CHAPTER THREE

COMMISSIONING TEST FOR POWER TRANSFORMER, CIRCUIT BREAKER, BUS BAR AND EARTHING SYSTEM

3.1 Introduction

In this chapter the commissioning test for power transformer, circuit breaker, bus bar and earthing system are discussed. Power transformers are key components in power networks. Their availability and longevity have a major impact on grid reliability and profitability. Circuit breakers are important devices that break off current when a fault occurs. If they become faulty due to corrosion or mechanical problems, the electrical system can be damaged when an overload occurs. Bus bar as a junction points at all voltage levels, carrying energy in electric power schemes and power substation. buses are critical to scheme topology. Exposure to high-fault currents can lead to damage of the buses, and hence the substation. In a high voltage substation it is necessary to have a low impedance path to ground for protecting people and equipment. For all the above requirements it is essential to test all the mentioned equipment before put them into service to ensure that they are reliable and safe to transfer power and to meet the substation specifications.

3.2 Commissioning Test for power transformer

Commissioning tests are combination of special, routine and type tests and must be done at the site after installations and before putting the transformer in service. They can be divided into dielectric tests, transformer oil tests, impulse voltage test, transformer parameters calculations tests and transformer special or type tests.

3.2.1 Dielectric Test

The dielectric tests are done to check the insulation which is very important in transformer theory, and immediately the transformer will be lost when there is an insulation problem. Sixty percent 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. They can be performed by Megger, dielectric loss angle and partial discharge tests.

a. Megger Test

This test is called Megger test because it is done by the Megger device. The expected insulation resistance in new transformers may reach the scale of giga ohm. The transformer to be tested is put out of service and earth the tank, discharge any electrostatic in the transformer by a discharging rod or by using a Megger equipped with automatic discharge, a short is made in the terminals of high and low voltage independently without earthing and measure the resistance between high voltage and low voltage. Make the above step with earthing one side as shown in figure (3.1).

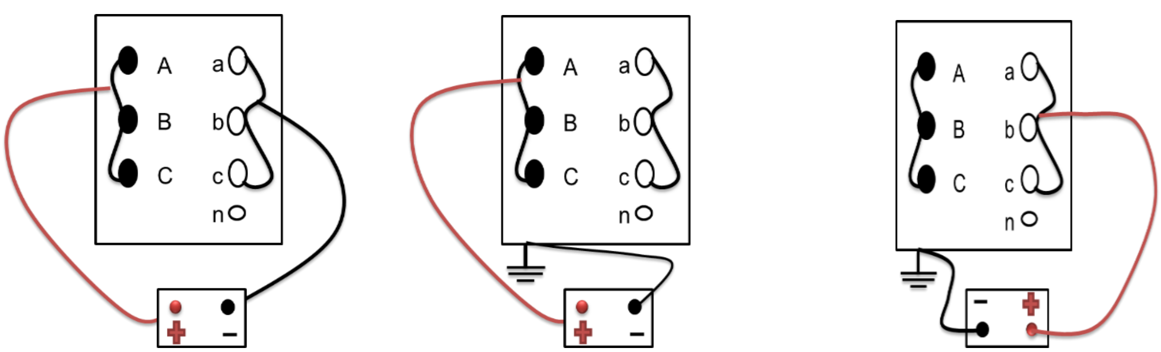

Figure 3.1 shows the connection of Megger test for transformer

First the test is done for 15 second and get the value of resistance, after that the test is done for 60 seconds and register the value of resistance, finally what is called the absorption factor is get by this formula:

Absorption factor = R60/R15 (3.1)

Where:

R15 is the resistance measured at 15 seconds

R60 is the resistance measured at 60 seconds

Another test is done for 1 minute and get the value of resistance, after that the test is done for 10 minutes and register the value of resistance. Finally what is called the polarization index is get by this formula:

Polarization index factor = R10/R1 (3.2)

Where:

R1 is the resistance measured at 1 minute

R10 is the resistance measured at 10 minutes

The insulation is good if the polarization index is above 2.0 and the absorption factor is between 1.25 and 2.5.

b. Dielectric Loss Angle (tan$^{\delta}$)

Connection diagram of the transformer under this test looks like the connection of the Megger test as shown in Figure (3.2). This test is done by special instrument measures the value and the angle of the currents that follow through the insulation during the test.

Tan delta tester also measures a capacitance value (C) in the range of Pico farad or nano farad according to transformer size, which also can give an indication of insulation state.

The value of $\tan^{\delta}$ is measured between 0 - 0.08 and of course the lower the value of $\tan^{\delta}$ the better the insulation. Some times the value of tan delta test is expressed by a percentage form and the range will be 0% - 8%.

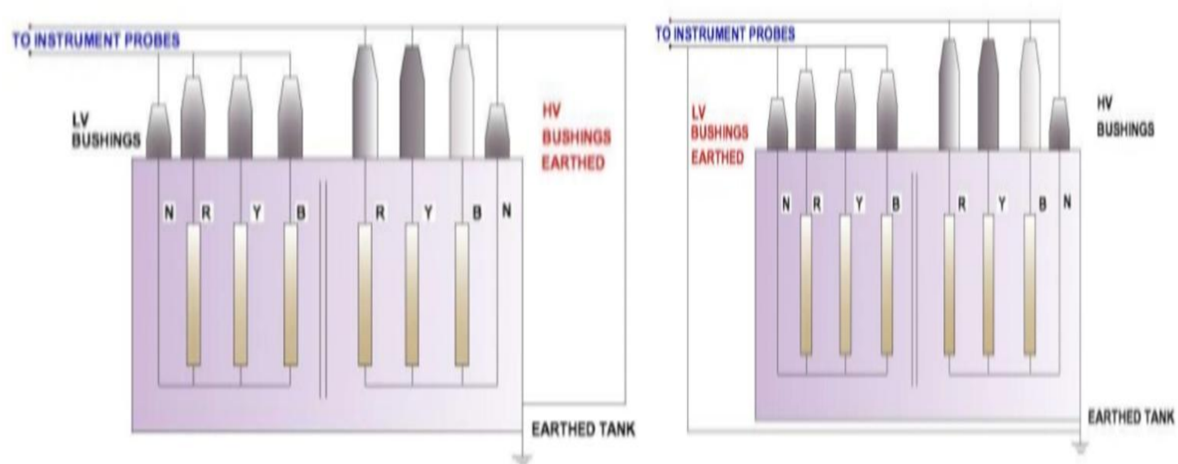

Figure 3.2 shows the connection diagram for direct loss angle

c. 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. Partial discharge will diagnose insulation faults before they happen and help us to take appropriate decision at right time.

The main reasons for the partial discharge in transformer are the moisture in the liquid insulation and cavity in the hard insulation because of manufacturing problems. The Partial discharge is a modern test used in early detecting insulation deteriorations problems, and it is used in much other electrical equipment like switchgear and cables. When partial discharge is initiated high frequency transient current pulses will appear and persist for nanoseconds to a microsecond then disappear and reappear repeatedly as the voltage sine wave goes through the zero crossing.

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 by oil test because the sample maybe took from a place which there is no partial discharge. The above problem is solved by analysis of the gas collecting inside the bucholz-relay chamber can give an indicator of partial discharge in the oil.

