effect of the inductance in the transformer, so the voltage can be reduced.

3. Fault in Transformer:

3.1 Gas Formation:

When any fault develops in the transformer oil liberates different kinds of gaseous product. The quantity of these gases depends upon type of fault. Partial discharge (corona), overheating (pyrolysis), arcing are some of the expected fault. If large amount of gas produce, Buchholtz relay will be active.

31.1 Partial Discharge: It is a low level energy fault usually occurs in gas-filled voids surrounded by oil impregnated material. The main cause of partial discharge is ionic bombardment of oil molecules.

The major gas produced is Hydrogen. The minor gas produced is Methane.

3.1.2 Thermal Faults: A small amount of decomposition occurs at normal operating temperatures. As the fault temperature rises, the formation of the degradation gases change from Methane (CH4) to Ethane (C2H6) to Ethylene (C2H4).

A thermal fault at low temperature (<300deg/C) produces mainly Methane and Ethane and some Ethylene. A thermal fault at higher temperatures (>300deg/C) produces Ethylene. The higher the temperature becomes the greater the production of Ethylene.

3.1.3 Arcing: It is a fault caused by high energy discharge. The major gas produced during arcing is acetylene. Power arcing can cause temperatures of over 3000deg/C to be developed.

If the cellulose material (insulating paper etc.) is involved, carbon monoxide and carbon dioxide are generated. A normally aging conservator type transformer having a CO2/CO ratio above 11 or below 3 should be regarded as perhaps indicating a fault involving cellulose provided the other gas analysis results also indicate excessive oil degradation.

4. Testing of Transformer Oil:

4.1 Conventional Approach:

4.1.1 Most Common

There are different processes of oil test. But the most common procedure is "Breakdown Voltage Test ". The procedure of this test is given below:

To assess the insulating property of dielectric transformer oil, a sample of the transformer oil is taken and its breakdown voltage is measured.

- The transformer oil is filled in the vessel of the testing device. Two standard-compliant test electrodes with a typical clearance of 2.5 mm are surrounded by the dielectric oil.
- A test voltage is applied to the electrodes and is continuously increased up to the breakdown voltage with a constant, standard-compliant slew rate of e.g. 2 kV/s.
- At a certain voltage level breakdown occurs in an electric arc, leading to a collapse of the test voltage.
- An instant after ignition of the arc, the test voltage is switched off automatically by the testing device. Ultra fast switch off is highly desirable, as the carbonisation due to the electric arc must be limited to keep the additional pollution as low as possible.
- The transformer oil testing device measures and reports the root mean square value of the breakdown voltage.
- After the transformer oil test is completed, the insulation oil is stirred automatically and the test sequence is performed repeatedly. (Typically 5 Repetitions, depending on the standard)
- As a result the breakdown voltage is calculated as mean value of the individual measurements.
- The lower the resulting breakdown voltage, the poorer the quality of the transformer oil!

Figure: Voltage Breakdown during testing

4.1.2 General Electrical and Physical Tests:

Test	Method
Water Content	IEC60814/ESK202
Dielectric Strength	IEC60156/ESK201
Acidity	ASTEM D974/ESK200/BS2634
Density	ESK204

Water Content: Water is harmful in power equipment because it is attracted to the places of greatest electrical stress. Water accelerates the deterioration of both the insulating oil and the paper insulation, liberating more water in the process (heat catalyzed).This is a never ending circle and once the paper insulation has been degraded (loss of mechanical strength) it can never (unlike the oil) be returned to its original condition.

Water can originate from two sources.

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.

(If oil can get out, water can get in).

Internal Sources

Paper degradation produces water.

Oil degradation produces water.

Wet insulation contaminates the oil, (temperature dependent).

If the moisture content of the oil is too high, vacuum degassing and filtering will usually bring it down to an acceptable level.

Dielectric Strength: The dielectric strength of insulating oil is a measure of the oils ability to withstand electrical stress without failure.

Water, sediment and conducting particle reduce the dielectric strength of insulating oil. Combination of these tends to reduce the dielectric strength to a greater degree.

Clean dry oil has an inherently high dielectric strength but this does not mean the absence of all contaminates, it may merely indicate that the amount of contaminants present is not large enough to affect the break down voltage of oil.

Careless sampling and testing techniques is the source of 99% of bad dielectric strength.

