9

High Voltage Testing

9.0 High Voltage Testing Procedure

Electrical equipment must be capable of withstanding overvoltages during operation. Thus by suitable testing procedure we must ensure that this is done.

High voltage testing can be broadly classified into testing of insulating materials (samples of dielectrics) and tests on completed equipment.

The tests carried out on samples of dielectric consist generally of the measurement of permittivity, dielectric loss per unit volume, and the dielectric strength of the material. The first two can be measured using the High Voltage Schering Bridge.

The tests carried out on completed equipment are the measurement of capacitance, the power factor or the total dielectric loss, the ultimate breakdown voltage and the flash-over voltage. The breakdown voltage tests on completed equipment is only done on a few samples since it permanently damages and destroys the equipment from further use. However since all equipment have to stand up to a certain voltage without damage under operating conditions, all equipment are subjected to withstand tests on which the voltage applied is about twice the normal voltage, but which is less than the breakdown voltage.

9.1 General tests carried out on High voltage equipment

9.1.1 Sustained low-frequency tests

Sustained low frequency tests are done at power frequency (50 Hz), and are the commonest of all tests. These tests are made upon specimens of insulation materials for the determination of dielectric strength and dielectric loss, for routine testing of supply mains, and for work tests on high voltage transformers, porcelain insulators and other apparatus.

Since the dielectric loss is sensitive to electric stress, the tests are carried out at the highest ultimate stress possible. For testing of porcelain insulators and in high tension cables, voltages as high as 2000 kV may be used.

High voltage a.c. tests at 50 Hz are carried out as Routine tests on low voltage (230 or 400 V) equipment. Each one of these devices are subjected to a high voltage of 1 kV + 2 × (working voltage). A 230 V piece of equipment may thus be subjected to about 1.5 to 2 kV. These tests are generally carried out after manufacture before installation.

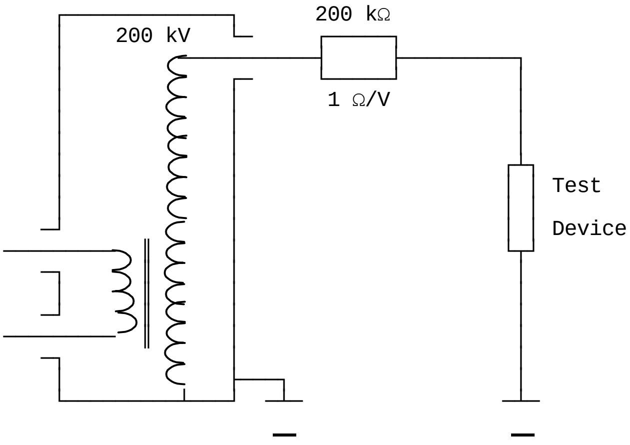

Figure 9.1 - a.c. generation test circuit

The high voltage is applied across the device under test by means of a transformer. The transformer need not have a high power rating. If a very high voltage is required, the transformer is usually build up in stages by cascading. By means of cascading, the size of the transformer and the insulation bushing necessary may be reduced in size. The transformers are usually designed to have poor regulation so that if the device under test is faulty and breakdown occurs, the terminal voltage would drop due to the high current caused. A resistance of about 1 ohm/volt is used in series with the transformer so as to limit the current in the event of a breakdown to about 1 A. The resistance used could be of electrolyte type (which would be far from constant, but would be a simple device) such as a tube filled with water.

In all high voltage tests, safety precautions are taken so as to ensure that there is no access to the testing area when the high voltage is on. There would be switches that would automatically be operated when the door to the area is opened etc..

9.1.2 High Voltage direct current tests

These tests are done on apparatus expected to operate under direct voltage conditions, and also where, due to the inconvenience of the use of high capacity transformers required for extra high tension alternating voltage tests and due to transport difficulties, alternating voltage tests cannot be performed after installation.

A special feature of importance of the d.c. test is the testing of cables which are expected to operate under a.c. conditions. If the tests are done under a.c. conditions, a high charging current would be drawn and the transformer used would have to have a current rating. It is thus normal to subject the cable (soon after laying it, but before energising it) to carry out a high voltage test under d.c. conditions. The test voltage would be about 2 (working voltage) and the voltage is maintained from 15 min to 1.5 hrs. This d.c test is not complete equivalent to the corresponding a.c. conditions , it is the leakage resistance which would determine the voltage distribution, while in the a.c. conditions, it is the layers of different dielectrics that determine the voltage distribution in the cable. Although the electric field differs in the 2 cases, it is likely that the cable will stand up to the required a.c. voltage.

The methods used to generate these high d.c. voltages have already been described.

9.1.3 High-frequency tests

High frequency tests at frequencies varying from several kHz are important where there is a possibility of high voltage in the lines etc., and in insulators which are expected to carry high frequency such as radio transmitting stations. Also in the case of porcelain insulators, breakdown or flashover occurs in most cases as a result of high frequency disturbances in the line, these being due to either switching operations or external causes. It is also found that high frequency oscillations cause failure of insulation at a comparatively low voltage due to high dielectric loss and heating.

High voltage tests at high frequency are made at the manufacturing works so as to obtain a design of insulator which will satisfactorily withstand all conditions of service.

In the case of power line suspension insulators, it is possible that breakdown or flash over would occur due to high frequency over voltages produced by faults or switching operations in the line. Sudden interruptions in the line would give rise to resonant effects in the line which would give rise to voltage waves in the line of high frequency. These might cause flashover of the insulators.

The behaviour of insulating materials at high frequencies are quite different to that at ordinary power frequency. The dielectric loss per cycle is very nearly constant so that at high frequencies the dielectric loss is much higher and the higher loss causes heating effects.The movements of charge carriers would be different.

At high frequency the polarity of electrodes might have changed before the charge carriers have travelled from one electrode to the other, so that they may go about half-way and turn back (figure 9.2).

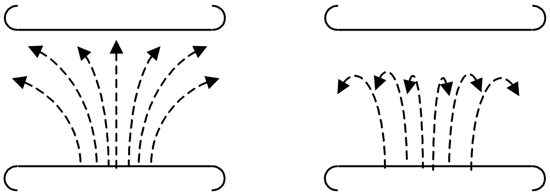

Figure 9.2 Movement of charge carriers

There are two kind of high frequency tests carried out. These are

(a) Tests with apparatus which produces undamped high-frequency oscillations.

Undamped oscillations do not occur in power systems, but are useful for insulation testing purposes especially for insulation to be in radio work.

(b) Tests with apparatus producing damped high-frequency oscillations.

When faults to earth or sudden switching of transmission lines occur, high frequency transients occur whose frequency depends on the capacitance and inductance of the line and will be about 50 kHZ to about 200 kHZ. These are damped out with time.

