CHAPTER TWO

HIGH VOLTAGE AND INSULATION RESISTANCE TESTS

2.1 Introduction

The equipment used in high voltage transmission substations, should be capable of withstanding high voltage stresses and well insulated to insure safe transmission of electricity. In addition to that normal high voltage and different over voltages withstanding capability, hence testing of the high voltage equipment is carried out to prove the performance of equipment before putting into service [2]. In this chapter two of the most important tests for high voltage equipment are discussed. One of these two is high voltage test and the other is insulation resistance test but first a general and brief idea about test categories is represented.

2.2 Test Categories

Tests are divided into routine, type and special tests. Routine test definition is a test to which each individual equipment is subjected. Each equipment may subject to routine test at least one time. Practically a routine test can be done to a certain equipment at the factory after manufacturing and at the site during commissioning tests.

Type test are performed on single specified Electrical Equipment of one type and are intended to check the design characteristics. They are usually relate to the first unit manufactured by a firm to given specification. Special tests definition is a test done for electrical equipment other than a type test or a routine test agreed by the manufacturer and the purchaser. Type test and special test are carried out on the specific requirement of customers.

Also electric equipment tests can be divided into factory acceptance and site acceptance tests. Factory Acceptance Tests (FAT) are carried out at the Manufacturer's Factory. They are combination of routine tests, special tests and type tests .Normally customers choose which tests to do from the above tests (routine, special, type). The FAT is performed according to the customer requirements at the witness of the customer or his representative.

Site Acceptance Tests (SAT) are done at the site and consists of Pre-commissioning tests, Commissioning tests, Maintenance tests (Troubleshooting tests) and Tests after replacement or repair. Pre-commissioning tests are done to assess the condition of an equipment after installation and comparing tests results to the factory test reports. For example Visual Check and Inspection of the whole equipment, some of routine tests and test on auxiliary equipment and Verification of correct wiring.

Commissioning tests Process by which an equipment, facility, or plant which is installed, or is complete or near completion is tested to verify if it functions according to its design objectives or specifications. They are combination of type, special and routine tests. Maintenance tests (Troubleshooting Test) are tests that are performed to identify equipment problems or diagnose equipment problems and to prove that the rest of the system has not been affected by the maintenance work. Tests after replacement or repair are performed to be sure that insulation of the whole system is not affected after changes have been made due to faults or if the system is extended or because of some additional features added to it. [3]

2.3 High Voltage Test

High voltage test is done during factory acceptance test for equipment, commissioning tests at the site and after equipment repairs or switchgear system extensions to determine that the equipment is in a proper condition to put in service after installation and to give some basis for predicting whether or not a healthy condition will remain or if deterioration is underway which can result in abnormally short life.

In order to understand what a high voltage test is and how it is performed, it is first necessary to discuss the theory of the high voltage test itself. The high voltage test, sometimes called a Dielectric Withstand test, is used to verify the strength of the insulation between an equipment's current carrying components and its chassis or enclosure. This is done by applying a high voltage from the main input lines to the chassis of the equipment and measuring the resulting leakage current flowing through its insulation. The theory is if a voltage much higher than the equipment would normally see is applied across the insulation without a breakdown (which results in an excessive amount of leakage current flow), the equipment will be able to operate safely when run under nominal operating conditions.

The high voltage test is so crucial because it is the best way to uncover workmanship and assembly defects in an electrical equipment that can lead to insulation breakdown. Mistakes during assembly or faulty components exist to an extent in any manufacturing environment, and the high voltage test can uncover units that are unfit and dangerous to sell. The high voltage tester is used to indicate whether or not a dielectric breakdown of the insulation has occurred by monitoring the leakage current resulting from the applied test voltage. [4]

2.3.1 High Voltage Tester

A high voltage tester is an electronic device used to verify the electrical insulation in a device or other wired assembly that could subject someone to a shock if it failed. It generally consists of a source of high voltage, a current meter and a switching matrix used to connect the high voltage source and the current meter to all of the contact points in an equipment. High voltage testers may also have a microcontroller and a display to automate the testing process and display the testing result.

