بسم الله الرحمن الرحيم

Sudan University of Science & Technology

College of Graduate Studies

Type Tests of the Power Transformer

الإختبارات النوعيه لمحول القدره

A THESIS SUBMITTED IN PARTIAL FULFILLMENT TO THE REQUIREMENTS OF THE DEGREE OF

Master of Science

in

Electrical Engineering (Power and Machine)

By

Ali Abbasher Omer Ahmed

Under the Supervision of

Dr. El Fadel Zakaria

October 2022

الآيـــة

قال الله سبحانه وتعالى:

(أفَمنْ أسَّسَ بُنْيانُهُ عَلى تَقْوَى مِنَ اللهِ وَ
رِضْوَانٍ خَيرٌ أَمَّنْ أَسَّسَ بُنْيَانَهُ عَلى شَفَا
جُرُفٍ هَارٍ فَانْهَارَ بِهِ فِي نَارِ جَهَنَّمَ وَاللهُ لاَ
يَهْدِي القَومَ الظَّالِمِينَ).

سورة التوبـة ـ الآية 109

Acknowledgement

Our thanks for all administration of Sudan University of science and technology specially my supervisor Dr. El-Fadil Zakaria, and special thanks for all teachers in the Electrical Engineering department whom they did the best for me.

I would like to thanks all those have faithfully contributed to make this project easy and interesting specially Sundanese Transformer Factory.

Dedication

I would like to dedicate this work to my mother who gives me inspiration and support to continue and to do the best all the time.

Abstract

Considering the significance of the power transformers as a key equipment for transfer and distribution of the electrical power system and to prevent their failure states bearing in mind their price, different types of tests are subjected to illustrate the momentary state of the equipment, which have specific relationship to the insulation condition of liquid, solid and gas.

Throughout this thesis data have been presented showing samples of transformer type tests which were performed to a prototype in the factory and compare the results with the typical range of the IEC standard and transformer data sheet.

It is suggested further that the necessity to perform other tests such as no-load, short circuit and transformer turn ratio tests before putting them into service.

المستخلص

بالنظر إلى أهمية محولات الطاقة كمعدات رئيسية لنقل وتوزيع الطاقه الكهربائيه ومنع الأعطال التي تحدث لها مع الأخذ في الاعتبار سعرها ، يتم إجراء أنواع مختلفة من الإختبارات لتوضيح الحالة اللحظية للمعدات ، والتي لها علاقة محددة بحالة العزل السائل أوالصلب أوالغازي داخل هذه المعده.

خلال هذه الأطروحة ، تم تقديم بيانات تظهر عينات من اختبارات المحولات النوعية التي تم إجراؤها على نموذج أولي في المصنع ومقارنة النتائج مع معيارIECوبيانات المحول.

تقترح الأطروحه ضرورة إجراء إختبارات أخرى مثل إختبار المفاقيد الحديدية وإختبار نسبة تحويل المحولات قبل وضعها في الخدمه.

Contents

Chapter Three: Commission Tests of Power Transformer

Chapter Four: Experimental and Results

Chapter Five: Conclusion and Recommendations

List of Figures

List of Tables

Chapter One

Introduction

Chapter One

Introduction

1.1 Background

Economic operation of electrical generation, transmission and distribution is closely related to power transformer's reliability and availability. To prevent failure, different types of measurement and tests are conducted.

Serious damages are occurring as a result to any kind of failures at the beginning of the manufacture passing by the mal-operation.

Power transformers failure may cause severe damage, not only to the asset itself, but also to the surroundings. In addition to that, this may endanger the company's staff as well as the public by defective transformer.

Replacing on a time-based principle is not the alternative since the replacing costs for these assets can be enormous. Therefore, preventing action is further more valuable by testing and doing a power transformer diagnoses taking such action is of utmost importance.

When transformers are received from the factory or reallocated from another location it is necessary to verify that each transformer is dry, no damage has occurred during shipping, internal connections have not been loosened, the transformer's ratio, polarity, and impedance agree with its nameplate, its major insulation structure is intact, wiring insulation has not been bridged, and the transformer is ready for service.

Transformer is the heart of any power system. Hence preventive maintenance is always effective and produce time saving. Any failure to the transformer can extremely affect the whole functioning of power system.

The most effective way to ensure the proper performance of the power transformer to keep it in good condition with testing at factory;

1. Type tests to prove that the transformer meets design expectations.
2. Routine test for confirming operational performance of individual unit.
3. Special test per customer requirement

At site;

1. Pre-commissioning tests to assess the condition of transformer after installation and compare the results with the factory test reports.
2. Periodic/condition monitoring tests after an event – relocation or warning.
3. Emergency tests after protection trip, over-current, overvoltage, earthquake….

This thesis explains the situations that damage the transformer, the breakdown insulation is one of the most common faults occur in transformer which has different kinds including breakdown in transformer oil, insulation paper and gases. Before putting transformer in service, it should be subjected to many tests, the research focuses in the type tests.

1.2 Problem Statement

The failure of the transformer which is most important and expensive device in electrical power systems will result in significant outage, and hence the economic operation of electrical power system is closely related to power transformers reliability and availability so to prevent their failure, different types of measurements are conducted, to select the optimum type test methods to ensure the system stability by guarantee equipment healthiness.

1.3 Objectives:

The objective of the research is to investigate and perform transformer type tests.

1.4 Methodology

To achieve the objective of the research, the following steps are adopted:

- Study the commissioning tests procedures.
- A 200KVA and 100KVA transformers has been taken as a case study.
- Compared with the case study results with the standard.

1.5 Thesis Layout

This thesis is as follows: chapter two is concerned with insulations, breakdown in insulation and dielectric strength of the power transformer. Chapter three presents the main type tests performed on the transformer. Chapter four is concerned with experiments and results performed on the transformer for type tests. Chapter five discuss the conclusion and recommendations.

Chapter Two

Breakdown in Transformer Insulations

Chapter Two

Breakdown in Transformer Insulations

2.1 Introduction

To prevent failure, different types of measurements were performed on the power transformer to make non-failure operation of the equipment. The conditions under which breakdown of composite liquid/ solid insulation can occur, e.g. in transformer, play an important role in designing such insulation. The liquid, mainly mineral oil, generally constitutes the weakest part of insulation and a great amount of work has been devoted to the study of streamers, which appear in the gaseous phase, and most often are triggering the failure of insulation.

There is no piece of electrical equipment that does not depend on electrical insulation in one form or other to maintain flow of electric current in desired path or circuits. Due to some reasons the current deviates from the desired path, the potential will drop. An example of this is a short circuit then should always be avoided. This is done by proper choice and application of insulation wherever there is potential difference between neighboring conducting bodies that carry current.

There are four principle areas where insulation must be applied:

a) Between coils and earth (phase – to – earth).
b) Between coils of different phases (phase - to – phase).
c) Between turns in a coil (inter – turn).
d) Between the coils of the same phase (inter – coil).

There are three categories of insulating materials, gases, liquids, and solids.

The insulating materials are classified manly based on the thermal endurance. The insulation is primarily meant to resist electrical stress. In addition to be able to withstand certain other stress which the insulation encounters during manufacture, storage and operation.

The performance of the insulation depends on its operating temperature. The higher will be the rate of its chemical deterioration; the lower will be its useful life. If a reasonably long life of insulation is expected, its operating temperature must be maintained low. Therefore, it is necessary to determine the limits of temperature for the insulation which will ensure safe operation over its expected life.[4]

2.2 Applications in Power Transformers

Transformers are the first destination to encounter lighting and other high voltage surges. The transformer insulation has to withstand very high impulse voltages many times the power frequency operating voltages. The transformer insulation is divided into:

a) Turn – to – turn insulation.
b) Coil – to – coil insulation.
c) Low voltage coil – to – earth insulation.
d) High voltage coil – to – low voltage coil insulation.
e) High voltage coil – to – ground insulation.

The low voltage coil – to – ground and the high voltage coil – to – low voltage coil insulations normally consist of solid tubes combined with liquid or gas filled spaces. The liquid or gas in the spaces help to remove the heat from the core and coil structure and also help to improve the insulation strength.

The inter-turn insulation is directly applied on the conductor in smaller rating transformers. In the large transformers papers or glass tape is wrapped on the rectangular conductors. In the case of layer to layer, coil – to – coil and coil – to – ground insulations, Kraft paper is used in smaller transformers, whereas thick radial spacers made of pressboard glass fabric or Porcelain are used in the case of higher rating transformers.

Of all the materials, oil impregnated paper, and pressboard are extensively used in liquid filled transformers. the lack of thermal stability at higher temperature limits the use of this type insulation to be used continuously up to 105$\overset{o}{C}$.

Paper and its products absorb moisture very rapidly from the atmosphere and hence this type of insulation should be kept free of moisture during its life in a transformer.[1]

2.3 Electrical or Dielectric Breakdown

It is a rapid reduction in the resistance of an electrical insulator when the voltage applied across it exceeds the breakdown voltage. This results in a portion of the insulator becoming electrically conductive. Electrical breakdown may be a momentary event (as in an electrostatic discharge), or may lead to a continuous arc discharge if protective devices fail to interrupt the current in a high power circuit. Under sufficient electrical stress, electrical breakdown can occur within solids, liquids, gases or vacuum. However, the specific breakdown mechanisms are significantly different for each, particularly in different kinds of dielectric medium. Partial discharge is localized electrical event of short duration, which occurs in certain material when subjected to high voltages.

The sudden redistribution of charges associated with a partial discharge causes a pulse, which can be detected using various external instruments.

Energy release is known to be an inherent characteristic of partial discharges. As a result, a quantitative evaluation of the energy dissipated during a partial discharge could serve as a suitable estimation of potential level of destruction involved with the partial discharge.

The failure of especially large power transformers is an area if extreme concern for electrical utilities. Failures that occur without any warning cause service disruptions, which are difficult to circumvent and may cost millions of dollars in replacement and customer outages.

The ability to identify the existence of partial discharges before they pose any danger of failure of the transformer unit is therefore highly desirable.

The accurate detection and localization of the partial discharge in transformer could provide an indication to the integrity of insulation.

Unfortunately, liquids are easily contaminated, and may contain solids, other liquids in dissolved gasses. The effect of these impurities is relatively small for short duration pulses (10 sec).

However, if the voltage is applied continuously, the solid impurities line up at right angles to equipotential, and distort the field so that breakdown occurs at relatively low voltage. The lineup of particles is a fairly slow process, and is unlikely to affect the strength on voltages lasting for less than 1 ms.

