INSULATION COORDINATION

Insulation Coordination is defined by the values of test voltages which the insulation of equipment under test must be able to withstand. In the earlier days of electric power, insulation levels commonly used were established on the basis of experience gained by utilities. As laboratory techniques improved, so that different laboratories were in closer agreement on test results, an international joint committee, the Nema-Nela Committee on Insulation Coordination, was formed and was charged with the task of establishing insulation strength of all classes of equipment and to establish levels for various voltage classification. In 1941 a detailed document18 was published giving basic insulation levels for all equipment in operation at that time. The presented tests included standard impulse voltages and one-minute power frequency tests.

In today‘s systems for voltages up to 245 kV the tests are still limited to lightning impulses and one-minute power frequency tests, see section 5.3.Above 300 kV, in addition to lightning impulse and the one-minute power frequency tests, tests include the use of switching impulse voltages. Tables 5.2and 5.3 list the standardized test voltages for 245 kV and above ½300 kV respectively, suggested by IEC for testing equipment. These tables are based on a 1992 draft of the IEC document on insulation coordination.

Table 5.7 Standard insulation levels for Range II (Um > 245 kV) (From IEC document 28

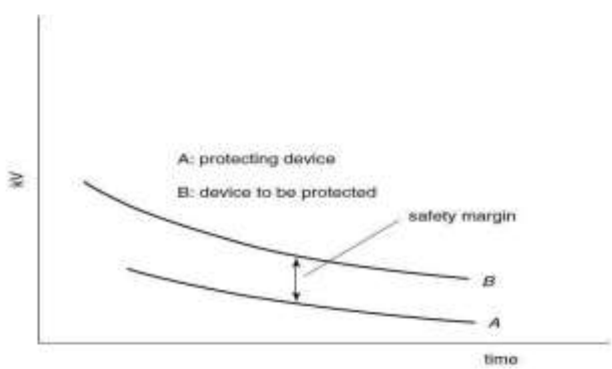
CO 58, 1992, Insulation coordination Part 1: definitions, principles and rules)

Highest Voltage for equipment Um KV (rms Value)	Longitudinal Insulation (+) KV Peak Value	Standard lighting withstand voltage phase to earth value (Peak Value)	Phase to phase (ratio to phase to earth peak value)	Standard lighting withstand voltage (Peak Value)
300	750	750	1.50	850 950
362	750	850	1.50	950 1050
420	850	850	1.50	950 1050
	850	950	1.50	1050 1175
	850	850	1.60	1050 1175
525	950	950	1.50	1175 1300
	950	1050	1.50	1300 1425

	950	950	1.70	1425
				1425
	950	1050	1.60	1550
				1800
	950	1175	1.50	1675
				1800
	950	1300	1.70	1800
				1425
765	1175	1425	1.60	1675
				1800
	1175	1550	1.70	1800

Statistical approach to insulation coordination

In the early days insulation levels for lightning surges were determined by evaluating the 50 per cent flashover values (BIL) for all insulations and providing a sufficiently high withstand level that all insulations would withstand. For those values a volt–time characteristic was constructed. Similarly the protection levels provided by protective devices were determined. The upper curve represents the common BIL for all insulations present, while the



lower represents the protective voltage level provided by the protective devices. The difference between the two curves provides the safety margin for the insulation system. Thus the Protection ratio=Max. Voltage it permits/Max.

This approach is difficult to apply at e.h.v. and u.h.v. levels, particularly for external insulations. Present-day practices of insulation coordination rely on a statistical approach which relates directly the electrical stress and the electrical strength. This approach requires knowledge of the distribution of both the anticipated stresses and the electrical strengths. The statistical nature of over voltages, in particular switching over voltages, makes it necessary to compute a large number of over voltages in order to determine with some degree of confidence the statistical over voltages on a system. The e.h.v. and u.h.v. systems employ a number of non-linear elements, but with today‘s availability of digital computers the distribution of over voltages can be calculated. A more practical approach to determine the required probability distributions of a system‘s over voltages employs a comprehensive systems simulator, the older types using analogue units, while the newer.

Employ real time digital simulators (RTDS).For the purpose of coordinating the electrical stresses with electrical strengths it is convenient to represent the overvoltage distribution in the form of probability density function (Gaussian distribution curve as shown in Figure) and theinsulation breakdown probability by the cumulative distribution function. The knowledge of these distributions enables us to determine the _risk of failure‘. If Va is the average value of overvoltage, Vk is the kth value of over voltage, the probability of occurrence of overvoltage is p0Vk du, where as the probability of breakdown is PbVkor the probability that the gap willbreak down at an overvoltage Vk is PbVkp0Vk du. For the total voltage range we obtain for the total probability of failure or _risk of failure‘.