9.1.4 Surge or impulse tests

These tests are carried out in order to investigate the influence of surges in transmission lines, breakdown of insulators and of the end turns of transformer connections to line. In impulse testing, to represent surges generated due to lightning, the IEC Standard impulse wave of 1.2/50 μs wave is generally used. By the use of spark gaps, conditions occurring on the flash over to line are simulated. The total duration of a single lightning strike os about 100 μs, although the total duration of the lightning stroke may be a few seconds.

Overvoltages of much higher duration also arise due to line faults, switching operations etc, for which impulse waves such as 100/5000 μs duration may be used.

In surge tests it is required to apply to the circuit or apparatus under test, a high direct voltage whose value rises from zero to maximum in a very short time and dies away again comparatively slowly . Methods of generating such voltages have already been discussed earlier.

While impulse and high frequency tests are carried out by manufacturers , in order to ensure that their finished products will give satisfactory performance in service , the most general tests upon insulating materials are carried out at power frequencies .

Flash-over Tests

Porcelain insulators are designed so that spark over occurs at a lower voltage than puncture, thus safeguarding the insulator, in service against destruction in the case of line disturbances. Flash-over tests are very importance in this case .

The flash-over is due to a breakdown of air at the insulator surface, and is independent of the material of the insulator. As the flash-over under wet conditions and dry conditions differ , tests such as the one minute dry flash-over test and the one minute wet flash-over test are performance.

(i) 50 percent dry impulse flash-over test, using an impulse generator delivering a positive 1/50 μs impulse wave.

The voltage shall be increased to the 50 percent impulse flash-over voltage (the voltage at which approximately half of the impulses applied cause flash-over of the insulator)

(ii) Dry flash-over and dry one-minute test

In this the test voltage (given in the B.S.S.) is applied . The voltage is raised to this value in approximately 10 seconds and shall be maintained for one minute. The voltage shall then be increased gradually until flash- over occurs .

(iii) Wet flash-over and one minute rain test

In this the insulator is sprayed throughout the test with artificial rain drawn from source of supply at a temperature within 10 degrees of centigrade of the ambient temperature in the neighborhood of the insulator. The resistivity of the water is to be between 9,000 and 11,000 ohm cm.

In the case of the testing of insulating materials , it is not the voltage which produces spark-over breakdown which is important , but rather the voltage for puncture of a given thickness (ie. dielectric strength) . The measurements made on insulating materials are usually , therefore , those of dielectric strength and of dielectric loss and power factor , the latter been intimately connected with the dielectric strength of the material.

It is found that the dielectric strength of a given material depends , apart from chemical and physical properties of the material itself, upon many factors including,

(a) thickness of the sample tested
(b) shape of the sample
(c) previous electrical and thermal treatment of the sample
(d) shape , size , material and arrangement of the electrodes
(e) nature of the contact which the electrodes make with the sample
(f) waveform and frequency of the applied voltage (if alternating)
(g) rate of application of the testing voltage and the time during which it is maintained at a constant value .
(h) temperature and humidity when the test is carried out
(i) moisture content of the sample.

9.2 Testing of solid dielectric materials

9.2.1 Nature of dielectric breakdown

Dielectric losses occur in insulating materials, when an electrostatic field is applied to them. These losses result in the formation of heat within the material. Most insulating materials are bad thermal conductors,so that, even though the heat so produced is small, it is not rapidly carried away by the material. Now, the conductivity of such materials increases considerably with increase of temperature, and the dielectric losses, therefore, rise and produce more heat, the temperature thus building up from the small initial temperature rise. If the rate of increase of heat dissipated, with rise of temperature, is greater than the rate of increase of dielectric loss with temperature rise, a stable condition (thermal balance) will be reached. If, however, the latter rate of increase is greater than the former, the insulation will breakdown owing to the excessive heat production, which burns the material.

Now, the dielectric losses per cubic centimetre in a given material and at a given temperature, are directly proportional to the frequency of the electric field and to the square of the field strength. Hence the decrease in breakdown voltage with increasing time of application and increasing temperature and also the dependence of this voltage upon the shape, size, and material of the electrodes and upon the form the electric field.

The measurement of dielectric loss in insulating materials are very important, as they give a fair indication as to comparative dielectric strengths of such materials. In the case of cable, dielectric loss measurements are now generally recognized as the most reliable guide to the quality and condition of the cable.

9.2.2 Determination of dielectric strength of solid dielectrics

A sheet or disc of the material of not less than 10cm in diameter, is taken and recessed on both sides so as to accommodate the spherical electrodes (2.5 cm in diameter) with a wall or partition of the material between them 0.5mm thick. The electrical stress is applied to the specimen by means of the two spheres fitting into the recesses without leaving any clearance, especially at the centre. The applied voltage is of approximately sine waveform at 50Hz. This voltage is commenced at about 1/3 the full value and increased rapidly to the full testing voltage.

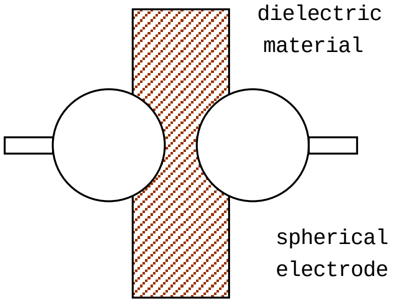

Figure 9.3 - solid sample

Sometimes insulators after manufacture are found to contain flaws in the form of voids or air spots.These spots (due to non-homogeneity) have a lower breakdown strength than the material itself, and if present would gradually deteriorate and cause ultimate breakdown after a number of years.

High degree ionisations caused in these spots would give rise to high energy electrons which would bombard the rest of the material, causing physical decomposition. In plastic type of materials,there might be carbonizations, polymerisations, chemical decomposition etc.,which would gradually diffuse into the material the by-products, causing chemical destruction.

The useful life of a component using such material will depend on the weak spots and the applied voltage. If the applied voltage is small, the life of the component is longer. From design considerations the voltage to be applied if a particular life span is required can be calculated.
The schering bridge type of measurement gives an average type of measurement,where the p.f. and the power loss indicates the value over the whole of the length.Thus small flaws if present would not cause much of a variation in the overall p.f. Thus in the schering bridge type of measurement such flaws would not be brought out.

The loss factor of a material does not vary much for low voltages, but as the voltage is increased at a certain value it starts increasing at a faster rate. This is the long time safe working voltage, since beyond this, the specimen would keep on deteriorating.