Under the action of the electric field, dissolved gasses may come out of solution, forming a bubble. The gas in the bubble has a lower strength than the liquid, so that more gas is produced and the bubble grows, ultimately causing breakdown. Because, of the tendency to become contaminated, liquids are not usually used alone above 100 kV/cm in continuously energized equipment, however, they are used at much higher tresses (up to 1 MV/cm) in conjunction with solids.

Liquids can be made to act as barriers, preventing the line-up of solid impurities and localizing of any bubbles which may form.[6]

2.4 Failure of Electrical Insulation

Electrical breakdown is often associated with the failure of solid or liquid insulating materials used inside high voltage transformers in the electricity distribution grid, usually resulting in a short circuit or a blown fuse. Electrical breakdown can also occur in transformer or across the insulators that suspend overhead power lines, within underground power cables, or lines arcing to nearby branches of trees.

2.5 Mechanism of Breakdown

Breakdown mechanisms seem to differ in solid, liquid and gaseous materials depending on the density. Breakdown is influenced by electrode material, curvature of conductor material (resulting in electric stress) and the gap between the electrodes. In solid materials (e.g. power cables) prior to breakdown a partial discharge will be found over a long time finally creating a small channel of carbonized material that accelerates electron transport.

Several mechanisms have been discussed for liquid materials. In liquefied gases (boiling Helium at 4.2 K and Nitrogen at 96 K for superconductivity) bubbles should induce breakdown. Some authors propose a thermal effect because breakdown (in 50/60 ac lines) can occur long after the maximum voltage is reached. Different explanations are found for oil transformers, where the field strength for breakdown is about 20 MV/m. Despite the purified liquids small particles are blamed for breakdown. Due to hydrodynamics breakdown in liquids seems to be more complicated: using two spheres in the gap between the electrodes additional pressure is exerted by the non-linear field strength.[6]

2.6 Breakdown in Solid

Solid insulating materials are used almost in all electrical equipments, they will be in electric heater or a 500 MW generator, transformer or a circuit breaker, solid insulation forms an integral part of all electrical equipments especially when the operating voltages are high. The solid insulation not only provides insulation to the live parts of the equipment from the grounded structures, it sometimes provides mechanical support to the equipment. In general, of course, suitable combinations of solid, liquid and gaseous insulations are used.

The processes responsible for the breakdown of gaseous dielectrics are governed by the rapid growth of current due to emission of electrons from the cathode, ionization of the gas particles and fast development of avalanche process. When breakdown occurs the gases regain their dielectric strength very fast, the liquids regain partially and solid dielectrics lose their strength completely. The breakdown of solid dielectrics not only depends upon the magnitude of voltage applied but also it is a function of time for which the voltage is applied. Roughly speaking, the product of the breakdown voltage and the log of the time required for breakdown is almost a constant.[7] The characteristics is shown in Fig 2.1

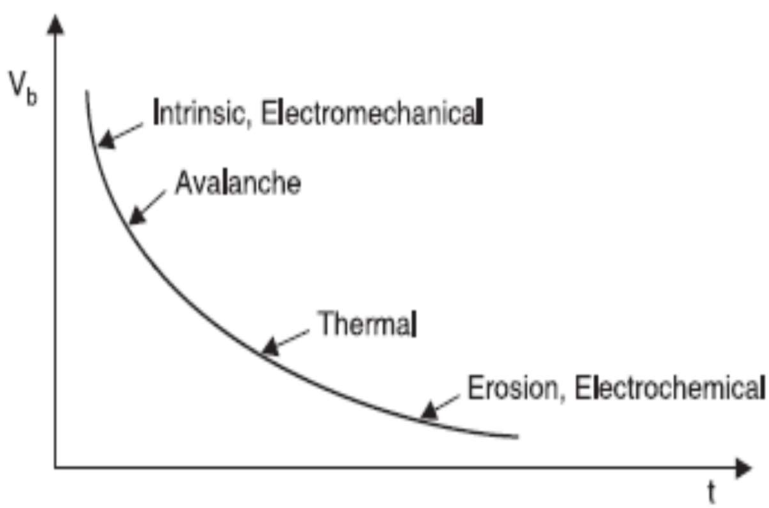

Fig 2.1 Variation of V_b with time of application

The dielectric strength of solid materials is affected by many factors like ambient temperature, humidity, duration of test, impurities or structural defects whether a.c., d.c. or impulse voltages are being used, pressure applied to these electrodes etc.

In the mechanism of breakdown in solids the time of application plays an important role in the process, for discussion purposes, it is convenient to divide the time scale of voltage application into regions in which different mechanisms operate. [6]

The various mechanisms are:

(*i*) Intrinsic Breakdown

(*ii*) Electromechanical Breakdown

(*iii*) Breakdown Due to Treeing and Tracking

(*iv*)Thermal Breakdown

(*v*) Electrochemical Breakdown

2.6.1 Intrinsic Breakdown

If the dielectric material is pure and homogeneous, the temperature and environmental conditions suitably controlled and if the voltage is applied for a very short time of the order of 10–8 second, the dielectric strength of the specimen increases rapidly to an upper limit known as *intrinsic dielectric strength*.

The intrinsic strength, therefore, depends mainly upon the structural design of the material *i.e.,* the material itself and is affected by the ambient temperature as the structure itself might change slightly by temperature condition. In order to obtain the intrinsic dielectric strength of a material, the samples are so prepared that there is high stress in the centre of the specimen and much low stress at the corners as shown in Fig 2.2

Fig 2.2 intrinsic strength

The intrinsic breakdown is obtained in times of the order of 10–8 sec. and, therefore, has been considered to be electronic in nature. The stresses required are of the order of one million volt/cm.

The intrinsic strength is generally assumed to have been reached when electrons in the valance band gain sufficient energy from the electric field to cross the forbidden energy band to the conduction band. In pure and homogenous materials, the valence and the conduction bands are separated by a large energy gap at room temperature, no electron can jump from valance band to the conduction band. The conductivity of pure dielectrics at room temperature is, therefore, zero. However, in practice, no insulating material is pure and, therefore, has some impurities and/or imperfections in their structural designs.

The impurity atoms may act as traps for free electrons in energy levels that lie just below the conduction band is small. An amorphous crystal will, therefore, always have some free electrons in the conduction band. At room temperature some of the trapped electrons will be excited thermally into the conduction band as the energy gap between the trapping band and the conduction band is small. An amorphous crystal will, therefore, always have some free electrons in the conduction band. As an electric field is applied, the electrons gain energy and due to collisions between them the energy is shared by all electrons.

In an amorphous dielectric the energy gained by electrons from the electric field is much more than they can transfer it to the lattice. Therefore, the temperature of electrons will exceed the lattice temperature and this will result into increase in the number of trapped electrons reaching the conduction band and finally leading to complete breakdown.

When an electrode embedded in a solid specimen is subjected to a uniform electric field, breakdown may occur. An electron entering the conduction band of the dielectric at the cathode will move towards the anode under the effect of the electric field. During its movement, it gains energy and on collision it loses a part of the energy. If the mean free path is long, the energy gained due to motion is more than lost during collision.

The process continues and finally may lead to formation of an electron avalanche similar to gases and will lead finally to breakdown if the avalanche exceeds a certain critical size.

2.6.2 Electromechanical Breakdown

When a dielectric material is subjected to an electric field, charges of opposite nature are induced on the two opposite surfaces of the material and hence a force of attraction is developed and the specimens is subjected to electrostatic compressive forces and when these forces exceed the mechanical withstand strength of the material, the material collapses.

If the initial thickness of the material is d_0 and is compressed to a thickness d under the applied voltage V, then the compressive stress developed due to electric field is:

$$F = \frac{1}{2}\varepsilon_0 \epsilon_r \frac{V^2}{d^2} \qquad (2.1)$$

Where ε_r is the relative permittivity of the specimen

2.6.3 Breakdown due to Treeing and Tracking

We know that the strength of a chain is given by the strength of the weakest link in the chain. Similarly, whenever a solid material has some impurities in terms of some gas pockets or liquid pockets in it the dielectric strength of the solid will be more or less equal to the strength of the weakest impurities.

Suppose some gas pockets are trapped in a solid material during manufacture, the gas has a relative permittivity of unity and the solid material εr, the electric field in the gas will be εr times the field in the solid material. As a result, the gas breaks down at a relatively lower voltage.

The charge concentration here in the void will make the field more non-uniform to be quite large to give fields of the order of 10 MV/cm which is higher than even the intrinsic breakdown.

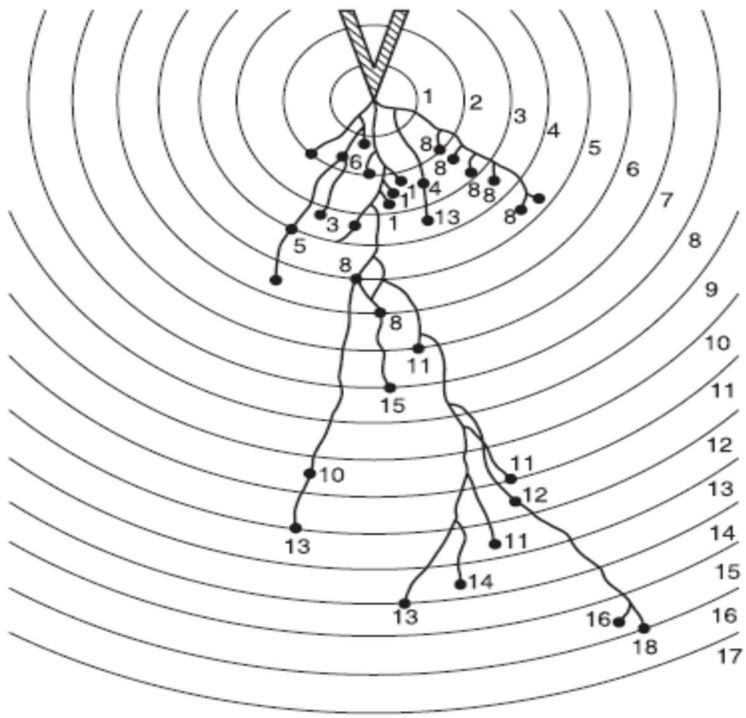

Fig 2.3 tree structure

These charge concentrations at the voids within the dielectric lead to breakdown step by step and finally lead to complete rupture of the dielectric. Since the breakdown is not caused by a single discharge channel and assumes a tree like structure as shown in Fig 2.3, it is known as breakdown due to treeing.

