Sudan University of Science& Technology

College of Engineering

Electrical Engineering department

Power Transformers Performance and Tests

إختبارات وأداء محولات القوى

A Project Submitted In Partial Fulfillment for the Requirement of the Degree of B.Sc.(Honor) In Electrical Engineering

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قال تعالى:

(اقرأ باسم ربك الذي خلق*خلق الإنسان من علق*اقرأ وربك الأكرم*الذي علم بالقلم*علم الإنسان ما لم يعلم)

العلق – الآيات 1~5

Dedication:

To

Our Endless love

Our mothers

To

Men whom teach us to be real men

Our fathers

To

Our teacher & our colleagues

We say: Thank you

Acknowledgment

We thank very much. Dr. Salah Eldeen Gasim Mohamed, who oversaw this research.

We would like to thank as well as director of the Sudanese Electricity Distribution Transformer Workshop and Sudatraf factory for thier good dealings with us and understand the problem.

ABSTRACT

Transformer is one of the most important components and components of the electric power system, which is indispensable in the electrical power system and according to that importance. This study was to analyze the performance and work of electrical transformers by conducting routine tests of all types of transformers to evaluate their performance in the system, which helps to stabilize the system.

This study dealt with the types of electrical transformers in the electrical power system of different and location and the function of each type on.

المستخلص

تعتبر المحولات الكهربائية من أهم عناصر ومكونات منظومة القدرة الكهربائية التي لاغنى عنها في المنظومة وتبعا لتلك الأهمية جاءت هذه الدراسة لتحليل أداء وعمل المحولات الكهربية عن طريق اجراء الإختبارات الروتينية بأنواعها للمحولات وذلك لتقييم أداءها في المنظومة والتي تساعد على استقرارية النظام .

كما أنه تناولت هذه الدراسة أنواع المحولات الكهربائية الموجودة في منظومة القدرة الكهربائية بأنواعها واماكنها المختلفة ووظيفة كل نوع منها على حدى .

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Symbol	Mean
V_p	primary voltage
V_s	secondary voltage
N_p	number of primary turns
N_s	number of secondary turns.
I_p	primary current
I_s	secondary current
V_1	primary voltage
V_2	secondary voltage
e_1	Primary induced emf
e_2	Secondary induced emf
I_0	no load current
I_1	Primary current
I_2	Secondary load current
$I_{2'}$	load component of total primary current (reflected secondary current)
R_0	Magnetizing core resistance
R_1	Primary winding resistance
R_2	Secondary winding resistance
X_0	Magnetizing core reactance
X_1	Primary winding reactance
X_2	Secondary winding reactance

N_1	Primary coil number of turns
N_2	Secondary coil number of turns

CHAPTER ONE

INTRODUCTION

1.1 Background

Transformers are generally very important in our daily lives. The transformer is an electrical machine that allows the transmission and distribution of electrical energy simply and inexpensively, since its efficiency is from 95% to 99%, i.e., the transformer operates more efficiently than most electrical devices.

They are involved in the formation of various electronic devices and power electrical grids. When we talk about power transformers, we refer those step up and step down transformers used in generation, transmission and distribution networks.

Power transformers are in the second place in importance after the generator, so it is one of the most equipment that is many protections are provided for them, so it is necessary to make specific, preventive, diagnostics and corrective tests for them from birth (manufacturing stage) through their lifespan, until they reach their end of life.

This research relates to the work side of various tests on distribution transformers in particular. The aim of it is to shed light on the various tests being conducted in Sudan, and the mechanism in which these tests are carried out, as well as the most important and missing tests in Sudan, then mention the modern equipments used to conduct those tests.

An attempt was also made to simulate some of tests by using matlab simulink program, this simulation simplifies understanding of how such tests are done.

1.2 General Concept (Overview)

This research shows -throw its different chapters- the power transformer from many different aspects. The most important aspect covered by this research is the aspect of doing tests to the power transformer.

1.3 Problem Statement

It is clear to us that the electricity network in Sudan suffers from a lack of stability and continuous interruption of electricity, and this instability is because several reasons, some of these reasons related in general to the follow-up of the situation of transformers. That is why it important to discuss the various important tests conducted on the transformers in Sudan, and mention the other important tests that aren't conducted in it, which will be recommended.

1.4 Objectives

- Find out what types of transformers are manufactured in Sudan and what tests are conducted on them.
- Collect practical data for the tests that have been done.
- Know the equipment used in the particular test, and its quality.
- Checking the interest of transformers while in service.
- Trying to designing a simulation for some of those tests, to help the transformer specialists know the expected results of the test.

1.5 Methodology

Many techniques and methods are utilized to fulfill the objectives of this research. These include field visits, collecting data from a transformer factory and from a transformer repair and maintenance service, monitor how the transformer tests are performed, and finally using MATLAM/SIMULINK program for simulate some of the tests.

1.6 Project layout

- Chapter two: represents the construction of the power transformer, and gives many examples for many different types of it.
- Chapter three: represents the main subject of this project “Power transformer tests” you will find it here. the tools and devises which we used to make the tests done.
- Chapter four: represents results of the tests which we make if at the factories. Also, you find the simulation of some of these tests.
- Chapter five: represents the project conclusion and recommendations

CHAPTER TWO
CONSTRUCTION AND TYPES OF TRANSFORMER

2.1 Introduction:-

The construction of a simple two-winding transformer consists of each winding being wound on a separate limb or core of the soft iron form which provides the necessary magnetic circuit.

This magnetic circuit, know more commonly as the “transformer core” is designed to provide a path for the magnetic field to flow around, which is necessary for induction of the voltage between the two windings.

However, this type of transformer construction were the two windings are wound on separate limbs is not very efficient since the primary and secondary windings are well separated from each other. This results in a low magnetic coupling between the two windings as well as large amounts of magnetic flux leakage from the transformer itself. But as well as this “O” shapes construction, there are different types of “transformer construction” and designs available which are used to overcome these inefficiencies producing a smaller more compact transformer.

Increasing and concentrating the magnetic circuit around the coils may improve the magnetic coupling between the two windings, but it also has the effect of increasing the magnetic losses of the transformer core.

As well as providing a low reluctance path for the magnetic field, the core is designed to prevent circulating electric currents within the iron core itself.

In all types of transformer construction, the central iron core is constructed from of a highly permeable material made from thin silicon steel laminations assembled together to provide the required magnetic path with the minimum of losses. The resistivity of the steel sheet itself is high reducing the eddy current losses by making the laminations very thin.

Transformer construction is divided into two parts:

- Main.
- Auxiliary.

2.2 Main Construction: -

2.2.1Core type of transformer: -

Generally, the name associated with the construction of a transformer is dependent upon how the primary and secondary windings are wound around the central laminated steel core. The two most common and basic designs of transformer construction are the Closed-core Transformer and the Shell-core Transformer.

In the “closed-core” type (core form) transformer, the primary and secondary windings are wound outside and surround the core ring. In the “shell type” (shell form) transformer, the primary and secondary windings pass inside the steel magnetic circuit (core) which forms a shell around the windings as shown in Fig (2.1).

In both types of transformer core design, the magnetic flux linking the primary and secondary windings travels entirely within the core with no loss of magnetic flux through air. In the core type transformer construction, one half of each winding is wrapped around each leg (or limb) of the transformers magnetic circuit as shown Fig (2.1).

The coils are not arranged with the primary winding on one leg and the secondary on the other but instead half of the primary winding and half of the secondary winding are placed one over the other concentrically on each leg inorder to increase magnetic coupling allowing practically all of the magnetic lines of force go through both the primary and secondary windings at the

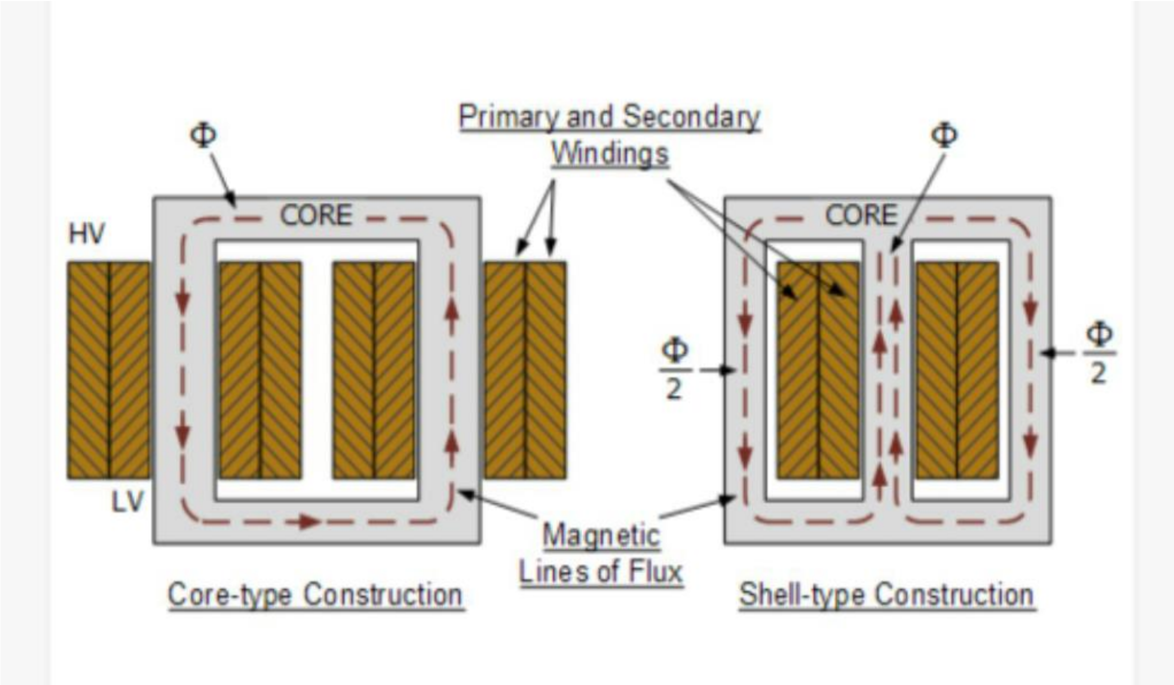


Figure 2.1: Construction type

same time. However, with this type of transformer construction, a small percentage of the magnetic lines of force flow outside of the core, and this is called “leakage flux”.

Shell type transformer cores overcome this leakage flux as both the primary and secondary windings are wound on the same center leg or limb which has twice the cross-sectional area of the two outer limbs. The advantag e here is that the magnetic flux has two closed magnetic paths to flow around external to the coils on both left and right hand sides before returning back to the central coils.

2.2.2 Transformer construction of the winding:-

The windings consist of the current-carrying conductors wound around the sections of the core, and these must be properly insulated, supported and cooled to withstand operational and test conditions.

The terms winding and coil are used interchangeably in this discussion. Copper and aluminum are the primary materials used as conductors in power-transformer windings.

While aluminum is lighter and generally less expensive than copper, a larger cross section of aluminum conductor must be used to carry a current with similar performance as copper. Copper has higher mechanical strength a nd is used almost exclusively in all but the smaller size ranges, where aluminum conductors may be perfectly acceptable.

As mentioned previously, the type of winding depends on the transformer rating as well as the core construction. Several of the more common winding types are discussed below.

2.2.2.1 Pancake Windings:-

Several types of windings are commonly referred to as “pancake” windings due to the arrangement of conductors into discs. However, the term most often refers to a coil type that is used almost exclusively in shell-form transformers.

The conductors are wound around a rectangular form, with the widest face of the conductor oriented either horizontally or vertically.

Figure 2.2: Pancake winding during winding process

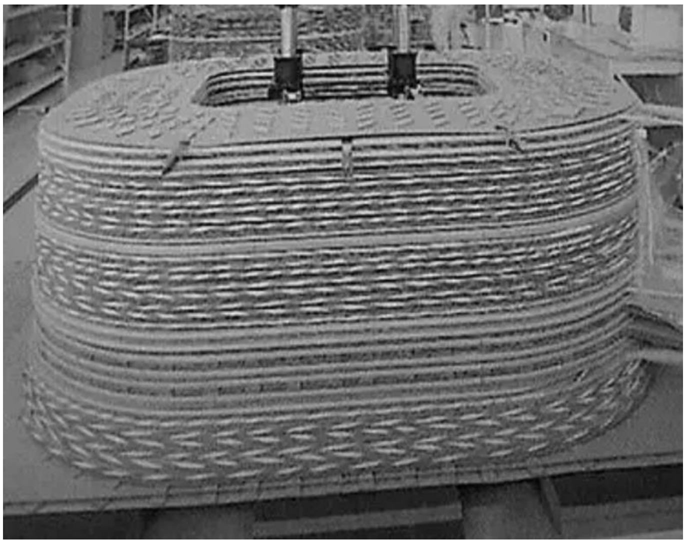


Figure 2.3: Stacked pancake windings

2.2.2.2 Layer (Barrel) Windings: -

Layer (barrel) windings are among the simplest of windings in that the insulated conductors are wound directly next to each other around the cylinder and spacers.