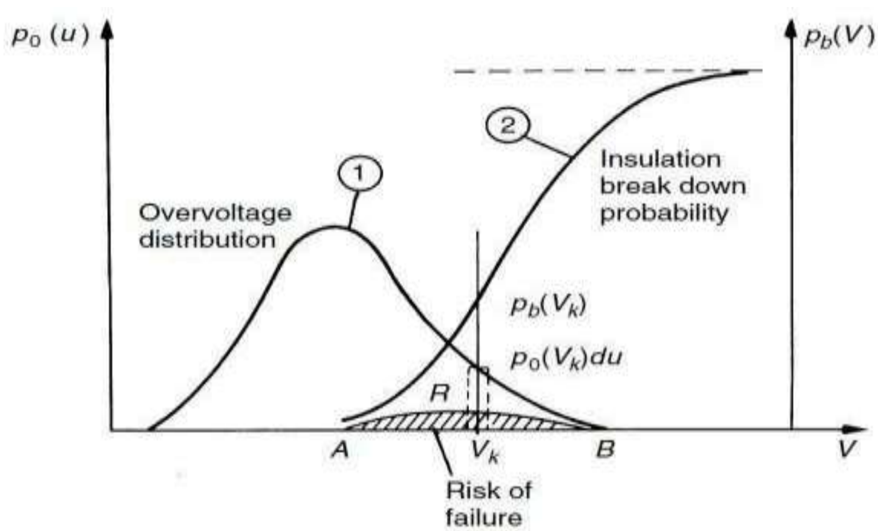


Figure: Method of describing the risk of failure.

1. over voltage distribution–Gaussian function. 2. Insulation breakdown probability–cumulative distribution)

$$R = \int_0^{\infty} Pb(Vk)P0(Vk)du$$

The risk of failure will thus be given by the shaded area under the curve R. In engineering practice it would become uneconomical to use the complete distribution functions for the occurrence of overvoltage and for the withstand of insulation and a compromise solution is accepted as shown in Figs 5.18 (a) and (b) for guidance. Curve (a) represents probability of occurrence of over voltages of such amplitude Vs that only 2 per cent (shaded area) has a chance to cause breakdown. VS are known as the _statistical overvoltage‘. In Fig. 5.18(b) the voltage Vw is so low that in 90 per cent of applied impulses, breakdown does not occur and such voltage is known as the _statistical withstand voltage‘ Vw.

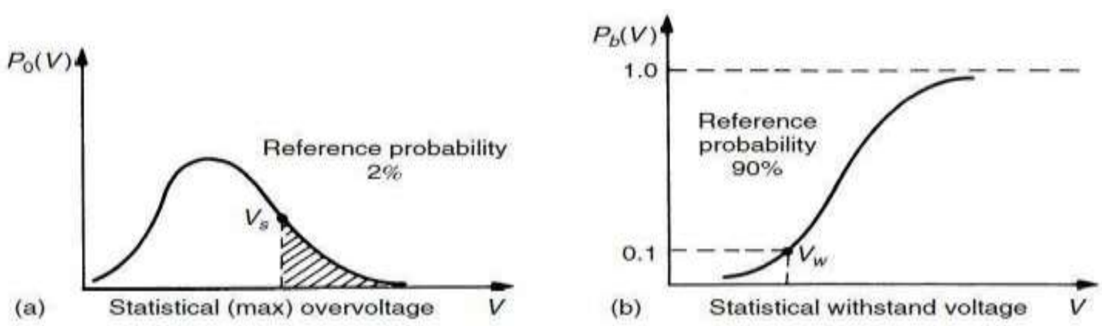


Figure: 5.18 Reference probabilities for overvoltage and for insulation withstand strength

In addition to the parameters statistical overvoltage _VS‘ and the statistical withstand voltage _VW‘ we may introduce the concept of statistical safety factor 4. This parameter becomes readily understood by inspecting Figs 5.19(a) to (c) in which the functions Pb V and p0Vk are plotted for three different cases of insulation strength but keeping the distribution of overvoltage occurrence the same. The density function p0Vkis the same in (a) to (c) and the cumulative function giving the yet undetermined withstand voltage is gradually shifted along the V-axis towards high values of V.