The treeing phenomenon can be readily demonstrated in a laboratory by applying an impulse voltage between point plane electrodes with the point embedded in a transparent solid dielectric.

2.6.4 Thermal Breakdown

When an insulating material is subjected to an electric field, the material gets heated up due to conduction current and dielectric losses due to polarization.

The conductivity of the material increases with increase in temperature and a condition of instability is reached when the heat generated exceeds the heat dissipated by the material and the material breaks down. Fig 2.4 shows various heating curves corresponding to different electric stresses as a function of specimen temperature. Assuming that the temperature difference between the ambient and the specimen temperature is small, Newton's law of cooling is represented by a straight line.

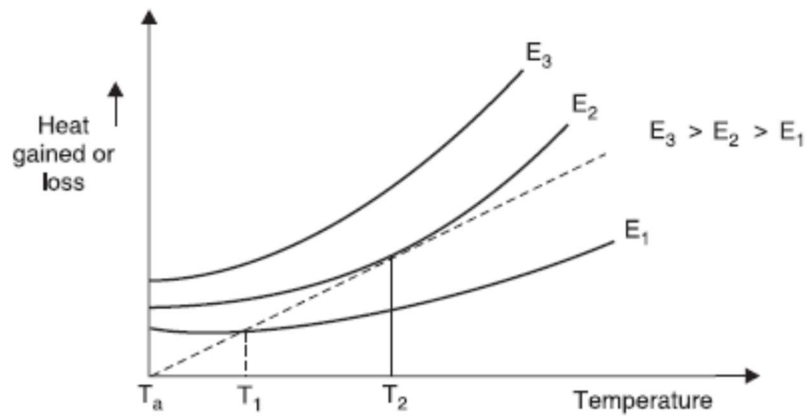

Fig 2.4 various heating curves

2.6.5 Electrochemical Breakdown

When the cavities are formed in solid dielectrics, the dielectric strength in this solid specimen will decrease. When the gas in the cavity breaks down, the surfaces of the specimen provide instantaneous anode and cathode. Some of the electrons dashing against the anode with sufficient energy shall break the chemical bonds of the insulation surface. Similarly, positive ions bombarding against the cathode may increase the surface temperature and produce local thermal instability. Similarly, chemical degradation may also occur from the active discharge products *e.g.,* O3, NO2 etc. formed in air. The net effect of all these processes is a slow erosion of the material and a consequent reduction in the thickness of the specimen. Normally, it is desired that with ageing, the dielectric strength of the specimen should not decrease. However, because of defects in manufacturing processes and/or design, the dielectric strength decreases with time of voltage application or even without voltage application and in many cases; the decrease in dielectric strength (*Eb*) with time follows the following empirical relation.

$$t.\ E_b^{\,n} = C \qquad (2.2)$$

Where the exponent *n* depends upon the dielectric material and C is constant, the ambient temperature, humidity and the quality of manufacture.[6]

2.7 Breakdown in Vacuum

A vacuum system is one in which the pressure maintained is at a value below the atmospheric pressure and is measured in terms of mm of mercury. One standard atmospheric pressure at 0°C is equal to 760 mm of mercury. One mm of Hg pressure is also known as *one torr* after the name of Torricelli who was the first to obtain pressures below atmosphere, with the help of mercury barometer. Sometimes 10–3 torr is known as one micron. It is now possible to obtain pressures as low as 10–8 torr. In a Townsend type of discharge, in a gas, the mean free path of the particles is small and electrons get multiplied due to various ionization processes and an electron avalanche is formed. In a vacuum of the order of 10–5 torr, the mean free path is of the order of few meters and thus when the electrodes are separated by a few mm an electron crosses the gap without any collision. Therefore, in a vacuum, the current growth prior to breakdown cannot take place due to formation of electron avalanches.

However, if it could be possible to liberate gas in the vacuum by some means, the discharge could take place according to Townsend process. In the vacuum arc,

the neutral atoms, ions and electrons do not come from the medium in which the arc is drawn but they are obtained from the electrodes themselves by evaporating its surface material. Because of the large mean free path for the electrons, the dielectric strength of the vacuum is a thousand times more than when the gas is used as the interrupting medium.

In this range of vacuum, the breakdown strength is independent of the gas density and depends only on the gap length and upon the condition of electrode surface. Highly polished and thoroughly degassed electrodes show higher breakdown strength.

Electrodes get roughened after use and thus the dielectric strength or breakdown strength decreases which can be improved by applying successive high voltage impulses which of course does not change the roughened surface but removes the loosely adhering metal particles from the electrodes which were deposited during arcing.

2.8 Breakdown in Gases

Air has been the insulating ambient most commonly used in electrical installations. Among its greatest assets, in addition to its abundance, is its self-restoring capability after breakdown. Liquid and solid insolents in use often contain gas voids that are liable to break down. An electrical discharge in a gas gap can be either a partial breakdown (corona) over the limited part of the gap where the electrical stress is highest or a complete breakdown. The complete breakdown of an entire gap initially takes the form of a spark requiring a high voltage and through it relatively small current flows. Depending on the source and the gas-gap conditions, the spark may be either extinguished or replaced by a highly conductive conducting arc.

2.9 Breakdown in liquids

Liquid dielectrics are used for filling transformers, circuit breakers and as impregnates in high voltage cables and capacitors. For transformer, the liquid dielectric is used both for providing insulation between the live parts of the transformer and the grounded parts besides carrying out the heat from the transformer to the atmosphere thus providing cooling effect.

For circuit breaker, again besides providing insulation between the live parts and the grounded parts, the liquid dielectric is used to quench the arc developed between the breaker contacts. The liquid dielectrics mostly used are petroleum oils. Other oils used are synthetic hydrocarbons and halogenated hydrocarbons and for very high temperature applications silicone oils and fluorinated hydrocarbons are also used.

Liquids dielectric because of their inherent properties appear as though they would be more useful as insulation material than either solids or gas this is because liquids and solids are usually 10^3 times denser than gas , but oil is about 10 times more efficient than gasses and solids .

Liquids dialectic is used mainly as impregnates in high voltage cables and capacitors, and for fitting up of transformers. Petroleum oils (Transformer Oil) are the most commonly used liquid dielectrics.

Transformer oil provides the required dielectric strength and insulation and also cools the transformer by circulating through the core and the coil structure. The transformer oil, therefore, should be in the liquid state over the complete operation range of temperature between -40° C and +50° C. The oil gets oxidized when exposed to oxygen at high temperature, and the oxidation results in the formation of peroxides, water, organic acids and sludge. These products cause chemical deterioration of the paper insulation and the metal parts of the transformer.

When an arc discharges, it produces hydrogen and gaseous hydrocarbons which may lead to explosion. And hence, oil insulated transformer are seldom used inside buildings or other hazardous locations like mines. Under such conditions dry type sulphur hexafluoride (SF6) gas filled transformer are used.

The most important factor that affects the electric strength of insulation oil is the percentage of water in the form fine droplets suspended in the oil and the fibrous impurities.

The percentage of even 0.01% water in the transformer oil reduces its electric strength to 20% of the dry oil value and the presence of fibrous impurities brings down the dielectric strength much sharply.

These oils are used for providing electrical insulation; these should be free from moisture, products of oxidation and other contaminants. Oil in the transformer is subjected to prolonged heating of high temperature of 95 ^{o} C, and consequently it undergoes gradual ageing process. With time the oil becomes darker due to the formation of acids resins, or sludge in the liquid which occurred reducing in circulation of oil, and thus its heat transfer capability gets reduced.

The three most important properties of liquid dielectric are:

(i) The dielectric strength

(*ii*) The dielectric constant and

(*iii*) The electrical conductivity.

Other important properties are viscosity, thermal stability, specific gravity, flash point etc. The main consideration in the selection of a liquid dielectric is its chemical stability. The other considerations are the cost, the saving in space, susceptibility to environmental influences etc. The use of liquid dielectric has brought down the size of equipment tremendously. In fact, it is practically impossible to construct a 765 kV transformer with air as the insulating medium. Table 2.1 shows the properties of some dielectrics commonly used in transformer.

Table 2.1 Dielectric properties of some liquids

NO	Property	Transformer Oil
1	Relative permittivity 50Hz	2.2 _ 2.3
2	Breakdown strength at 20°C 2.5mm 1 min	12KV/mm
3	(a) tanδ 50Hz (b) 1KHz	10^{-3} $5*10^{-4}$
4	Resistivity ohm-cm	$10^{12} – 10^{13}$
5	Maximum permissible water content (ppm)	50
6	Acid value mg/gm of KOH	NIL
7	Specification mg of KOH/gm of oil	0.01
8	Specific gravity at 20°C	0.89

Once an electron is injected into the liquid, it gains energy from the electric field applied between the electrodes. It is presumed that some electrons will gain more energy due to field than they would lose during collision. These electrons are accelerated under the electric field and would gain sufficient energy to knock out an electron and thus initiate the process of avalanche. The threshold condition for the beginning of avalanche is achieved when the energy gained by the electron equals the energy lost during ionization (electron emission) and is given by:

$$e\lambda E = Chv \qquad (2.3)$$

Where λ is the mean free path, hv is the energy of ionization and C is a constant. Table 2.3 gives typical values of dielectric strengths of some of the highly purified liquids.

Table 2.2 Dielectric strengths of pure liquids

Liquid	Strength (MV/cm)
Benzene	1.1
Goodoil	1.0-4.0
Hexane	1.1-1.3
Nitrogen	1.6-1.88
Oxygen	2.4
Silicon	1.0-1.2

The theory of liquid insulation breakdown is less understood as of today as compared to the gas or even solids. Many aspects of liquid breakdown have been investigated over the last decades but no general theory has been evolved so far to explain the breakdown in liquids. Investigations carried out so far, however, can be classified into two schools of thought.

The first one tries to explain the breakdown in liquids on a model which is an extension of gaseous breakdown, based on the avalanche ionization of the atoms caused by electron collision in the applied field.

The electrons are assumed to be ejected from the cathode into the liquid by either a field emission or by the field enhanced thermionic effect (Shottky's effect). This breakdown mechanism explains breakdown only of highly pure liquid and does not apply to explain the breakdown mechanism in commercially available liquids. It has been observed that conduction in pure liquids at low electric field (1 kV/cm) is largely ionic due to dissociation of impurities and increases linearly with the field strength. At moderately high fields the conduction saturates but at high field (electric), 100 kV/cm the conduction increases more rapidly and thus breakdown takes place.