Several layers can be wound on top of one another, with the layers separated by solid insulation ducts or a combination. Several strands can be wound in parallel if the current magnitude so dictates.

Figure 2.4: Layer windings (single layer with two strands wound in parallel)

2.2.2.3 Helical Windings: -

Helical windings are also referred to as screw or spiral windings, with each term accurately characterizing the coil's construction.

A helical winding consists of a few to more than 100 insulated strands wound in parallel continuously along the length of the cylinder, with spacers inserted between adjacent turns or discs and suitable transpositions included to minimize circulating currents between parallel strands.

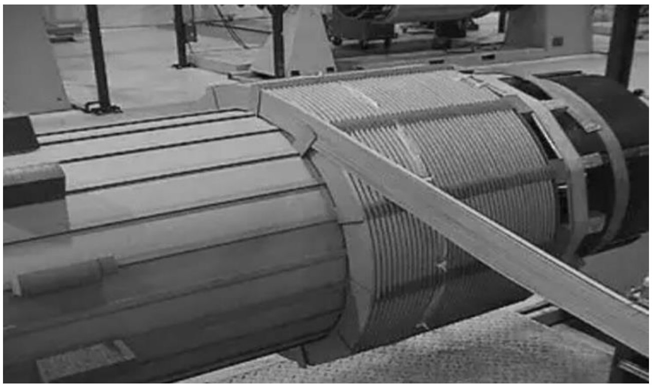


Figure 2.5: Helical winding during assembly

Helical windings are used for the higher-current applications frequently encountered in the lower-voltage classes.

2.2.2.4 Disc Windings:-

A disc winding can involve a single strand or several strands of insulate d conductors wound in a series of parallel discs of horizontal orientation, with the discs connected at either the inside or outside as a crossover point. Each disc comprises multiple turns wound over other turns, with the crossovers alternating between inside and outside.

2.3 Auxiliary part of transformer:-

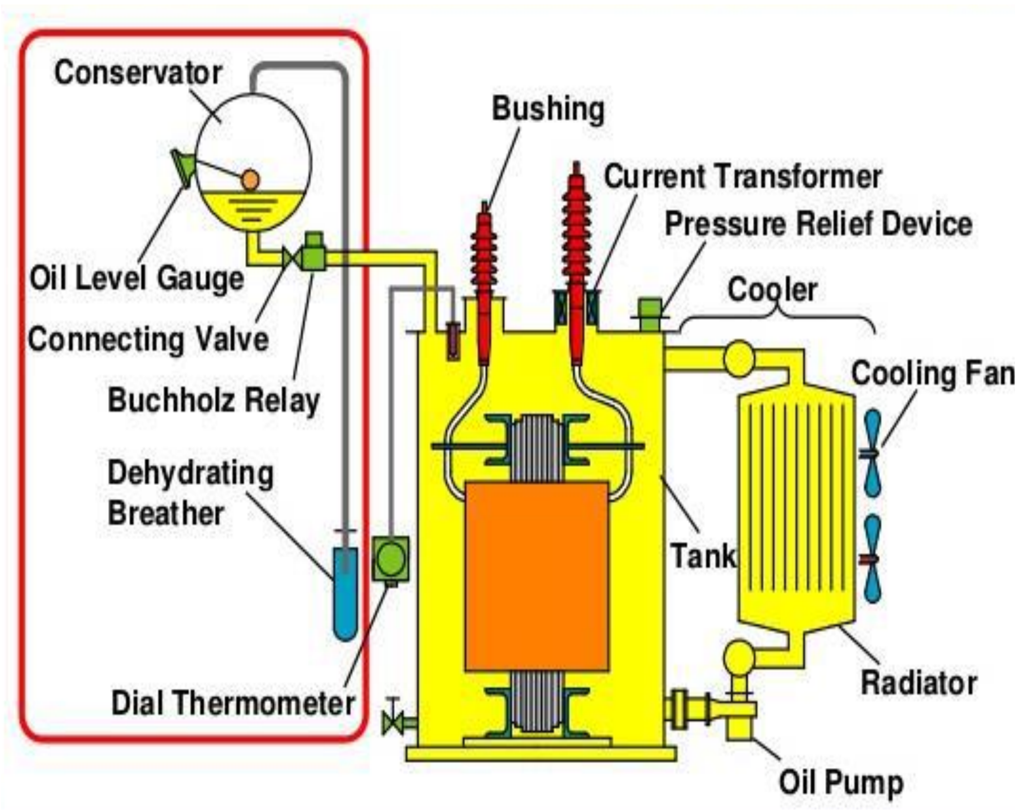


Figure 2.6: Auxiliary part transformer

2.3.1 Distribution transformer main parts

- Main oil tank
- Radiators
- Breather unit
- Conservator
- Pressure relief system
- Oil level indicator
- Temperature dial
- Tap changer
- HV/ LV bushing
- Oil filling plug
- Drain plug
- Cable box

1- Main oil tank : winding are placed and soaked in oil

2- Expansion oil tank (conservator): installed above the main oil tank on the outer transformer frame and is connected to the main tank through a metallic tube. Oil can freely contract and expand during loading and thus the temperature of the oil increases and decreases. Loading can increase expansion up to 8% .Tank compensates any loss in oil that may occur in the main tank.

3- Bucchloz relay: placed when a conservator tank is used, as it indicated faults and errors such as oil loss when oil level goes low, improper oil flow between the oil tank and the transformer. Moreover, it shows gas emission inside transformer due to any unusual operation (excessive loading or short circuit) and can issue a control signal which can be used to disconnect the transformer. It is equipped with a release valve in case oil exceeded its level.

Bucchloz relay the gas color actually indicated the type of fault in the transformer:

- White fumes : insulation paper failure
- Yellow fumes : insulation fiber burn
- Black fumes : oil decomposition and burn out

4- Breather unit: As mentioned earlier, any decrease in oil is being compensated by the conservator tank which leads to decrease in oil in the conservator tank itself and thus the air gap widens in the tank and air is pulled from outside through what is known as “dehydrated breathing unit”which contains “silica gel” that absorbs any moisture present in the oil. Silica changes its color from blue to pink if its unable absorbs moisture.

5- Oil indicator: Indicates level of oil in the conservator unit. Decrease in oil can cause flashover if it is not corrected.

6- Temperature detector and contacts: to monitor oil temperature and if temperature exceeded a certain limit, transformer is disconnected from service

7- Pressure relief device and explosion vent: reduces pressure inside the transformer through external pressure release to avoid explosion of transformer

8- Thermal relay: used as indicator of winding temperature and also can be used to activate fans or alarms (used with large transformers)

9- Radiator: added to increase cooling efficiency of the transformer and is equipped with a pump which continuously pumps oil in the radiator. In this case, cooling is assumed to be “natural air” as it depends on natural circulation and air cooling the oil. Sometimes fans are added to the radiator. Radiator action is called “forced action” as it employs fans and radiator pump.

10- Bushing: responsible for connecting the internal windings of the transformer with the external electrical network. It isolates the internal windings from the transformer body. Bushings are fixed using flanges to avoid any humidity, dirt and dust from reaching the points of contact.

2.4 Types of transformer:-

There are different types of transformer.

2.4.1 Power transformers:-

A power transformer is a passive electromagnetic device that transfers energy from one circuit to another circuit by means of inductive coupling. Power transformers differ from other transformer types in that they are designed to comply with regulatory requirements for mains power interfacing, working at mains voltages and relatively high currents. The most important specification of a power transformer is its primary to secondary transformer galvanic isolation, which is usually specified in kV. This is a fundamental safety aspect in protecting humans from potentially lethal earth fault conditions.

Power transformers typically have a single primary (mains side) winding and one or more secondary windings. The secondary winding may be tapped at different points to generate multiple voltage outputs. A power transformer operates according to Faradays Law of Induction. Transformers are extremely efficient when operating within their design specifications.

Core type is an important consideration. Typical power transformer supplies include laminated core. Laminations can be important as they help prevent eddy currents flowing in the core that cause loss of efficiency. The maximum output current is specified at the point where the core is saturated, or the windings current rating is exceeded. Power transformers are found in any application that requires mains power.

Power transformers play an important and significant role in the power system to connecting the subsystems and delivering the electricity to the consumers. They are one of the most expensive elements in the power system, which is why focusing on their status of parameters is the primary task. This seminar paper will focus on highlighting certain important aspects of voltage selection and thermal aspects.

Voltage selection goes for determining and calculating transformer voltage ratio, the specification of insulation levels, examples of voltage regulation, rating, tap ranges and impedance calculations.

Thermal aspects go for specification of temperature rise and ambient conditions. Also, constructional features of different types of a transformer in common use together with the purpose and selection of accessories.

2.4.1.1 Transformer equivalent circuit:-

Transformer equivalent circuit is the essential basis for different calculations including voltage drop or regulation under various load conditions. In Fig (2.6), the magnetizing circuit is taken as a shunt-connected impedance. The magnetizing current is rich in harmonics which must be kept in check. This is done by keeping the flux density within specified limits. When the transformer is being energized, the transient current inrush rich in second harmonic will result. A mentioned effect can be uncovered using transformer protection relays in a way that they control the existence of the second harmonic component, so that the anomalous tripping is avoided.

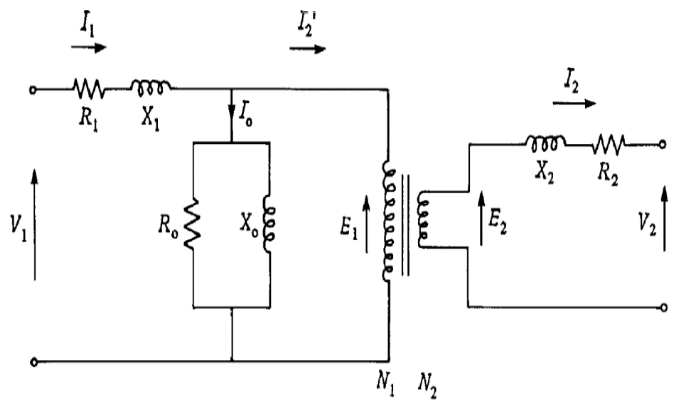


Figure 2.7: Transformer equivalent

circuitV1 (U1)– primary terminal voltage

e1 – primary induced emf (theoretical)

V2 (U2)– secondary terminal voltage

e2 – secondary induced emf (theoretical)

I0 no load current

I1 – primary current

I2 – secondary load current

I2’ – load component of total primary current (reflected secondary current)

X0 & R0 – magnetizing and core reactance and resistance

X1 &R1 – primary winding reactive leakage and coil resistance

X2 & R2 – secondary winding reactance and resistance

N1 – primary coil number of turns

N2 – secondary coil number of turns

2.4.2 Distribution Transformer

The step down transformers used for electric power distribution purpose are referred as distribution transformer. There are several types of transformer used in the distribution system. Such as single phase transformer, three phase transformer, pole mounted transformer, pad mounted transformer, and underground transformer. Distribution transformers are generally small in size and filled with insulating oil. These transformers are available in the market in various sizes and efficiencies. Selection of distribution transformer depends upon the purpose and budget of the end users.

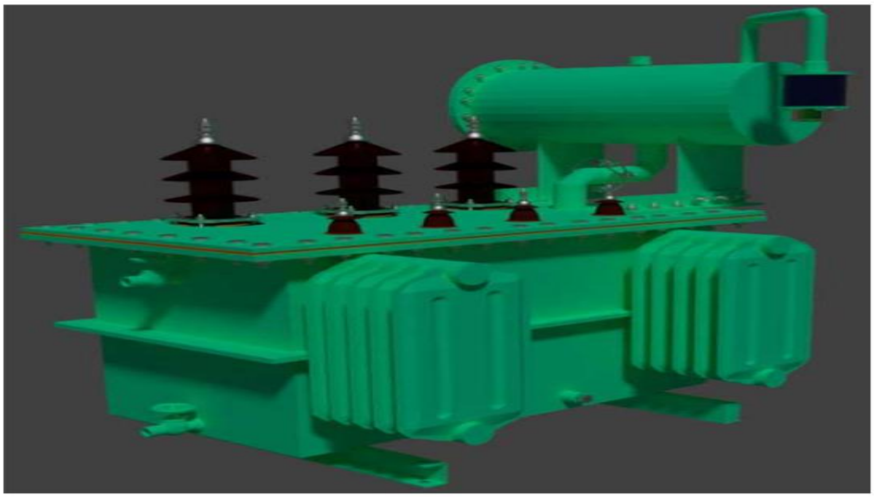


Figure 2.8: distribution transformer

2.4.2.1 Secondary Terminals of Distribution Transformer

Secondary terminals of distribution transformer deliver electrical power at a utilization voltage level to the consumer end via energy metering system. In case of three phase distribution system three phase four wire secondary systems are adopted. Here, three phases, which means red, yellow and blue phase conductors, come out from three low voltage bushing studs of the transformer. The neutral wire is connected to the fourth bushing which is also referred as a neutral bushing of the transformer. The neutral point of the distribution transformer is projected from the tie point of 3–phase winding inside the transformer. In case of industrial heavy three phase load, four wire system is directly delivered to the consumer end, but in case of single phase light load, one phase and neutral connection of the three phase distribution transformer, are connected to the consumer's energy meter.