There are two ways for measuring the level of the partial discharge, the electric method and the sound method.

1. Electric Method

The voltage across the tested transformer is increased gradually till the rated value and see if the partial discharge starts to happen. The value of the voltage in which the partial discharge starts is called the inception voltage. After that degrading the voltage is started until the partial discharge stops and this point is called the extinction voltage. Now if the value of the extinction voltage is low than the operating voltage, this means that the partial discharge will not stop when the transformer is supplied 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.

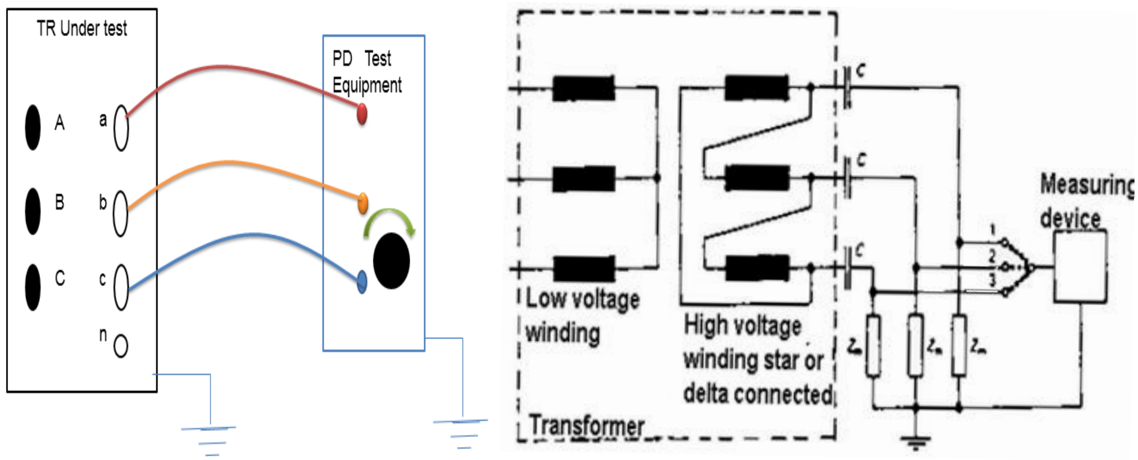

Figure 3.3 shows the electric method for measuring the level of the partial discharge

2. Using Sound Method

special sensors are put in the surface of the transformer at the place the partial discharge is suspected to be existing, these sensors send signals to electric analyzer to make filtering for the noise comes from the place of the sensor to determine the partial discharge. Waveforms are captured from the sensors with the testing unit and software is used to examine the waveform shapes.

3.2.2 Transformer Oil Test

Functions of oil in transformer acts as insulation between phases and between phases-to-ground, coolant medium to transfer heat from the coils to the radiators or surface of a transformer and arc quenching medium. A sample should be taken in a clean, dry glass container. The size of the container should be at least three times the size of the test cell (A container of approximately 1 liter is sufficient). During sampling rinse the glass container with little quantity of oil and drain, the container is filled with oil until the container over flows, free air space inside the container should not exist, and air bubbles are not allowed inside the container. Sampled container should be closed with cork or any other nonreactive material. In case the oil is to be transported to a larger distances, ensure that oil is stored in a clean and dry place and transported with utmost care. Before filling the oil in the test cell, gently agitate the container without creating air bubbles. Rinse the walls of the test cells with little of oil and drain it. Ensure that the electrodes of the test cell are clean. The oil sample is filled until overflow into the test cell without formation of air bubbles. The test should not be started for at least for 5 minutes after filling the test sample. The test includes oil dielectric strength test, dissolved gas analysis (DGA) and the rate of humidity in the oil and oil acidity tests

a. Oil Dielectric Strength Test

In this test an oil sample is taken and checked in the oil test device shown in figure (3.4), at the start the voltage is increased gradually (2-5KV/second) till the spark appears, the test is done about 5 times and take the average. Compare the results with the factory test.

Figure 3.4 shows the oil dielectric test set

b. Dissolved Gas Analysis (DGA)

Dissolved gas analysis 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 and existence of partial discharge (PD) .This test is done in a special chemical laboratory. The normal operating temperature may affect the transformer oil causing Carbon dioxide (CO_2) to appear in the oil. Also there will be some gases in the oil without presence of any faults gases present due to some processes in the factory like, drying the windings in the oven and putting the coils inside the tank, some maintenance processes like copper welding inside the tank during changing a damaged coil and also due to oil filtering. 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. These are the probable reasons for presence of every gas in the dissolved gas analysis test as shown in table (3.1).

Table 3.1**:** shows probable reasons for presence of every gas in the dissolved gas analysis test

Types of gas	Caused by
Carbon monoxide, co Carbon dioxide, co2	Ageing
Hydrogen , h2 Acetylene, c2h2	Electric arcs
Ethane, c2h6 Ethane, c2h4 Propane, c3h6	Local overheating
Hydrogen, h2 Methane, ch4	Corona

c. The Rate of Humidity in the Oil and Oil Acidity Tests

A sample of the oil in the transformer is taken and it is tested chemically to find the water content (humidity) and acidity. 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. An acid formed during oxidation of the oil due to humidity and affects oil's dielectric properties and also affects circulation of oil inside the transformer. Acids deteriorate cellulose paper used in the insulation.

3.2.3 Impulse Voltage Test

In this test extra high voltage is supplied for a very little time to simulate the case of high transient due to lightning or normal 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 a surge generator is used consists of capacitors charged from low voltage supply. This test is done to simulate two cases happen for a transformer in service:

1. The high transient waves which produces due to normal switching of circuit breakers, capacitor and reactors that can affect the transformers, and the wave form which is produced from the surge generator to simulate this case is as shown in figure(3.5).

2. Impulse voltage test is done to simulate the travelling waves that produced during thunder and lightning storm, and the wave form for this test is as below in figure (3.6)