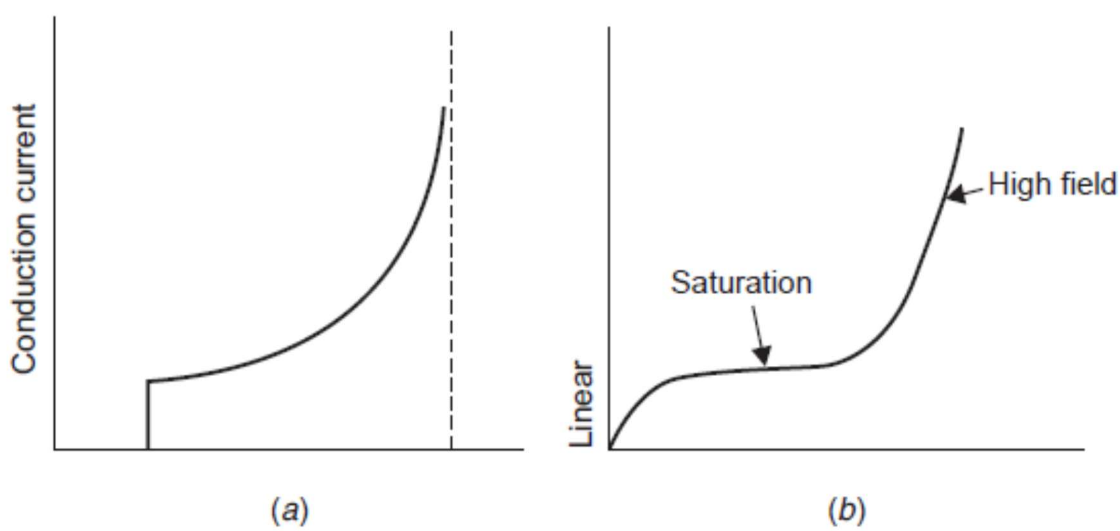

Fig 2.5 Variation of current as a function of electric field

Fig 2.5 shows the variation of current as a function of electric field for hexane since (a) for high fields and (b) for low fields. This is the condition nearer to breakdown. However, if the figure is redrawn starting with low fields, a current-electric field characteristic as shown in Fig 2.5b will be obtained. This curve has three distinct regions as discussed above.

The second school of thought recognizes that the presence of foreign particles in liquid insulations has a marked effect on the dielectric strength of liquid dielectrics. It has been suggested that the suspended particles are polarizable and are of higher permittivity than the liquid. These particles experience an electrical force directed towards the place of maximum stress. With uniform field electrodes the movement of particles is presumed to be initiated by surface irregularities on the electrodes, which give rise to local field gradients. The particles thus get accumulated and tend to form a bridge across the gap which leads finally to initiation of breakdown. The impurities could also be in the form of gaseous bubbles which obviously have lower dielectric strength than the liquid itself and hence on breakdown of bubble the total breakdown of liquid may be triggered.[3]

2.10 Breakdown of Composite Insulation

Almost no complete electrical insulation consists of one insulating phase. Usually more than one insulating material will be involved, either in series, parallel or both. The simplest form of composite insulation system consists of 2 layers of the same material. In this case advantage is taken of the fact that two thin sheets have a higher electric strength than a single sheet of the same total thickness. In other cases, composite dielectrics occur either due to design considerations (ex: paper with an impregnating liquid as in transformer) or due to practical difficulties of fabrication (ex: air in parallel with solid insulation).

In certain cases, the behavior of the composite insulation could be predicted from the behavior of the components.

Chapter Three

Commission Tests of Power Transformer

Chapter Three
Commission Tests of Power Transformer

3.1 Introduction

When transformers are manufactured, it is important to ensure the mainly expectation of the design, internal connections, the transformer's ratio, polarity, and impedance agree with its nameplate, its major insulation structure is intact, wiring insulation by testing prototype unit.

There are a multitude of checks and tests performed. The engineer may not directly perform all of the following tests and inspections but must be sure they are satisfactorily completed, so that the final report over the transformer design can be shown.

Some tests and procedures may be performed by specialists during the assembly phase. Special tests, other than those listed, may also be required. Many require special equipment and expertise that construction electricians do not have and are not expected to provide. Some tests are performed by an assembly crew, while other tests are done by the person(s) making the final electrical tests on the transformers.

The importance of commissioning test is summarized as follow:

i. Necessity to prove the performance before putting into service.

ii. Evolution of standards for HV/MV sides of power transformers.

iii. Globalization resulting in common methods to assess the performance of equipment from different manufacturers of different countries.

iv. To give confidence about performance and safety to the end user before acceptance.

While the main purposes of testing are:

i. Finished product includes many components independently tested and need final tests once assembled.

ii. All parts not visible hence need for a common method to check capability under actual working conditions.

iii. Base line test results used as basis for future comparisons of performance.

3.2 Type tests:

The IEC definition of type test is a test made on a transformer which is representative of other transformers, to demonstrate that these transformers comply with the specified requirements.

3.3 Components of type test of Transformer

i. Dielectric tests of transformer.

ii. Withstand voltage tests.

iii. Transformer Oil Tests group.

iv. Transformer Parameters Calculations Tests.[4]

3.3.1 Dielectric Tests group

Dielectric tests to check the insulation which is very important in transformer theory, and we immediately lose the transformer when there is an insulation problem. 60% of transformer failure comes from weakness in the insulation, and with the absence of the periodical insulation test there will be a problem that may lead to lose the transformer itself. The dielectric tests contains: the Insulation Resistance (IR), Dielectric Loss Angle (δ) and Partial Discharge tests.

3.3.1.1 Insulation Resistance Test (IR)

This test is called Megger Test because it is done by the Megger device. The Megger gives us DC Volt from 500V till 1000V for the low voltage equipment's, and from 2500V till 15000V for high voltage equipment. The expected insulation resistance for MV applications will be in MΩ and not less than KΩ, In new transformers may reach the scale of GΩ, the Steps of Megger Test for a Transformer;

1. Put the transformer to be tested out of service and earth the tank.
2. Discharge any electrostatic in the transformer by a discharging rod or by using a Megger equipped with automatic discharge.
3. Make a short in the terminals of high and low voltage independently without earthing and measure the resistance between HV and LV.
4. Make the above step with earthing one side and see the values.
5. First we do the test for 15 second and get the value (R15), after that we do the test for 60 seconds and register (R60), finally we get what is called the ABSORPSION FACTOR by this formula: R60/R15.
6. Another test is done for 1 minute and gets the value (R1), after that we do the test for 10 minutes and register (R10), finally we get what is called the Polarization Index by this formula: R10/R1.

From the previous chart you notice that R10 is greater a little than R1 because the leakage current decreases with the time. The value of Absorption Factor and Polarization Index is acceptable if it lies between 1.5 and 2.5.

Factors affect the Megger test values

1- Transformer temperature

When the temperature is high the resistance of the insulation materials will degrade and this will affect the measurement of the Megger (degrade the value). The standard temperature is 20˚C and we make the correction as in Table 3.1:

Table 3.1transformer temperature

Temperature in ˚C	10	20	30	40	50	60	70
Correction factor	0.78	1	1.4	2.33	3.5	5	7

2- Insulators cleaning

Sometimes when the transformer insulators surpass are dirty or polluted by old oil leakage, we find that the values of the Megger test affect a little and we need to clean up the insulators with a clean piece of cloth to reduce the value of the leakage currents through the dirt on the insulators.

3- Using Wrong Wires of Megger (not original):

The Megger wires are insulated enough to be used with the Megger, and you cannot use AVO meter leads because the insulation values will not be accurate.

i. The results are good, if the insulation resistance value in GΩ range and the absorption factor lay between 1.5 and 2.5.

ii. The results are critical, if the insulation resistance value is less than 1MΩ/1KV.

iii. The results are bad, if the absorption factor is less than 1.2 and all the values is low.

3.3.1.2 Dielectric Loss Angle/Dissipation factor/ (tanδ)

This test is done by special instrument and this instrument measures the angle between the voltage and the current which path through the insulation of the tested transformer. In Megger test we use DC but in tanδ test AC is used. The general concept of TAN DELTA TEST is that the equipment under test being as a capacitor, (and in a perfect capacitor the voltage and current are phase shifted 90 degrees) this makes the current through insulation capacitive. Tan delta tester also measures a capacitance value (C) in PICO FARAD between winding to ground and windings together, which also can give an indication of insulation state If there are impurities in the insulation, the resistance decreases, resulting in an increase in resistive current through the insulation. The insulation is no longer a perfect capacitor and an angle δ is exists.

The tan delta test is more accurate than a Megger test, because it takes into account not only surpass conditions of the insulators but also the internal Voids, deterioration, moisture absorption and changes in dielectric constant due to ageing of insulation. The value of tanδ is measured between 0 - 0.08 or 0% - 8%, and of course the lower the value of $\tan^{\delta}$ the better the insulation. The ideal value of tanδ is 0.05 at 20 C, and there will be a measuring for the value of the capacitance at the time of the testing, the value of the capacitance will be in the range of PICO FARAD according the size and capacity of the transformer.

3.3.1.3 Partial Discharge Tests

When there is an insulation problem inside the transformer, a discharge may happen at that area accompanied by emission of sound, heat and chemical reactions This test is done by applying voltage (little above rated voltage) at one side of a transformer while the other side is open .The partial discharge sometimes happens in the oil and there will be hydrogen dissolved in the oil, in this case it is very difficult to discover the partial discharge in the oil because the oil sample maybe took from a place which there is no partial discharge. The analysis of the gas collecting in the buchholz -relay chamber can give an indicator of partial discharge in the oil. The reasons of the partial discharge are:

i. Moisture in the liquid insulation.

ii. Cavity in the hard insulation because of manufacturing problems.

There are two ways for measuring the level of the potential difference, the electric method and the sound method.

3.3.1.3.1 Electric Method

As shown in fig 3.1 increasing the voltage across the tested transformer gradually till the rated value and see if the partial discharge starts to happen, we call the value of the voltage in which the partial discharge starts the inception voltage knowing it by the increase of the leakage current in the testing equipment.

After that we start degrading the voltage until the partial discharge stops and we call this point the extinction voltage.