2.4.3 Phase shifting transformer

2.4.3.1 Introduction

The necessity to control the power flow rose early in the history of the development of electrical power systems. When high-voltage grids were super imposed on local systems, parallel-connected systems or transmission lines of different voltage levels became standard. Nowadays large high-voltage power grids are connected to increase the reliability of the electrical power supply and to allow exchange of electrical power over large distances. Complications, attributed to several factors such as variation in power-generation output and/or power demand, can arise and have to be dealt with to avoid potentially catastrophic system disturbances. Additional tools in the form of phase-shifting transformers (PSTs) are available to control the power flow to stabilize the grids. These may be justified to maintain the required quality of the electrical power supply. To transfer electrical power between two points of a system, a difference between source voltage (VS) and load voltage (VL) in quantity and/or in phase angle is necessary.

$$Z=R+jX=Z*e^{jy_z} \quad (2.1)$$

$$Z=\sqrt{(R^2+X^2)} \quad (2.2)$$

$$y_z=\tan^{-1}(X/R) \quad (2.3)$$

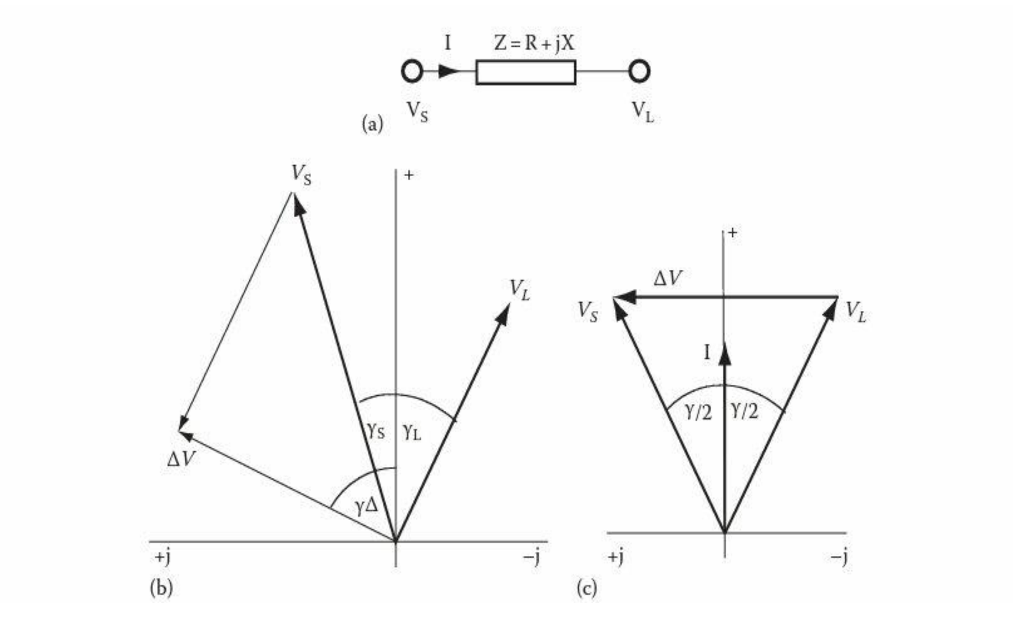


Figure 2.9**:** Power shifting transformer diagram

V_s=v_s*$(\cos(ys) + j\sin(ys))$ (2.4)

V_l=v_l*$(\cos(yl) + j\sin(yl))$ (2.5)

ΔV=V_s-V_l (2.6)

ΔV=$(v_s\cos(ys) - v_l\cos(yl)) + j(v_s\sin(ys)$-$v_l\sin(yl))$=$\Delta V * e^{-jy\Delta}$ (2.7)

ΔV=$\sqrt{}(V_s^2 - 2 * V_s * V_l * \cos(ys - yl) + V_l^2)$ (2.8)

$y_\Delta = \tan^{-1}((\frac{v_s\cos(ys) - v_l\cos(yl))}{v_s\sin(ys) - v_l\sin(yl))})$ (2.9)

I=$\Delta V/Z$ *$e^{-j(y\Delta - yz)}$ (2.10)

For symmetrical condition V_s=V_l, and ys=y/2, and

yl=-y/2,R<<X,

then

ΔV=V*2*sin$\left(\frac{y}{2}\right)$ (2.11)

yΔ=$\Pi/2$ (2.12)

I=$\frac{V*2*\sin\left(\frac{y}{2}\right)}{X}$ (2.13)

2.4.3.2 Basic Principle of Application

Because of the predominantly inductive character of the power system, an active power flow between source and load must be accomplished with a phase lag between the terminals. Phase-shifting transformers are a preferred tool to achieve this goal. Two principal configurations are of special interest: (1)the power flow between transmission systems operating in parallel where one system includes a PST and (2) where a single transmission line which includes a PST is connecting two otherwise independent power systems. The latter is in fact a special case of the first, but it has become more important nowadays for the interconnection of large systems. For the following considerations, it is assumed that the ohmic resistance R is small compared with the reactance X and thus has been neglected. One practical basic situation is that a location where power is need ed (load side) is connected to the source side through two systems that need not necessarily have the same rated voltage level. See Fig (2.8). Without any additional measure, the currents I1 and I2 would be distributed in proportion to the ratio of the impedances of the systems,

$$I_1 = \frac{I*X2}{X1+X2} \tag{2.14}$$

$$I_2 = \frac{I*X1}{X1+X2} \tag{2.15}$$

and there is no doubt that system 2 would take only a small part of the load because of the additional impedances of the two transformers in that branch. If the power flow in system 2 should be increased, an additional voltage ΔV must be introduced to compensate the increased voltage drop in system 2. Presuming that active power should be supplied to the load side and considering the inductive character of the systems, this voltage must have a 90° phase lag to the line-to-ground voltages of the system (VL). In principle, the source of ΔV could be in stalled in each of the two systems. Fig (2.10) shows the voltage diagrams of both options. Fig (2.10a) corresponds to Fig 2.8 with the PST installed in

system 2, the system with the higher impedance. The additional voltage reduces the voltage drop in system 2 to that of system 1. The voltage at the output or load side of the PST VL* leads the voltage at the input or source side VS. Per definition, this is called an advanced phase angle. If the PST were installed in system 1 (Figure 2.10b), the additional voltage would increase the voltage drop to that of system 2. In this case, the load-side voltage VL* lags the source side voltage VS,

and this is defined as retard phase angle. As can also be seen from the diagrams, an advanced phase angle minimizes the total angle between source and load side.

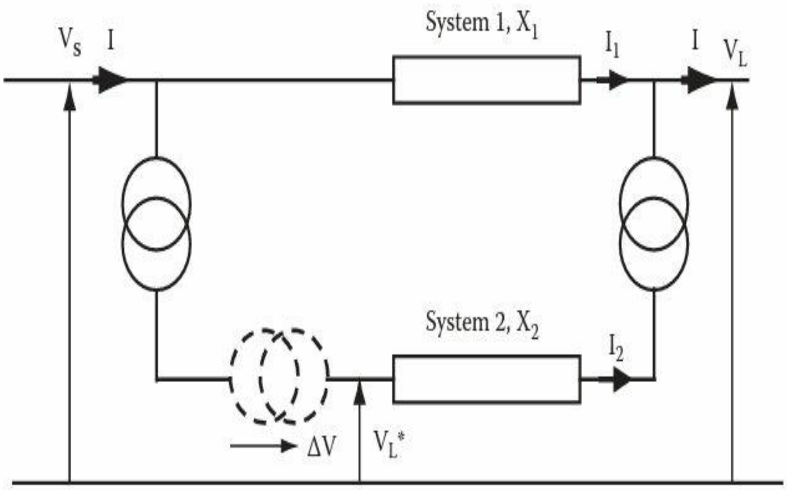


Figure 2.10: Parallel systems.

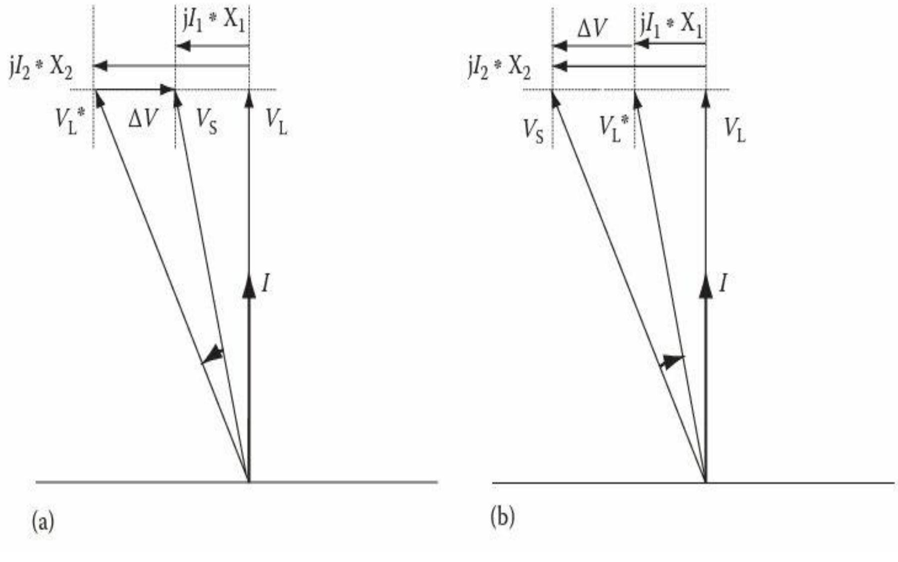


Figure 2.10: No-load voltage diagram of parallel systems. (a) Advanced phase angle VL* leads VS (b) retard phase angle VL lags VS

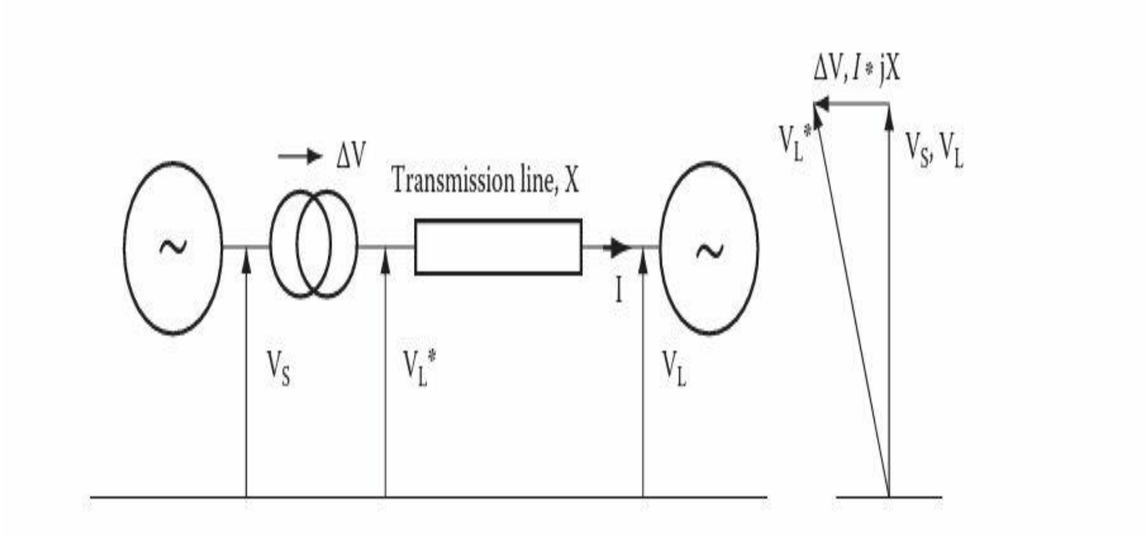


Figure 2.11: Connection of two systems.