If the dielectric strength of the oil is to low, the normal remedy is to filter the oil.

Acidity: As time goes, the insulating oil become aged. Water, heat, oxygen, to certain extent accelerate ageing, alcohols, organic acids, peroxides , ketones, and some other gases produce from oil decomposition /oxidation. Acids come from some external sources (atmosphere).

Acidity level above 0.2 mg KOH/g is not tolerable for normal operation of transformer. This is the critical acid number deterioration increases rapidly once this level exceed.

If acidity level crosses tolerable range sludge production will start. Sludge is a polymeric type substance, which is hygroscopic and partially conductive. It is also a heat insulator. The sludge tends to clog up the cooling ducts, thus generating more heat and causing a snowball effect.

If the acidity is too high, the transformer operator has two options: either replace the oil completely, or have it regenerated. Regeneration is a filtration process where the polar compounds in the oil are absorbed on Fuller's earth or some proprietary material.

Interfacial Tension (IFT): it is a process of measuring tension at the interface between oil and water which don't mix. It expressed in dyne/cm. It is a very sensitive test.

Good oil will have an interfacial tension between 40 and 50 dyne/cm. Oil oxidation reduce the interfacial tension in out range. Interfacial tension less than 18 dyne/cm express the worst condition of oil.

Quality Index System (QQIN): Good oil has a fixed QQIN. It is measured by the ratio of Interfacial tension (IFT) to Neutralization number **(NN).**Generally for a good oil QQIN is 1500.

$$OQIN = \frac{IFT}{NN}$$

Transformer oil classification is possible by measuring all the above value.(see the table given below)

	TRANSFORMER OIL CLASSIFICATIONS*	
1.	**Good Oils**	
	NN	0.00 - 0.10
	IFT	30.0 - 45.0
	Colour	**Pale Yellow**
	OQIN	300-1500
2.	**Proposition A Oils**	
	NN	0.05 - 0.10
	IFT	27.1 - 29.9
	Colour	**Yellow**
	OQIN	271 - 600
3.	**Marginal Oils**	
	NN	0.11 - 0.15
	IFT	24.0 - 27.0
	Colour	**Bright Yellow**
	OQIN	160 - 318
4.	**Bad Oils**	
	NN	0.16 - 0.40
	IFT	18.0 - 23.9
	Colour	**Amber**
	OQIN	45 - 159
5.	**Very Bad Oils**	
	NN	0.41 - 0.65
	IFT	14.0 - 17.9
	Colour	**Brown**
	OQIN	22 - 44
6.	**Extremely Bad Oils**	
	NN	0.66 - 1.50
	IFT	9.0 - 13.9
	Colour	**Dark Brown**
	OQIN	6 - 21
7.	**Oils in Disastrous Condition**	
	NN	1.51 or more
	Colour	Black

4.1.3 Transformer Oil Gas Analysis:

When any fault develops in the transformer oil liberates different kinds of gaseous product. The quantity of these gases depends upon type of fault. By means of dissolve gas analysis (DGA) it is possible to identify what kind of fault will occur in long run. Partial discharge (corona), overheating (pyrolysis), arcing are some of the expected fault. If large amount of gas produce, Buchholtz relay will be active.

By doing this analysis we will be able to determine –

- Advance warning of developing fault
- A means of conveniently scheduling repairs.
- Monitor the rate of fault development.

4.1.3.a Partial Discharge: It is a low level energy fault usually occurs in gas-filled voids surrounded by oil impregnated material. The main cause of partial discharge is ionic bombardment of oil molecules.

The major gas produced is Hydrogen. The minor gas produced is Methane.

4.1.3.b Thermal Faults: A small amount of decomposition occurs at normal operating temperatures. As the fault temperature rises, the formation of the degradation gases change from Methane (CH_4) to Ethane (C_2H_6) to Ethylene (C_2H_4).

A thermal fault at low temperature (<300deg/C) produces mainly Methane and Ethane and some Ethylene. A thermal fault at higher temperatures (>300deg/C) produces Ethylene. The higher the temperature becomes the greater the production of Ethylene.

4.1.3.c Arcing: It is a fault caused by high energy discharge. The major gas produced during arcing is acetylene. Power arcing can cause temperatures of over 3000deg/C to be developed.