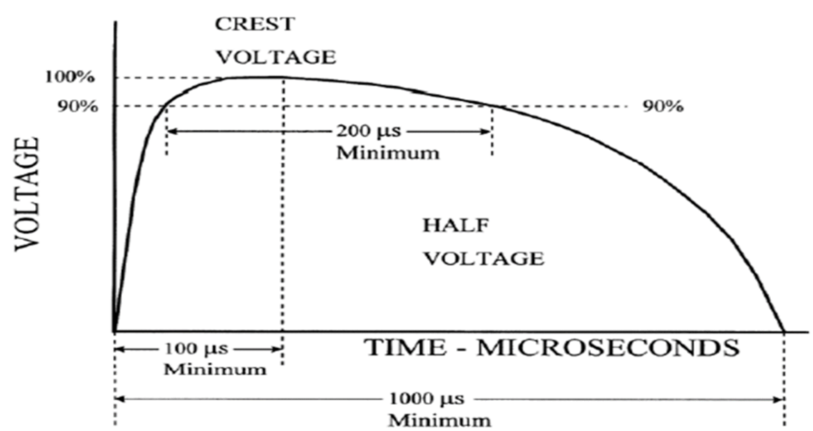

Figure 3.5 shows the wave form which is produced from the surge generator

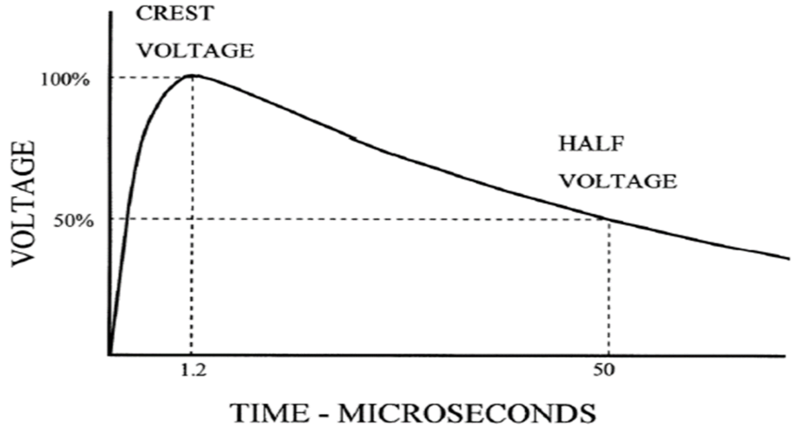

Figure 3.6 shows the travelling waves that produced during thunder and lightning storm

3.2.4 Transformer Parameters Calculations Tests

Transformer parameters calculations tests include transformer turn ratio test transformer, winding DC resistance, open circuit test (no load losses test) and short circuit test.

a. Transformer Turn Ratio Test (TTR)

This test is done to be sure that the transformer has not an internal fault before opening the tank, because the procedure of opening the tank takes a lot of time and effort. It 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 tab. It is preferable to put the voltage of the test in the height voltage side to be sure that the voltage in the other side will not exceed the measurable values as shown in figure (3.7). This method is easy to check transformer ratio when we have no ratio tester and it just need 3ϕ supply plus avometer set. Line to line and line to neutral values should be measured and see if it is balance and same as declared ratio in the name plate. 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. The set gives the ratio of each phase and also the ratio error.

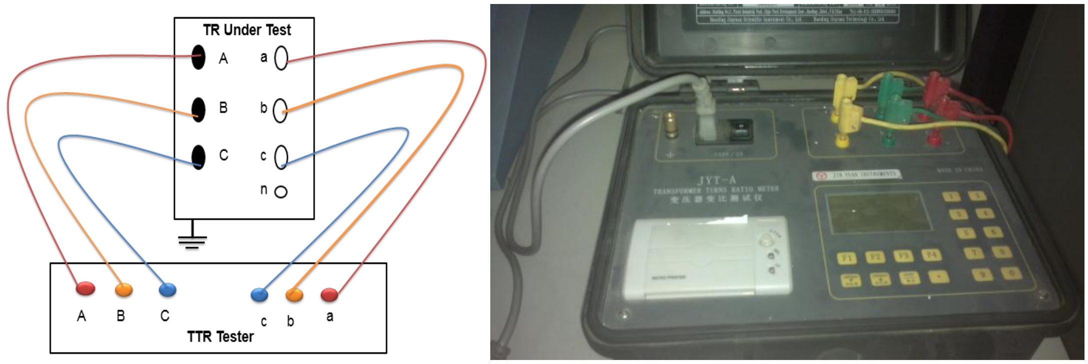

Figure 3.7 shows test set and connection circuit for turn ratio test

Normally the error in the transformer turn ratio test must not exceed 0.5% as in the formula below:

TTR acceptable Error = Measured Value – Rated Value (3.3)

b. Transformer Winding DC Resistance

In this test the resistance for each winding should be measured per ohm and see if it is the same as in the transformer name plate. Just DC supply is connected to the tested winding and the resistance is measured using (V/I) formula. This test is very useful to determine if there is a loose connection, for example around the tab or in the bushings, because bad connection makes high contact resistance. This test also shows whether the windings joints are in order and the windings are correctly connected, so transformer winding resistance test is done in defect analysis and in identification and tests before maintenance to detect internal faults. The transformer winding resistance test can be done by any sensitive ohmmeter, but recently there is a modern instrument to do the test accurately as shown in figure (3.8).

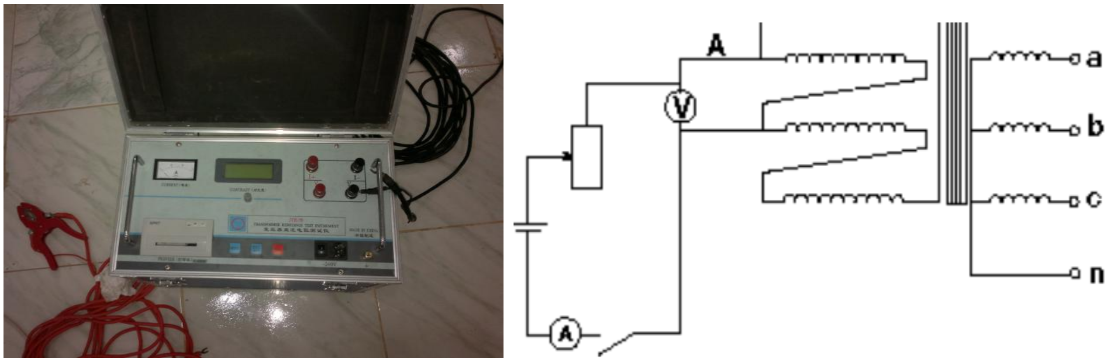

Figure 3.8 shows test set and connection circuit for winding resistance test

For more accurate test values the winding resistance tester uses two pairs of test wires, one to supply the test current and the other to measure directly the voltage applied to the tested transformer. The measuring current value should be high enough to obtain a correct and precise measurement, and small enough not to change the winding temperature. In practice the value of measuring current:

$$1.2*I_{\circ} > \text{Measuring current} > 0.1*IN \qquad (3.4)$$

$I_{\circ}$ = no load current.

IN = rated current.

Famous faults that to be identified by winding resistance test are poor connections, short turns, open turns and defective tap changers.

c. Open Circuit Test

In this test one side of the transformer is connected to a supply with its rated voltage value and the other is let open as shown in figure (3.9). The Wattmeter measures the no load losses or (core losses), while the ammeter measures the no load current ($I_{\circ}$) which consist of two components.

Iw = active or working or iron loss component.

Iɥ = magnetizing component

Normally in this test the low side is supplied and the high voltage side is let open because the low voltage supply is easy and available. This test helps to find the value of the no load losses because I_o 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. 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.