V_s=ΔV-I*jX-V_l (2.16)

For

V_s=V_l=V

Hence

ΔV-I*jX=0

The second important application is the use of a PST to control the power flow between two large independent grids Fig (2.10). An advanced phase angle is necessary to achieve a flow of active power from system 1 to system 2.

2.4.4 Transformer Tap Changer

A transformer tap is a connection point along a transformer winding that allows the number of turns to be selected. By this means, a transformer with a variable turns ratio is produced, enabling voltage regulation of the secondary side. Selection of the tap in use is made via

a tap changer mechanism Supply authorities are under obligation to their

customers to maintain
the supply voltage between certain limits. Tap changers offer variable control to keep the supply voltage within these limits.

2.4.4.1 Regulating Transformer

The transformer which changes the magnitude and phase angle at the certain point in the power system is known as the regulating transformer. It is mainly used for controlling the magnitude of bus voltage and for controlling the power flow, which is controlled by the phase angle of the transformer. They provide the small component of voltage between the line or phase voltage.

The main function of the regulating transformer is to control the magnitude of voltage and power flow of the transmission line. The regulating transformer is of two types. One is used for changing the magnitude of voltage which is called online tap changing transformer and the other is called phase shifting transformer. The regulating transformer compensates the fluctuation of voltage and current. The arrangement of the regulating transformer is shown in the Fig (2.12).

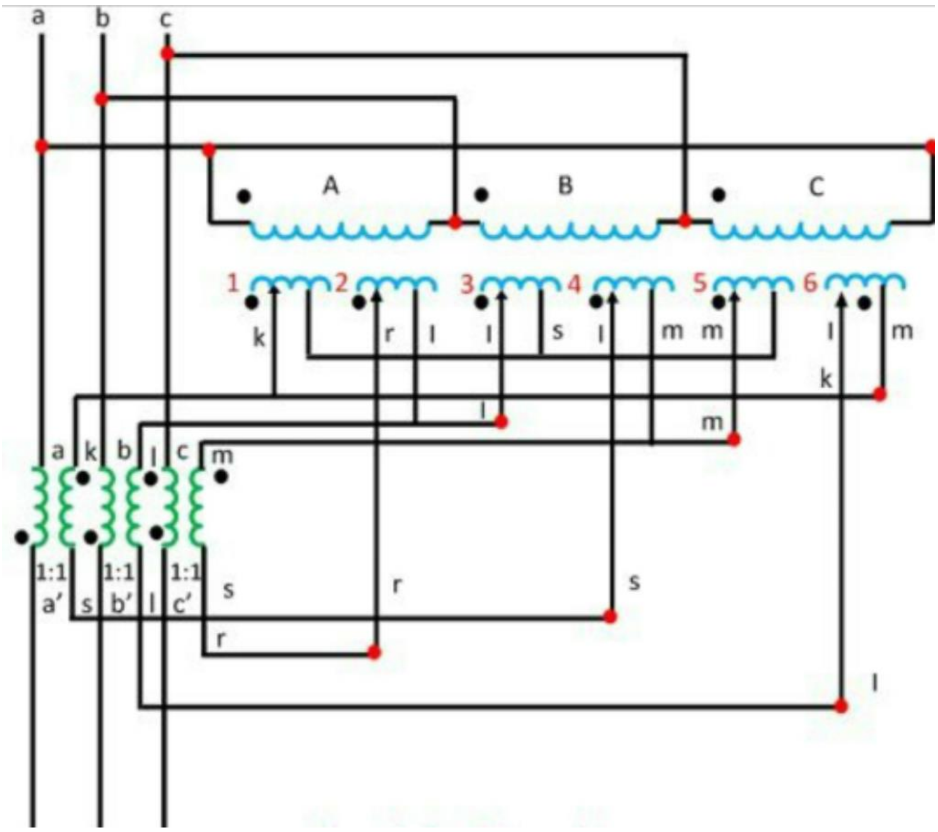


Figure 2.12: regulating transformer

The main application of power system is to reduce the circulating current and minimize the losses in the power system. The regulating transformer reduces the losses in the power system network, and it also controls the unwanted exchange of the reactive power in the system.

CHAPTER THREE

POWER TRANSFORMER TESTS

3.1 Introduction

The safety of the transformer is very important to the stability of network so it was necessary to perform tests on the transformer to calculate what can afford this transformer of all damages and malfunctions that can occur on the network.

3.2 General Classifications of Power Transformer Tests:

- Type tests
- Routine tests
- Special tests

- Type test: Type Tests are the tests that performed on single specified transformer, which is representative of others, to demonstrate that these equipments comply with specified requirements not covered by routine tests.
- Routine test: The IEC definition of routine tests is a test to which each individual transformer is subjected. Each equipment may subject to routine test at least one time.
- Special tests: The IEC definition of a special test is a test done for electrical equipments other than a type test or a routine test agreed by the manufacturer and the purchaser.
- Commissioning tests: are done at site with all the associated equipment and switchgear in place, before charging the transformer.

The details of tests under each category may be classified as figure 3.1

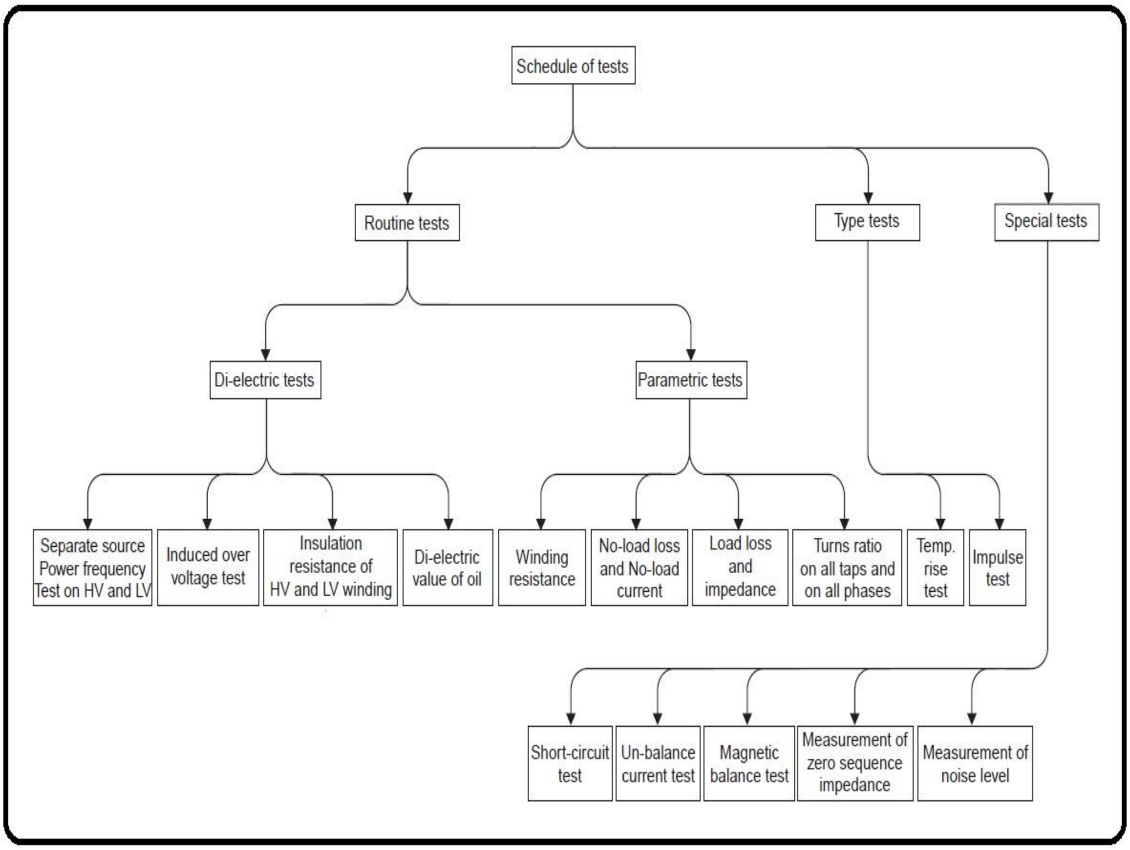


Figure 3.1: Schematic diagram indicating the schedule of tests (for Um <72.5KV)

The Routine tests are making in the factories for all transformers after the establishing it to check the performance.

3.3 Dielectric Tests:

The Purpose of Dielectric Tests: Insulation is one of the most important constituents of a transformer. Any weakness in the insulation may cause failure of transformer. To ensure the effectiveness of the insulation system of a transformer, it must confirms the dielectric tests.

IEC classifies the dielectric tests to four tests:

- Induced AC voltage test
- Separate source AC withstand voltage test

- Switching Impulse test
- Lighting Impulse test

3.3.1 Induced AC Voltage Test:

Induced voltage test is a factory routine test normally done inside factories and not in commissioning at sites.

Induced voltage test is a hard test for transformer insulation because we inducing the transformer under test to twice its rated voltage and twice of its rated frequency. Although it is a hard test for the transformer insulation, it is useful because the double voltage and double frequency checks the insulation between the windings layers by discovering the air gap between these layers.

The purpose of the test is to be sure about the quality of the insulation both between phases and between turn to turn insulation layers of the windings, tapping leads and terminals. Also to insure that the insulation terminals withstand the temporary over voltages and switching over voltages to which the transformer may be subjected during its lifetime.

Test procedures on transformers with uniformly insulated windings, all three-phase transformers shall be tested with a symmetrical three-phase supply by applying the three-phase symmetrical voltage to low voltage while the high voltage side is opened. So, we do that at the low voltage side with the help of high voltage device shown in Figure 3.2. If a transformer has a neutral, it should be earthed during the test. Only phase-to-phase tests are carried out here, Phase-to-earth tests are covered by separate source AC test according to IEC 60076-3.

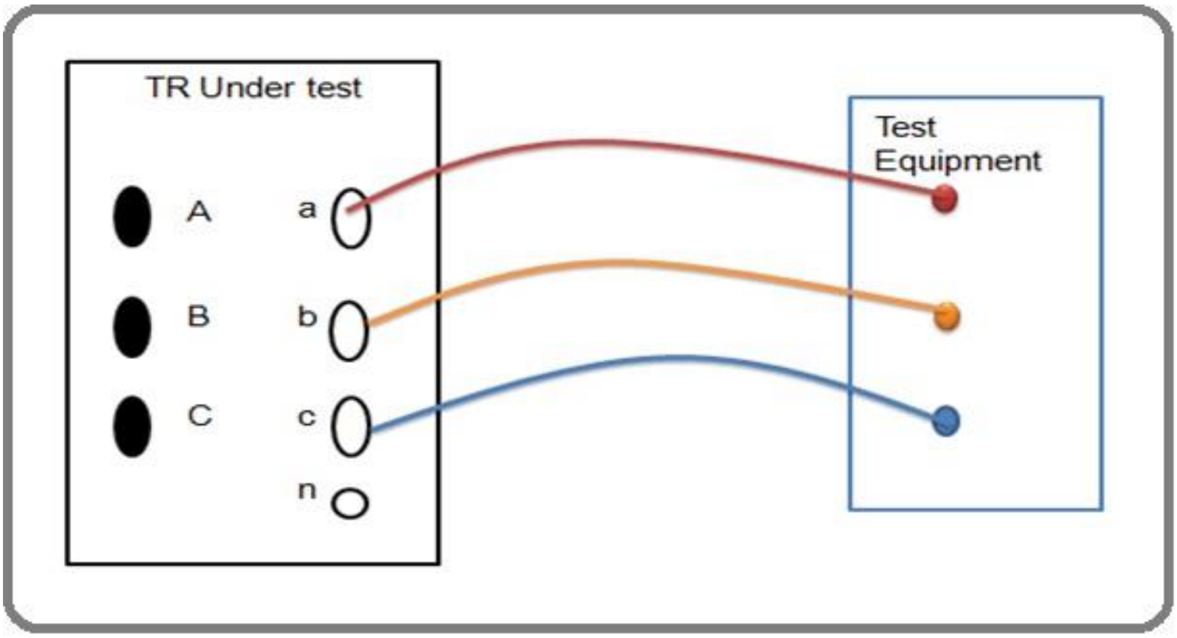


Figure 3.2: Induced withstand voltage test connection

A high frequency was used in This Test: To prevent the core from saturation due to doubling the test voltage and to discover air gaps and weak insulation between coil layers.

Test period which should not be less than 15 seconds, is calculated according to the equation below;

$$t = 120 * \frac{\text{rated frequency}}{\text{test frequency}}$$

But it is not less than 15 seconds

The test is successful if:

- No collapse of the test voltage occurs
- Apparent charge at U2 does not exceed 300 PC on all measuring terminals.
- The partial discharge behavior shows a continuing rising tendency.

3.3.2 Transformer Winding DC Resistance:

This test is required to be carried out on all transformers.