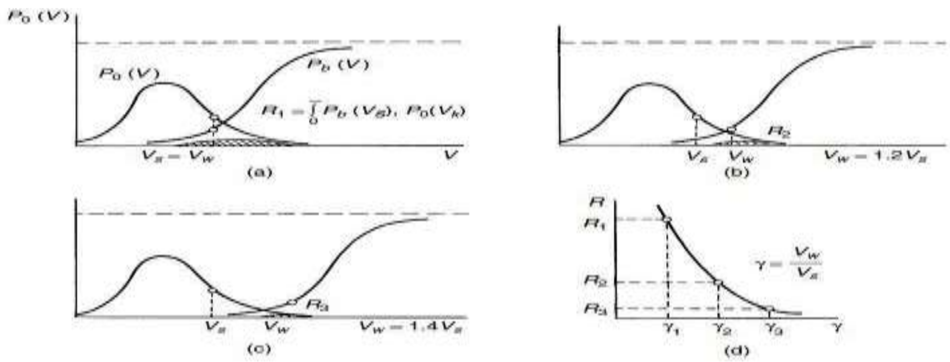


Figure: 5.19 The statistical safety factor and its relation to the risk of failure

This corresponds to increasing the insulation strength by either using thicker insulation or material of higher insulation strength. As a result of the relative shift of the two curves [PbV and p0Vk] the ratio of the values Vw/Vs will vary. This ratio is known as the statistical safety factor.

TESTING OF BUSHINGS

Bushings are an integral component of high voltage machines. A bushing is used to bring high voltage conductors through the grounded tank or body of the electrical equipment without excessive potential gradients between the conductor and the edge of the hole in the body. The bushing extends into the surface of the oil at one end and the other end is carried above the tank to a height sufficient to prevent breakdown due to surface leakage.

Following tests are carried out on bushings:

(i) Power Factor Test

The bushing is installed as in service or immersed in oil. The high voltage terminal of the bushing is connected to high voltage terminal of the Schering Bridge and the tank or earth portion of the bushing is connected to the detector of the bridge. The capacitance and p.f. of the bushing is measured at different voltages as specified in the relevant specification and the capacitance and p.f. should be within the range specified.

(ii) Impulse Withstand Test

The bushing is subjected to impulse waves of either polarity or magnitude as specified in the standard specification. Five consecutive full waves of standard wave form (1/50 μ sec.) are applied and if two of them cause flash over, the bushing is said to be defective. If only one flash

(iii) Chopped Wave and Switching Surge Test

Chopped wave and switching surge of appropriate duration tests are carried out on high voltage bushings. The procedure is identical to the one given in (ii) above.

(iv) Partial Discharge Test

In order to determine whether there is deterioration or not of the insulation used in the bushing, this test is carried out. The shape of the discharge is an indication of nature and severity of the defect in the bushing. This is considered to be a routine test for High voltage bushings.

(v) Visible Discharge Test at Power Frequency

The test is carried out to ascertain whether the given bushing will give rise to ratio

interference or not during operation. The test is carried out in a dark room. The voltage as specified is applied to the bushing (IS 2099). No discharge other than that from the grading rings or arcing horns should be visible.

(vi) Power Frequency Flash Over or Puncture Test

(Under Oil): The bushing is either immersed fully in oil or is installed as in service condition. This test is carried out to ascertain that the internal breakdown strength of the bushing is 15% more than the power frequency momentary dry withstand test value.

Testing Of power capacitor

power capacitor are one of part of the modern power system. These are used to control the voltage profile of the system. Following tests are carried out on shunt power capacitors (IS 2834):

(i) Routine Tests

Routine tests are carried out on all capacitors at the manufacturer‘s premises. During testing, the capacitors should not breakdown or behave abnormally or show any visible deterioration.

(ii) Test for Output

Ammeter and Voltmeter can be used to measure the kVAr and capacitance of the capacitor. The kVAr calculated should not differ by more than –5 to +10% of the specified value for capacitor units and 0 to10% for capacitors banks. The a.c. supply used for testing capacitor should have frequency between 40 Hz to 60 Hz, preferably as near as possible to the rated frequency and the harmonics should be minimum.