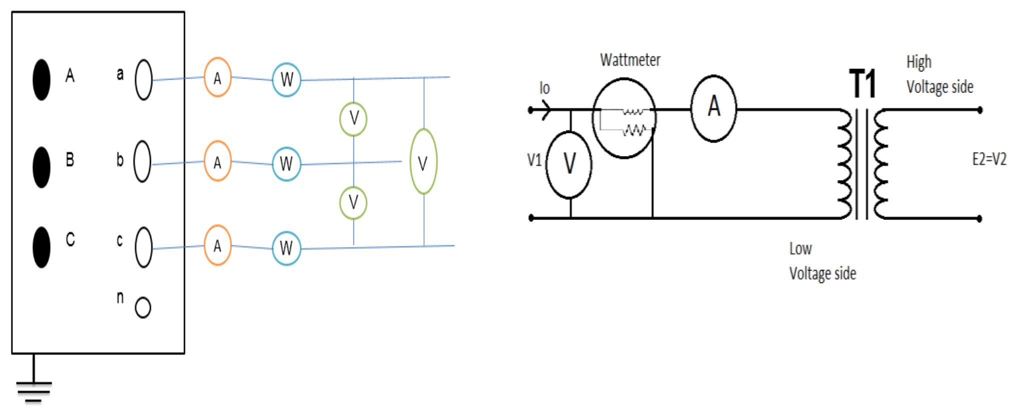

Figure 3.9 shows connection for open circuit test

4. Short Circuit Test

In the short circuit test the wattmeter measures the full load losses, while the voltmeter measures the short circuit voltage (Vsc) needed to circulate the rated current at both sides of the transformer when one side is shorted .The Ammeter measures the rated current of the transformer if the voltage applied is the short circuit voltage Vsc. The short circuit voltage value (Vsc) is calculated directly from the formula:

$$Vsc = \text{Rated Voltage} * Z\% \tag{3.5}$$

Z% is called per unit impedance because its value nearly equal whether it is calculated at high or low side. The Z% value is written on the nameplates of the transformers, and it is calculated directly from the 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. An important point to mention is that you can use any available voltage to do the short circuit test for calculating Z%. As the shorted side load is zero impedance, a very small value of voltage may circulate the rated current in the other side and this voltage is named impedance voltage or short circuit voltage (Vsc).In addition to identifying the parameters mentioned above, short circuit test is helpful to discover any deformation in the winding due to shipping and transportation, internal short circuit, wrong connection for the winding after maintenance.

Each manufacture has what is called declare value of his transformer losses. The tolerances of transformer losses are as below:

Total Losses = +10% of the total declared losses (3.6)

Component losses = +15% of each component loss (3.7)

3.2.5 Transformer Polarity Test

The Importance of polarity an understanding of polarity is essential to correctly construct three-phase transformer banks and to properly parallel single or three-phase transformers with existing electrical systems. Knowledge of polarity is also required to connect potential and current transformers to power metering devices and protective relays. The following pictures illustrate the real meaning of the polarity term in general.

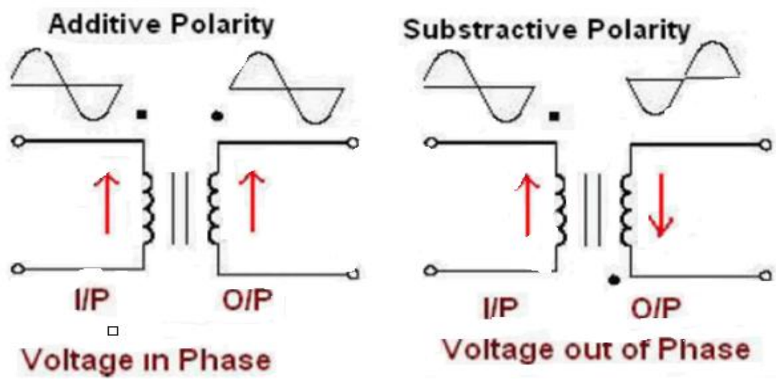

Figure 3.10 shows the polarity in transformers.

There are two common methods for testing the polarity of transformers:

a. Polarity Test by DC Flashing Method

The DC flashing test uses 1.5-V to 6-V dry-cell batteries and a DC voltmeter with 1.5V to 10V scales. Meter deflection directions will be more discernible if the meter's mechanical zero position can be adjusted in an upscale direction to allow deflecting in both directions. The test is conducted by connecting the voltmeter to the transformer low-voltage terminals and connecting the battery intermittently to the high-voltage winding as shown in figure (3.11). Transformer polarity is subtractive if the meter shows an upscale kick when test connection SW is closed and a downscale kick when test connection SW is opened. Transformer polarity would be additive if the meter shows a downscale kick when test connection SW is closed and upscale kick when test connection SW is opened.

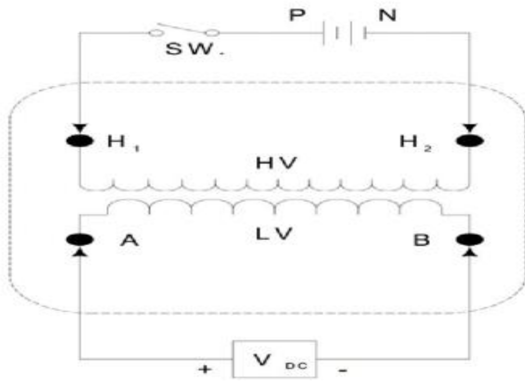

Figure 3.11 Shows DC flashing method circuit connection

b. Polarity Test by the Ac Method

If the AC method is used to determine winding polarity, a voltage may be applied to the high voltage winding (H1 to H2) and the two adjacent bushings of the high and low voltage windings (H2 to B) are jumper together as shown in figure (3.12). For the voltmeter when

$$V_{pol} = V_h - V_x \quad (3.8)$$

Where:

Vpol is the voltage across high voltage and low voltage side.

Vh is the voltage across high voltage side.

Vx is the voltage across low voltage side.

The transformer functions with subtractive polarity. Conversely when:

$$V_{pol} = V_h + V_x \quad (3.9)$$

The transformer has additive polarity.

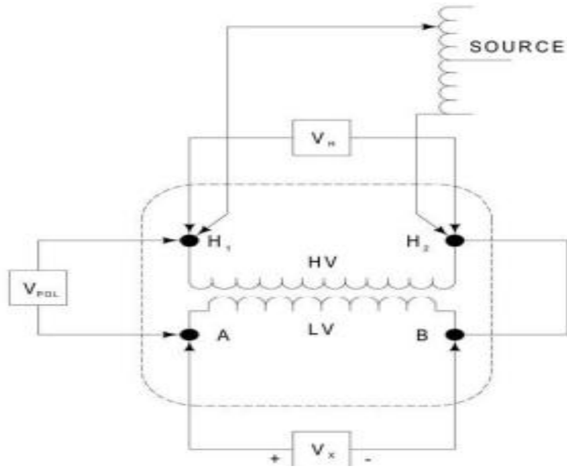

Figure 3.12 shows the polarity AC method circuit connection

3.2.6 Transformer Vector Group Test

The vector group symbol of a transformer illustrates the way of connecting windings in each side delta or star and the phase shift between primary and secondary windings.

For example The vector group of the power transformers as general is Dy11 which is mean that the primary windings is connected delta while the secondary windings is connected star, The number 11 means that the vector shift between primary windings and secondary windings is 30˚. The vector group of the power transformers as general is Dy5 which is mean that the primary windings is connected delta while the secondary windings is connected star, The number 5 means that the vector shift between primary windings and secondary windings is 150˚(5*30˚). Figure (3.13) shows different vector groups of transformers. The testing of the vector group for a transformer is achieved by supplying a voltage across one side and measure the voltage and angle at the other side for each phase, if two transformers are paralleled with different vector group together a fault will occurred because there will be a phase shift between each typical phases.