2.3.2 High Voltage Test Specifications

High voltage tests can be performed using either an AC or a DC voltage. Manufacturers may or may not be required to perform a specific type of high voltage test depending on the equipment and the standard to which it is being tested. Both AC and DC high voltage tests have inherent advantages and disadvantages that become evident depending on the characteristics of the equipment under test. In AC high voltage test slow ramping of the test voltage isn't necessary due to the changing polarity of the applied waveform. It's also unnecessary to discharge the tested equipment after the test and testing stresses the insulation alternately in both polarities. In DC test, it can be performed at a much lower current level, saving power and with less risk to the test operator and Leakage current measurement is a more accurate representation of the real current and sometimes DC testing is the only option for some circuit components: diodes, capacitors, etc. These differences between AC and DC waveforms necessitate a variation in high voltage test procedures. Although the test is basically the same, the test operator needs to take into account the relationship between a DC waveform and its equivalent AC waveform. AC waveforms are often listed as RMS (root mean squared). This RMS value, known as the effective value, provides a load with the same amount of energy as a DC waveform of the same voltage for example a 25 volt DC source provides the same amount of effective energy as a 25 volt rms AC source.

The actual quantitative value of the RMS AC waveform is much higher at the peaks of the sine wave. In fact, the difference between a peak AC waveform measurement and the RMS measured value is 1.414. The calculation is as follows:

Volts peak = 1.414* volts RMS (2.1)

Since a high voltage test stresses the insulation of an equipment with a high voltage, the applied test voltage must be the same value whether it is AC or DC. It is unnecessary to worry about the effective RMS value since the energy delivered to the equipment under test is of no importance; the peak (maximum) voltage is the concern.

A good rule of thumb for determining the test voltage during an AC high voltage test is to multiply the nominal input voltage (usually from a wall outlet given as an RMS voltage) by 2 and add 1000 volts.

AC high voltage test voltage=Nominal input voltage*2+1000 (2.2)

For a DC test use the following procedure to assure that the DC voltage is the same value as the peak of the AC waveform

DC high voltage test voltage = AC high voltage test voltage * 1.414 (2.3)

By performing this operation, the DC voltage is applied at the same level as the peak of the AC voltage waveform. The amount of time high voltage must be applied during testing is also specified in many safety agency standards. The most common test durations are one second for production tests and one minute for design tests.

2.3.3 High Voltage Test for Switchgear

Switchgear includes panel enclosure, bus bars, CTs, VTs and circuit breakers. Before starting high voltage test, precautions should be taken a visual inspection will be made to ensure dust and moisture on the surface has been removed from the component under test. Ensure the component under test is isolated from other connected system which may feed back to the other components or circuits not under test. VTs and surge arrestors shall be isolated from the equipment under test.

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. After the above test, another test shall be repeated after opening all circuit breakers or contactors and applying test voltage across opening distance between poles with three poles shorted on both sides and grounded on one side only. The figures (2.1) and (2.2) explain high voltage test for switchgear