If the cellulose material (insulating paper etc.) is involved, carbon monoxide and carbon dioxide are generated. A normally aging conservator type transformer having a CO2/CO ratio above 11 or below 3 should be regarded as perhaps indicating a fault involving cellulose provided the other gas analysis results also indicate excessive oil degradation.

4.1.3.d Testing Method of Gas Analysis: There are various international guidelines on interpreting dissolved gas analysis (DGA) data. These guidelines show that the interpretation of DGA is more of an art than an exact science. Some of these guidelines are:

Dornenburg Ratio Method

Rogers Ratio Method (See Table 1 in Appendix)

Amount of Key Gases - CSUS (See Table 2 in Appendix)

Total Combustible Gases-Westinghouse (See Table 3 in Appendix)

Combustible Concentration Limits

CEGB/ANSI/IEEE (See Table 4 in Appendix)

HYDRO QUEBEC – Canada (See Table 5 in Appendix)

BBC - Switzerland (See Table 5 in Appendix)

OY STROMBERG - Finland (See Table 5 in Appendix)

SECR - Japan (See Table 6 in Appendix)

EDF - France (See Table 7 in Appendix)

The combustible Concentration Limits differ from country to country, continent to continent and transformer to transformer. It is not practical to set concentration limits because of the many variations involved.

The Gas Concentrations in the oil depend upon:

- The volume of oil involved (dilution factors)
- The age of the transformer (new or old)
- The production of gases and their quantity depends on equipment variables such as type ,location, and temperature breathing ,Construction of Tap changer)

4.1.4. Disadvantages of Current Methods:

1.Depends on Equipment type, location, temperature, Solubility of various gas in oil, preservation system, kinds of material contact with fault, variables associated with sampling with measuring procedure.

2.Time consuming

3.Expensive

4.Requirement of expertise

5.Need to take oil outside transformer

4.2. Proposed Techniques:

As we have seen the difficulties of above methods, we are trying to do a new method by which we can find the quality of oil as well as transformer by measuring capacitance. Before going to the procedure first we will know a brief idea about capacitance.

4.2.1 Capacitance:

A capacitor consists of two plates separated by an insulating medium known as a dielectric. (A dielectric is similar to an insulator but is more electrically "flexible".The formula for determining the capacitance of a capacitor is given below left. A table of some typical capacitor dielectric materials along with the approximate dielectric constant K is included below right. As the dielectric constant K is in the numerator of the formula, the capacitance C of the capacitor is directly proportional to this value. An increase in the value of K will result in an increase in capacitance. The value of capacitance is proportional to the area of plates, number of plats and inversely proportional to the distance between the plates.

Capacitance Parallel Plate Capacitor

$$C = 0.224 \frac{K\,S\,(N - 1)}{d}$$

Where

C = Capacitance in picofarads

K = Dielectric Constant

S = Area of one plate in square inches

N = Number of plates

d = Distance between plates in inches

If we modify the above equation into meter we will get -

$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d}$$

Here

$\varepsilon_0 = 8.854 \ x \ 10^{-12} \ F/m$

K= Relative permittivity of the dielectric material between the plates.

A= Area of parallel metallic plates in square meter.

d= Distance between plates in meter

Dielectric value of some material is given below :

Material	Dielectric Strength (K)
Vacuum	1.0
Paper, bond	3.0
Paper, Royal Grey	3.0
Paper, telephone, treated	2.5 - 4
Paper, Parafin Coated	2 -3.5
Paper, Kraft	2.2
Oil, Castor	4.67
Oil, Mineral, Squibb	2.7
Oil, Mineral	2.2
Oil, Transformer	2.1 - 2.5
Rubber	3.0
Rubber, Hard	3.0
Rubber, Vulcanized	3.2 - 3.9
Fibre	5.0 - 7.5
Fibre, Red	5.0
Mica	4.5 - 8.0
Mica, Ruby	5.4
Quartz	3.8 - 5.0
Quartz (Fused)	4.2
Shellac	2.5 - 4.0
Spar Varnish	4.8 - 5.5
Steatite, low loss	5.8
Steatites (Magnesium silicate,etc)	5.5 - 7.5
Cambric (Varnished)	4.0
Alsimag 196	5.7
Gutta Percha	4.0
Amber	3.0 - 7.0
Resin	2.4 - 2.5
Enamel	5.1
Mycalex	7.4
Silicone RTV	3.6
Wood	2.0 - 5.2
Wax (Parafin)	2.1 - 2.5
Beeswax	2.9 - 3.0
Slate	7.0
Barium titanate(25 C)	1200
Bariam titanate	6000