Purpose of the winding DC resistance test to measure transformer windings and terminal connections.

Winding resistance measurements can assure that the connections are made correctly and that no opens or shorts are present.

It shows whether the windings joints are in order and the windings are correctly connected.

Also, the measured resistances are needed in connection with the load loss measurement when the load losses are corrected to correspond to the reference temperature.

Transformer winding resistance test is done at:

(1) Factory test.

(2) Installation and commissioning.

(3) Periodic (Scheduled) transformer maintenance.

(4) Troubleshooting tests.

(5) Internal transformer inspections.

Test procedure: We use a Winding resistance tester from NDB company for making this test done.

This tester injects a DC current through the windings and measures the voltage drop. The instrument calculates the resistance (R) by

$R = E/I$

Two pairs of test wires are used for more accurate test values the winding resistance tester, one to supply the test current and the other to measure directly the voltage applied to the tested transformer as shown in Fig (3.3).

The challenge in winding resistance measurements is that the voltage across an inductor is defined by V=L(di/dt), where L is the inductance of the winding and (di/dt) is rate of change of current. Therefore small changes in the current, as may be caused by poor regulation, can make it impossible to measure the DC resistance.

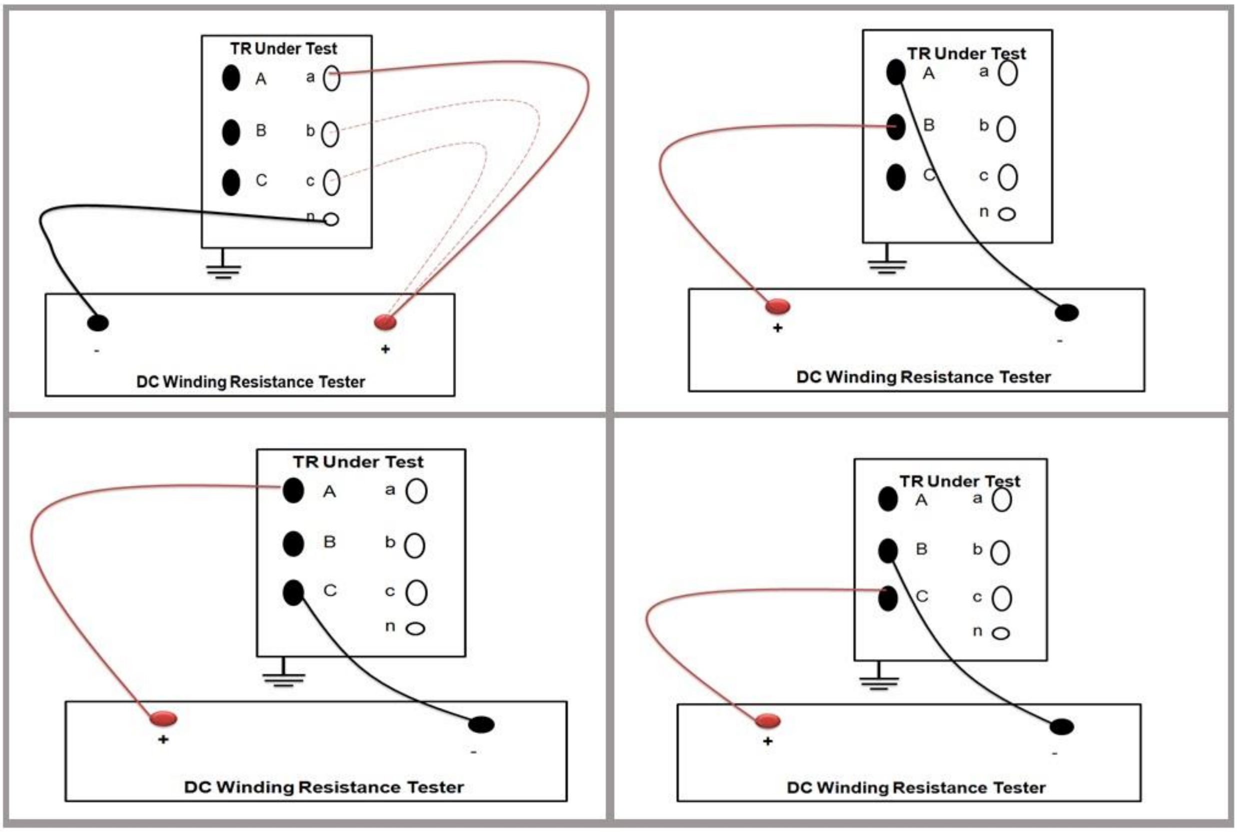


Figure 3.3: Transformer Winding Resistance Test Connection

The famous faults that to be identified by winding resistance test like:

(1) Determine if there is a loose connection, for example around the TAP or in the bushings, because bad connection makes high contact resistance.

(2) Short turns.

(3) Open turns.

(4) Defective tap changers.

These conditions will typically lead to hotspots in the winding or the affected areas and generate hot metal gases in the oil.

3.3.3 Measurement of Voltage Ratio test:

Purpose of voltage ratio test: The purpose of the measurement is to check that the deviation of the voltage ration does not exceed the limit of the transformer standard (generally 0.5%). The no-load voltage ratio between two windings of a transformer is called Turn Ratio

This test is carried out on all transformers during factory tests. Measurements are made at all tap positions and all phases.

We can summarize the Ratio measurements purposes in transformers by the following:

- ensure design specifications
- To verify the accuracy of the ratio
- To verify quality of manufacturing process
- To establish present condition and condition trend
- To determine if damage has occurred
- To detect abnormality of tap changer

The targets may indicate by the test:

- Manufacturing defect in winding

– Improper turns

– Incorrect polarity

– Incorrect winding configuration

• Insulation failure

– Damaged turn-to-turn insulation resulting in shorted windings

– Major insulation failure: inter-winding or winding-to-ground

• Defective tap-changer

– Incorrect assembly of winding connections

– High resistance connections

– Incorrect tap-changer setting

A direct relationship exists between the number of turns and the voltage ratio of the primary to the secondary, and is expressed by:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} = \frac{I_S}{I_P} \tag{3.1}$$

Test Procedure:

- Isolate the equipment, apply working grounds to all incoming and outgoing cables and disconnect all incoming and outgoing cables from the transformer bushing terminals connections.

Disconnected cables should have sufficient clearance from the switchgear terminals greater that the phase spacing distance. Use nylon rope to hold cable away from incoming and outgoing terminals as required.

- Connect the H designated three-phase test lead with the military style connector at one end to the mating connection on the test set marked with an H. Ensure that the connector’s index notch lines up properly.
- Connect the X designated three-phase test of lead military style connect or at one end to the mating connection on the test set marked with an X.

Ensure that the connector's index notch lines up properly.

- Connect the H1, H2, H3 designated test lead to the corresponding H1, H2, H3 transformer terminal / bushing. Connect the H0 test lead if H0 terminal/bushing is present.
- Connect the X1, X2, X3 designated test leads to the corresponding X1, X2,X3 transformer terminals / bushings. Connect the X0 test lead if X0 terminal/bushing is present.

Perform turns ratio measurements for all tap positions.

- Confirm that the measured ratios is within 0.5% of the calculated ratios.

TTR device measures the vector group also.

3.3.4 Determining the Connection Group:

Purpose of determining vector group of transformer is an essential property which shows the way of connecting the High voltage winding and Low voltage winding inside the transformer and the electrical phase shifting between them. It is a very important issue when paralleling two transformers together. If two transformers of different vector groups are connected in parallel then phase difference exist between the secondary of the transformers and large circulating current flows between the two transformers which is very detrimental.

Methods of testing the Transformer Vector Group :

One of the methods to detect the connection vector group is the transformer turn ratio tester (TTR), Transformer turn ratio tester measures the vector group by applying a voltage wave and receive it at the secondary side to see the shift angle.

The vector group symbol of a transformer illustrates:

(1) The way of connecting windings in each side (delta or star).

(2) The phase shift between primary and secondary windings.

The phase angle between the high voltage and the low voltage windings varies between 0^0 and 360^0.

3.3.5 No Load Losses Test (Open Circuit Test):

The test is required to be carried out on all transformers. The no-load current represents the real value of current that is required to magnetize the magnetic core. The no-load losses represent the power that is absorbed by the transformer core when rated voltage and rated frequency are applied to one winding (e.g., secondary) and the other winding (e.g., primary) is open-circuited.

The Purpose of No-Load Loss Measurements: A transformer dissipates a constant no-load loss as long as it is energized at constant voltage, 24 hours a day, for all conditions of loading. This power loss represents a cost to the user during the lifetime of the transformer. Maximum values of the no-load loss of transformers are specified and often guaranteed by the manufacturer. No-load-loss measurements are made to verify that the no load loss does not exceed the specified or guaranteed value.

Nature of the Quantity Being Measured

The no-load loss comprises three components:

1. Core loss in the core material
2. Dielectric loss in the insulation system
3. I^2R loss due to excitation current in the energized winding

The test procedure by the rated voltage is applied to the LV side while the HV side is left open circuited. That is because the low voltage supply is easy and available. We connect the three connection wires to the secondary side of the transformer, as shown in Fig, and supply the voltage on it with full rated. The device calculates the no-load current and no-load losses.

The applied voltage is measured by the voltmeter, the no-load current I0 by ammeter and no-load input power W0 by wattmeter.

Figure 3.4: Transformer under open circuit test

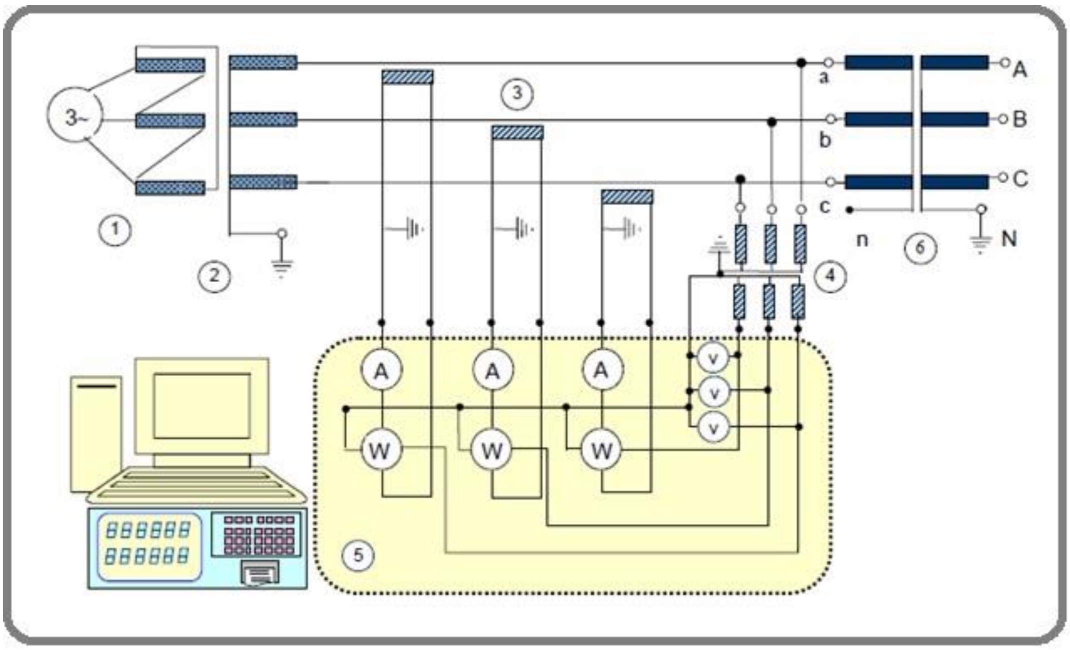


Figure 3.5: Connection diagram for measuring no-load losses

1- Power supply
2- Supply (intermediate) Transformer
3- Current Transformers
5- Power Analyser
6- Transformer under test
4- Voltage Transformers

Analysis:

The up normal asymmetry of the no load current values is an indication of a problem existing inside a transformer.

If there is a different between the measured values and nameplate values for the no load losses and no load current, 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. Core loss shall not exceed design value by more than 10% maximum excitation current:

If there is a different between the measured values and name plate values for the no-load losses and no-load current, 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 the there is an unsymmetrical structure in the core.

As per (IEC 60076-3) the tolerance for no-load current is 30% of the declared value. And the tolerance for no-load losses is 15% of the guaranteed no-load losses.

3.3.6 Short-circuit test:

The test is required to be carried out on all transformers.

The Purpose of Load Loss Measurements:

A transformer dissipates a load loss that depends upon the transformer load current. Load loss is a cost to the user during the lifetime of the transformer. Maximum values of the load loss of transformers at rated current are specified and often guaranteed by the manufacturer. Load-loss measurements are made to verify that the load loss does not exceed the specified or guaranteed value.