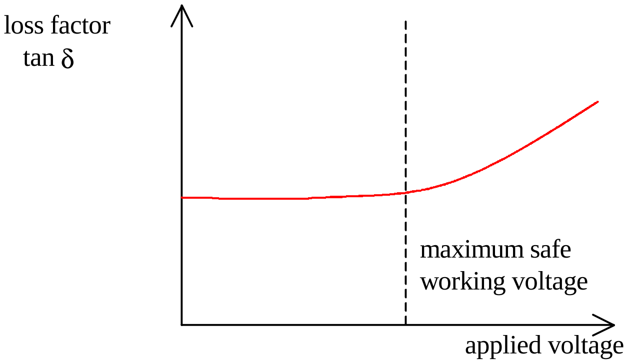

Figure 9.4 - variation of loss factor

If the apparatus need be used only for a short period, the applied voltage can be higher than this safe value.

In a long length of cable, the greater part of the cable would be in good conditions but with a few weak spots here and there.

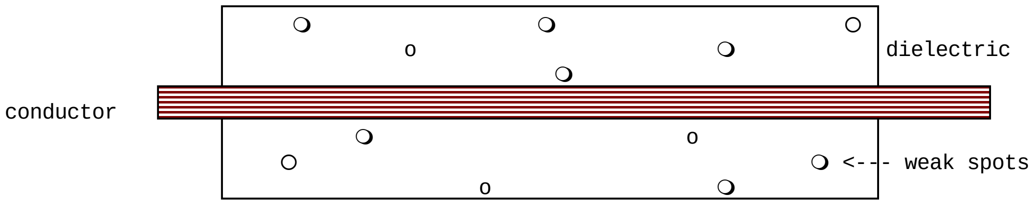

Figure 9.5 - sample of cable showing weak spots

In a Schering bridge type of measurement, since it measures the overall loss, such small individual spots cannot be detected. It is necessary that such spots are detected as these increase with time and finally cause its breakdown.

In high voltage transformers also there might be such small discharges occurring which would not be measured by the schering bridge.

The method is to apply suitable high voltage to sample, and subject it to a number of duty cycles (heat cycles, make and break cycles). Discharges caused are made to give pulses to a high frequency amplifier. The discharges caused are observed before and after such duty cycles to see whether there is any appreciable increase in the pulse intensity after the cycle of operation. The methods of discussion have been discussed in an earlier chapter.

9.3 Impulse Testing

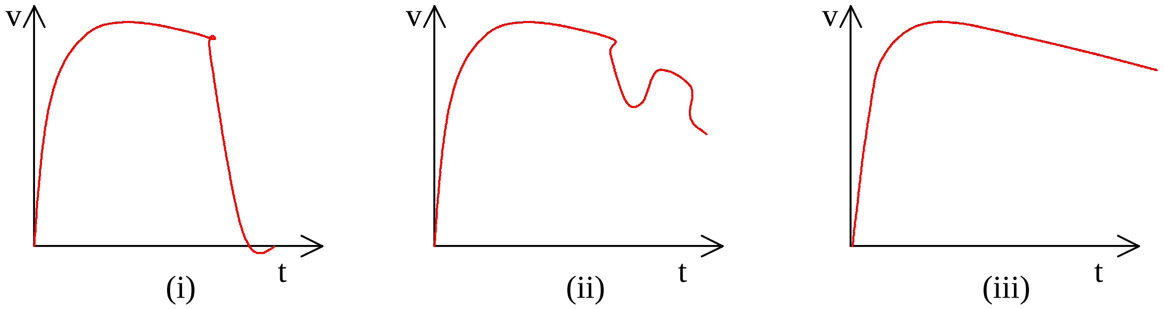

Figure 9.6 - Observed impulse waveforms

These are done as tests on sample of apparatus. The impulse test level is determined by the operating level (4 to 5 times the normal operating value) Apply on to the sample a certain number (say 10) positive impulse and 10 negative impulses of this particular value. They should withstand this voltage without any destruction.

To test the ultimate impulse strength, apply increasing amounts of impulse voltage until destruction occurs; during the tests it is necessary to see whether there is any damage. The damage may not be immediately visible, so we have it on a high frequency (single sweep and high speed) oscilloscope.
In the event of complete damage, breakdown of the insulator due to the application of the impulse voltage will be indicated as in (i). If the insulator has suffered only a minor damage the wave form would show no distortion , but would show as in (ii). If there is no damage caused due to the impulse, the waveform will be complete and undistorted as in (iii).

In testing high voltage insulators whose actual breakdown is in air (i.e flashover takes place before breakdown of insulator) the porcelain itself can be tested by immersing the whole insulator in liquid of high permeability so that there would be no outside flashover, and actual breakdown of the insulator would occur.

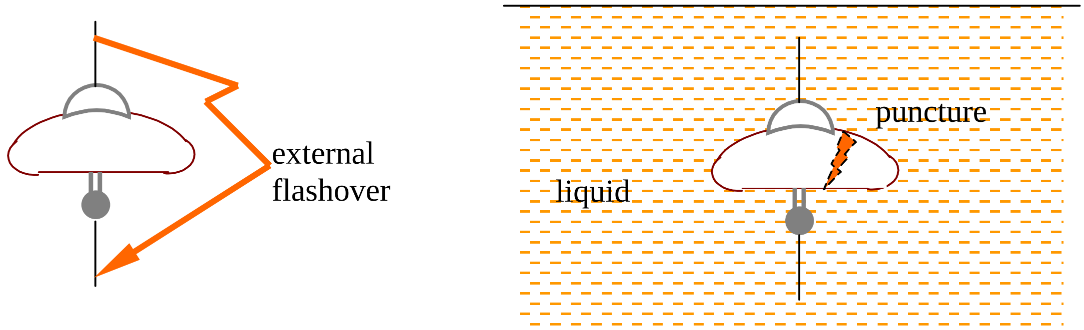

Figure 9.7 - Breakdown of insulator unit

In specifying the flashover characteristic in air we give the 50% flashover characteristic.This is done as flashover occur at the same voltage on each application of the impulse . We apply different values of test voltages (impulse) and the voltage at which there is 50% probability of breakdown is taken as 50% flashover voltage.The impulse flashover voltage also depends on the time lag of the applied impulse before flashover time lag of the applied impulse before flashover occurs. Thus we have also got to determine the time lag characteristics for breakdown.