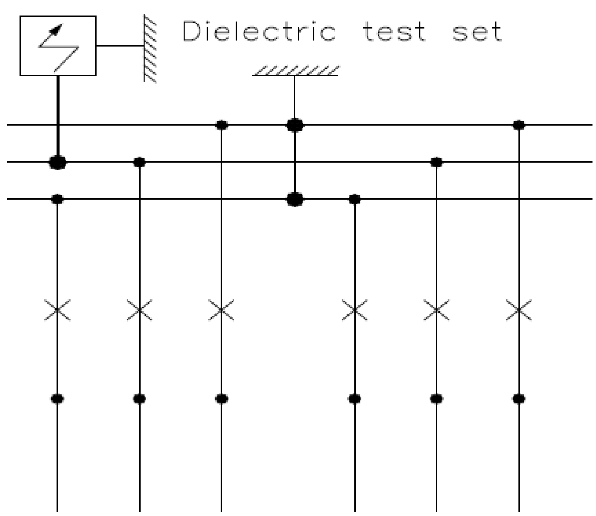

Figure 2.1 high voltage test for switchgear

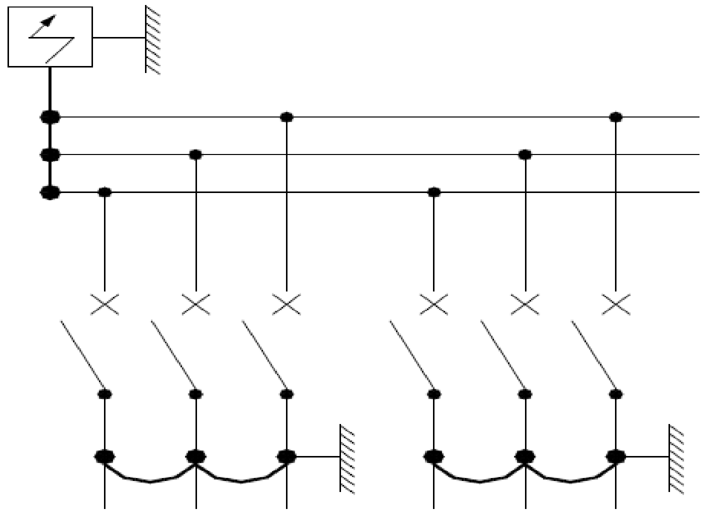

Figure 2.2 high voltage test for opening distance

2.3.4 High Voltage Test For Power Cables

Following precautions shall be made before conducting test. Cable under test should be clean and free of dust especially at insulators and stress cones, Shields of all cables should be grounded and tied together at the near end of the cable and at far end bare conductor should be taped with some insulation. Cable under test should be disconnected at both ends. This will assure that the cable under test will not feedback to circuits or components not under test. Cable can be tested by DC or AC voltage.

a. DC Voltage Test

Dc voltage shall be raised slowly up to (4 x Vo) (rated power frequency voltage between conductor and earth or metallic screen) and maintained for 15 minutes between one phase and other phases and metallic screen of all phases connected with ground. After elapse of test time, voltage shall be reduced slowly to zero and the cable shall be discharged. Testing shall be repeated for other phases as mentioned above.

b. AC Voltage Test (Alternate method)

An AC voltage may be applied as (1 or 2) below:

1. Test for 5 minutes with phase-to-phase voltage of the system applied between the conductor and the metallic screen.

2. Test for 24 hours with the normal operating voltage Vo of the system.

Note: Normally cables have three voltages specified: i.e. Vo,V and Vm.

Where:

Vo is the rated Phase to earth/screen voltage

Vis the rated Phase to phase voltage

Vm is the rated maximum Phase to phase voltage

For cables used for solidly earthed system screen current for the earth fault will be high but cable Vo rating is low i.e. Vo=V/1.732.

For cables used for resistance earthed system screen current will be low for earth fault but cable Vo rating is high i.e. Vo.

For Switchgear and cables no flashover or disruptive discharge should occur during test. Corona Discharge noise may be heard during this test.

2.4 Insulation Resistance Test

Insulation is needed for Prevention of short circuits arc between phases and phase to ground, to avoid electrocution and to retain the voltage at the terminals in order to drive the necessary current. The purpose of insulation around a conductor is much like that of a pipe carrying water as shown in figure (2.3).