(iii) Test between Terminals

Every capacitor is subjected to one of the following two tests for 10secs:

(iii) D.C. test; the test voltage being Vt = 4.3 V0

(iv) A.C. test Vt = 2.15 V0,

where V0 is the rms value of the voltage between terminals which in the test connection gives the same dielectric stress in the capacitor element as the rated voltage Vn gives in normal service.

(iv) Test between Line Terminals and Container (For capacitor units)

An a.c. voltage of value specified in column 2 of Table 5.1 is applied between the terminals (short-circuited) of the capacitor unit and its container and is maintained for one minute, no damage to the capacitor should be observed. Figures with single star represent values corresponding to reduced insulation level (Effectively grounded system) and with double star full insulation level (non-effectively grounded system).

(v) IR Test:

The insulation resistance of the test capacitor is measured with the help of a megger. The megger is connected between one terminal of the capacitor and the container. The test voltage shall be d.c. voltage not less than 500 volts and the acceptable value of IR is more than 50 megohms.

(vi) Test for efficiency of Discharge Device:

In order to provide safety to personnel who would be working on the capacitors, it is desirable to connect very high resistance across the terminals of the capacitor so that they get discharged in about a few seconds after the supply is switched off. The residual capacitor voltage after the supply voltage is switched off should reduce to 50 volts in less than one minute of the capacitor is rated up to 650 volts and 5 minutes if the capacitor is rated for voltage more than 650 volts. A d.c. voltage 2 × rms rated voltage of the capacitor is applied across the parallel combination of R and C where C is the capacitance of the capacitor under test and R is the high resistance connected across the capacitor. The supply is switched off and the fall in voltage across the capacitor as a function of time is recorded. If C is in microfarads and R in ohms, the time to discharge to 50 volts can be calculated from the formula $t = 2.3 \times 10^{-6} CR (\log_{10} V - 1.7)$ secs Where V is the rated rms voltage of the capacitor in volts.

Type Tests

The type tests are carried out only once by the manufacturer to prove that the design of capacitor complies with the design requirements:

(i) Dielectric Loss Angle Test (p.f. test):

High voltage Schering Bridge is used to measure dielectric power factor. The voltage applied is the rated voltage and at temperatures 27°C ± 2°C. The value of the loss angle tan δ should not be more than10% the value agreed to between the manufacturer and the purchaser and it should not exceed 0.0035for mineral oil impregnates and 0.005 for chlorinated impregnates.

(ii) Test for Capacitor Loss:

The capacitor loss includes the dielectric loss of the capacitor and the V2/R loss in the discharge resistance which is permanently connected. The dielectric loss can be evaluated from the loss angle as obtained in the previous test and V2/R loss can also be calculated. The total

power loss should not be more than 10% of the value agreed to between the manufacturer and consumer.

(iii) Stability Test:

The capacitor is placed in an enclosure whose temperature is maintained at ±2°C above the maximum working temperature for 48 hours. The loss angle is measured after 16 hours, 24 hours and 48 hours using High voltage Schering Bridge at rated frequency and at voltage 1.2 times the rated voltage. If the respective values of loss angle are tan δ1, tan δ2 and tan δ3, these values should satisfy the following relations (anyone of them):

(a) $\tan\delta_1 + \tan\delta_2 \le 2\tan\delta_2 < 2.1\tan\delta_1$ or (b) $\tan\delta_1 \ge \tan\delta_2 \ge \tan\delta_3$

(iv) Impulse voltage test between terminal and container:

The capacitor is subjected to impulse voltage of 1/50 μ sec. Wave and magnitude as stipulated in column 3 of Table 5.1. Five impulses of either polarity should be applied between the terminals (joined together) and the container. It should withstand this voltage without causing any flash over.

TESTING OF CIRCUIT BREAKERS

Equipments when designed to certain specification and is fabricated needs testing for its performance. The general design is tried and the results of such tests conducted on one selected breaker and are thus applicable to all others of identical construction. These tests are called the type tests. These tests are classified as follows:

(i) Short circuit tests:

- Making capacity test.
- Breaking capacity test.
- Short time current test.
- Operating duty test

2. Dielectric tests:

Power frequency test:

- One minute dry withstand test.
- One minute wet withstand test.
- Impulse voltage dry withstand test.

3. Thermal test.

4. Mechanical test

Once a particular design is found satisfactory, a large number of similar C.Bs. are manufactured for marketing. Every piece of C.B is then tested before putting into service. These tests are known as routine tests. With these tests it is possible to find out if incorrect assembly or inferior quality material has been used for proven design equipment. These tests are classified as

(i) operation tests (ii) mill volt drop tests, (iii) power frequency voltage tests at manufacturer's premises, and (iv) power frequency voltage tests after erection on site.