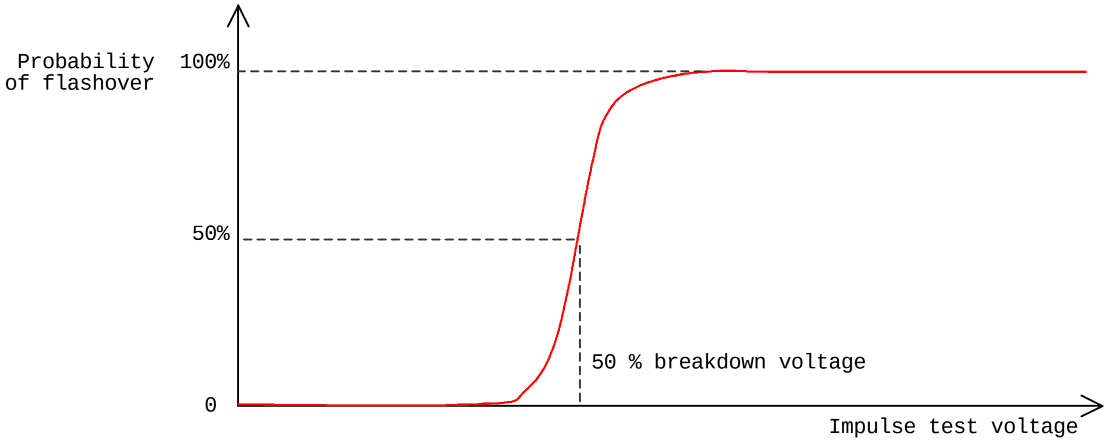

Figure 9.8 - Probability of flashover

If the voltage remains above a critical value long enough, flashover occurs.

The time lag before flashover occurs depends on the statistical time lag and on the formation time lag.

Depending on the volume of space between the gap, and also depending on the nature of shielding, a certain time will be taken for enough free electrons to be set free.This is the statistical time lag.

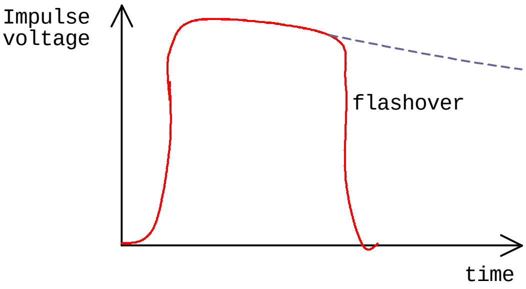

Figure 9.9 - Chopped impulse waveform

Once the electrons appear, depending on the voltage applied, they multiply and ionise the space. once the space becomes conducting, flashover occurs. This is formation time lag.

To determine the time lag characteristic of a device, we can use the impulse generator to generate impulses of gradually increasing amplitude and determine the time of breakdown. At each value, the test must be repeated a number of times so as to obtain consistent values.

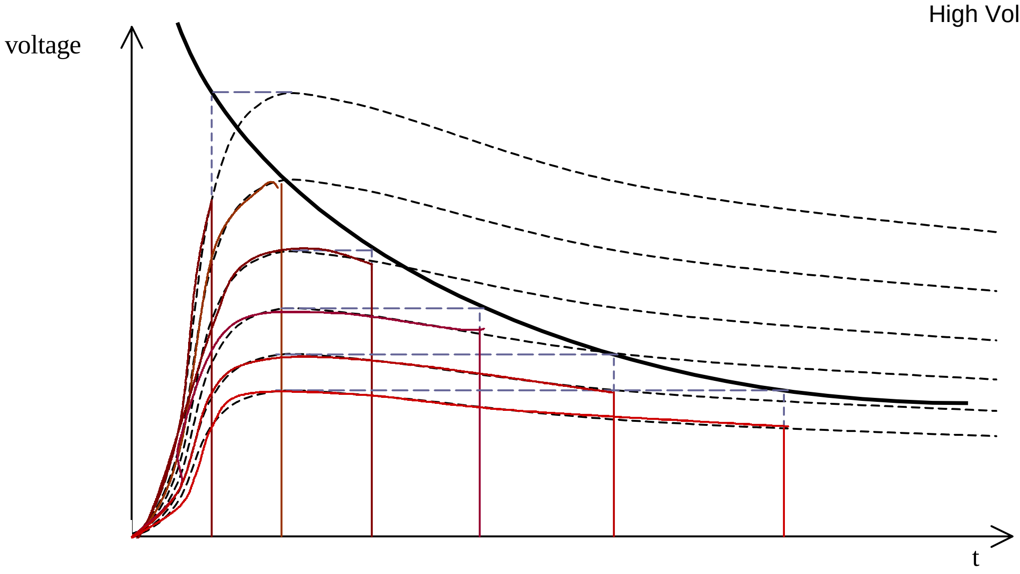

Figure 9.10 - Time lag characteristic

This type of characteristic is important in designing insulators.If a rod gap is to protect a transformer. Then the breakdown voltage characteristic of the rod gap must be less than that of the transformer so as to protect it. If the characteristic cross, protection will be offered only in the region where the rod gap characteristic is lower than that of the transformer.

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

In obtaining the breakdown characteristic of a transformer we do not attempt such tests that cause total destruction on transformers as they are expensive. What is done is we take a sample of the material used as insulators for the transformers and then apply these tests till puncture takes place. Thus the transformer characteristic is obtained by such tests on samples.

To obtain one point on the voltage vs time lag characteristic we would have to do a large number of tests and take the mean,as these values vary from sample to sample. The sample would have to be surrounded by a liquid material of high permittivity so that external flashover would not occur.

The impulse test voltage recommended by I.E.C. (International Electrotechnical Commission) are given in the table 9.1.

The recommendation is that device when subjected to this voltage should not suffer permanent damage or minor partial damage. The voltage is set at slightly less than the withstand voltage and gradually increase to test value. About 10 positive impulses and 10 negative impulses are applied.

9.4 Voltage Distribution in a Transformer Winding

Consider the entering of an impulse voltage on the terminating transformer, as shown in figure 9.11.