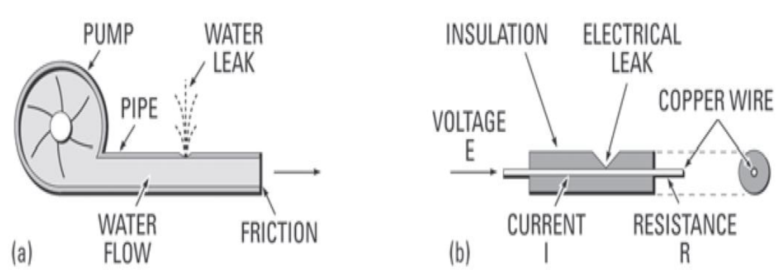

Figure 2.3 shows the purpose of insulation

Pressure on water from a pump causes flow along the pipe, and if the pipe has a leak, you would waste water and lose some water pressure. With electricity, voltage is like the pump pressure that causing electricity to flow along the copper wire, and if there is a weak point in the insulation a fault will happen. At normal conditions resistance is much less along the wire than it is through the insulation.

Degradation of an insulating system happens due to Cracks in the hard insulators, Presence of humidity in the liquid insulators like oil and Ionization happened to strange materials that accumulated in the surface of the hard insulators due to high voltage, and this will make a low resistance path for leakage currents. Insulation 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) and before putting equipment back into service after a shutdown (maintenance or after a repair or after a prolonged shutdown).

Equipment that are tested for insulation on substations are Transformers, Switchgear and circuit breakers, Insulators and bushings and Cables. Three techniques are used to do insulation test and they are Megger test, tan delta test and Partial discharge test.

2.4.1 Megger Test

Testing of insulation based on Ohm’s law. Insulation Resistance exists between phases and between phases to ground. The larger the insulation resistance the lesser the chance for bypassing the active current or voltage through the main equipment. Degradation happens to any insulation system and this is a natural phenomenon, but the unnatural is the high rate of degradation especially in early period of insulation age. Insulation resistance is high at the time of manufacture, but slowly reduces during insulation life. Insulation material constantly stressed by the rated voltage (during normal operation). Continuous monitoring of insulation resistance is needed to ascertain condition of insulation. When a High DC voltage is applied across any electrical equipment Charging current (Capacitive current) (Ic), Dielectric absorption current (Ida) and Resistive (Leakage current) (Ir) are flow through the insulation as shown in figure (2.4).

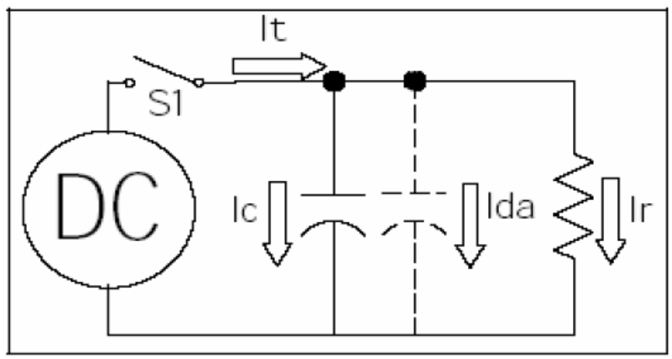

Figure 2.4 show flowing currents during insulation resistance test

Insulation is basically a resistance in parallel with a capacitance. When DC voltage is applied the capacitance starts drawing more current which stops after a time. This current is called charging current **(I_c)** also called capacitive current. Also molecules get realigned when DC voltage is applied and absorb energy from this voltage. Current dies off quickly once realignment is completed as shown in figure (2.5).This current is called dielectric absorption current of insulation **(I_{da})**.