Material	Dielectric Strength (K)
Titanium dioxide	125
Cellulose acetate	3.3 - 3.9
Casein, Moulded	6.4
Polytetraflourethylene	2.0
Aluminum oxide	8.7
Tantalum pentoxide	22
Glass	

Glass	4.8 - 10
Plate Glass	6.8 - 8.4
Pyrex Glass	4.8 - 10
Window Glass	7.6 - 7.8
Ceramics	

Cordierite ceramics	5.0 - 5.5
Magnesium titanate ceramic	12 - 18
Porcelain	5.1 - 7.5
Titanium dioxide ceramic	70 - 90
Titanium-zirconium dioxide ceramic	40 - 60
Plastics	

Bakelite	4.4 - 5.8
Bakelite, Mica filled	4.7
Epoxy Circuit Board	5.2
Formica	4.6 - 4.9
Nylon (lowest values of 3 types)	3.2
PVC (rigid type)	2.95
Plexiglass	2.8
Polyethylene	2.2 - 2.3
Polycarbonate (Lexan)	2.96
Polyethylene Terphthalate (Mylar)	3.0 - 3.1
Polystyrene	2.5 - 2.6
Teflon	2.1
Gases	

Air (dry air at 1 atm)	1.0006
Air (20 atm, 19 deg. C)	1.0108
Carbon dioxide (1 atm, 0 deg. C)	1.000985
Carbon dioxide (20 atm, 15 deg. C)	1.020
Hydrogen (1 atm,0 deg.C)	1.000264

4.2.2 Methodology:

As we have seen the capacitance consists of two conducting plate and between those two there is a dielectric material. At the same time if we see the physical construction of transformer we find its body is a conducting material and inside the body there is oil which works as an insulator. That means we can say its physical construction is approximately same as capacitance. As we know capacitance value varies with the number of conducting plates, area of conducting plates, distance between conducting plates and dielectric values. In the case of transformer it is not possible to change the number of conducting plates, area of conducting plates and the distance between conducting plates. So the only variable is dielectric constant. According to the given above it is seen if any fault occur in the transformer or any initiative of fault degrades the oil produce the different gases and weaken the dielectric strength of the oil. That means dielectric value will vary according to the fault. That time if we measure the capacitance we will get different value as measured previously when oil was pure. So if we measure the capacitance of transformer oil and make a relationship with fault type and value of capacitance we may be able to easily find the fault occurred or the expected faults.

Implementation of proposed procedure is given below:

Initially we short all three phases both primary and secondary. We consider this one as one of the conducting plate and body is the other conducting plate. As we know oil is inside the transformer which separates body and the phases both primary and secondary. So we can consider this one as a two conducting plate capacitor. But in this case the area of two conducting plate is not equal like the conventional two parallel plate capacitor. Now take a multi-meter that can measure capacitance or any capacitor meter. Put one probe in body and other probe in shorted three phases (for three phases transformer) and take the value of capacitance shown in the display of the miter. This is the way how capacitance will be measured. Capacitance value will increase as the area of two conducting plate increases and distance between two conducting plate decreases like traditional two conducting plate capacitor. According to the capacitance law as dielectric value increases capacitance value increase proportionally. This thing also happens in this case of transformer. From the dielectric value of k for transformer we know its value varies from 2.1 to 2.5. In transformer when oil gets polluted its dielectric value increases. But it does not mean its strength increases. Because that time oil doesn't behave as oil as moister and some other ingredients mix up with oil. That is why as oil gets polluted transformers capacitance value increases.

Beside this three (area, distance, dielectric constant) there are some other factors affecting the value of capacitance which is still unknown. That is why in this research there is no accurate equation to prove the value of capacitance theoretically. But practically gained values showed that capacitance value mainly varies with area, distance and dielectric constant. Although there is no accurate theoretical equation but this process is almost reliable.

In this research GEM (General Engineering Manufacturing Co. Ltd, Bangladesh) and POWERMAN Bangladesh Ltd. transformers are used. For same KVA rating the area of body and coil for all company is almost same (±10 percent).