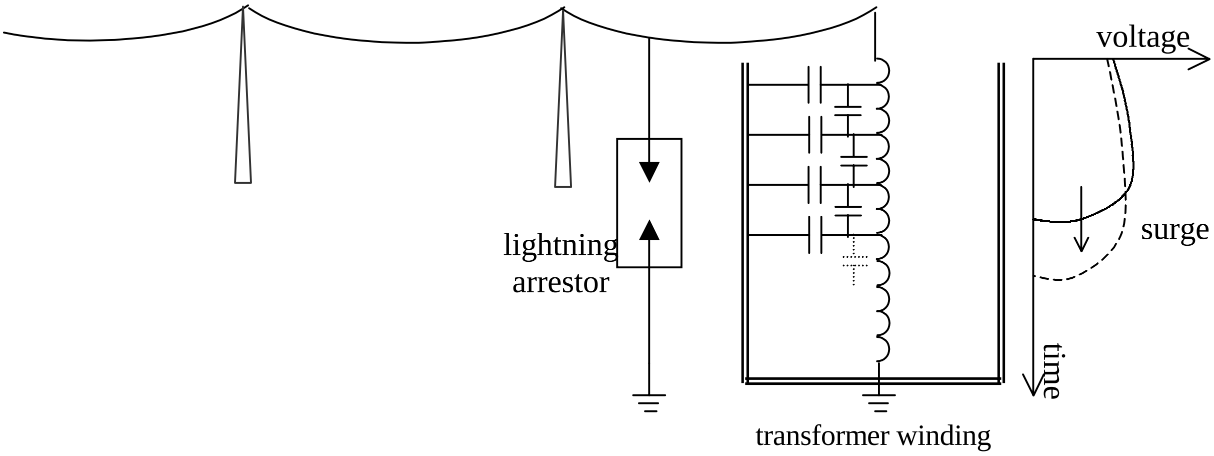

Figure 9.11 - Surge propagation in transformer winding

Due to the presence of the interwinding capacitance and the capacitances to earth of the transformer windings, the upper elements of the transformer windings tend to be more heavily stressed than the lower portions.

Due to the velocity of propagation of the impulse voltage would not be evenly distributed in the winding. Due to sharp rise of the voltage of the surge. there is a large difference of voltage caused in the winding as the wave front travels up the winding. Thus there would be an overvoltage across adjacent windings.

Depending on the termination, there will be reflections at the far end of the winding. If the termination is a short circuit, at the lowest point the voltage wave whose amplitude is same as the original wave but of opposite polarity is reflected. For a line which is open circuited, the reflected wave would be of the same magnitude and of the same sign.

Arising out of the reflections at the far end , there would be some coils heavily stressed. The position of the heavily stressed coils depending on the velocity of propagation.

If flashover occurs at the gap (lightning arrestor) the voltage of the impulse suddenly drops to zero when flashover occurs. This can be represented by a full wave, and a negative wave starting from the time flashover occurs. The chopped wave, though it reduces the voltage of the surge to zero, will have a severe effect of the winding due to sharp drop in the voltage. Thus it is always necessary to subject the transformer during tests to chopped wave conditions. Generally the method is to apply full-waves and see whether damage has occurred and then to apply the chopped waves and to see whether damage has occurred and then to apply the chopped waves and to see whether damage has occurred.

Example

A rectangular voltage V is impressed at the line terminal of a winding of a high voltage transformer , the neutral point being isolated from earth.The capacitance to earth of the complete winding is Cw.Prove that the voltage at a point in the winding distant X from the neutral is

$$v_x = V \cdot \frac{\cosh \frac{a}{l} x}{\cosh a}, \quad \text{where } a^2 = \frac{C_g}{C_w}, \quad l = \text{length of winding}$$

If C_g = 900 pF and Cw = 10 pF , calculate the ratio of the maximum initial voltage gradient in the winding to the average voltage gradient.How will the initial voltage distribution in the winding be effected if the wavefront has a duration of several microseconds ?

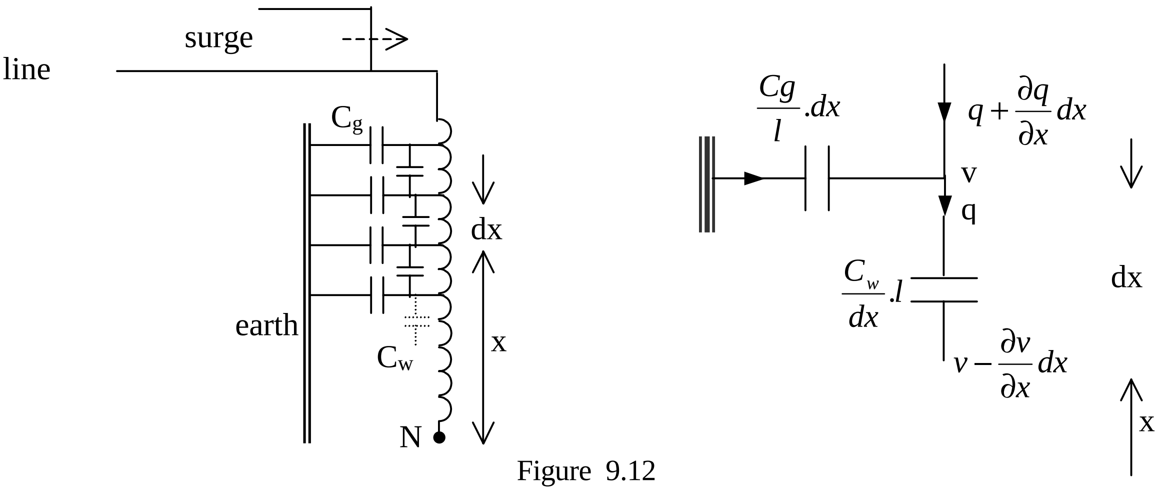

Figure 9.12

In the case of a voltage with a vertical front incident on the transformer winding , the voltage variation being instantaneous , the charging up is instantaneous and the presence of the inductance of the winding may be neglected.

$$\text{Thus,}\quad \frac{\partial q}{\partial x}.dx = \frac{C_g}{l}.dx.v, \qquad \frac{\partial v}{\partial x}.dx.\frac{C_w}{dx}.l = q$$

$$\therefore \qquad \frac{\partial q}{\partial x} = \frac{C_g}{l}.v, \qquad C_w.l.\frac{\partial v}{\partial x} = q$$

$$\therefore \qquad \frac{\partial^2 v}{\partial x^2} - \frac{C_g}{C_w}.\frac{1}{l^2}.v = 0$$

$$\therefore \qquad v = A\cosh\frac{a}{l}x + B\sinh\frac{a}{l}x$$

$$\text{at } x = l,\ v = V;\ \text{ so that } v = A\cosh\frac{a}{l}x + B\sinh\frac{a}{l}x$$

$$\text{at } x = 0, \quad q = 0, \quad \text{so that } q = C_w l.\frac{\partial v}{\partial x} = C_w l(A.\frac{a}{l}\sinh 0 + B.\frac{a}{l}\cosh 0) = 0$$

$$\therefore \quad B = 0, \quad \text{giving} \quad A = \frac{V}{\cosh a}$$

$$\therefore \quad v = \frac{V\cosh\frac{a}{l}.x}{\cosh a}, \quad \text{also} \quad \frac{\partial v}{\partial x} = \frac{V.\frac{a}{l}.\sinh\frac{a}{l}.x}{\cosh a} \quad \text{initially.}$$

$$\text{Substituting figures we have} \quad a^2 = \frac{900}{10} = 90, \quad \therefore \ a = 9.48$$

$$\text{Maximum initial voltage gradient (at } x = l) = V.\frac{a}{l}.\tanh(9.48) \approx V.\frac{a}{l}$$

$$\text{average stress} = \frac{1}{l}\int_o^l \frac{V.a}{l.\cosh a}.\sinh\frac{a}{l}.x.dx$$

$$= \frac{V}{l}.\left[1 - \frac{1}{\cosh a}\right] \approx \frac{V}{l}$$

$$\therefore \text{ maximum stress/average stress} = a \approx 9.48 \quad \text{initially}$$