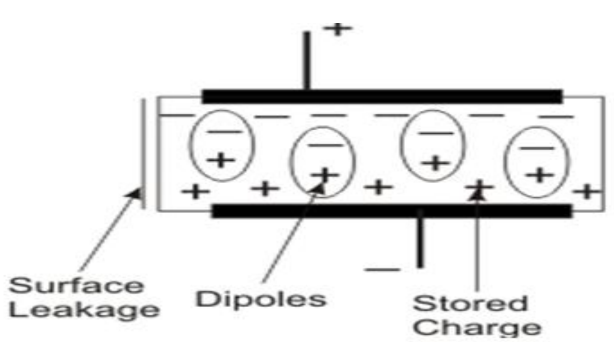

Figure 2.5 shows the realignment of molecules when DC voltage is applied

The actual current that decides the property of the insulation is called resistive leakage. For good insulation, resistance is high, leakage current is minimal. For bad insulation, resistance is low, leakage current is more. Property of insulation depend on leakage current measured after stoppage of **(I_c)** and **(I_{da})** .Figure (2.6) shows currents curves which flow in insulation test.

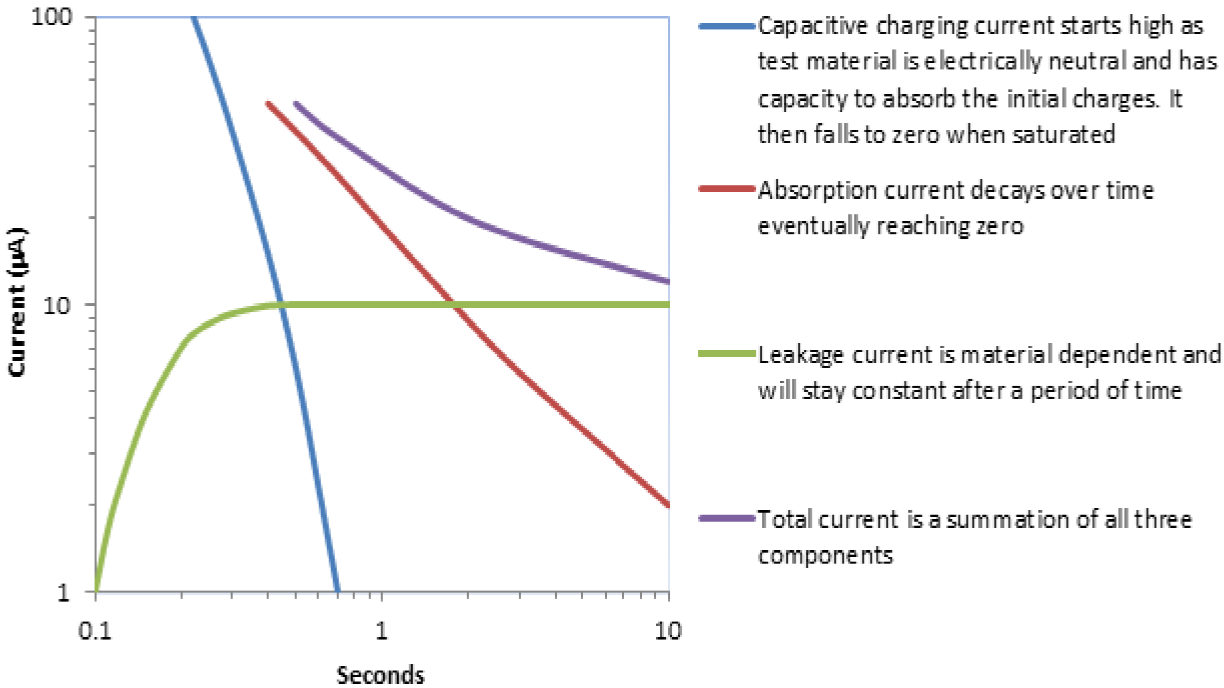

Figure 2.6 show currents flowing in insulation test

Megger is used in insulation resistance technique. Megger uses Ohm law to convert the leakage current to a resistance value based on voltage applied. The instrument itself generates the required DC voltage. This voltage is applied for 1 minute till the resistance value stabilizes (i.e. after charging and dielectric absorption currents become negligible and leakage current stabilizes).

a. Guard Wire in Megger

By guard wire we mean the third terminal that is found in megger set as shown in figure (2.7). Guard wire is not necessary in application with lower insulation resistance values less than 100MΩ such as in wiring of low voltage building application. The use of the guard terminal is often important with a value of insulation above 100MΩ as found in high voltage insulation application. The purpose of guard terminal is to eliminate the effect of leakage current through paths in parallel with the insulation you want to test. The surface leakage is essentially a resistance in parallel with the true insulation resistance of the material being tested. The guard intercepts currents caused by these unwanted parallel paths and connect them to ground by passing the current as in the diagram.