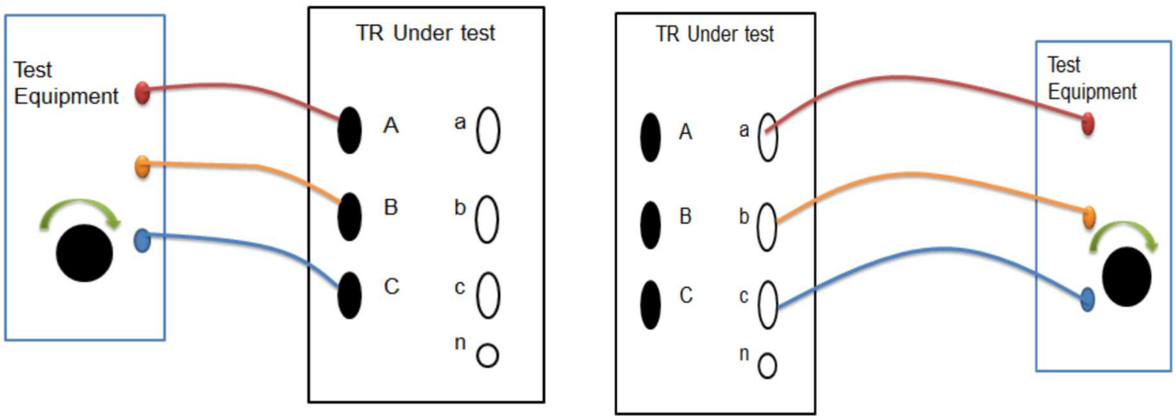

Fig 3.1 Electric method

Now if the value of the extinction voltage is low than the operating voltage, this means that the partial discharge will not stop when we supply the transformer with its normal voltage and of course our tested transformer is facing a real danger. If the value of the extinction voltage is higher than the operating voltage, this mean that the existing partial discharge is not dangerous now but in the future may cause problem.

3.3.1.3.2 Using sound method

In this way the tested transformer is in service and just we put special sensors (Partial Discharge Detector) in the surpass of the transformer, these sensors send signals to electric analyzer (PC) to make filtering for the noise comes from the place of the sensor to determine the partial discharge as shown in fig.3.2.[5]

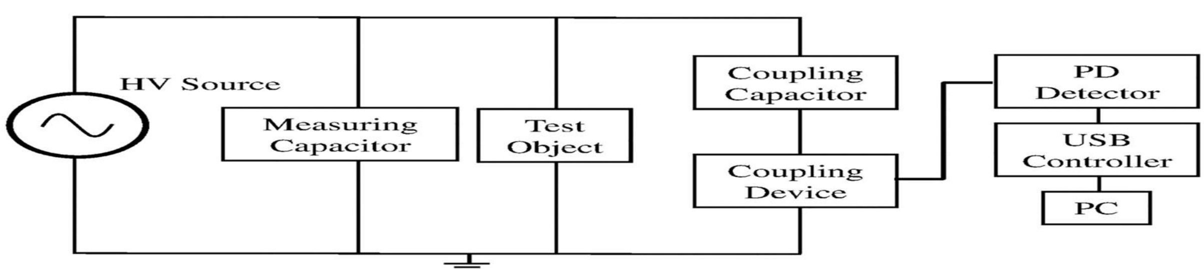

Fig 3.2 Sound Method

3.3.2 Withstand Voltage Tests group

The main purpose of these tests is to be sure that if the insulation of the transformer can withstand the normal operating voltages and the high voltages which come from surges.

3.3.2.1 Normal voltage applied test

In this test we apply voltage equal to 2VL (double of the line voltage) for 1 minute to see if the windings withstand this voltage. The applied voltage depends upon the operating voltage of the winding for example we apply about 28KV for 11KV winding and 70KV for 33KV winding as shown in fig 3.3.

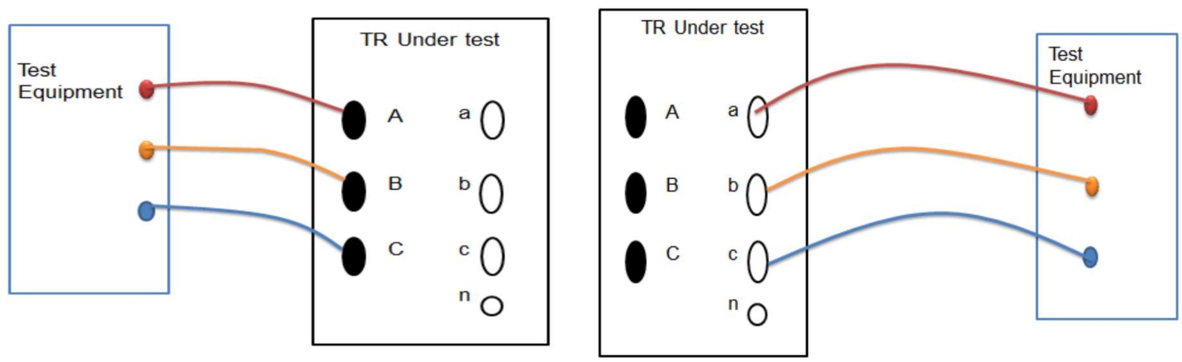

Fig 3.3 Normal voltage applied test

3.3.2.2 Induced voltage test:

The main purpose of this test is to be sure about the quality of the insulation turn-to-turn. Sometime this test is called double voltage double frequency test because of applying the double normal voltage and double normal frequency at the same time for about 30 second. We use double frequency to prevent the core from saturation due to high excitation. In this test we apply the tested voltage in the primary while the secondary is open.

3.3.2.3 Impulse voltage test

In this test we apply extra high voltage for a very little time to simulate the case of high transient due to lightning or switching in the network. In this test the applied voltage must be according to the specification to prevent the tested transformer from total damage, and we use a SURGE GENERATOR consists of capacitors charged from low voltage supply. Table 3.2 shows the I.E.C impulse withstand voltage values:

Table 3.2 I.E.C impulse withstand voltage values

System voltage	**I.E.C Impulse Withstand Voltage**
11KV	75KV
33KV	170KV
66KV	325KV
132KV	550KV
275KV	1050KV

This test is done to simulate two cases happen for a transformer in service:

1. Normal switching of circuit breakers, capacitor and reactors produces high transient waves can affect the transformer. The wave form which is produced from the surge generator for this test is as shown in fig 3.4.

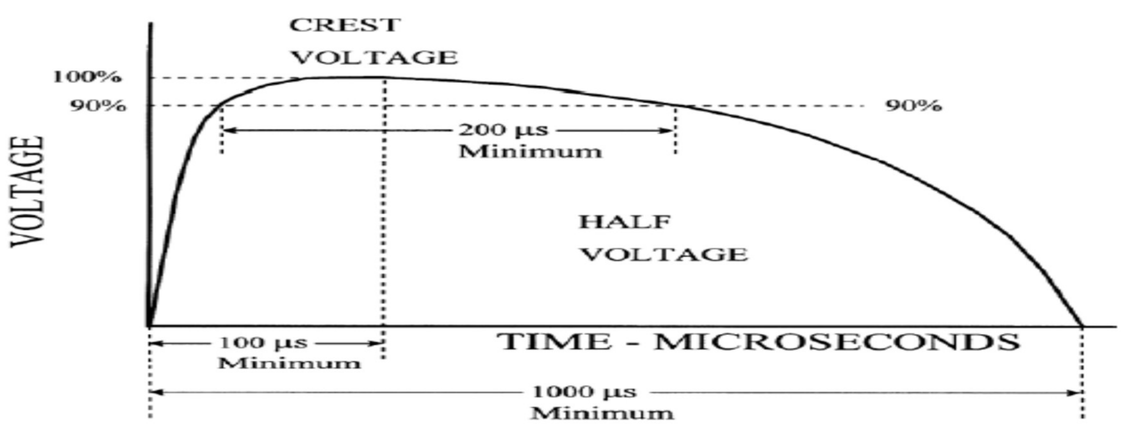

Fig 3.4 Normal switching

2. Thunder and lightning send travelling waves in the transmission lines, and the wave form for this test is as shown in fig 3.5.

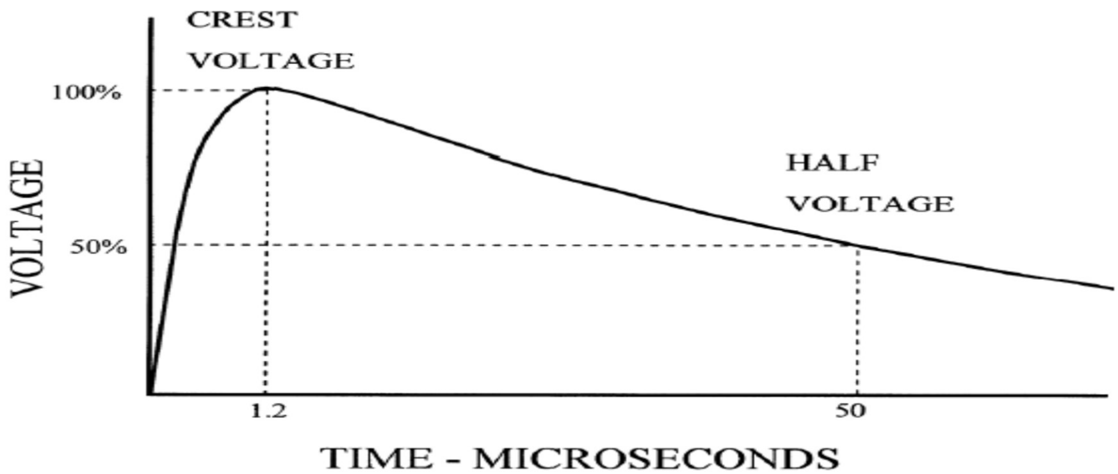

Fig 3.5 Travelling wave

3.4.2 Transformer Oil Tests group

Before details the tests we must know the need for transformer oil testing normally Oxidation happens due to high operating temperature and faults, causing sludge which affects oil properties, normal deterioration of oil dielectric properties due to age.

Purifications decreases oil property of cooling, and transformer life time depends on operating temperature (every 10ºC rise over maximum permitted temperature reduces the life by half) and it is necessary to avoid transformer failure.

The most famous and important transformer oil tests are:

i. Oil Dielectric Strength Test.

ii. Dissolved Gas Analysis (DGA) Test.

iii. Rate of Humidity in the Oil Test.

iv. Power factor (tanδ) Test.

v. Transformer Oil Acidity Test.