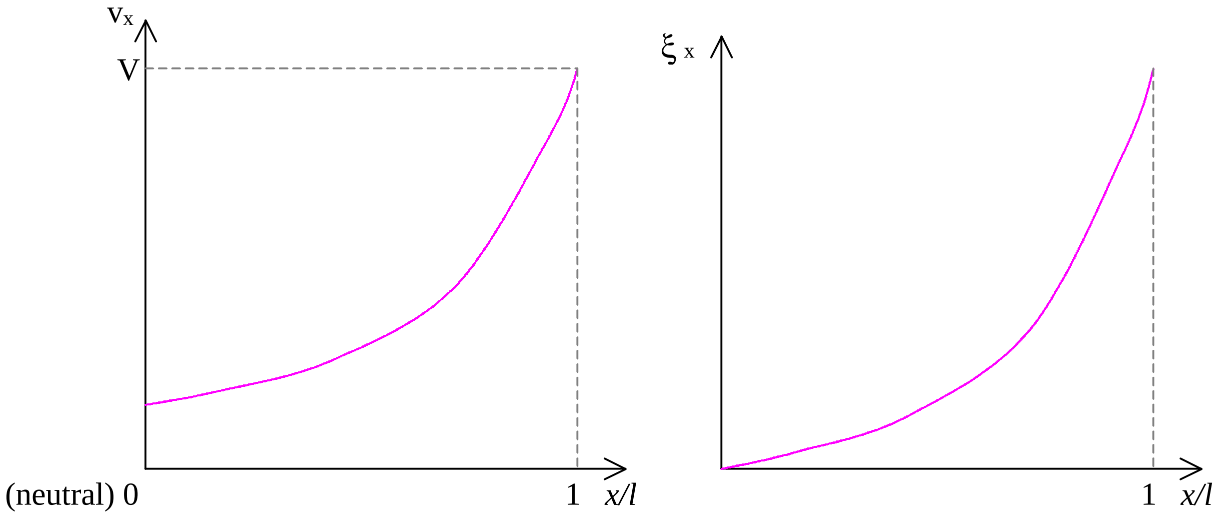

Figure 9.13 - variations of voltage and voltage gradient

The voltage distribution along the winding and the stress distribution (initially) are as shown in figure 9.13.

If the wave-front time is of several micro-seconds duration, the charging up would not be instantaneous, and the effect of the inductance during this period may not be neglected. The winding then behaves similar to a transmission line with distributed inductances and shunt capacitances. The effect of the surge would cause a lesser stress than in the case of a surge with a vertical front.

The differential equation governing the variation of the voltage would be a fourth order partial differential equation.

9.5 Tests on Insulators

The tests on insulators can be divided into three groups. These are the type tests, sample tests and the routing tests.

9.5.1 Type tests

These tests are done to determine whether the particular design is suitable for the purpose.

(a) Withstand Test: The insulator should be mounted so as to simulate practical conditions. A 1/50 μs wave of the specified voltage (corrected for humidity, air density etc.,) is applied. Flashover or puncture should not occur. [If puncture occurs, the insulator is permanently damaged]. The test is repeated five times for each polarity.

(b) Flash-over test: A 1/50 μs wave is applied. The voltage is gradually increased to the 50% impulse flash-over voltage. The test is done for both polarities. There should be no puncture of insulation during these tests.

(c) Dry One-minute test: The insulator, clean and dry, shall be mounted as specified and the prescribed voltage (corrected for ambient conditions) should be gradually brought up (at power frequency) and maintained for one minute. Thee shall not be puncture or flash-over during the test.

Dry flash-over test: The voltage shall then be increased gradually until flash-over occurs. This is repeated ten times. There shall be no damage to the insulator.

(d) One-minute Rain test: The insulator is sprayed throughout the test with artificial rain drawn from a source of supply at a temperature within 10^{o} C of the ambient temperature of the neighbourhood of the insulator. The rain is sprayed at an angle of $45\ ^{o}$ on the insulator at the prescribed rate of 3 mm/minute. The resistivity of the water should be 100 ohm-m ± 10%. The prescribed voltage is maintained for one minute.

Wet flash-over test: The voltage shall then be increased gradually until flash-over occurs. This is repeated ten times. There shall be no damage to the insulator.

(e) Visible discharge test: This states that after the room has been darkened and the specified test voltage applied, after five minutes, there should be no visible signs of corona.

9.5.2 Sample Tests

The sample is tested fully, up to and including the point of breakdown. This is done only on a few samples of the insulator.

(a) Temperature cycle test: The complete test shall consist of five transfers (hot-cold-hot-....), each transfer not exceeding 30 s.

(b) Mechanical loading test: The insulator shall be mechanically loaded up to the point of failure. When failure occurs, the load should not be less than 2000 lbf.

(c) Electro-mechanical test: The insulator is simultaneously subjected to electrical and mechanical stress. (i.e. it shall be subjected to a power frequency voltage and a tensile force simultaneously. The voltage shall be 75% of dry flash-over voltage of the unit. There should be no damage caused.

(d) Overvoltage test: The insulator shall be completely immersed in an insulating medium (oil), to prevent external flashover occurring. The specified overvoltage must be reached without puncture. The voltage is then gradually increased until puncture occurs.

(e) Porosity test: Freshly broken pieces of porcelain shall show no dye penetration after having been immersed for 24 hours in an alcoholic mixture of fushing at a pressure of 2000 p.s.i.

9.5.3 Routine Tests

These are to be applied to all insulators and shall be commenced at a low voltage and shall be increased rapidly until flash-over occurs every few seconds. The voltage shall be maintained at this value for a minimum of five minutes, or if failures occur, for five minutes after the last punctured piece has been removed. At the conclusion of the test the voltage shall be reduced to about one-third of the test voltage before switching off.

Mechanical Routine Test: A mechanical load of 20% in excess of the maximum working load of the insulator is applied after suspending the insulator for one minute. There should be no mechanical failure of the insulator.

9.6 Tests on Transformers

The following sequence of tests is generally adopted for transformers.

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

(1) Apply full wave impulse at 75% I.E.C. withstand value. Since the transformer should be able to withstand the I.E.C.voltage, there should be no damage to the transformer. The values of R and C in the impulse generator are adjusted after deriving to get the required waveform.

