HIGH VOLTAGE TESTING OF ELECTRICAL EQUIPMENTS

higher and higher operating voltages (say above 1000 kV) certain problems are associated with the testing techniques. Some of these are:

(*i) Dimension of high voltage test laboratories.*
(*ii) Characteristics of equipment for such laboratories.*
(*iii) Some special aspects of the test techniques at extra high voltages.*

The dimensions of laboratories for test equipments of 750 kV and above are fixed by the following main considerations:

(*i) Figures (values) of test voltages under different conditions.*

(*ii) Sizes of the test of equipments in a.c., d.c. and impulse voltages.*

(*iii) Distances between the objects under high voltage during the test period and the earthed* surroundings such as floors, walls and roofs of the buildings. The problems associated with the characteristics of the equipments used for testing are summarised here.

Terms used in standards

1. Normal voltage of three phase system
2. Highest voltage of three phase system
3. External insulation
4. Creepage distance
5. Internal insulation
6. Disruptive discharge voltage
7. Self restoring insulation
8. Non Self restoring insulation
9. Flashover
10. Over voltage
11. Power frequnecy over voltage
12. Lightning over voltage
13. Switching over voltage
14. Withstand over voltage
15. 100% flash over voltage
16. 50% flash over voltage
17. Reference atmospheric conditions

TESTING OF OVERHEAD LINE 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.

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.

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.

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.*

(*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.

(*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.

(*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.

(*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.*
Here *T = (15 + W/1.36) where W is the weight of the insulator in kgs.*

(*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.

(*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.

(*viii) Porosity test.*

The insulator is broken and immersed in a 0.5% alcohol solution of fuchsin under a pressure of 13800 kN/m2 for 24 hours. The

(*ix) Puncture test.*

The voltage is 1/50 μ sec. wave with amplitude twice the 50% impulse flash over voltage and negative polarity. Twenty such applications are applied. The procedure is repeated for 2.5, 3, 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 cables

High voltage power cables have proved quite useful especially in case of HV d.c. transmission.

Preparation of Cable Sample

The length of the sample cable varies between 50 cms to 10 m.

A cable is subjected to following tests:

(i) Bending tests.
The cable is bent round a cylinder of specified diameter to make one complete turn. It is then unwound and rewound in the opposite direction. The cycle is to be repeated three times.

(ii) Loading cycle test.
A test loop, consisting of cable and its accessories is subjected to 20 load cycles with a minimum conductor temperature 5°C in excess of the design value and the cable is energized to 1.5 times the working voltage.

(*iii) Thermal stability test.*
the cable is energized with a voltage 1.5 times the working voltage for a cable of 132 kV rating (the multiplying factor decreases with increases in operating voltage) and the loading current is so adjusted that the temperature of the core of the cable is 5°C higher than its specified permissible temperature.

(*iv) Dielectric thermal resistance test.*
The ratio of the temperature difference between the core and sheath of the cable and the heat flow from the cable gives the thermal resistance of the sample of the cable.

(*v) Life expectancy test.*
In order to estimate life of a cable, an accelerated life test is carried out by subjecting the cable to a voltage stress higher than the normal working stress.

(*vi) Dielectric power factor test.*
High Voltage Schering Bridge is used to perform dielectric power factor test on the cable sample. The power factor is measured for different values of voltages *e.g. 0.5, 1.0, 1.5 and 2.0 times the* rated operating voltages.

(*vii) Power frequency withstand voltage test.*

Cables are tested for power frequency a.c. and d.c. voltages. During manufacture the entire cable is passed through a higher voltage test and the rated voltage to check the continuity of the cable.

(*viii) Impulse withstand voltage test.*

The test cable is subjected to 10 positive and 10 negative impulse voltage of magnitude as specified in specification, the cable should withstand 5 applications without any damage.

(*ix) Partial discharge test.*

Partial discharge measurement of cables is very important as it gives an indication of expected life of the cable and it gives location of fault, if any, in the cable.

TESTING OF BUSHINGS

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 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 and 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.

(*iii) Chopped Wave and Switching Surge Test*

Chopped wave and switching surge of appropriate duration tests are carried out on high voltage bushings.

(*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.

(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.