The main objectives of the short circuit test are to determine the equivalent resistance, reactance, impedance and full load copper loss.

The short-circuit loss and the short-circuit voltage show the performance of the transformer. These values are recorded and guaranteed to the customer and important for operational economy. The short-circuit voltage value is an important criteria especially during parallel operations of the transformers. The short-circuit loss is a data which is also used in the heat test.

From this test, we want to determine, by test and calculation, the load losses and total losses of a transformer under test. Also, to determine the impedance voltage of the transformer, expressed as a percentage of the rated primary voltage, from which may be calculated the winding currents under short circuit conditions.

Test Procedure:

The LV terminals are short-circuited by a thick conductor and the HV terminals are connected to a variable AC voltage source. The measuring instruments (e.g. wattmeters, ammeters) are connected to the HV (usually) to measure $\boldsymbol{P_{sc}}$,$\boldsymbol{V_{sc}}$, $\boldsymbol{I_{sc}}$**.** The Voltage is than applied to the HV and increased until rated current at the primary winding reaches its nominal value, this value of the voltage called short-circuit voltage V_{sc}.

Since, the applied voltage V_{sc} is quite small compared to rated voltage, so core loss due to the small applied voltage can be neglected. We apply voltage on the primary side and rise it up until the rated current on the secondary side.

Hence the wattmeter reading can be taken as equal to copper losses in transformer. The measurements shall be performed quickly so that temperature rises do not cause significant errors.

These values are referred to the HV side of transformer as because the test is conducted on HV side of the transformer.

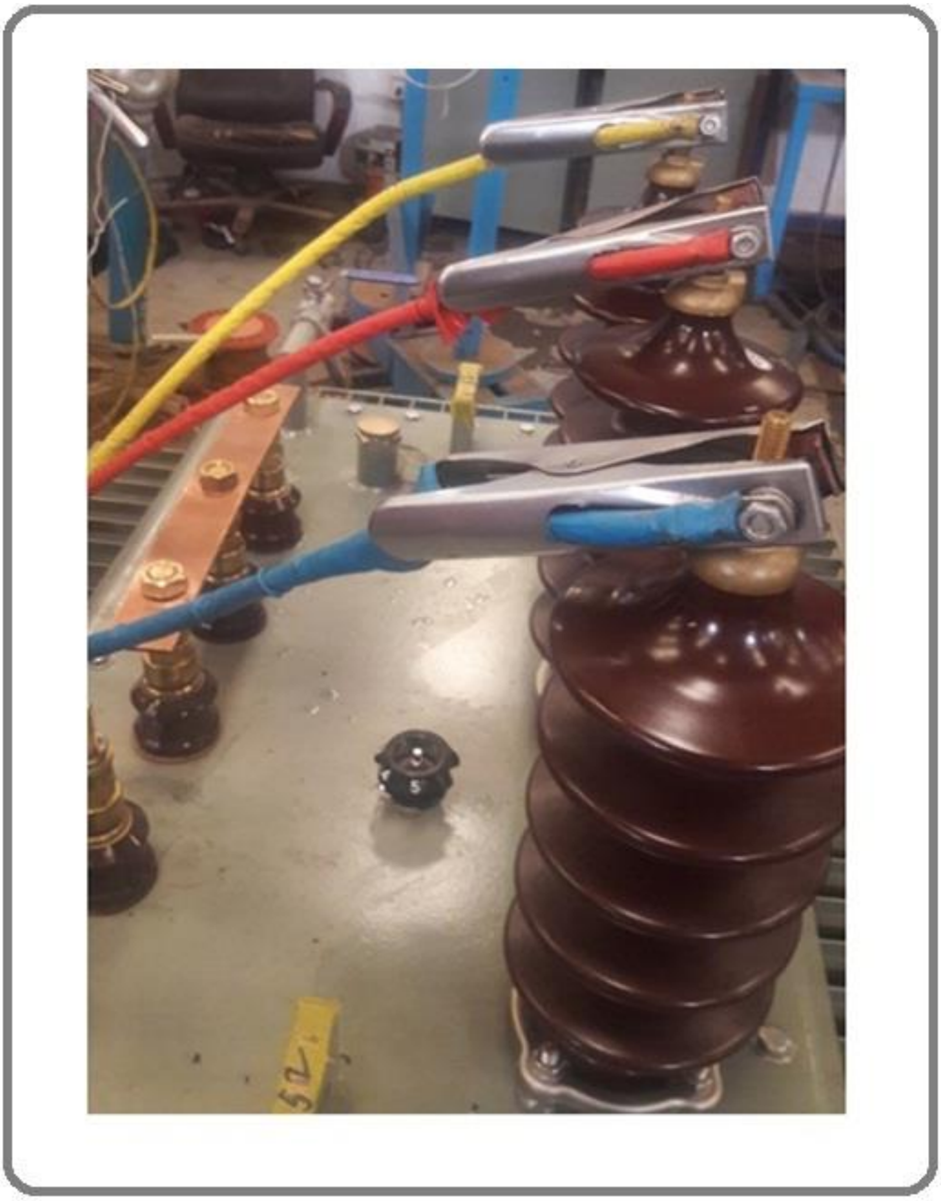


Figure 3.6: Transformer under short-circuit test

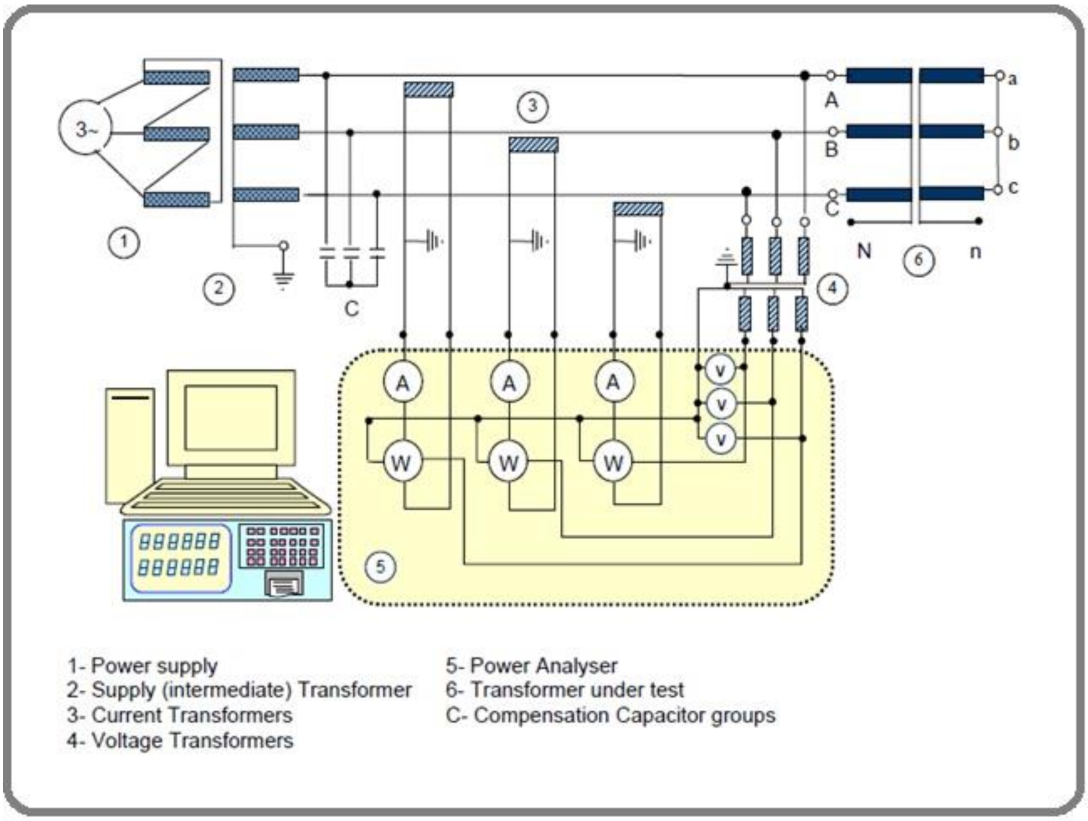


Figure 3.7: Short-circuit losses measurement connection diagram

Short-circuit impedance (per unit impedance) “Z%”:

Z% is called per unit impedance and its value nearly equal whether it is calculated at high or low side.

Z% value is written on the nameplates of the transformers and it is calculated directly from the short circuit test

Z%=(V_{sc}/V_{rated})*100

(3.2)

So, The short circuit voltage value (V_{sc}) is calculated directly from the formula :

V_{sc}=V_{rated}*Z%

(3.3)

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.

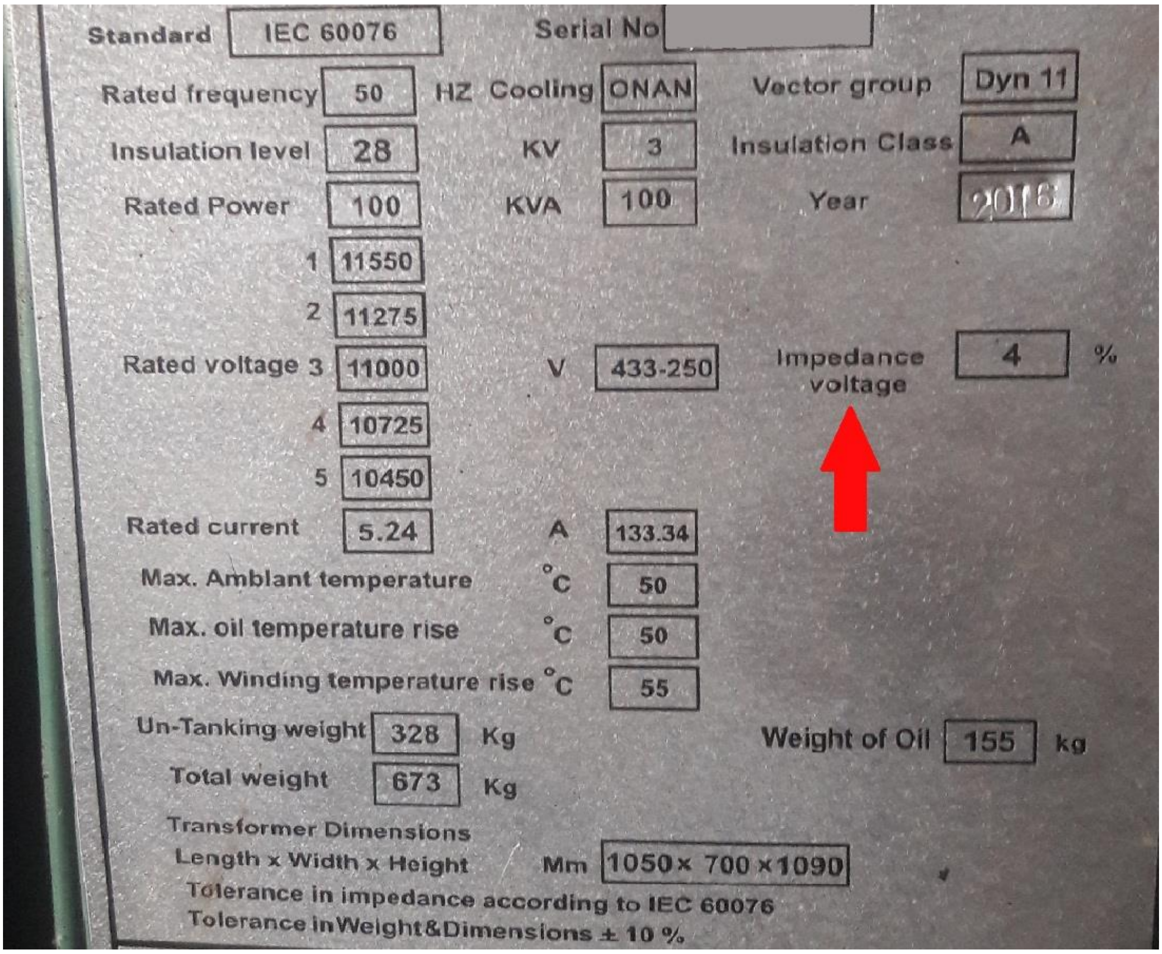


Figure 3.8: Name-plate of a transformer

The percentage impedance can also be calculated by:

$Z\% = Z_{Actual}/Z_{Base}$

(3.4)

$Z_{Base} = (KV)^2/MVA$

(3.5)

Z_{Actual} Impedance referred to one side of a transformer

(Z_{eq} For HV side or Z_{eq} for LV side)

3.3.7 Measurement Of Insulation Resistance:

In practical, no insulation is perfect (which means has infinite resistance) so some electricity does flow along the insulation or through it to ground. Such a current may only be a millionth of an ampere (one microampere) but it is the basis of insulation testing equipment.
When Meggering any electrical equipment, following current flow through the insulation:

1- Charging current (Capacitive current)
2- Dielectric absorption current
3- Resistive (leakage) current

These currents change heavily according to humidity of the insulator, foreign materials in the insulator and temperature.