(2) Apply full wave at 100% I.E.C. withstand value and observe whether there is any breakdown. The waveform observed should be identical to applied waveform (other than for amplitude) : then the device has passed the test.

(3) Chopped wave test at 115% fullwave amplitude : For this kind of test , the impulse generator would have to be fitted with a rod gap or controlled trigatron type gap.

Since there is no voltage across insulator after chopping takes place, from the waveform it is not possible to say whether any damage has taken place.

(4) Therefore apply full wave test again and compare the wave and at 100% of I.E.C. voltage and see whether there is any distortion in the waveform indicating damage.(same as test 2)

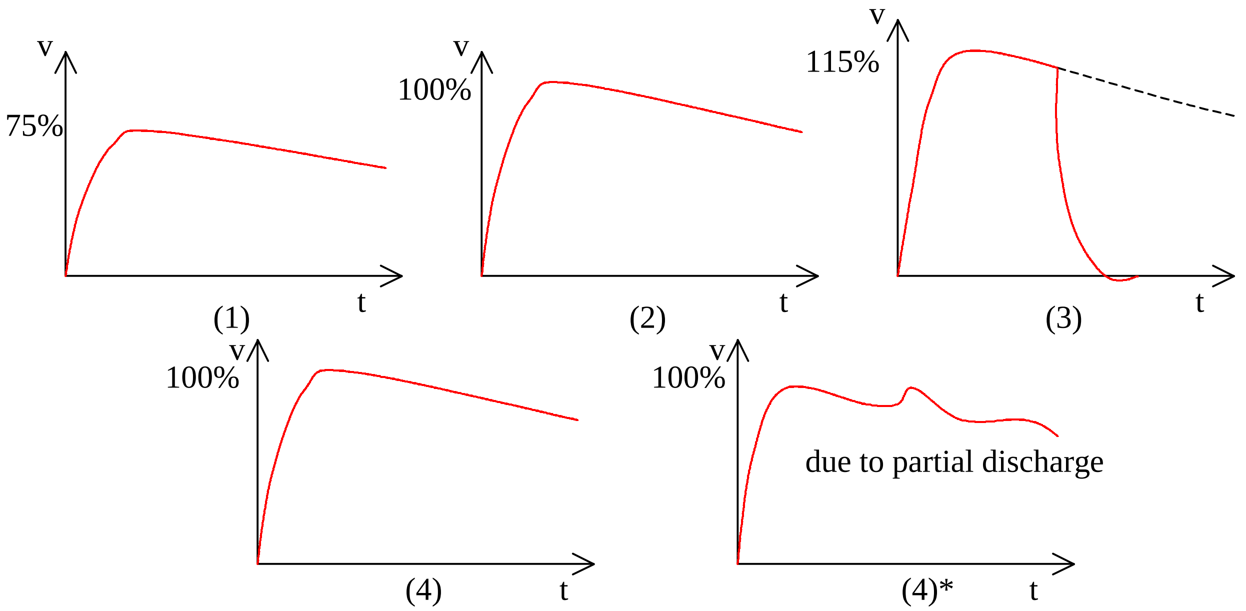

Figure 9.14 - Test waveforms

Since the chopped wave test exerts considerable stress on the winding, there is some controversy on the requirement of this test.

Thus the chopped wave requirement is not universal. In the American industry, the chopped wave is conducted at 150% full wave and such that the chopping is done at less than the peak value. In this case the stress might in fact be very much more than in the British method.

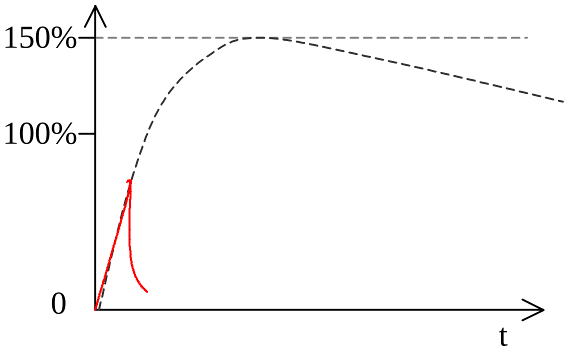

Figure 9.15 - chopped waveform at 150% voltage

9.7 Tests on Cables

For cables not in the supper voltage class the tests to be carried out are laid down in the appropriate British standard specifications.

Thus for paper impregnated insulated cables with lead or alloy sheaths, BS 480 Part I: 1954, the tests (purely electrical) are as follows;

(1) Acceptance Tests at Works

(a) Conductor resistance

(b) Voltage test: The applied voltage must be of approximately sinusoidal shape and of any frequency between 25 and 100 Hz. It must be increased gradually to the full value and maintain continuously for 15 minutes between conductors and between each conductors and sheath. The required values of the test voltages are tabulated in the specification and, as one illustration of the magnitude relative to the normal voltages, the figures for the 11 kV cables for earthed system are given in the table.

Voltage Designation	Belted Cables				Single-core, S.L. & Screened Cables	
	(i)		(ii)		(ii)	
	(1)	(2)	(1)	(2)	(1)	(2)
11 kV	24 kV	36 kV	14 kV	21 kV	15 kV	22 kV

where (i) Between conductors, (ii) Between any conductor and sheath
(1) Cable as manufactured, (2) After bending test

It will be seen that a voltage test is made before and after a bending test. In this the cable has to be bent around a cylinder of specified diameter to make one complete turn: it is then unwound and the process repeated in the opposite direction . The cycle of process has to be carried out three times.

(c) Dielectric power-factor / Voltage test (for 33 kV cables only) :

Each core of every drum of completed cable is tested for dielectric power factor at room temperature at the following a.c. single phase 50 Hz voltages : 9.5 kV , 19 kV , 28.5 kV, 38.0 kV.

The measured power-factor at normal working voltage shall not the value declared by the manufacturer and shall in no case exceed 0.01 .

The ionization - ie. the difference in power-factor between half the normal working voltage and the twice the normal working voltage - shall not exceed the value declared by the manufacture and shall no case exceed 0.0006 for 3-core screened cable or 0.001 for single core and screened S.L.type cable. The manufacturer can also be asked to produced evidence to show that the power factor at normal working voltage does not exceed 0.01 at series of temperature ranging from 15 C to 65 C.

(2) Sample test at works

These include bending test above and a dripping or drainage test for cables which have to be installed vertically.

(3) Test when installed

A voltage test similar to the above is carried out in the same manner but with some what reduced voltages. Thus the value of 24 kV, 14 kV and 11 kV for belted cable as manufactured and the value 15 kV for single core, S.L. and screened cables, become 20 kV, 11.5 kV and 12 kV respectively.