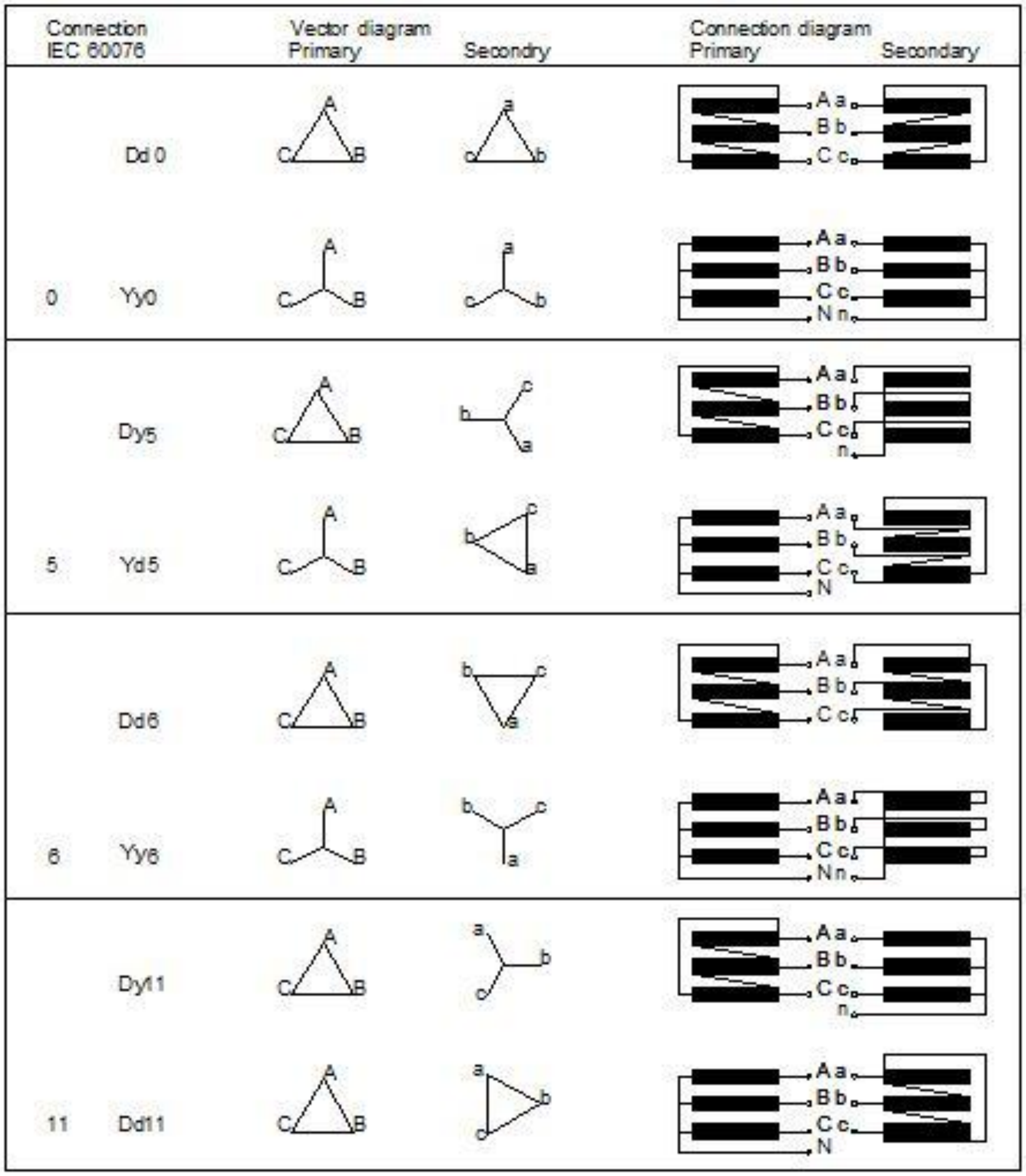

Figure 3.13 shows the vector group of transformers

3.2.7 Noise level Test

When transformer is energized, noise is generated due to vibration in the magnetic circuit and this noise can be minimized by rigidly binding and clamping the core laminations, but the noise cannot be made zero. Sometimes the transformer generates more noise because of over excitation or higher operating flux density. Noise level is expressed in decibel (dB).The noise level of large sized power transformer should be restricted to an acceptable value of approximately 60 to 80 dB .Transformer noise level test is done when the surrounding of the transformer is reasonably calm and quiet. The measurements are done by a battery operated meter known as (Noise Level Meter).The transformer noise level test steps are record the noise level of the surrounding without energizing the transformer and take it as reference, the transformer is energized at its full rated voltage without load and the noise level shall be recorded at a distance approximately one meter away from the transformer, the difference {step (2) – step (1)} equal the noise level of the transformer under test.

3.2.8 Temperature Rise Test

If the transformer is well designed, it must operate with its full rated power without any significant temperature increase. Temperature rise test is done to be sure about the cooling system design of the transformer. In this test the transformer is loaded with its full rated power and the temperature is measured every hour till the top oil temperature rise does not vary more than 1˚C per hour during four consecutive hourly readings. Depending on the choice of the manufacturer loading is achieved by a direct loading method connect the transformer under test to a suitable load such that rated currents flow in both windings and short circuit method this method is commonly employed by most of the manufacturers, and here the short circuit test is just done for the transformer under test.

3.3 Commissioning Test for Circuit Breaker

Circuit breakers tend to gather dirt, moisture, and contaminants while in service. Their insulation systems can also weaken due to the heat created by arc interruption. Circuit breakers used in hostile environments can be exposed to various corrosive contaminants, such as hydrogen sulfide ($H2S$ in oil and gas well equipment) or chlorine (water treatment plants). These aggressive chemicals corrode and damage not only the insulation of the breaker, but also its metal components. Circuit breaker is used to control the power flow from supply to the load. Circuit breakers are classified based on the insulating medium of the interrupter. Types of circuit breakers are vacuum, air and $SF6$. Circuit breaker main components are the main contacts with a technique to extinct the spark, the trip coil, close coil which release the mechanism to operate the circuit breaker and a DC Motor to charge the spring of the mechanism. Commissioning test of high voltage circuit breaker will be discussed to ensure that they are safe to use. Tests will include insulation resistance, high voltage, timing and contact resistance.

3.3.1 Insulation Resistance Test

This test is carried out to check the insulation level between the phases and between phases and the earth; also to check the insulation level of the insulating medium. The test is carried out in open position to check the insulation level of the insulating medium, then in close position between the phases and between phases and the earth.

The test voltage shall be applied for 10minutes and readings are taken every 15sec for the first minute and every minute for 10 minutes. Dielectric absorption factor, polarization index could be calculated as below:

Dielectric absorption factor = 60sec reading/ 15sec reading. (3.10)

Polarization index = 10min reading / 1min reading. (3.11)

For good insulation polarization index should be above 2.0 and absorption factor should lie between 1.25 and 2.5.