There are some capacitance value of different kinds of transformer is given below:

KVA Rating	Condition of Oil	Capacitance value(nf)		
		Sample 01	Sample 02	Sample 03
100 KVA	Good	1.9	2.0	1.9
	Refine	2.4	2.4	2.3
	Damage	18.3	24	10
200 KVA	Good	2.2	2.4	2.2
	Refine	3.7	3.8	3.5
	Damage	5.9	Infinite	6.0
250 KVA	Good	2.5	2.5	2.6
	Refine	5.0	4.9	4.8
	Damage	6.5	6.9	6.6

There are some data (length, width, height, length and radius of coil etc.) of transformer are given below to understand how area of transformer and coil according to KVA rating increase.

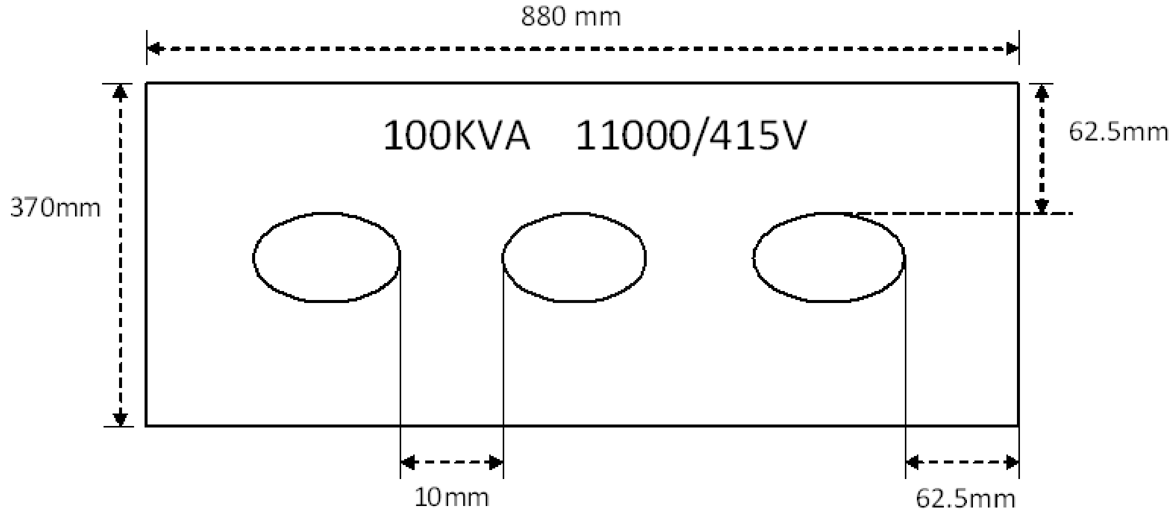


Figure: Side view of a transformer

Body: length= 880 mm

Width= 370 mm

Height= 780 mm

High Tension Side

Length of coil= 1921000 mm

Radius of coil= .61 mm

Number of Turn= 2814

Low Tension Side

Length of coil= 30140m m

Number of Turn= 60

Size=8*3*2

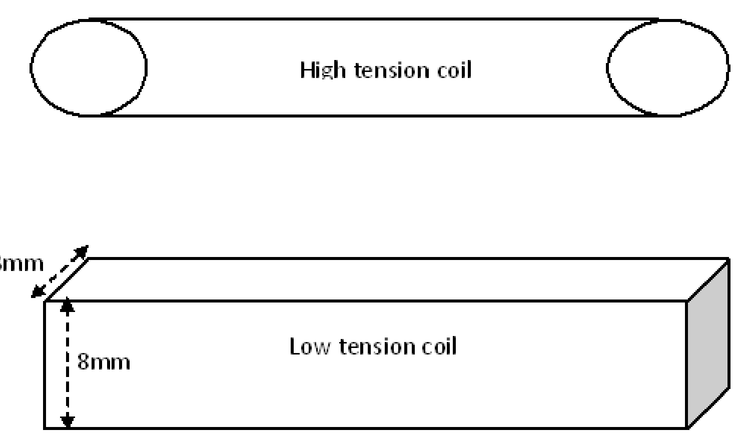


Figure: Internal Data of 100 KVA Transformer

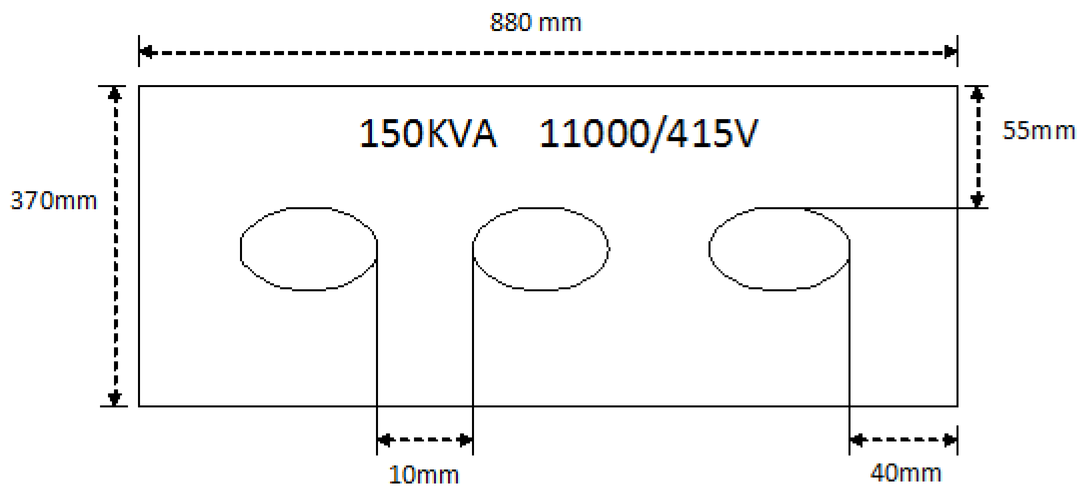


Figure: Side view of a transformer

Body: length= 880 mm

Width= 370 mm

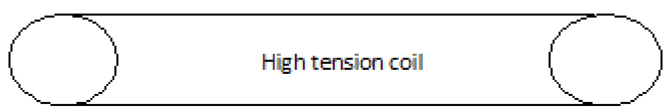
Height= 840 mm

High Tension Side

Length of coil= 1747000 mm

Radius of coil= .71 mm

Number of Turn= 2446



Low Tension Side

Length of coil= 28570mm

Number of Turn= 52

Size=8*3*3

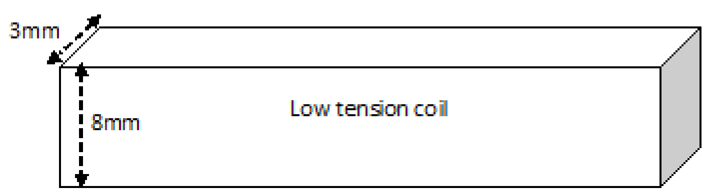


Figure: Internal Data of 150 KVA Transformers

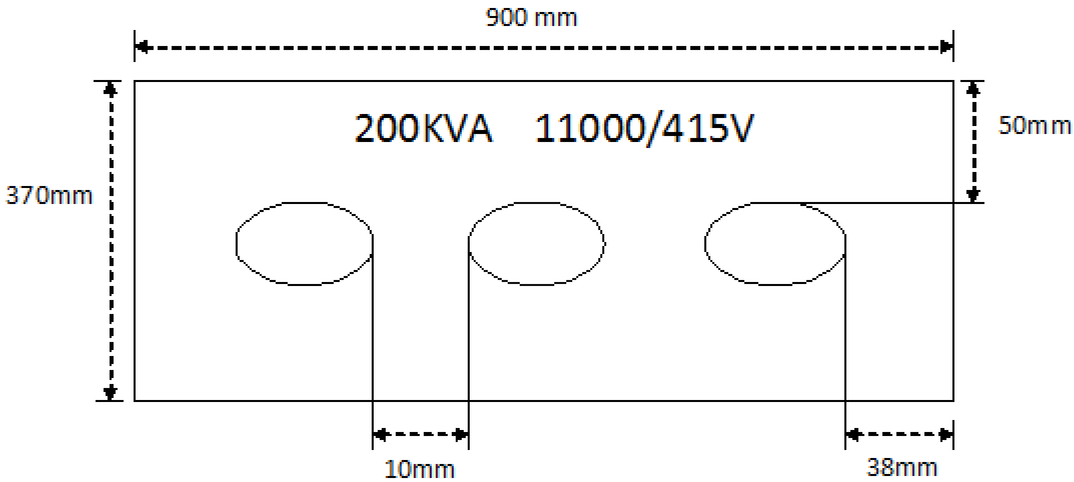


Figure: Side view of a transformer

Body: length= 900 mm

Width= 370 mm

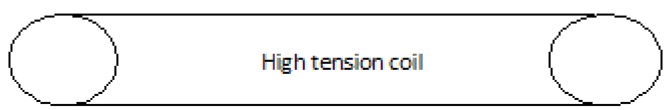
Height= 920 mm

High Tension Side

Length of coil= 1560000 mm

Radius of coil= .815 mm

Number of Turn= 2070



Low Tension Side

Length of coil= 22130mm

Number of Turn= 38

Size=8*3*4

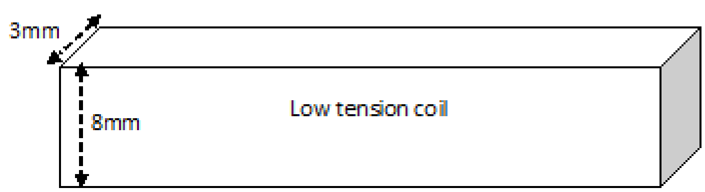


Figure: Internal Data of 200 KVA Transformers