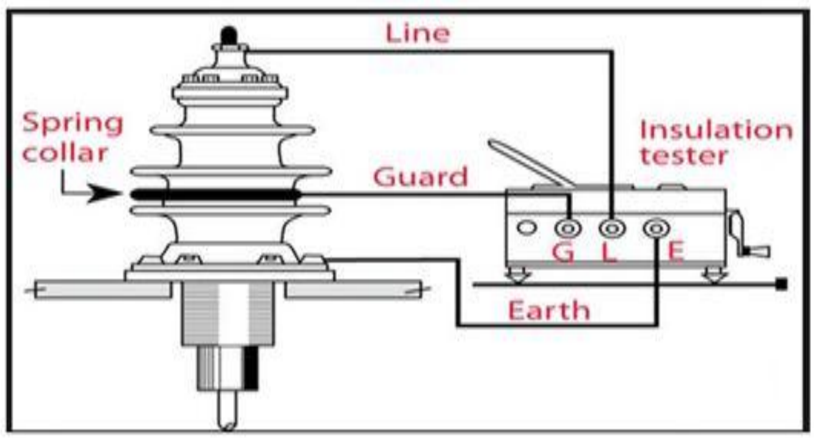

Figure 2.7 shows megger test with guard wire

There are some cautions during insulation resistance test should be taken, the positive terminal should be grounded after test, voltage is gradually applied during the test and the tested item should be drained before re-energizing with test voltage. The condition of insulation can be determined by polarization index or absorption factor.

b. Polarization Index (PI)

The voltage with the megger is applied and the insulation resistance value is taken after one minute (R1). Continue with the test voltage for 9 more minutes.

the insulation resistance reading is taken again at the end of 10^{th} minute (R10). Calculate the polarization Index (PI) by the formula (R10/R1).Them condition of insulation is determined as shown in table (2.1).

Table 2.1: shows the condition of insulation according to polarization index

Condition	**Polarization index(PI)**
Dangerous	Less than 1.0
Poor	1.0to1.1
Questionable	1.1to1.25
Fair	1.25to2.0
Good	Above 2.0

c. Absorption Factor

The voltage with a megger is applied and the insulation resistance value is taken after 15 second (R15).Continue with the test voltage for 45 more second. The insulation resistance reading is taken again at the end of sixty second (R60). The absorption factor is calculated by the formula (R60/R15). The results are good when absorption factor is lies between 1.25 and2.5.

Megger test is affected by temperature, insulation surface cleaning and using of the correct wires of megger. When the temperature is high the resistance of the insulation materials will degrade and this will affect the measurement of the Megger (degrade the value).The standard temperature is 20˚C and the correction is made as shown in table (2.2).

Sometimes when the surface of the insulation is dirty or polluted by dust, oil leakage or other materials, the values of the megger test affects a little and clean up the insulators is needed to reduce the value of the leakage currents through the dirt on the insulators.

Table 2.2: shows temperature correction factor for insulation resistance test

Degree ◦c	**Correction factor**
0	.25
5	.36
10	.5
15	.72
20	1.00
30	1.98
40	3.95
50	7.85

2.3.2 Tan Delta Test

Insulation test can be done by another technique called tan delta .tan Delta, also called Loss Angle or Dissipation Factor testing, is a diagnostic method of testing equipment to determine the quality of the equipment insulation. If the insulation of an equipment is free from defects, the equipment approaches the properties of a perfect capacitor. It is very similar to a parallel plate capacitor with the conductor and the neutral being the two plates separated by the insulation material. In a perfect capacitor, the voltage and current are phase shifted 90 degrees and the current through the insulation is capacitive as shown in figure (2.8). If there are impurities in the insulation, like those mentioned above, the resistance of the insulation decreases, resulting in an increase in resistive current through the insulation. It is no longer a perfect capacitor. The current and voltage will no longer be shifted 90 degrees. It will be something less than 90 degrees. The extent to which the phase shift is less than 90 degrees is indicative of the level of insulation contamination, hence quality and reliability.