We will discuss first the type tests. In that also we will discuss the short circuit tests after the other three tests. Dielectric Tests The general dielectric characteristics of any circuit breaker or switchgear unit depend upon the basic design i.e. clearances, bushing materials, etc. upon correctness and accuracy in assembly and upon the quality of materials used. For a C.B. these factors are checked from the viewpoint of their ability to withstand over voltages at the normal service voltage and abnormal voltages during lightning or other phenomenon.

The test voltage is applied for a period of one minute between (i) phases with the breaker closed, (ii) Phases and earth with C.B. open, and (iii) across the terminals with breaker open. With this the breaker must not flash over or puncture.

These tests are normally made on indoor switchgear. For such C.Bs the impulse tests generally are unnecessary because it is not exposed to impulse voltage of a very high order. The

high frequency switching surges do occur but the effect of these in cable systems used for indoor switchgear are found to be safely withstood by the switchgear if it has withstood the normal frequency test. Since the outdoor switchgear is electrically exposed, they will be subjected to over voltages caused by lightning. The effect of these voltages is much more serious than the power frequency voltages in service. Therefore, this class of switchgear is subjected in addition to power frequency tests, the impulse voltage tests. The test voltage should be a standard 1/50 μsec wave, the peak value of which is specified according to the rated voltage of the breaker. A higher impulse voltage is specified for non-effectively grounded system than those for solidly grounded system. The test voltages are applied between (i) each pole and earth in turn with the breaker closed and remaining phases earthed, and (ii) between all terminals on one side of the breaker and all the other terminals earthed, with the breaker open. The specified voltages are withstanding values i.e. the breaker should not flash over for 10 applications of the wave. Normally this test is carried out with waves of both the polarities. The wet dielectric test is used for outdoor switchgear. In this, the external insulation is sprayed for two minutes while the rated service voltage is applied, the test overvoltage is then maintained for 30 seconds during which no flash over should occur. The effect of rain on external insulation is partly beneficial, insofar as the surface is thereby cleaned, but is also harmful if the rain contains impurities.

Thermal Tests

These tests are made to check the thermal behavior of the breakers. In this test the rated current through all three phases of the switchgear is passed continuously for a period long enough to achieve steady state conditions. Temperature readings are obtained by means of thermocouples whose hot junctions are placed in appropriate positions. The temperature rise above ambient, of conductors, must normally not exceed 40°C when the rated normal current is less than 800 amps and 50°C if it is 800amps and above.

An additional requirement in the type test is the measurement of the contact resistances between the isolating contacts and between the moving and fixed contacts. These points are generally the main sources of excessive heat generation. The voltage drop across the breaker pole is measured for different values of d.c current which is a measure of the resistance of current carrying parts and hence that of contacts.

Mechanical Tests

A C.B. must open and close at the correct speed and perform such operations without mechanical failure. The breaker mechanism is, therefore, subjected to a mechanical endurance type test involving repeated opening and closing of the breaker. B.S. 116: 1952 requires 500 such operations without failure and with no adjustment of the mechanism. Some manufacture feel that as many as 20,000operations may be reached before any useful information regarding the possible causes of failure maybe obtained. A resulting change in the material or dimensions of a particular component may considerably improve the life and efficiency of the mechanism.

Short Circuit Tests

These tests are carried out in short circuit testing stations to prove the ratings of the C.Bs. Before discussing the tests it is proper to discuss about the short circuit testing stations.

There are two types of testing stations; (i) field type, and (ii) laboratory type. In case of field type stations the power required for testing is directly taken from a large power system. The breaker to be tested is connected to the system. Whereas this method of testing is economical for high voltage C.Bs. it suffers from the following drawbacks:

- The tests cannot be repeatedly carried out for research and development as it disturbs the whole network.

- The power available depends upon the location of the testing stations, loading conditions, Installed capacity, etc.
- Test conditions like the desired recovery voltage, the RRRV etc. cannot be achieved conveniently. In case of laboratory testing the power required for testing is provided by specially designed generators.

This method has the following advantages:

1. Test conditions such as current, voltage, power factor, restricting voltages can be controlled accurately.
2. Several indirect testing methods can be used.
3. Tests can be repeated and hence research and development over the design is possible.