We have tested limited number of transformers (100 to 300KV) and found that capacitance value varies from 1.5nf to 3nf respectively for new oil and 2nf to 4nf respectively for refined oil. If capacitance value increases by 3to 4nf approximately from the initial value it indicates that oil is losing its insulation property. That means transformers normal operation can be hampered in coming days. So to maintain efficient operation of transformer oil should be immediately refined or replaced. Generally capacitance value does not exceed the range of 30nf. In some cases capacitor meter don't show any value or show 1 which indicates that any of three phases gets internally shorted with the body. Generally this occurs when transformers are seriously damaged.

4.2.3. Advantages of this method over conventional methods:

In this method we only need a capacitance meter to measure the condition of the transformer which is available and less expensive than existing method.

Capacitance value generally doesn't very with time, place or materials. So in this method we will get approximately exact condition of transformer by see the value of capacitance.

In existing method experienced people are needed to measure the transformer condition because it various with different types of situation. In this method don't need such an experience people. It needs only a person who knows how to measure capacitance.

In all existing method it is necessary to take the oil out of the transformer for testing purpose. But in proposed method it is not required.

Most importantly in this method it is possible to measure the transformer condition on the spot rather than taking the oil in the laboratory.

In this method there is no accurate equation to theoretically measure the value of capacitance. So in future more research can be done to find out what are the other factors that affect the value of capacitance and come to an accurate solution to find out the theoretical equation.

4.2.4 Limitations:

1. This method is only accurately applicable for low value like 50 to 300KVA transformers. Because high KVA transformers were not available for testing.

2. This method can forecast the immediate failure of transformer but it cannot accurately tell how many days transformer can operate before being damaged.

5. Conclusion:

Measuring the capacitance of transformer is a unique way of identifying problems occurring within a transformer. By measuring the capacitance of transformer the condition of the transformer can be monitored.

If faults are found to be occurring, outages can be planned ant the fault can be rectified before major damage can occur.

The exiting methods (interpretation of transformer oil gas analysis) are still an art and not an exact science. The interpretation should be left to a specialist and his advice and recommendations should be followed. Samples should be taken regularly and records kept. But now it will be possible to identify the condition of oil outside the transformer.

6. References:

1. Retrieved from. www.satcs.co.za/Transformer_Oil_Analysis.pdf

2. IEEE GUIDE for the Interpretation of Gases Generation in Oil- Immersed Transformers.
3. Retrieved from. www.electronics-project-design.com/Capacitors.html
4. Retrieved from. www.transcheck.co.za/Transformer_General%20Information.pdf

7.Appendex:

TABLE 1

Code for examining analysis of gas dissolved in mineral oil

		Code of range of ratios			
	IEC 599	$\frac{C_2H_2}{C_2H_4}$	$\frac{CH_4}{H_2}$	$\frac{C_2H_4}{C_2H_6}$	
	Ratios of characteristic gases				
	< 0.1	0	1	0	
	0.1-1	1	0	0	
	1-3	1	2	1	
	> 3	2	2	2	