Resistive (leakage) current is the actual current that decides the property of the insulation for good insulation, resistance is high, leakage current is low. For bad insulation, resistance is low, leakage current is high.

The low initial insulation resistance is partly caused by the high initial capacitance charging current. This capacitance current rapidly decreases to a negligible value (usually within 15 sec.) as the insulation becomes charged.

The low initial insulation resistance is also partly caused by the high initial dielectric absorption current. This current also decreased with time, but more gradually, requiring from 10 minutes to several hours to decay to a negligible value. However, for the purpose of insulation resistance meter tests, the change in dielectric absorption current after 10 minutes can be disregarded.

The leakage current does not change with time of voltage application, and this current is the primary factor on which insulation quality may be judged. Insulation resistance varies directly as the thickness and inversely as the area of the insulation being tested.

This test is required to be carried out on all transformers.

The measurements of insulation resistance are carried out to check the healthiness of the insulation condition.
It is not a withstand test, which means it is non-destructive.

insulation resistance test is done on equipment

- Before dispatch from a factory.
- Before putting equipment into service.
- At periodic intervals during the life of the equipment (generally once in a year).
- Before putting equipment back into service after a shutdown (maintenance or after a repair or after a prolonged shutdown).

Test Procedures:

Megger technique applies a DC voltage (less than the testes equipment rated voltage) across the insulation and measures the leakage current through the resistance is high at the time of manufacturing, but slowly reduces during the insulation life, it has to be measured at factory so to give basis for future measurements.

The sequence of tests should be as given below:

First a short circuit between the terminals of the HV side and a short circuit between the terminals of LV side are made before beginning into the test.

(a) We connect the positive terminal of Megger to the HV side and the negative terminal to the Tank (Ground) and then apply the test voltage and record the results.

(b) Connect the positive terminal of Megger to the LV side and the negative terminal to the Tank (Ground) and then apply the test voltage and record the results.

(c) At last, connect the positive terminal of Megger to the HV side, and the negative to the LV side, operate the Megger tester and record the results.

Guard terminal can be used to the terminals to eliminate surface leakage over terminal bushings.

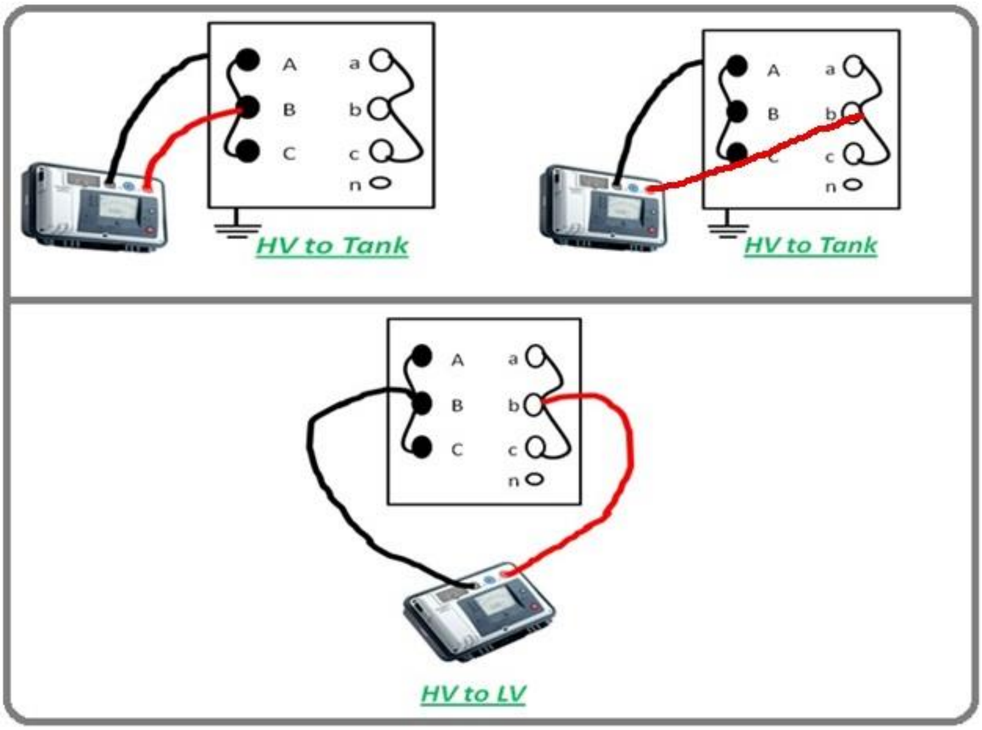


Figure 3.9: IR test connections

The insulation resistance reading shall not be taken until the test current stabilizes. The oil/air temperature should be recorded immediately prior to test because Insulation resistance varies inversely with temperature.

Shorting transformer terminals when Meggering is to:

1- To detect the insulation failures in case of open conductor.
2- To Distribute test voltage equally to the winding.
3- Shorting transformer terminals reducing the time of testing.

Factors affecting on IR value of Transformer

The IR value of transformers are influenced by

- Surface condition of the terminal bushing
- Quality of oil
- Quality of winding insulation
- Temperature of oil
- Duration of application and value of test voltage

Analysis: Insulation resistance is high at the time of manufacturing, but slowly reduces during the insulation life.

The analysis of IR test results depends on:

(1) The FAT megger values of equipment.
(2) The equipment life time.
(3) The previous Megger test results (for comparison).
(4) Difference between the results of different connections (HV-tank), (LV tank), (HV-LV) to guess what is happened inside transformer.

Polarization Index (PI) (R10/R1):

- Apply the voltage with the a MEGGER and take the IR value after one minute (R_1).
- Continue with the test voltage for 9 more minutes.
- Take the IR reading again at the end of 10^{th} minute (R_{10}).
- Calculate the polarization Index (PI) by the formula R_{10}/R_1

TABLE 3.1: Condition of Insulation Indicated by Dielectric Absorption Ratios

INSULATION CONDITION	60/30-SECOND RATIO	10/1-MINUTE RATIO (POLARIZATION INDEX)
Dangerous	—	Less than 1
Questionable	1.0 to 1.25	1.0 to 2
Good	1.4 to 1.6	2 to 4
Excellent	Above 1.6	Above 4

3.4 Tools

- **Megger s1-1068**

Insulation resistance IR quality of an electrical system degrade with time, environment condition, i.e., temperature, humidity, moisture and dust particles. It also gets impacted negatively due to the presence of electrical and mechanical stress.

so it’s become very necessary to check the IR (Insulation resistance) of equipment at a constant regular interval to avoid any measure fatal or electrical shock

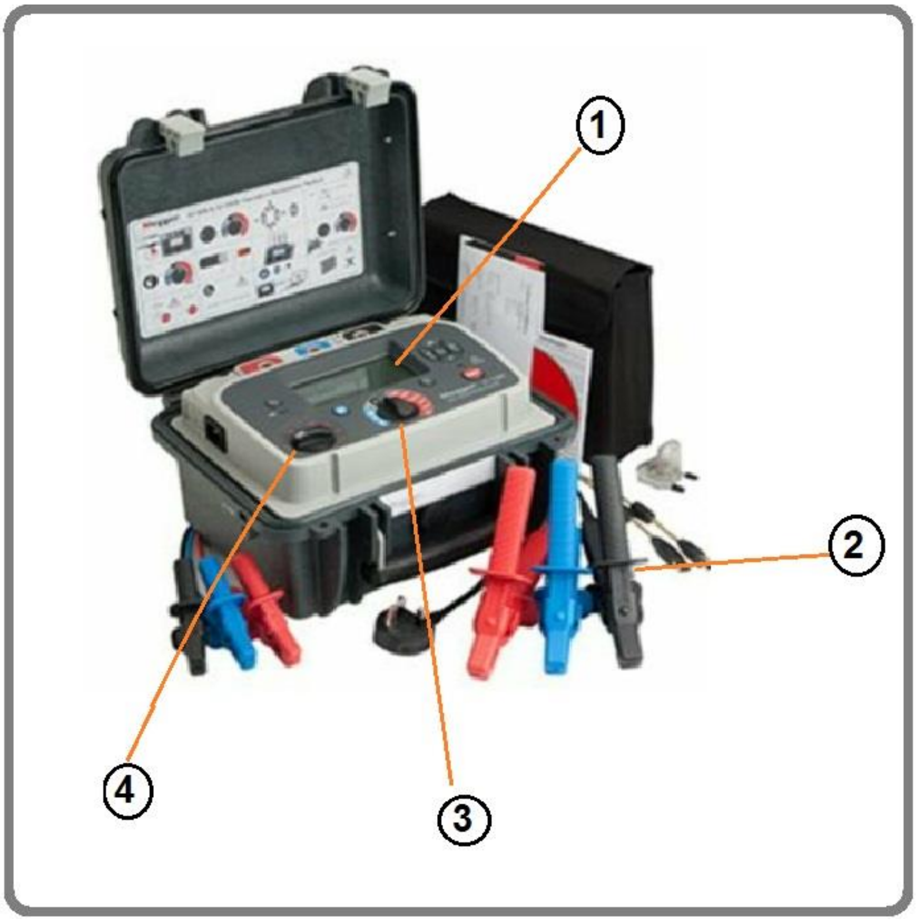


Figure 3.10: Electronic type megger

Important parts:-

1- Digital Display: - A digital display to show IR value in digital form.

2- Wire Leads: - Two nos of wire leads for connecting megger with

3- electrical external system to be tested.

4- Selection Switches: - Switches use to select electrical parameters ranges.

5- Indicators: - To indicates various parameters status i.e. On-Off. For example Power, hold, Warning, etc.

Insulation resistance IR quality of an electrical system degrade with time, environment condition, i.e., temperature, humidity, moisture and dust particles. It also gets impacted negatively due to the presence of electrical and mechanical stress, so it’s become very necessary to check the IR (Insulation resistance) of equipment at a constant regular interval to avoid any measure fatal or electrical shock.

The device enable us to measure electrical leakage in wire, results are very reliable as we shall be passing electric current through device while we are testing. The equipment basically uses for verifying the electrical insulation level of any device such as motors, cables, generators, windings, etc. This is a very popular test being carried out since very long back. Not necessary it shows us exact area of electrical puncture but shows the amount of leakage current and level of moisture within electrical equipment/winding/system.

- **Chauvin Arnoux Ca8333 Qualistar/ Power Analyser**

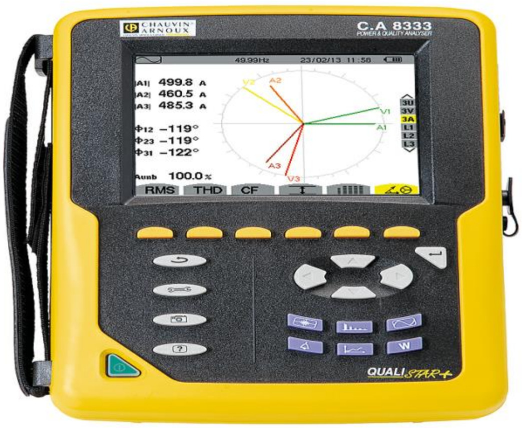


Figure 3.11: Chauvin C.A 8333

Designed for test and maintenance departments working in industrial or administrative buildings, the Qualistar+ C.A 8333 can be used to obtain a snapshot of the main features characterising the quality of the electrical network. The analyser's functions make it the ideal instrument for preventive or corrective maintenance. It can also be used to perform a complete energy survey of an installation.

The C.A 8333 captures and records all the parameters, transients, alarm s and waveforms simultaneously. When current sensors are connected to the C.A 8333, it recognizes them automatically. It also offers the possibility of mixing different types of current sensors and configuration of the ratios allow s direct reading of the measurements.

When current sensors are connected to the C.A 8333, it recognizes the automatically. It also offers the possibility of mixing different types of current sensors and configuration of the ratios allows direct reading of the measurements.

Raytech TR spy mark II (transformer ratio tester):

Figure 3.12: Raytech TR spy markII

Power transformer turns ratio test was tested by Raytech TR spy markII. Power transformer turns ratio test is an AC low voltage test which determines the ratio of the high voltage winding to all other windings at no-load. The turns ratio test is performed on all taps of every winding.

The Transformer Turns Ratio tester (TTR) is device used to measure the turns ratio between the windings (example shown below).

Voltage is applied on the H marked leads and measured of the X marked lead by the test set.