3.3.2 Timing Test

Opening and closing time of a circuit breaker are measured during this test. It's important to note that opening time is more important because in case of a current fault the circuit breaker must trip to prevent damage of the load. To measure the circuit breaker closing and opening a circuit breaker timing tester and a circuit breaker analyzer equipment is used as shown in figure (3.14). The tester generates open and close commands to the circuit breaker and by means of feedback from the circuit breaker poles it measures the time between the command signal and feedback signal. Compare the results with the factory test values. Usually a healthy circuit breaker opening and closing times are between 40 to70 milliseconds.

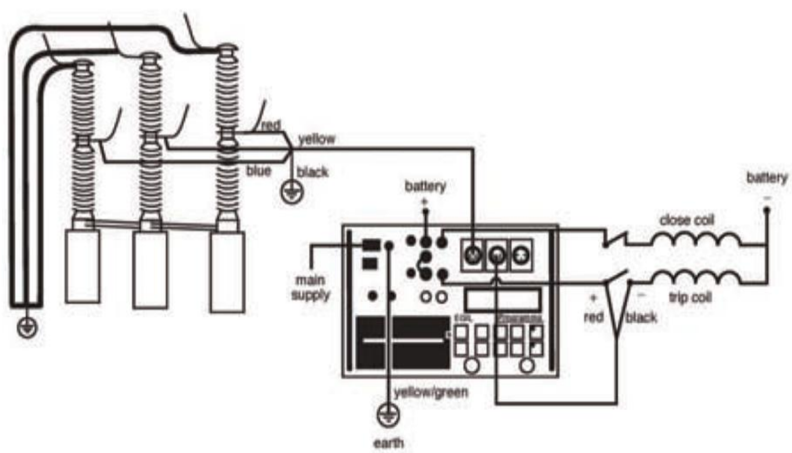

Figure 3.14 shows the circuit breaker timing test

3.3.3 Contact Resistance Test

During the circuit breaker is closed the current flows to the load so the contact points of the poles have a specific resistance (ideal case zero), this resistance causes heat and deterioration of the circuit breaker life time. In this test a micro-ohmmeter is used. The micro ohmmeter injects current and voltage to get the resistance from ohm law as shown in figure (3.15). The values of the contact resistance in this test are not exceeding (50 – 60 micro ohms).

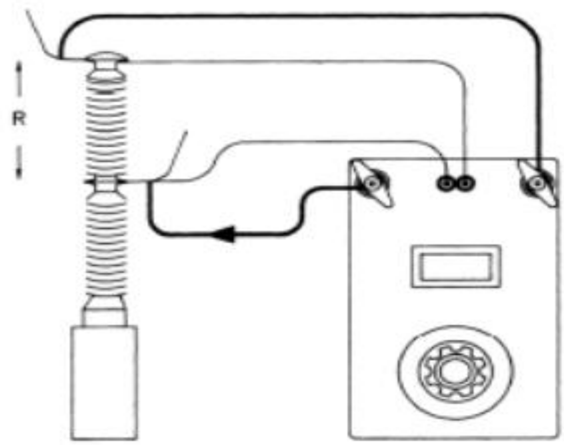

Figure 3.15 shows the circuit breaker contact resistance

3.3.4 High Voltage Test

Before putting any circuit breaker in service you need to be sure about its general insulation status. In this test single phase AC voltage is applied to each pole of the circuit breaker using single phase high voltage tester equipment. This test is done after contact resistance test to discover minor problem in the insulation like micro cracks in porcelain or small partial discharge (PD) somewhere. Before starting a high voltage test for the circuit breakers earthing switches is put in off position. Circuit breaker is put in close position. Injecting 80% of the testing voltage used in the factory to every phase is done when the two other phases are shortened and connected to earth.

3.4 Commissioning Test for Bus Bar

A bus bar is a thick strip of copper or aluminum that transfers power within a switchboard, distribution board, substation or other electrical apparatus. Bus bars are used to carry very large currents, or to distribute current to multiple devices within switchgear or equipment. High voltage bus bars tests will include insulation resistance, contact resistance test and high voltage test.

3.4.1 Insulation Resistance Test

Before starting the testing a visual inspection will be made to ensure the surface dust and moisture has been removed from the component under test and Ensure the component is isolated from other connected system, which may feedback to other components or circuits not under test. On testing, voltage shall be applied between one phase and other phases connected with ground, the test voltage shall be applied for 10minutes and readings are taken every 15sec for the first minute and every minute for 10 minutes.

Dielectric absorption factor and Polarization index can be calculated as:
Dielectric absorption factor = 60sec reading/ 15sec reading (3.12)
Polarization index = 10min reading / 1min reading. (3.13)

For good insulation polarization index should be above 2.0 and absorption factor should lie between 1.25 and 2.5. Testing shall be repeated for other phases as mentioned above.

3.4.2 Contact Resistance Test

The contact resistance test (commonly known as the Ductor test) measures the resistance of electrical connections such as joints, terminations, connectors, etc. These can be connections between any two conductors, for instance bus bar sections or cable connections. The test measures the resistance at the micro or mille ohm level and is used primarily to verify that electrical connections are made properly, and can detect problems like loose connections, adequate tension on bolted joints, eroded contact surfaces and contaminated or corroded contact. This is particularly important for contacts that carry large amounts of current as higher contact resistance leads to higher losses and lower current carrying capacity. The test shall be done with circuit breakers inserted and closed. The contact dc resistance is measured between panels by injecting 100 A DC current as shown in figure (3.16).

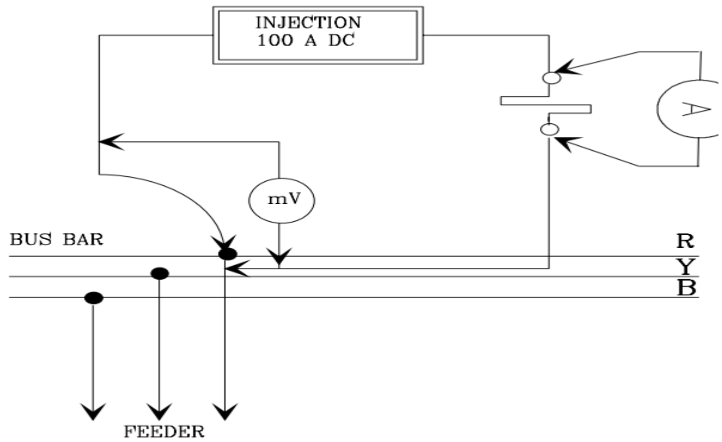

Figure 3.16 shows the bus bar contact resistance test

3.4.3 High Voltage Test

In this test injecting 80% of the testing voltage used in the factory is applied, the required test voltage shall be raised gradually and maintained for one minute between one phase and the other phases connected to the ground and then reduced slowly to zero, test shall be repeated for other phases as mentioned above and leakage current shall be recorded during each test. No flashover or disruptive discharge should occur during test.