The limitations of this method are the cost and the limited power availability for testing the breakers.

TESTING OF INSULATORS

Various types of overhead line insulators are (i) Pin type (ii) Post type (iii) String insulator unit(iv) Suspension insulator string (v) Tension insulator.

Arrangement of Insulators for Test String insulator unit should be hung by a suspension eye from an earthed metal cross arm. The test voltage is applied between the cross arm and the conductor hung vertically down from the metal part on the lower side of the insulator unit.

Suspension string with all its accessories as in service should be hung from an earthed metal Cross arm. The length of the cross arm should be at least 1.5 times the length of the string being tested and should be at least equal to 0.9 m on either side of the axis of the string. No other earthed object should be nearer to the insulator string then 0.9 m or 1.5 times the length of the string whichever is greater. A conductor of actual size to be used in service or of diameter not less than 1 cm and length 1.5times the length of the string is secured in the suspension clamp and should lie in a horizontal plane.

The test voltage is applied between the conductor and the cross arm and connection from the impulse generator is made with a length of wire to one end of the conductor. For higher operating voltages where the length of the string is large, it is advisable to sacrifice the length of the conductor as stipulated above. Instead, it is desirable to bend the ends of the conductor over in a large radius. For tension insulators the arrangement is more or less same as in suspension insulator except that it should be held in an approximately horizontal position under a suitable tension (about 1000 Kg.).For testing pin insulators or line post insulators, these should be mounted on the insulator pin or line post shank with which they are to be used in service. The pin or the shank should be fixed in a vertical position to a horizontal earthed metal cross arm situated 0.9 m above the floor of the laboratory.

A conductor of 1 cm diameter is to be laid horizontally in the top groove of the insulator and secured by at least one turn of tie-wire, not less than 0.3 cm diameter in the tie-wire groove. The length of the wire Should be at least 1.5 times the length of the insulator and should over hang the insulator at least 0.9 mon either side in a direction at right angles to the cross arm. The test voltage is applied to one end of the conductor. High voltage testing of electrical equipment requires two types of tests: (i) Type tests, and (ii) Routine test. Type tests involves quality testing of equipment at the design and development level i.e. samples of the product are taken and are tested when a new product is being developed and designed or an old product is to be redesigned and developed whereas the routine tests are meant to check the quality of the individual test piece. This is carried out to ensure quality and reliability of individual test Objects.

High voltage tests include (i) Power frequency tests and (ii) Impulse tests. These tests are carried out on all insulators.

(i) 50% dry impulse flash over test

The test is carried out on a clean insulator mounted as in a normal working condition. An impulse voltage of 1/50 μ sec. wave shape and of an amplitude which can cause 50% flash over of the insulator, is applied, i.e. of the impulses applied 50% of the impulses should cause flash over. The polarity of the impulse is then reversed and procedure repeated. There must be at least 20 applications of the impulse in each case and the insulator must not be damaged. The magnitude of the impulse voltage should not be less than that specified in standard specifications.

(ii) Impulse withstand test

The insulator is subjected to standard impulse of 1/50 μ sec. wave of specified value under dry conditions with both positive and negative polarities. If five consecutive applications do not cause any flash over or puncture, the insulator is deemed to have passed the impulse withstand test. If out of five, two applications cause flash over, the insulator is deemed to have filed the test.

(iii) Dry flash over and dry one minute test

Power frequency voltage is applied to the insulator and the voltage increased to the specified value and maintained for one minute. The voltage is then increased gradually until flash over occurs. The insulator is then flashed over at least four more times, the voltage is raised gradually to reach flash over in about 10 seconds. The mean of at least five consecutive flash over voltages must not be less than the value specified in specifications.

(iv) Wet flash over and one minute rain test

If the test is carried out under artificial rain, it is called wet flash over test. The insulator is subjected to spray of water of following characteristics:

Precipitation rate 3 ± 10% mm/min. Direction 45° to the vertical

Conductivity of water 100 micro Siemens ± 10%Temperature of water ambient +15°C

The insulator with 50% of the one-min. rain test voltage applied to it, is then sprayed for two Minutes, the voltage rose to the one minute test voltage in approximately 10 sec. and maintained therefore one minute. The voltage is then increased gradually till flash over occurs and the insulator is then flashed at least four more times, the time taken to reach flash over voltage being in each case about10 sec. The flash over voltage must not be less than the value specified in specifications.