9.7.1 Tests on Pressurised Cables

Type approval tests, are stipulated for each design of cable and accessory. These tests are carried out on the maximum and the minimum conductor sizes for each design and voltage rating, and if successful, no further type tests are required, except in the case of changes in the design. The dielectric thermal resistance test included in the schedule is applied only to the minimum conductor sizes.

The tests are as follows:

(a) Loading cycle test: A test loop, comprising the cable and each type of accessory to be subjected to 20 load cycles to a minimum conductor temperature 5^o C in excess of the design value, with the cable energised to 1.5 times the working voltage. The cable to be tested at a stipulated minimum internal pressure.

(b) Thermal stability test (132 kV cables only): After test (a), the cable to be energised to 1.5 times working voltage and the loading current adjusted to give a maximum temperature 5^o C in excess of the design value. The current to be maintained at this value for a period of 6 hours, with other test conditions unaltered, to prove that the cable is thermally stable. For 275 kV cables, 1.33 times the working voltage is proposed.

(c) Impulse test: A test loop, comprising cable and each type of accessory to be subjected to 10 positive and 10 negative impulses at test voltage.
[Ex: Working voltage 132 kV, Impulse test voltage 640 kV, Peak working voltage ratio during impulse test 6.0]

(d) Cold power-factor/voltage test: The power factor of a 100 m length of cable to be measured at 0.5, 1.0, 1.5 and 2 times the working voltage with the cable at the stipulated minimum internal pressure. The values not to exceed the makers' guaranteed values.

(e) Dielectric thermal resistance test: The thermal resistance of the cable is measured.

(f) Mechanical Test of metallic reinforcement: A sample of cable to withstand twice the maximum specified internal pressure for a period of seven days.

(g) Binding test: The cable to be subjected to three binding cycles round a drum of diameter 20 times the diameter of the pressure retaining sheath. The sample then to withstand the routine voltage test carried out on all production lengths of cable.

9.8 Tests on High Voltage Bushings

9.8.1 Bushing

A single or composite structure carrying a conductor or providing passage for a conductor, through a partition, such as a wall or tank cover, or through a ring type current transformer and insulating it there from, it includes the means of attachment to the partition.

(i) Solid Bushing: A bushing consisting of a single piece of solid insulating material which is continuous between its outer surface and the inner conducting surface, which may be the main conductor or a conducting layer connected thereto.

(ii) Plain Bushing: A bushing consisting of a single piece of solid insulating material, with a space between the conductor and the inner surface of the solid insulation. The space is occupied by air, oil or other insulating medium which forms part of the insulation. [See item (iii)]

(iii) Oil filled Bushing: A bushing consisting of an oil-filled insulating shell, the oil providing the major radial insulation.
[Note: The conductor may be further insulated by a series of spaced concentric cylinders which may be provided with cylindrical conducting layers with the object of controlling the internal and external electric fields.]

(iv) Condenser busing: A bushing in which cylindrical conducting layers are arranged coaxially with the conductor within a solid body of insulating materials, (including materials impregnated with oils or other impregnants),the lengths and diameters of the cylinders being designed with the object of controlling the internal and external electric fields
[Note:A conductor bushing may be provided with a weather shield, in which case the intervening space may be filled with oil or other insulating medium.it is recommended that the term **condenser bushing with oil filling** be used for this type.]

9.8.2 Tests on Bushings

Rating of bushings: Some of the relevant clauses from the standard is given in the following sections.

Clause 4: A bushing shall be rated in terms of the following:

a) voltage(refer table 1, clause 5)
b) normal current (refer tables 2 and 3 clause 6)
c) frequency (refer clause 7)
d) insulation level (see clause 8 below)

Clause 8: The insulation level of bushing is designed by a voltage which the bushing must be capable of withstanding under the specified test conditions

For impulse tested bushings the rated insulation level is expressed as an impulse voltage value i.e. the impulse withstand voltage with 1/50 μs full wave

For non-impulse tested bushings the rated insulation level is expressed as a power frequency voltage value i.e. one minute dry withstand voltage.

Type Tests

Clause 14:	Power frequency test
Clause 15:	Impulse test
Clause 17:	Momentary dry withstand test (power frequency voltage)
Clause 18:	Visible discharge test (power frequency voltage)
Clause 19:	Wet withstand test (power frequency voltage)
Clause 20:	Puncture withstand test (power frequency voltage)
Clause 21:	Full wave withstand test (impulse voltage)
Clause 22:	Puncture withstand test (impulse voltage)

Sample Tests

Clause 23:	Temperature rise test
Clause 25:	Thermal stability test
Clause 26:	Temperature cycle test
Clause 27:	Porosity test

Routine Tests

Clause 29:	One minute dry withstand test (power frequency voltage)
Clause 30:	Oil lightness test
Clause 31:	Power factor voltage test

9.9 Tests on Porcelain and toughened glass insulators for overhead power lines

Specifications B.S.137:1960 (3.3 kV and upwards)

Classification of tests

Tests are divided into three groups, as shown.

Tests in Group I (Type tests)

These tests are intended to verify those characteristics of an insulator or set, pin or line post insulator which depend on shape and size of the insulator and of its metal parts and accessories. They are normally made once only to establish design characteristics.

Clause 18: Impulse withstand voltage tests and 50% dry impulse flashover test

Clause 19: Power frequency voltage one-minute wet test and wet flashover test

Clause 20: Visible discharge test

Tests in Group II (Sample tests)

These tests are for the purpose of verifying certain characteristics of a string insulator unit,line post insulator or pin insulator and pin and the quality of the materials used. They are made on insulators taken at random from every batch offered for acceptance.

Clause 23: Verification of dimensions

Clause 24: Temperature cycle test

Clause 25: Mechanical failing load test or

Clause 26: Electro-mechanical failing load test

Clause 27: Overvoltage tests

Clause 28: Porosity test on porcelain insulators

Clause 29: Thermal shock test on toughened glass insulators: The glass shall not shatter when the sample insulators are completely immerses in water at a temperature not exceeding 50 C, the temperature of the insulators immediately before immersion being at least 100 C higher than that of the water.

Clause 30: Galvanizing test: The galvanized samples shall be tested in accordance with B.S.729 and shall satisfy the requirements of that standard.

Tests in Group III (Sample tests)

These tests are for the purpose of eliminating insulators with manufacturing defects. They are made on every insulator offered for acceptance.

Clause 32: Electrical test on porcelain insulators

Clause 33: Thermal shock test on toughened glass insulators

Clause 34: Mechanical test on string insulator units: Every string unit shall be subjected to a tensile load of at least 40% of the specified minimum failing load, for a period of not less than 10 seconds.