3.5 Commissioning Test for Earthing System

Earthing system provides protection for both human and equipment inside a substation as it ensures that all exposed conductive surfaces are at the same electrical potential as the surface of the Earth and to avoid the risk of electrical shock if a person touches a device in which an insulation fault has occurred. It ensures that in the case of an insulation fault "short circuit", a very high current flows which will trigger an over current breaker that disconnects the power supply. All metallic parts in a substation must be connected to the earthing system via suitable cables or bus bars. The tests are presented below

3.5.1 Earth Resistance or Impedance Measurements

Earth resistance measurements are used to determine the overall resistance of a substation earthing system or individual earth electrodes during commissioning of a substation and at maintenance intervals. The overall substation earth resistance is used with the ground return current to calculate the earth potential rise (EPR). There are various ways to measure the earth resistance of individual earth electrodes and complete substation earthing systems. In a substation, earthing resistance must not exceed 1ohm. Fall of potential method and comparative method are used to determine earth resistance.

a. Fall of Potential Method

The most commonly used method for measuring substation earth resistance or impedance is the fall of potential method. The method injects a small current into the substation earth system using a standard four terminal earth tester. The current return is via a test probe located at a distance from substation. A voltage gradient is set up around the test probe which is measured by a second potential probe connected to the earth tester. The connections are shown in figure (3.17). A suitable test route free of buried metallic cables and pipes is selected. Terminals C1 and P1 of a four terminal earth tester are connected to the earthing system under test, the C2 current probe is placed away from the earthing system under test using the distances specified earlier and connect to the earth tester, the P2 probe is placed at a distance of 80% of the defined C2 distance, the lead is connected to the earth tester and the resistance is recorded. Further resistance measurements at 70%, 65%, 60%, 55%, 50%, 40%, 30% and 20% are taken and the results are plot as a curve of resistance against distance for each route as shown in figure (3.18). The actual value of resistance can then be determined using the ’61.8%’. The result should be compared with the factory test.

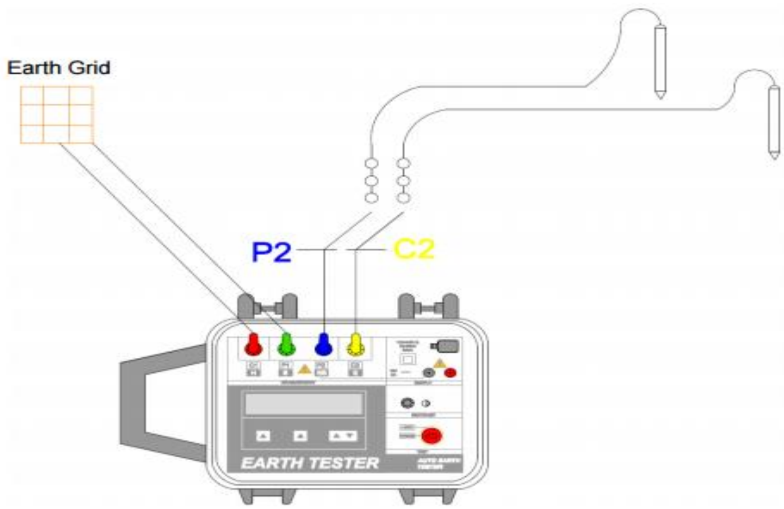

Figure 3.17 shows the connection of potential method for measuring substation earth resistance

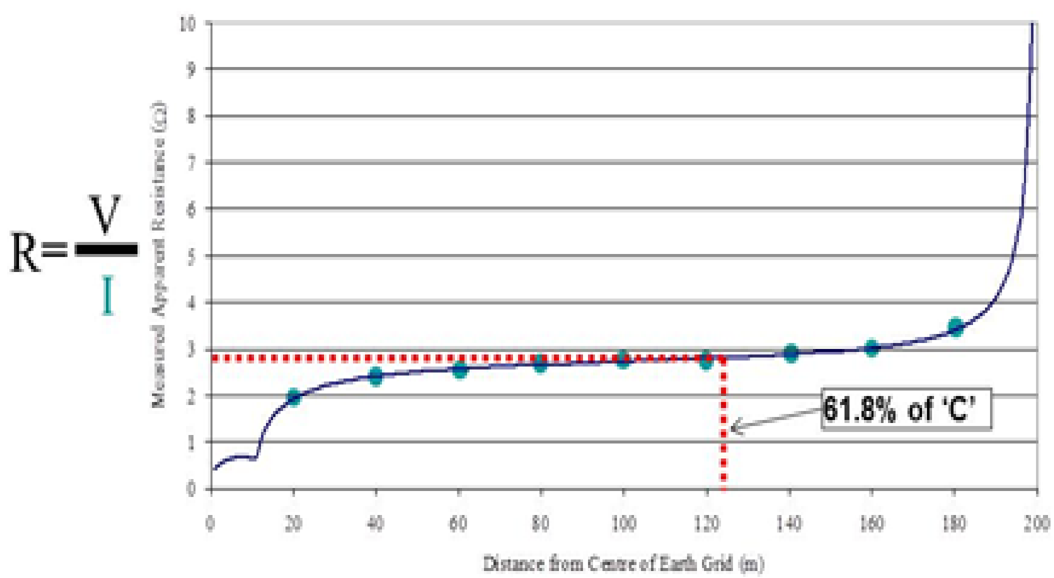

Figure 3.18 shows the earth resistance curve

b. Comparative Method

The comparative method is used to measure the earth resistance of small individual electrode components within a large interconnected earthing system. This method is most effective where a relatively high resistance electrode is measured in comparison to a 'reference earthing system' which has a much lower resistance. The method uses a four terminal earth tester and requires the earth electrode under test to be disconnected from the remainder of the substation earthing system. Therefore this method of test shall only be used prior to energization during commissioning of new or refurbished substations. terminals C1 and P1 are connected of a four terminal earth tester to the earth electrode under test, terminals C2 and P2 are connected to reference earth the as shown in figure (3.19). A current is circulated around the earth loop containing the electrode and the reference earth resistances and the voltage developed across them is measured. Ohm's Law is used to calculate the series 'loop resistance' and if the reference earth resistance is sufficiently low relative to the electrode resistance the measured value will approach the electrode resistance.

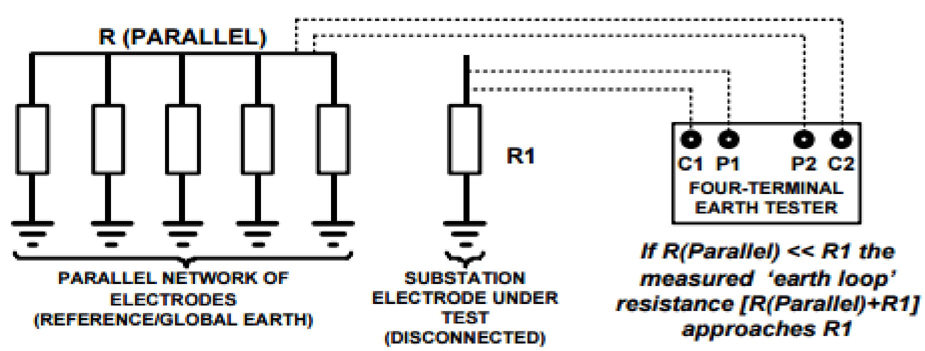

Figure 3.19 shows the earth resistance test connection by comparative method

3.5.2 Earth Conductor Joint Resistance Measurements

This measurement is used to measure the resistance across an earth joint to check its electrical integrity. This test should be carried out across every joint created at a new substation prior to backfilling and also at a sample of above ground joints during periodic maintenance assessments. The method uses a micro-ohmmeter to measure electrical resistance across a joint using the connection arrangement shown in figure (3.20). Terminals C1 and P1 are connected of the micro-ohmmeter to one side of the joint using earth clamps with sharp pins that can penetrate through paint or surface corrosion to reach the metal underneath. Terminals C2 and P2 are connected of the micro-ohmmeter to the other side of the joint. Ideally, the connectors should be no more than 25mm either side of the joint. A suitable scale is selected on the micro-ohmmeter (normally a minimum current of 10A is required to measure in the micro-ohm range) and record the average value after the test polarity has been reversed. Compare the result with the factory test. Finally the joint is given a firm tap with a steel hammer to ensure it is mechanically robust.