(v) Temperature cycle test

The insulator is immersed in a hot water bath whose temperature is 70° higher than normal water bath for T minutes. It is then taken out and immediately immersed in normal water bath for T minutes. After T minutes the insulator is again immersed in hot water bath for T minutes. The cycle is repeated three times and it is expected that the insulator should withstand the test without damage to the insulator or glaze. Here T = (15 + W/1.36) where W is the weight of the insulator in Kg‘s.

(vi) Electro-mechanical test

The test is carried out only on suspension or tension type of insulator. The insulator is Subjected to a 2½ times the specified maximum working tension maintained for one minute. Also, simultaneously 75% of the dry flash over voltage is applied. The insulator should withstand this test without any damage.

(vii) Mechanical test

This is a bending test applicable to pin type and line-post insulators. The insulator is subjected to a load three times the specified maximum breaking load for one minute. There should be no damage to the insulator and in case of post insulator the permanent set must be less than 1%. However, in case of post insulator, the load is then raised to three times and there should not be any damage to the insulator and its pin.

(viii) Porosity test

The insulator is broken and immersed in a 0.5% alcohol solution of fuchsine under a pressure of 13800 kN/m2 for 24 hours. The broken insulator is taken out and further broken. It should not show any sign of impregnation.

(ix) Puncture test

An impulse over voltage is applied between the pin and the lead foil bound over the top and side grooves in case of pin type and post insulator and between the metal fittings in case of suspension type insulators. The voltage is 1/50 μ sec. wave with amplitude twice the 50% impulse flash overvoltage and negative polarity. Twenty such applications are applied. The procedure is repeated for 2.5, 3, and 3.5 times the 50% impulse flash over voltage and continued till the insulator is punctured. The insulator must not puncture if the voltage applied is equal to the one specified in the specification.

(x) Mechanical routine test

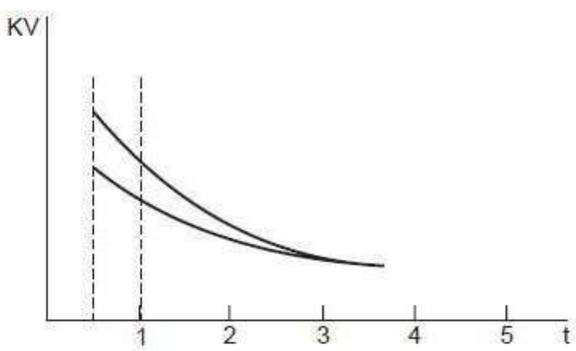
The string in insulator is suspended vertically or horizontally and a tensile load 20% in Excess of the maximum specified working load is applied for one minute and no damage to the string should occur.

TESTING OF POWER TRANSFORMERS

Transformer is one of the most expensive and important equipment in power system. If it is not suitably designed its failure may cause a lengthy and costly outage. Therefore, it is very important to be cautious while designing its insulation, so that it can withstand transient over voltage both due to switching and lightning. The high voltage testing of transformers is, therefore, very important and would be discussed here. Other tests like temperature rise, short circuit, open circuit etc. are not considered here. However, these can be found in the relevant standard specification. Partial Discharge Test The test is carried out on the windings of the transformer to assess the magnitude of discharges. The transformer is connected as a test specimen similar to any other equipment as discussed in and the discharge measurements are made. The location and severity of fault is ascertained using the travelling wave theory technique as explained. The measurements are to be made at all the terminals of the transformer and it is estimated that if the apparent measured charge exceeds 104picocoulombs, the discharge magnitude is considered to be severe and the transformer insulation should be so designed that the discharge measurement should be much below the value of 104 Pico-coulombs.

Impulse Testing of Transformer

The impulse level of a transformer is determined by the breakdown voltage of its minor insulation (Insulation between turn and between windings), breakdown voltage of its major insulation (insulation between windings and tank) and the flash over voltage of its bushings or a combination of these. The impulse characteristics of internal insulation in a transformer differ from flash over in air in two main respects.



Firstly the impulse ratio of the transformer insulation is higher (varies from 2.1 to 2.2) than that of bushing (1.5 for bushings, insulators etc.). Secondly, the impulse breakdown of transformer insulation in practically constant and is independent of time of application of impulse voltage.