The equipment to be tested must be de-energized and each end isolated. Using a tan delta test equipment, the test voltage is applied to the cable while the tan delta controller takes measurements. Typically, the applied test voltage is raised in steps, with measurements first taken up to Vo (normal line to ground operating voltage). If the tan delta numbers indicate good cable insulation, the test voltage is raised up to (1.5 – 2)*Vo.

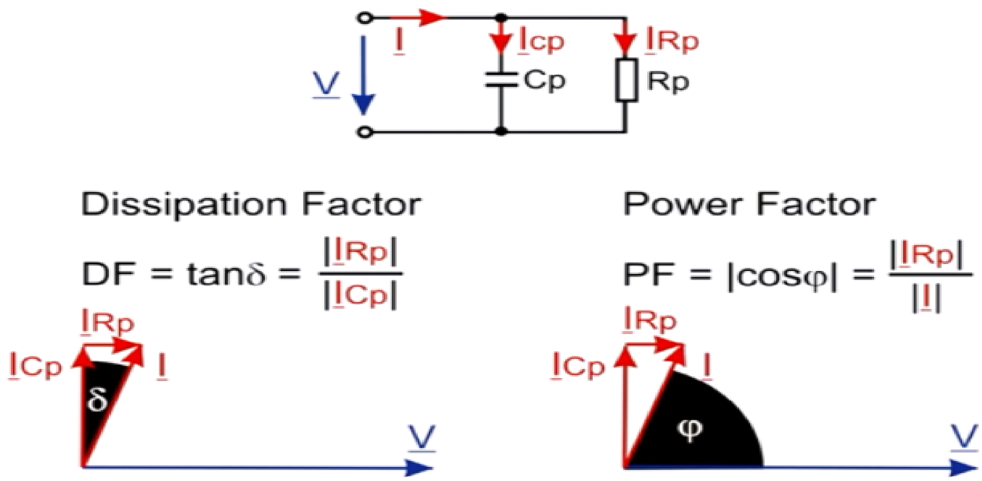

Figure 2.8 shows dissipation and power factor angles in Tan Delta test.

2.3.3 Partial Discharge Test (PD)

Partial Discharge is a localized dielectric breakdown with a small portion in a solid or fluid electrical insulation system under high voltage stress, and this dielectric breakdown does not reach the level to bridge the space between the conductors to cause a fault. Partial discharge test occurs in a gaseous, liquid or solid insulating medium and it often starts within cracks, gas voids such as voids in solid insulation or bubbles in transformer oil. It can also occur along the surface of solid insulating materials if the surface electric field is high enough to cause the partial discharge, and this phenomenon happens on contaminated insulators surface during days of high humidity.

Partial discharge can erode solid insulation and eventually lead to breakdown of insulation. Partial discharge within solid insulation system is not visible and it dissipates energy in the form of heat, sound and light. The localized heating from partial discharge may cause thermal degradation for the insulation. Generally there are two ways for measuring the level of partial discharge, Firstly is the electrical Method (off line method), here the equipment (transformer, cable, motor...etc.) is de-energized, and the voltage is supplied gradually (1.8*Vo) to see if there is partial discharge started. Secondly Sound Method (On line method), here the tested equipment is in service and special sensors are monted on the surface of the equipment at the place where the partial discharge is expected to be exist, these sensors send signals to electric analyzer for filtering the noise emitted from the place of sensors.