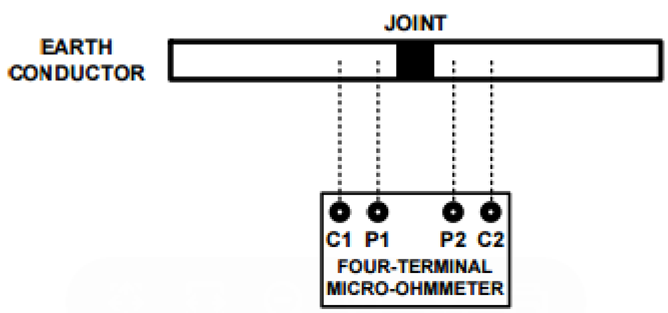

Figure 3.20 shows the earth conductor joint resistance test connection

3.5.3 Earth Connection Resistance Measurements

This measurement is used to measure the resistance between an item of equipment and the main substation earthing system to check bonding adequacy. This test should be carried out during commissioning of a new substation to confirm that each item of equipment is effectively connected to the main earthing system. It is also useful as an ongoing maintenance check. The method is based upon the principle of measuring the resistance between a set point (and points) on the main electrode system and individual items of earthed equipment. A micro ohmmeter is used and the connection arrangement is illustrated in Figure (3.21). Measurements can be taken from one central point (such as the switchgear earth bar) or to avoid the use of unduly long leads, once a point is confirmed as being adequately connected. It can be used as a reference point for the next test and so on.

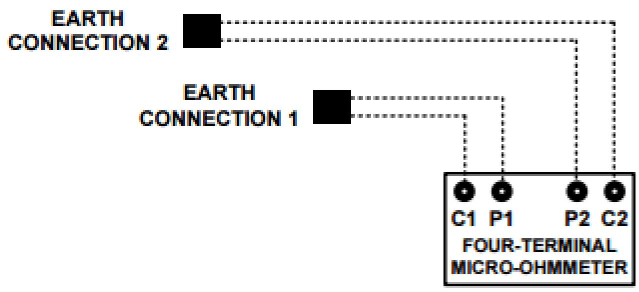

Figure 3.21 shows the earth connection resistance measurement

Terminals C1 and P1 are connected of the micro-ohmmeter to the substation earth grid using suitable earth clamps, terminals C2 and P2 are connected of the micro-ohmmeter to the earth terminal or structure of the equipment under test and Select a suitable scale on the micro-ohmmeter (an injection current of at least 100mA is recommended). The result should be compared with the factory test.

3.5.4 Step and Touch Voltage

Step Voltage is the voltage between the feet of a person standing near an energized grounded object. It is equal to the difference in voltage between two points at different distances from the "electrode". A person could be at risk of injury during a fault simply by standing near the grounding point. "Touch voltage" is the voltage between the energized object and the feet of a person in contact with the object.

a. Touch Voltage

Touch voltage is measured with digital voltmeter and 1kΩ resistance connected in parallel to the voltmeter to simulate the human body resistance. Measuring electrodes that simulate the feet, total surface area of 400 cm2 loaded with minimum20 kg each, will be used for measurement of touch voltage.

Both electrodes will be connected together to the voltmeter and the other side of voltmeter will be connected to point electrode as in figure (3.22). Point electrode will be used as the measurement electrode to simulate the hand. Any coats of paint on the place of measurement (but not insulation) shall be reliably pierced. When measuring the touch voltage on an installation component the electrode shall be set up 1meter away from the accessible installation component. The result should be compared with the factory test

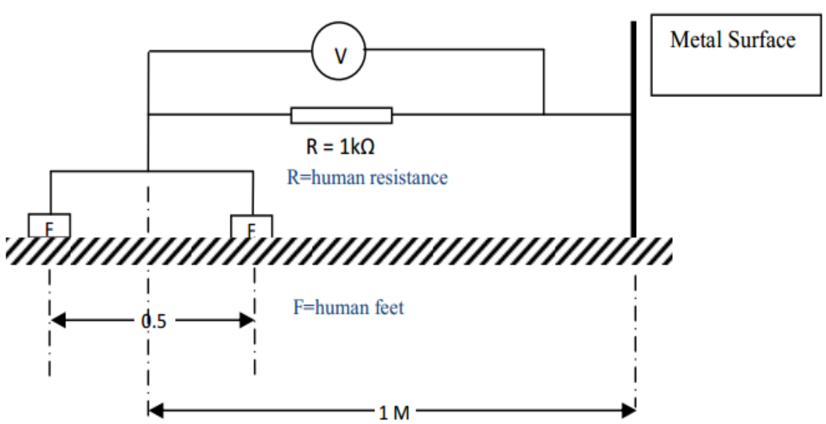

Figure 3.22 shows the touch voltage test

b. Step Voltage

Step voltage is measured with digital voltmeter and 1kΩ resistance connected in parallel to the voltmeter to simulate the human body resistance as in figure

(3.23). Measuring electrodes that simulate the feet, total surface area of 400 cm2 loaded with minimum 20Kg each, will be used for measurement of step voltage. Voltmeter will be connected between electrodes that simulate the feet.

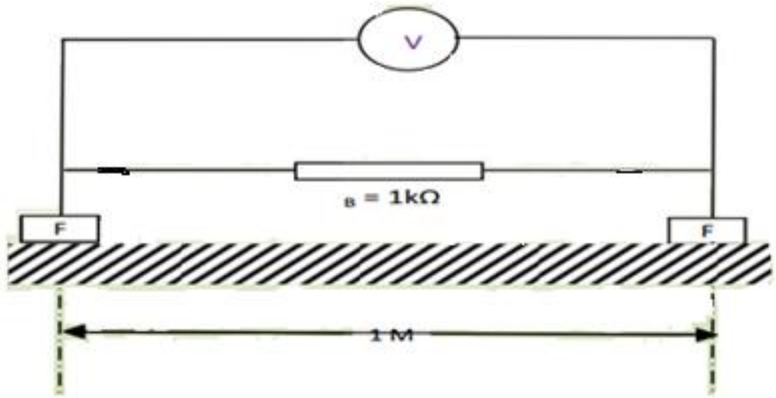

Figure 3.23 shows the step voltage test