(*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 CAPACITORS

Power capacitors is an integral 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 capacitor 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 to 10% 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 10 secs:

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

(*b) 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 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.

Power frequency and impulse test voltages
(Between terminals and the container)

System Voltage kV (rms)	*Power Frequency Test Voltage kV (rms)*	*Impulse Test Voltage kV (peak)*
12	28	75
24	50	125
36	70	170
72.5	140	325
145	230*	550*
	275**	650**
245	395*	900*
	460**	1050**

(*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*

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^{0}C

The value of the loss angle tan δ should not be more than 10% the value agreed to between the manufacturer and the purchaser and it should not exceed 0.0035 for mineral oil impregnants and 0.005 for chlorinated impregnants.

(ii) Test for Capacitor Loss

The capacitor loss includes the dielectric loss of the capacitor and the V^2/R *loss in the discharge resistance* which is permanently connected.

(iii) Stability Test

The capacitor is placed in an enclosure whose temperature is maintained +/-2^{0}C at 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):

$$(a)\ \tan\delta_1 + \tan\delta_2 \leq 2\tan\delta_2 < 2.1\tan\delta_1$$

or $$(b)\ \tan\delta_1 \geq \tan\delta_2 \geq \tan\delta_3$$

(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 . 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 overs.

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.

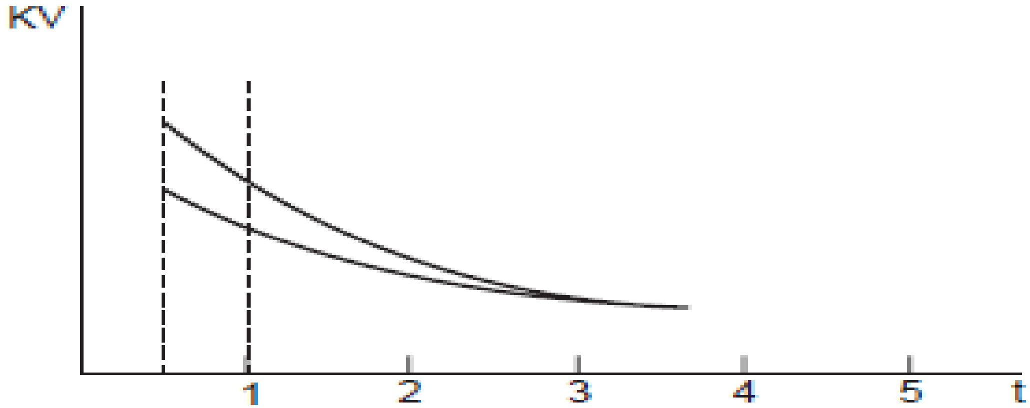
Partial Discharge Test

The test is carried out on the windings of the transformer to assess the magnitude of discharges.

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 10^4 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.



Volt time curve of typical major insulation in transformer

Fig. shows that after three micro seconds the flash over voltage is substantially constant.

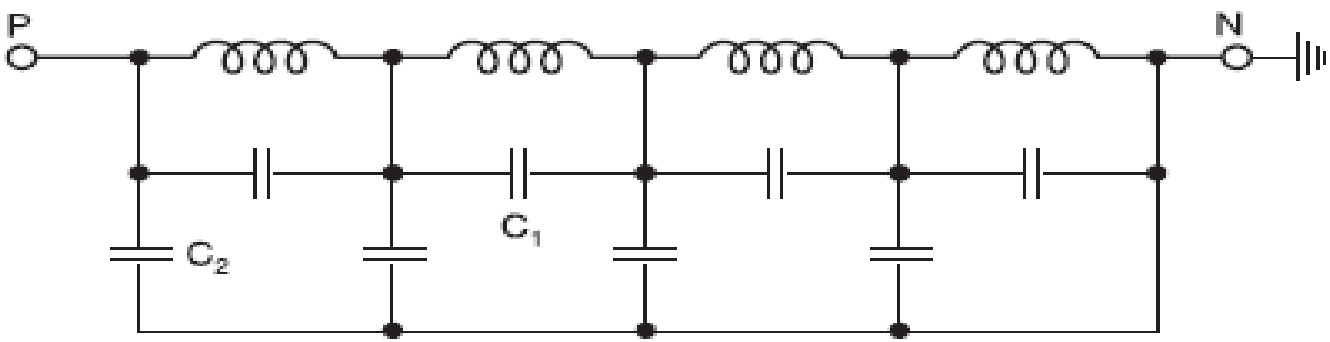


Fig. Equivalent circuit of a transformer for impulse voltage

Here *C1 represents inter-turn capacitance and C2 capacitance between winding and the ground* (tank). In order that the minor insulation will be able to withstand the impulse voltage, the winding is subjected to chopped impulse wave of higher peak voltage than the full wave.