Ratio measurements are conducted on all tap positions and calculated by dividing the induced voltage reading into the applied voltage value. When ratio tests are being made on three-phase transformers, the ratio is taken on one phase at a time with a three-phase TTR until the ratio measurements of all three phases are completed.

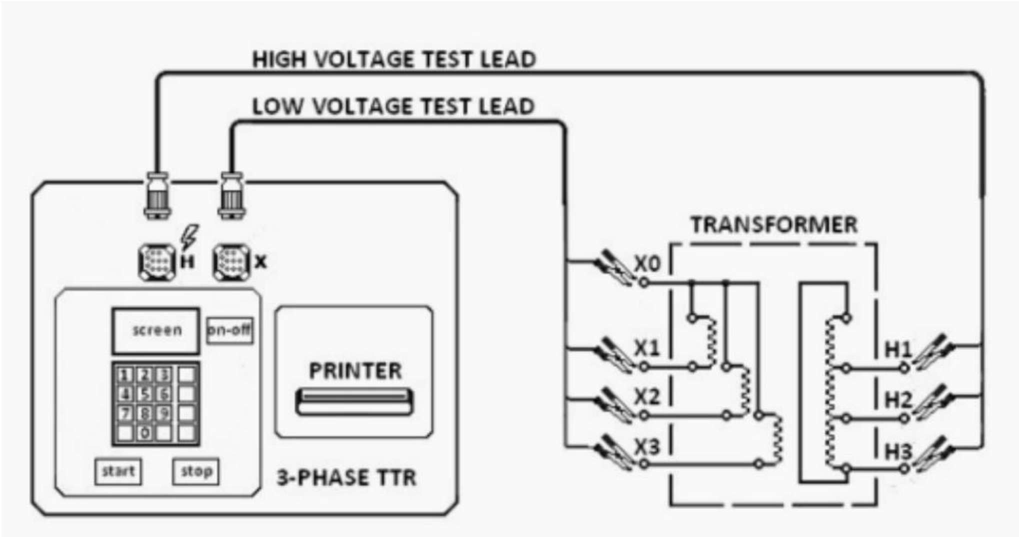


Figure 3.13: Raytech TR spy mark II connection

CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Introduction:

In this previous chapter you know how to test the transformer. This chapter is an important part of the research. In this chapter test results were calculated after practical application on a distribution transformer, and some tests were simulated by matlab Simulink.

4.2 Experimental Results

4.2.1 Sudatraf Test Report:

<table>
<tr><td colspan="2">Serial number</td><td></td><td>Phase</td><td colspan="2">3</td></tr>
<tr><td>Capacity</td><td colspan="2">200 KVA</td><td>Frequency</td><td colspan="2">50 Hz</td></tr>
<tr><td colspan="3">Voltage $\pm 2 \times 2.5\% 11000/433$ V</td><td colspan="3">Current 10.49/266.67 A</td></tr>
<tr><td colspan="6">I. Transformer ratio test</td></tr>
<tr><td>Tapping position</td><td colspan="3">High voltage</td><td colspan="2">Low voltage</td></tr>
<tr><td>1</td><td colspan="3">11550</td><td colspan="2" rowspan="5">433</td></tr>
<tr><td>2</td><td colspan="3">11275</td></tr>
<tr><td>3</td><td colspan="3">11000</td></tr>
<tr><td>4</td><td colspan="3">10725</td></tr>
<tr><td>5</td><td colspan="3">10450</td></tr>
</table>

II. voltage vector relation			
III. Connection symbol: Dyn11			
IV. Winding resistance measure			
	Primary side windings resistance		**Secondary side windings resistance**
R(AB)	11.462	r(ab)	6.82
R(BC)	12.31	r(bc)	6.83
R(CA)	11.566	r(ca)	6.88
V. Insulation test			
Induced over-voltage withstand test: low-voltage side supply 866 V 100Hz			
VI. Performance test:			
No-load current (A)	**No-load (W)**	**Load loss 75℃ (W)**	**Impedance voltage (%)**
5.5	488	3200	4.3

4.2.2 SEDC Transformer Workshop report result:

Capacity	200 KVA		**Frequency**		50 Hz
Voltage: 11KV±2×2.5% /433 V			Current: 10.5 / 266.6 A		
I. Transformation ratio test					
Tapping position	**On the-spot surrey transformer ration error**			**Primary side voltage (V)**	**Secondary side voltage (V)**
	1A1B/2a2b	**1B1C/2b2c**	**1C1A/2c2a**		
1	26.66	26.66	26.66	11550	433
2	26.02	26.02	26.02	11275	
3	25.40	25.40	25.40	11000	
4	24.75	24.75	24.75	10725	
5	24.11	24.11	24.11	10450	
II. **Voltage vector relation**					
Connection symbol: Dyn11					

III. **Windings resistance measure**						**25℃**
Tapping position	**Primary side windings resistance**			**Secondary side windings resistance**		
	1A1B	**1B1C**	**1C1A**	**2a2o**	**2b2o**	**2c2o**
1				5.420 mΩ	5.420 mΩ	5.420 mΩ
2						
3	7.599 Ω	7.580 Ω	7.583 Ω	**2a2b**	**2b2c**	**2c2a**
4				10.46 mΩ	10.46 mΩ	10.46 mΩ
5						

V. Insulation test		
Insulation resistance measure (M Ω)	At 32 ℃ with 5000 V meagger	
	High to low to Earth	60s: GΩ/ 8 GΩ
	Low to Earth	60s: 8 GΩ

VI. Performance test		
No-load Losses (W)	**Load losses (W)**	**Impedance Voltage (%)**
540	3200	3.8

Analysis: -

- From the two reports we can see that “turn ratio test” has been performed for all of the transformers taps. This is necessary to ensure the safety of the windings and the contact points of tap changer.
- The symbols like (1A, 2B, 1c, 2b), the number (1) refers to the primary side, and the number (2) refers to the secondary side, and the letter refers to the phase name. So the (1A1B) symbol means from phase (A) to phase (B) at the primary side. And the symbol (2a2o) means: from phase (a) to the neutral at the secondary side.
- For induced voltage test we see that they doubled the voltage and the frequency to 866V and 100 Hz at the secondary side (its rated voltage is 433V), that’s for the reasons mentioned at Chapter three at induced voltage section.

- At Megger test we see that the temperature was detected and mentioned at the report, that is because the winding resistance is sensitive to the temperature. Also we see that the value of this test in Gigabytes between primary and secondary and earth which means there is no electrical connection between them, and that is what we want.
- Open and short circuit tests are mentioned under the name (Performance test). No-load losses refer to the power consumed by the transformer core if there is no load connected to the secondary side. And Load losses refer to the power consumed by the windings if the transformer works with its rated power.

4.3 Simulation results

The simulation models are developed as stand-alone applications using MATLAB/Simulink which is a user-friendly programming language and easy to be learnt by new programmer. It practices the user-friendly application which the user just needs to give a desired data for processing stage and output performance result. This simulation shown in fig (4.1) was formed to detect the values extracted from Open-circuit and Short-circuit tests, you can but the values of your three-phase transformer and chose what test you want MATLAB to complete the test and calculates the results for you.

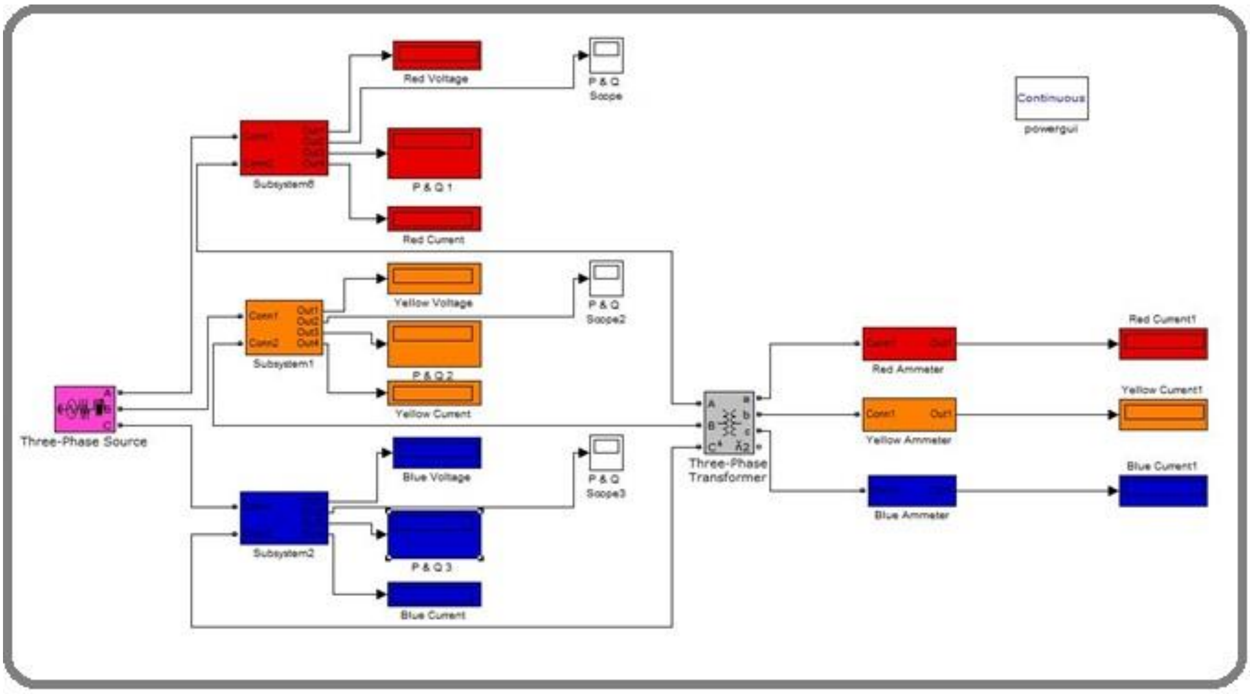
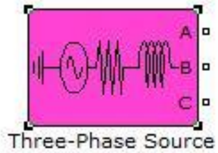
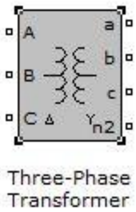
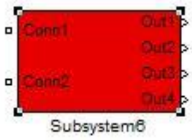
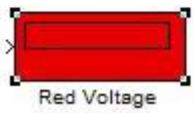
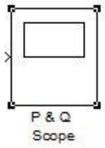


Figure 4.1: Simulation of open-circuit and short-circuit tests

Table 4.3: The Blocks Forming The Simulation And Its Function

Block pic.	Function
	simulates a three phase source for feeding the transformer
	simulates a three-phase transformer under test
	a subsystem including the current, voltage, real power and reactive power measurements
	displays the RMS phase voltage

	displays the real and reactive power value
	displays the phase current
	a block simulates the Ammeter device to calculate the secondary phase currents
	P & Q Scope block is to draw the real and reactive powers
	an important Environment block for Sim Power Systems models It is used to store the equivalent Simulink circuit that represents the state-space equations of the model.

CHAPTER FIVE
CONCLUSION & RECOMMENDATIONS

5.1 Conclusions

As a conclusion we have to alarmism once again that it is very important to check the condition of all power transformers which are exist in the grid, and make the suitable tests in the suitable cases. All of this is just a preventive action to reduce risk.

5.2 Recommendations

In order to avoid what we see from various problems in the electrical system in Sudan, this is for a number of reasons not all of them because not to detects the status of the power transformers and early detection of its situation and provide technical support for them, but we say that the above is one of the most important reasons for the weakness of the power system in Sudan.

In order to develop the field of transformer tests in Sudan, and make it highly efficient and serving those interested in the field of maintenance transformers and support them, we recommend the inclusion of a number of tests in the test regulations that will be conducted on the Power transformers, For example:

- Separate source AC withstand voltage test (beside the Induced over-voltage test)
- Measurement of dissipation factor (tanδ) and capacitance
- Lightening impulse test
- switching impulse test

- Measurement of noise level
- Temperature rise test
- Partial-discharge measurement
- Oil dielectric tests:

- Dissolved Gas Analysis (DGA).
- Rate of Humidity in the Oil.
- Power factor (tanδ) Test.
- Transformer Oil Acidity Test.
- Oil Flash Point Test

All of the above tests are important to include in the list of tests that will be conducted on power transformers in Sudan in order to increase network stability, and to ensuring that the transformers do not collapse before their lifetime, and ensure continuity of the electrical grid feed.

The above is related to the technical aspect, the next is related to the human aspect as it would not be useful to include these tests without the presence of highly qualified people. Therefore, we recommend the establishment of a partnership between us and a global Transformer company to train a number of engineers and technicians annually in the right way to deal with the modern testing devices and measurements equipments and the correct way to perform various tests.

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