3.4.2.1 Oil Dielectric Strength Test:

In this test an oil sample is taken and checked in the oil test device, we start increasing the voltage gradually (2-5KV/SECOND) till the spark appears, we do the test about 5 times and take the average Fig 3.6 Shows The Effect of Water on Dielectric Strength Values. These are the latest values that we say the oil is good or not: *Not less than 20KV/2.5mm for the voltage level 11KV.*

Not less than 25KV/2.5mm for the voltage level 35KV.

Not less than 35KV/2.5mm for the voltage level 220KV.

Not less than 45KV/2.5mm for the voltage level 500KV.

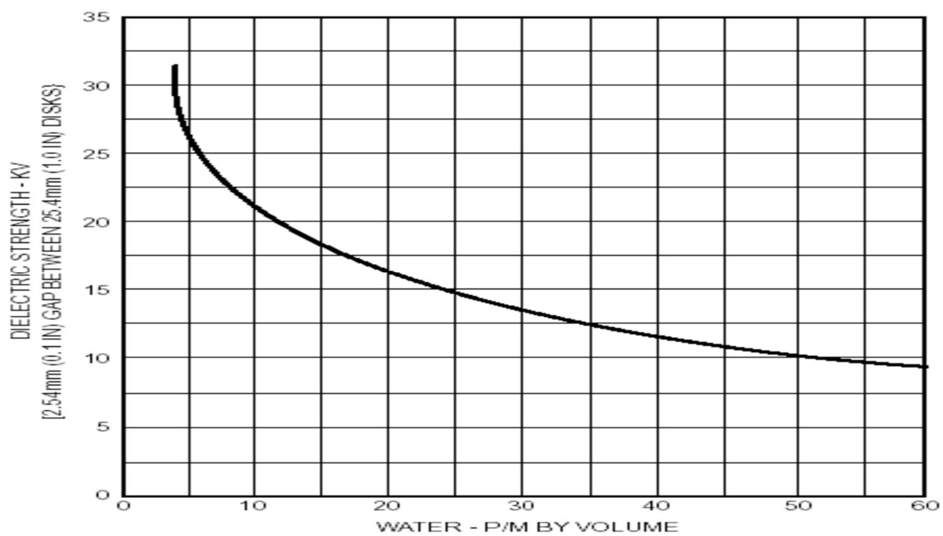

Fig 3.6 Effect of water on dielectric strength

3.4.2.2 Dissolved Gas Analysis (DGA) Test

DGA test mainly done to know the general status of the transformer oil. In addition to above this test early discovers many problems happen inside the transformer tank and affects the chemical properties of the oil, for example, existence of internal spark, existence of bad contact or hot spot, existence of partial discharge (PD), this test is done in a special chemical laboratory. The normal operating temperature may affect the transformer oil causing CO2 and C2O4 to appear in the oil.

Also there will be some gases in the oil without presence of any faults:

i. Gases present due to oil filtering (so breathing BUCHOLZ after filtering is needed).

ii. Gases present due to some processes in the factory like, drying the windings in the oven and putting the coils inside the tank.

iii. Gases present due to some maintenance processes like copper welding inside the tank during changing a damaged coil.

The international standards advice you to make analysis for the dissolved gas in the transformer oil after first operation and takes the results which is Called (Benchmark) as a reference for comparing in the future analysis. In the next slide a table shows the permissible concentration of the dissolved gases in the transformer oil per PPM (part per million).

3.4.2.3 Rate of Humidity in the Oil Test

This test is very important because an existence of 2000 PPM (part per million) of oxygen dissolved in oil is enough to damage the transformer. The acceptable values of this test are when an existence of humid 35 PPM at 60˚C in the transformer of voltage above 66KV is acceptable, or an existence of humid 12 PPM at 60˚C in the transformer of voltage above 220KV is acceptable.

3.4.2.4 Transformer Oil Power factor / tan δ test

Measures the oil insulation characteristics and normally done for bigger size transformers. A power factor value of 0.5% is considered unacceptable for bigger transformers at high voltages and a value of around 1% is still accepted for smaller transformers. At the chemical laboratory tests sheet you find this test and you can choose it with the others oil test to give you an indication of a problem.

3.4.2.5 Transformer Oil Acidity Test

An acid formed during oxidation of the oil due to humidity and affect oil's dielectric properties and also affects circulation of oil inside the transformer.

Acids deteriorate cellulose paper used in the insulation. From 0.03 to 0.05 is an acceptable value of acidity test, but values beyond 0.10 is unacceptable.[2]

3.4.3 Transformer Parameters Calculations Tests

The main and important transformer parameters calculations tests are:

i. Turn Ratio Test (TTR).

ii. Winding Resistance Test.

iii. Open Circuit Test (No load Losses Test).

iv. Short Circuit Test (Load Losses Test).

v. Polarity and Vector Group Test.

3.4.3.1 Transformer Turn Ratio Test (TTR)

This test is done by connecting one side of the tested transformer (always the high voltage side) to a small voltage and measure the voltage at the other side to give the ratio at each TAP as shown in fig 3.7. It is preferable to put the voltage of the test in the HV side to be sure that the voltage in the other side will not exceed the measurable values, now there is a modern computerized set to do this test, it has six terminals and each three terminals go to one side of the tested transformer, the set injects voltage in one side and measure the output voltage to give the ratio of the transformer in each tap, this test done in commissioning tests to ensure that the ratio at each tap of the tested transformer is typical to the name plate fixed in the transformer tank and also when we need to parallel two transformers together whereas at Transformer Maintenance Workshops is done to be sure that the transformer has an internal fault before opening the tank, because the procedure of opening the tank takes a lot of time and effort and also after the faulted transformer has repaired, the ratio test is done as a one of the known tests that done to release a test certificate for the transformer before leaving the workshop.

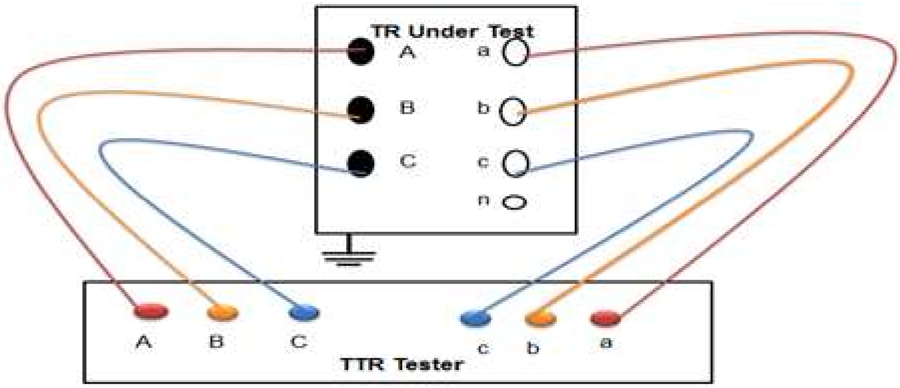

Fig 3.7 TTR test

3.4.3.2 Transformer Winding DC Resistance Test

In this test we measure the resistance for each winding per OHM and see if it is the same as in the transformer FAT sheets. Just we connect DC supply to the tested winding and measure the resistance using (V/I) formula. This test is very useful to determine if there is a loose connection, for example around the TAP or in the bushings, because bad connection makes high contact resistance. The TR winding resistance test can be done by any sensitive OHMMETER.

3.4.3.3 Open Circuit Test (No Load Losses Test)

As shown in fig 3.8 we connect one side of the transformer to a supply with its rated voltage value and let the other side open as shown on the next slide. The Wattmeter for measuring the no load losses or (core losses), while the ammeter measures the no load current (I_o).

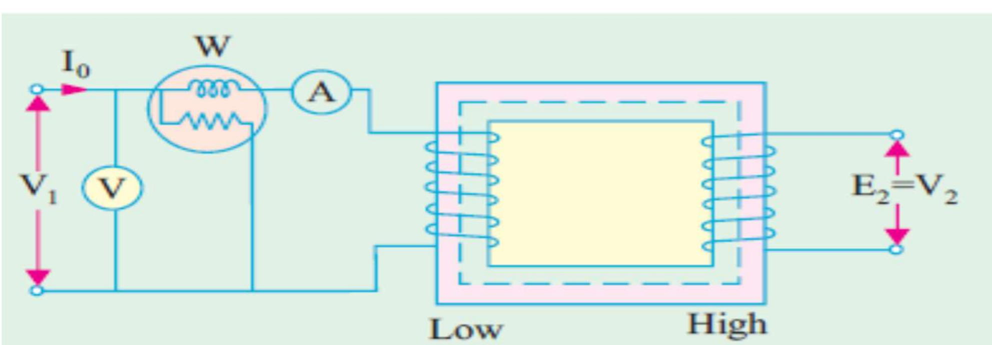

Fig 3.8 Open Circuit Test

Normally in this test we supply the LV side and let the high voltage side open because the low voltage supply is easy and available, for example if the tested transformer is 11KV/415V, we find that it is easy to prepare 415V supply than 11KV supply for testing. This test helps to find the value of the no load losses because $I_\circ$ is very small due to CU losses is negligibly small in primary and nil in secondary (it being opened). The no load losses or (core losses) are the same for all loads. $I_\circ$ consists of two components:

I_ω = active or working or iron loss component.

I_μ = magnetizing component.

Also the transformer open circuit test helps to obtain the value of the parameters $R_\circ$, $X_\circ$ which are stands for the resistance and the reactance of the core losses as in the equations below:

$$W = V_1 I_0 cos_{\emptyset 0} \quad (3.1)$$

$$cos_{\emptyset 0} = \frac{W}{V_1 I_\circ} \quad (3.2)$$

$$I_\mu = I_0 sin_{\emptyset 0} \quad (3.3)$$

$$I_\omega = I_0 cos_{\emptyset 0} \quad (3.4)$$

$$X_0 = V_1 / I_\mu \quad (3.5)$$

$$R_0 = V_1 / I_\omega \quad (3.6)$$

W stands for the dissipated core losses and $\mathbf{V_1}$ for the applied voltage while $\boldsymbol{cos_{\emptyset 0}}$ is core losses power factor.

In this test the current (I_o) not exceed 1% of the rated current value at the injected side and it represents just the exciting current. The core losses or (no load losses) consist of:

i. Hysteresis losses.

ii. Eddy current losses.

If there is a different between the measured values and the nameplate values, the core may have a problem like a short between the laminations or gaps between the layers of the core. If the no load current is different or unbalance this mean that there is an unsymmetrical structure in the core.