Figure: Volt time curve of typical major insulation in transformer

Fig. shows that after three micro seconds the flash over voltage is substantially constant. The voltage stress between the turns of the same winding and between different windings of the transformer depends upon the steepness of the surge wave front. The voltage stress may further get aggravated by the piling up action of the wave if the length of the surge wave is large. In fact, due to high.

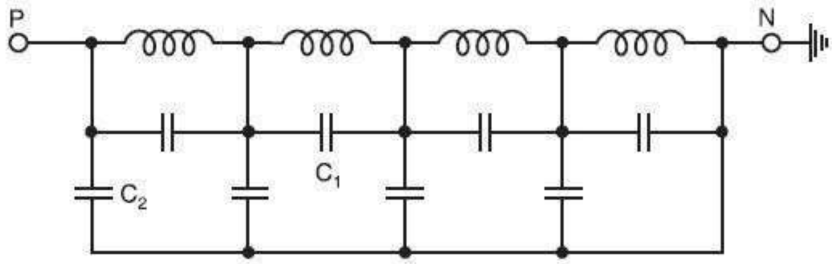
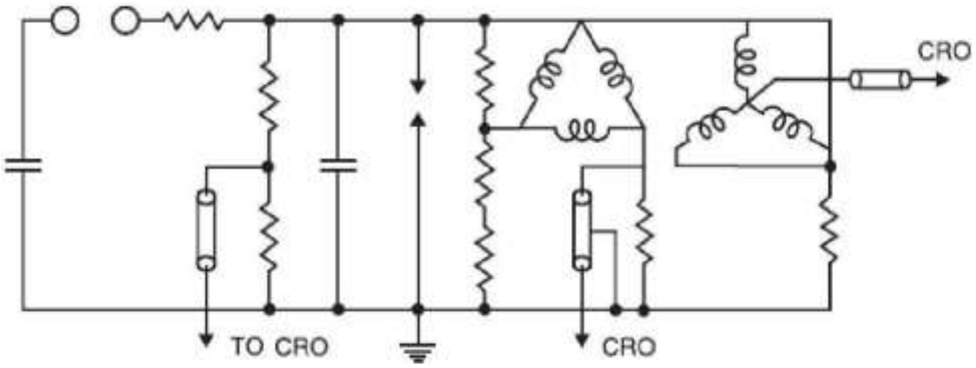


Figure: Equivalent circuit of a transformer for impulse voltage

Here C_1 represents inter-turn capacitance and C_2 capacitance between winding and the ground (tank). In order that the minor insulation will be able to

$$C_0 = \frac{P \times 10^8}{Z \times V^2} \mu F$$



withstand the impulse voltage, the winding is subjected to chopped impulse wave of higher peak voltage than the full wave. This chopped wave is produced by flash over of a rod gap or bushing in parallel with the transformer insulation. The chopping time is usually 3 to 6 micro seconds. While impulse voltage is applied between one phase and ground, high voltages would be induced in thesecondary of the transformer. To avoid this, the secondary windings are short-circuited and finally connected to transformer and hence poses problem in adjusting the wave front and wave tail timings of wave. Also, the minimum value of the impulse capacitance required is given by

Where P = rated MVA of the transformer Z = per cent impedance of transformer. V = rated voltage of transformer. Fig. 5.3 shows the arrangement of the transformer for impulse testing. CRO forms an integral part of the transformer impulse testing circuit. It is required to record to wave forms of the applied voltage and current through the winding under test.

Impulse testing consists of the following steps:

(iv) Application of impulse of magnitude 75% of the Basic Impulse Level (BIL) of the transformer under test.

(v) One full wave of 100% of BIL.

(vi) Two chopped wave of 115% of BIL.

(vii) One full wave of 100% BIL and

(viii) One full wave of 75% of BIL.

During impulse testing the fault can be located by general observation like noise in the tank or smoke or bubble in the breather. If there is a fault, it appears on the Oscilloscope as a partial of complete collapse of the applied voltage. Study of the wave form of the neutral current also indicated the type of fault. If an arc occurs between the turns or form turn to the ground, a train of high frequency pulses are seen on the oscilloscope and wave shape of impulse changes. If it is a partial discharge only, high frequency oscillations are observed but no change in wave shape occurs. The bushing forms an important and integral part of transformer insulation. Therefore, its impulse flash over must be carefully investigated. The impulse strength of the transformer winding is same for either polarity of wave whereas the flash over voltage for bushing is different for different polarity. The manufacturer, however, while specifying the impulse strength of the transformer takes into consideration the overall impulse characteristic of the transformer.