Case No.	Characteristic fault				Typical examples
0	No fault	0	0	0	Normal ageing
1	Partial discharges of Low energy density	0 but not significant	1	0	Discharges in gas-filled cavities resulting from incomplete impregnation, or super-saturation or cavitation or high humidity.
2	Partial Discharges of Low energy density	1	1	0	As above, but leading to tracking or perforation of solid insulation.
3	Discharges of low energy(see Note 1)	1-2	0	1-2	Continuous sparking in oil between bad connections of different potential or to floating potential. Breakdown of oil between solid materials.
4	Discharges of High Energy	1	0	2	Discharges with power follow-through. Arcing-breakdown of oil between windings or coils, or between coils to earth. Selector breaking current.
5	Thermal fault of Low Temperature <150°C(see Note 2)	0	0	1	General insulated conductor overheating
6	Thermal Fault of Low Temperature range 150°C-300°C(see Note 3)	0	2	0	Local overheating of the core due to concentrations of flux. Increasing hot spot tempretures;varying from small hot spots in core, overheating of copper due to eddy currents, bad contacts/joints(pyrolitic carbon formation) up to core and tank circulating currents.
7	Thermal fault of Medium temperature range 300°C-700°C	0	2	1	
8	Thermal fault of high temperature >700°C(see Note 4)	0	2	2	

TABLE 2

CALIFORNIA STATE UNIVERSITY
SACREMENTO
GUIDELINES FOR COMBUSTIBLE GAS

GAS	NORMAL	ABNORMAL	INTERPRETATION
H2	< 150 ppm	> 1000 ppm	Arcing corona
CH4	< 25 ppm	> 80 ppm	Sparking
C2H6	< 10 ppm	> 35 ppm	Local Overheating
C2H4	< 20 ppm	> 100 ppm	Severe Overheating
C2H2	< 15 ppm	> 70 ppm	Arcing
CO	< 500 ppm	> 1000 ppm	Severe Overloading
CO2	< 10 000 ppm	> 15 000ppm	Severe Overloading
N2	1-10 %	NA	-
O2	0.03 %	> 0.5 %	Combustibles

TABLE 3

WESTINGHOUSE
GUIDELINES ON
TOTAL COMBUSTIBLE GASES(TCG)

TOTAL COMBUSTIBLE GASSES	RECOMMENDED ACTION
0 - 500 ppm	Normal Aging Analyse again in 6-12 months
501 to 1200 ppm	Decomposition maybe in excess of normal aging Analyse again in 3 months
1201 to 2500 ppm	More than normal decomposition Analyse in 1 month
2500 ppm and above	Make weekly analysis to determine gas production rates Contact manufacturer

TABLE 4

CEGB/ANSI/1EEE GUIDE FOR
GAS CONCENTRATION LIMITS IN PPM V/V

GAS	GENERATOR TRANSFORMERS	TRANSMISSION
H2	240y	100
C0	580	350
CH4	160	120
C2H6	115	65
C2H4	190	30
C2H2	11	35

TABLE 5

OTHER INTERNATIONAL
GAS CONCENTRATION LIMITS
IN PPM V/V

GAS	HYDRO QUEBEC CANADA	BBC SWITZERLAND	OY STROMBERG FINLAND
H2	250	200	100
CO	850	1000	500
CH4	33	50	100
C2H6	15	15	150
C2H4	40	60	100
C2H2	25	15	30

TABLE 6

SECR - JAPAN
LIMITING VALUES
IN PPM V/V

GAS	TRANSFORMERS >275kV & >10MVA	TRANSFORMERS >275kV & <10MVA	TRANSFORMERS >500 kV
H2	400	400	300
CO	300	300	200
CH4	150	200	100
C2H6	150	150	50
C2H4	200	300	100
TCG	700	1000	400

TABLE 7

EDF - FRANCE
TRANSMISSION TRANSFORMERS
WITHOUT ON-LOAD TAP CHANGERS

GAS	GENERATOR TRANSFORMERS	TRANSMISSION TRANSFORMERS
H2	33	130
C0	770	1000
CH4	44	130
C2H6	33	150
C2H4	11	44
C2H2	0.4	0.4

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