3.4.3.4 Short Circuit Test

In this test we supply one side (usually the HV) and short the other side (LV) to measure W_{SC}, V_{SC}, I_{SC} as in the Fig 3.9:

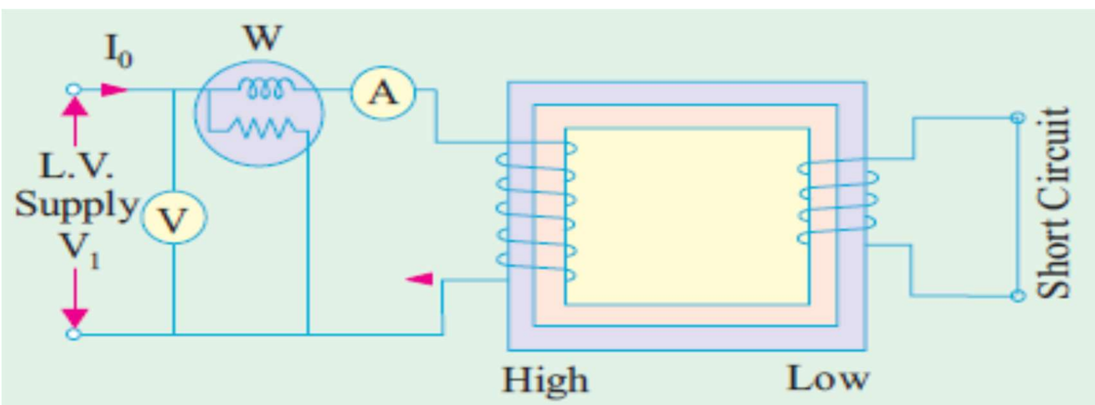

Fig 3.9 Short Circuit Test

The transformer which have Z% equal to 5% means that 5% of the rated voltage for each side is sufficient to circulate the rated current in the other side.

The following formulas are used with the short circuit test:

$$Z_{01} = {}^{V_{sc}}/_{I_1} \quad (3.7)$$

$$W = I_1^2 R_{01} \quad (3.8)$$

$$R_{01} = {}^{W}/_{I_1} \tag{3.9}$$

$$X_{01} = \sqrt{(Z_{01}^2 - R_{01}^2)} \tag{3.10}$$

V_{sc} stands for the applied voltage, **R_{01}, X_{01}** and **Z_{01}** are the transformer parameters at the short circuit, **I_1** is the short circuit current while **W** is the power dissipated.

In addition to identifying the parameters mentioned above, short circuit test is help to discover any deformation in the winding due to shipping and transportation, internal short circuit, wrong connection for the winding after maintenance etc.

3.4.3.5 Transformer Polarity and Vector Group Test

As shown in Fig 3.10 we notice that polarity defines the instantaneous direction of the voltage or current of the primary with respect to secondary. The vector group symbol of a transformer illustrates:

i. The way of connecting windings in each side- delta or star.

ii. The phase shift between primary and secondary windings.

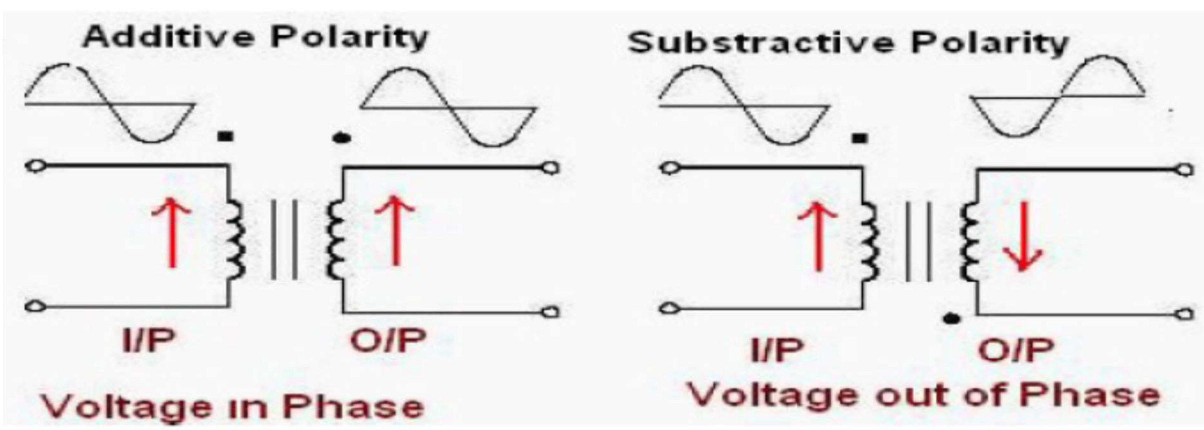

Fig 3.10 Vector Group Test

The vector group of the distribution transformers as general is Dyn11 which is mean that the primary windings is connected DELTA while the secondary windings is connected STAR with the neutral brought out the transformer tank.

The number 11 means that the vector shift between primary windings and secondary windings is 30˚ as we can see in fig 3.11.

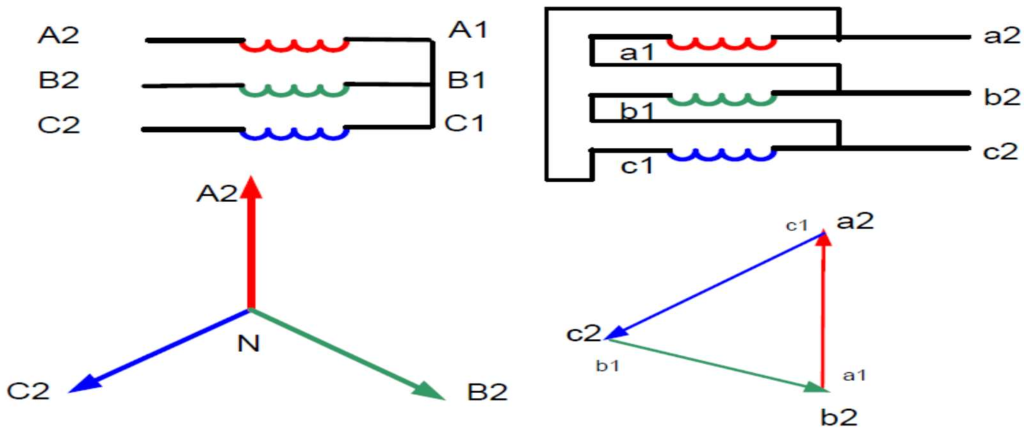

Fig 3.11 vector shift between primary windings and secondary windings

As we see in the diagrams the polarity affects directly the phase shift between primary and secondary windings.

Before operating two transformers in parallel we need to check the vector group to be sure that they are the same.[1]

Chapter Four

Experimental and Results

Chapter Four

Experimental and Results

4.1 Introduction

Four tests were performed in two different transformers. The Megger test and Transformer Winding DC Resistance were performed on a 200 KVA, 33KV/433V transformer; the specifications of the transformer are shown in the table 4.1. The impulse (induced voltage) test and withstand test (one Minuit) test were performed on a 100 KVA, 11KV/433V transformer with specifications shown in the table 4.2.

Table 4.1 Specification of the 200KVA Transformer

Rating	200KVA	Temp.Oil/Wind.	50/55 C ^{o}
Phase	3	Total mass	1065Kg
Frequency	60 Hz	Resistance HV	108.547Ω
Volt HV	33000V	Resistance LV	0.01127Ω4
Volt LV	433V	Impedance	4.85%
Amp HV	3.5A	Cooling Type	ONAN
Amp LV	267A	Year	2015

Table 4.2 Specification of the 100KVA Transformer

Rating	100KVA	Temp.Oil/Wind.	50/55C ^{o}
Phase	3	Total mass	720Kg
Frequency	50Hz	Impedance	4.0%
Volt HV	11000V	Cooling Type	ONAN
Volt LV	433V	Year	2015
Amp HV	5.23A	Amp LV	133.3A

4.2 Megger Test

The Megger gives us DC Volt from 500V till 1000V for the low voltage equipment's, and from 2500V till 15000V for high voltage equipments. The expected insulation resistance for our transformer (200KVA) will be in MΩ or GΩ and not less than KΩ and in the new transformers may reach to GΩ.

So, the following steps were performed:

i. The transformer need to be tested is set out of service and the tank is earthed.

ii. The terminals of high and low voltage should not be earthed.

iii. The resistance between HV and LV was measured (fig 4.1).

iv. The resistance between HV and Earth was measured (fig 4.2)

v. The resistance between LV and Earth was measured (fig 4.3).

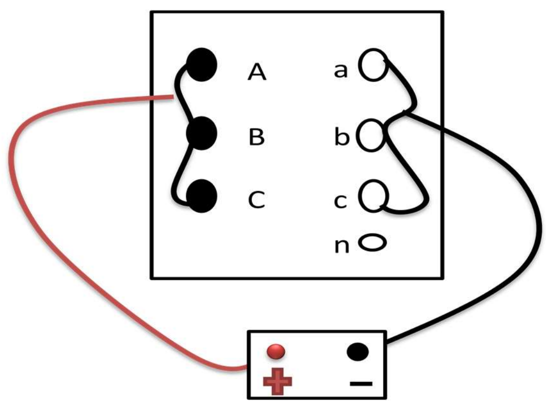

Fig 4.1 between HV & LV

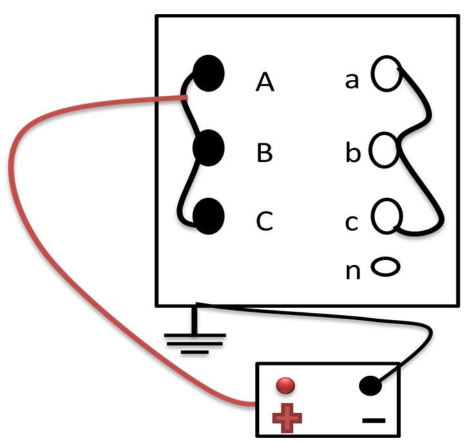

Fig 4.2 between HV & earth

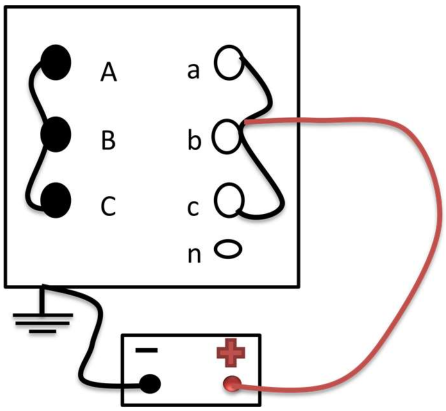

Fig 4.3 between LV & Earth

The readings which were observed are listed in the following table 4.3:

Table 4.3 Megger results

Insulation Resistance	*Between HV & Earth GΩ*	*Between LV & Earth GΩ*	*Between HV & LV GΩ*
Resulted value	218	159	233
IEC Standard Range	Minimum 1	Minimum 1	Minimum 1

4.3 Transformer Winding DC Resistance

In this test we measure the resistance for each winding per OHM and see if it is the same as in the transformer FAT sheets. This test is very useful to determine if there is a loose connection. The transformer winding resistance test can be done by using device called Transformer Resistance Test Instrument (TRTI).