the minimum value of the impulse capacitance required is given by

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

where P = rated MVA of the transformer Z = per cent impedance of transformer. V = rated voltage of transformer.

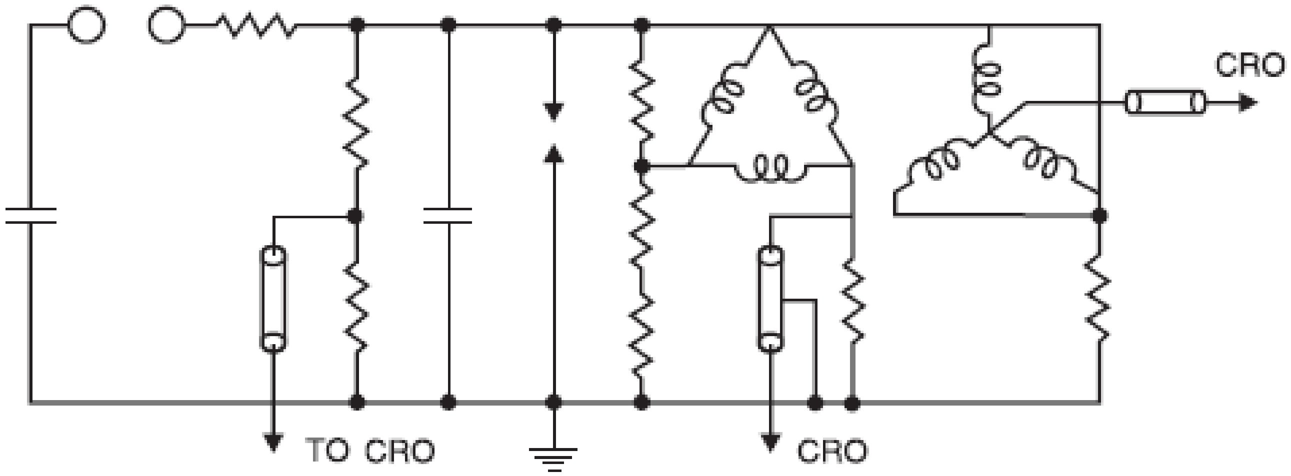


Fig. Arrangement for impulse testing of transformer

Impulse testing consists of the following steps:

(*i) Application of impulse of magnitude 75% of the Basic Impulse Level (BIL) of the transformer* under test.
(*ii) One full wave of 100% of BIL.*
(*iii) Two chopped wave of 115% of BIL.*
(*iv) One full wave of 100% BIL and*
(*v) 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.

TESTING OF CIRCUIT BREAKERS

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:

1. Short circuit tests:
(*i) Making capacity test.*
(*ii) Breaking capacity test.*
(*iii) Short time current test.*
(*iv) Operating duty test*

2. Dielectric tests:
(*i) Power frequency test:*
(*a) One minute dry withstand test.*
(*b) One minute wet withstand test.*
(*ii) Impulse voltage dry withstand test.*
3. Thermal test.
4. Mechanical test

Routine tests are classified as

(*i) operation tests,*

(*ii) millivoltdrop tests,*

(iii) power frequency voltage tests at manufacturer's premises, and

(iv) Power frequency voltage tests after erection on site.

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.

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.

The test voltage should be a standard 1/50 μ sec 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 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.

Thermal Tests

These tests are made to check the thermal behaviour 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 800 amps and above.

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.

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:

1. The tests cannot be repeatedly carried out for research and development as it disturbs the whole network.
2. The power available depends upon the location of the testing stations, loading conditions, installed capacity, etc.
3. 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, restriking 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.