DC supply is connected to the tested winding and measure the resistance between HV lines as shown in fig 4.4, between LV lines and between LV lines & Neutral as shown in fig 4.5.

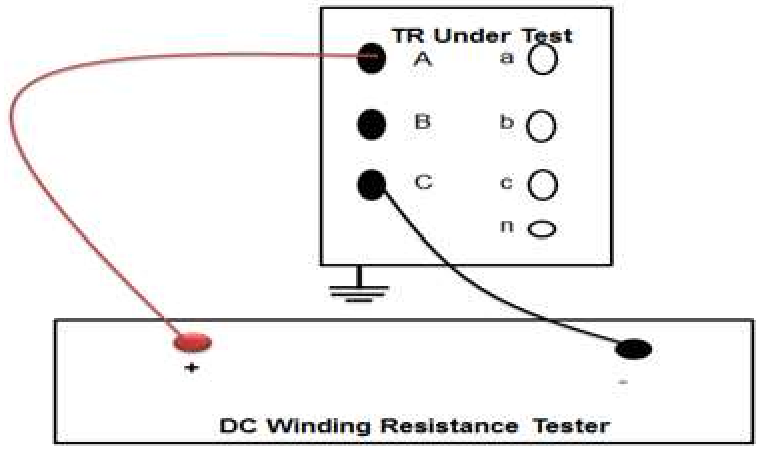

Fig 4.4 between HV Lines

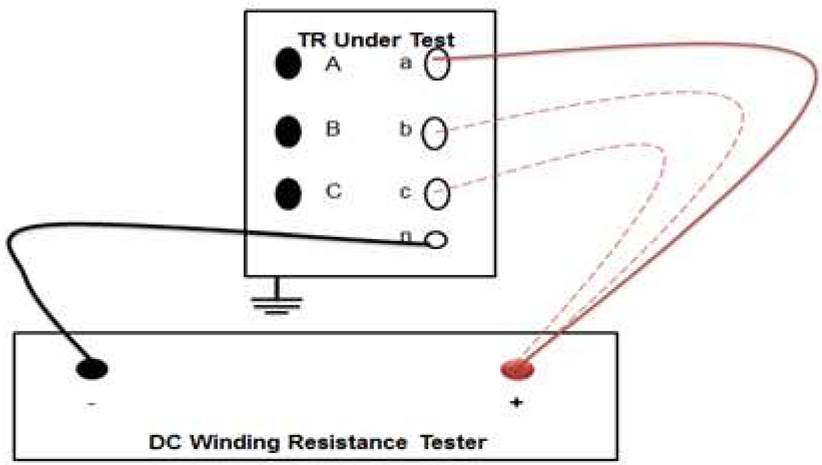

Fig 4.5 between LV Lines and between LV & N

The following tables are showing the readings taken from the (TRTI):

Table 4.4- Line-to-Line LV side readings:

L1-L2 (m*Ω*)	L1-L3 (m*Ω*)	L2-L3 (m*Ω*)
10.18	10.18	10.18

Table 4.5- Line-to-Neutral LV side readings:

L1-N (m*Ω*)	L2-N (m*Ω*)	L3-N (m*Ω*)
5.28	5.47	5.34

Table 4.6- Line-to- Line HV side readings:

L1-L2 (*Ω*)	L1-L3 (*Ω*)	L2-L3 (*Ω*)
92.04	92.36	92.31

All the above results are similar to the nameplate data.

4.4 Impulse Voltage Withstand Test

This test is done by applying standard impulse voltage to the specified value under dry conditions with both positive and negative polarities of the wave. If five consecutive waves do not cause flashover or puncture, the insulators are said to pass the test. If two applications cause flashover, the insulations are said to be failed the test. This test performed by a device called Three Times Frequency Testing table as shown in fig 4.6.

Fig 4.6 Three-time frequency testing table

The following steps should be performed

a) The transformer should be earthed.
b) A double voltage of the secondary side (433*2 = 866V) is adjusted by the voltage regulator, and then applied to the secondary side.
c) A three times of the rated frequency (50*3 = 150Hz) is applied to the transformer.
d) The timer was set on 40 seconds.
e) There is no flashover does not occur, so the transformer passed the test.

4.5 One minute withstand Test

Voltage specified is applied to the transformer; it has to withstand the applied voltage without flashover for one minute. The voltage is increased from 433V to n 3KV for LV side and from 11KV to 28KV for HV side.

The following steps should be performed:

i. The transformer should be earthed.

ii. The primary and secondary (H.T&L. T) windings are short circuited as shown in fig 4.7.

iii. The timer is adjusted to 60 seconds.

iv. A voltage of 28KV is applied to the H.T.

v. A voltage of 3KV is applied to the L.T.

vi. The transformer did not cause flashover, so it Said to be pass the test successfully.

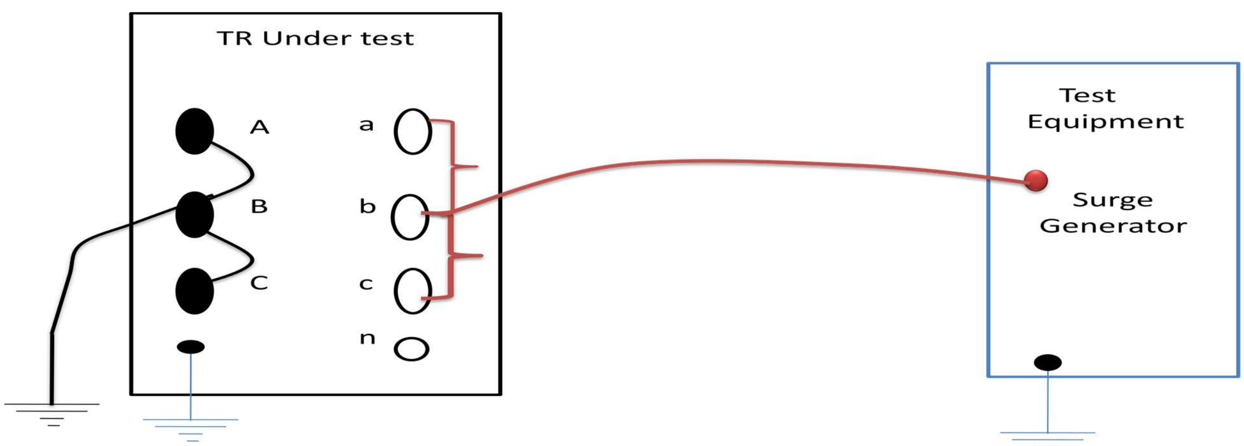

Fig 4.7 H. T&L. T short circuit and connection

Chapter Five

Conclusion and Recommendations

Chapter Five

Conclusion and Recommendations

5.1 Conclusion

Investigation and performing selected type tests were presented and alongside the procedures of these tests was shown upon 100KVA and 200KVA power transformers which had taken as a case study and the results were accepted with respect to the standard and the nameplate data sheets.

The purchase, preparation, assembly, operation and maintenance of transformers represent a large expense to the power system so after verification each transformer is dry, no damage has occurred during shipping, internal connections have not been loosened, the transformer's ratio, polarity, and impedance agree with its nameplate, its major insulation structure is intact, wiring insulation has not been bridged, then the transformer is ready for service.

Physical size, voltage class, and kVA rating are the major factors that dictate the amount of preparation required to put transformers in service. Size and kVA rating also dictate the kind and number of auxiliary devices a transformer will require. All of these factors affect the amount of testing necessary to certify that a transformer is ready to be energized and placed in service.

5.2 Recommendations

There are plenty of tests which performed for transformer which being assembled at a substation, these tests and inspections must be satisfactorily completed, so that the final decision over transformer readiness for energization can be made.

Other tests must be done at the site after installations and before putting the transformer in service such as:

1. Ratio Test for each tap position.
2. Losses tests/ impedance test.
3. Vector group test.

References

[1] *S. D. Myers, J. J. Kelly, R. H. Parrish.* **"A Guide of Transformer Maintenance"** 2nd *Edition Transformer Maintenance Institute, Ohio, USA.*

[2] *Hardik V Rupareliya[a], Nidhish G. Mishra[b]* **"Pre-Commissioning Tests on Dry Type Transformer"** *a) PG Student, Dept of Electrical Engineering, Gujarat Technological University, Gujarat, India b) Associate Professor, BVM Engineering College, Gujarat, India.*

[3] *J. Kudel ika[a], M. Gutten[b], M.Brandt[b]: Department of Measurement and Applied Electrical Engineering, Faculty of Electrical Engineering University of Zilina.* "**Development of Electrical Breakdown in Transformer Oil"** *a) Department of Physics, Faculty of Electrical Engineering b) Department of Measurement and Applied Electrical Engineering, Faculty of Electrical Engineering University of Zilina, Slovak.*

[4] *MRITI KESHARWANI "***TESTING & MAINTENANCE OF TRANSFORMER"** *ASST PROF. DEPARTMENT OF ELECTRICAL ENGINEERING, V RAMAN UNIVERSITY, KOTA C.G, India.*

[5] *Khalid Hassan Gharib[a] , Enrique L. Labrador[b]* **"ELECTRICAL COMMISSIONING MANUAL"** *a) Technical Author CSD TS&C Senior Engineer Design b) Layout Designer Transmission Engineer. A publication by Technical Services Business Unit, Commissioning Services Department of National Grid,KSA.*

[6] *SANJEEB MOHANTY* **"SOME STUDIES ON BREAKDOWN OF SOLID INSULATIONS AND IT'S MODELING USING SOFT COMPUTING TECHNIQUES"**, *Department of Electrical Engineering National Institute of Technology Rourkela-769008, India.*

[7] *Sreedhar Kumar Teella* **"Modeling of Breakdown voltage of Solid Insulating Materials Using Soft Computing Techniques''** *Department of Electrical Engineering National Institute of Technology, Rourkela-769008, India.*