# 12

# *Insulation Requirement and High Voltage Testing of Circuit Breakers*

Introduction—Conditions in Services—Design Aspects—Insulation failure—Some terms—Purpose of H.V. testing—Tests conducted—Application of voltage—definitions—Test voltage—Impulse tests—Power frequency voltage withstand test—Dry/wet—Test on auxiliary circuit—Standard test wave—Summary

## 12.1. INTRODUCTION

The current carrying parts of circuit-breakers are insulated from earth. Insulation is also provided between conducting parts of different phases. These insulations are subjected to normal voltages, internal and external overvoltages. The insulation in circuit-breakers serves three purposes :

— to provide insulation between phase and earth.
— to provide insulation in the contact-space during 'open' breaker.
— to provide insulation between phases.

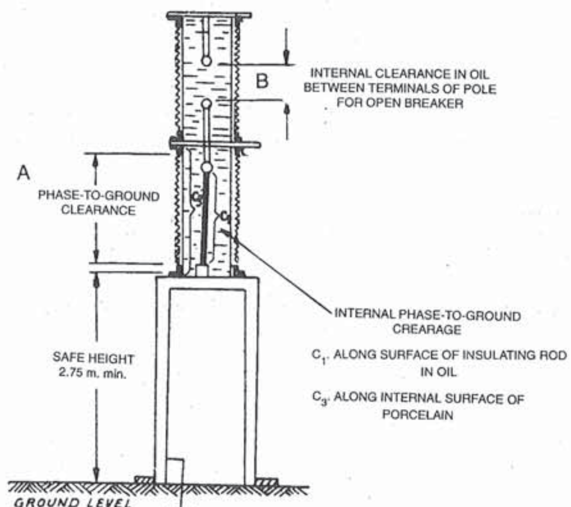



Fig. 12.1 Explaining insulation requirements of an outdoor circuit-breaker.



## 12.2. OVERVOLTAGES (Ref. Ch. 18. Ch. 46)

To insulators should withstand the over-voltages occurring due to internal and external causes.

The over-voltages are of three categories :

— Power frequency over-voltages, temporary over-voltages. *
— Impulse voltage surge due to lightning and switching.

The sustained power-frequency over-voltages occur due to regulation, Ferranti effect, etc. (Ch. 18)

The type of earthing (solid/resistance) influences the magnitude of over-voltages. For system above 145 kV the magnitude of internal over-voltages is significant. These are caused by switching, transients and travelling waves.

Impulse voltage surges occur due to lightning and switching. The switching impulse wave lasts for some hundreds of micro-seconds.

The performance of insulators is varified by power-frequency tests and impulse tests.

## 12.3. DESIGN ASPECTS (Ref. Sec. 2.18)

The following aspects should be considered

— Voltages to which the equipment is subjected during service conditions and during high voltage tests.
— The voltage gradient at conductor surfaces and along solid insulator surfaces at the voltages mentioned above.
— Technical data about electrical properties of the solid/liquid/gaseous dielectric materials employed in the equipment.

The stresses are calculated with the help of Electric Field Plots. Digital computation. The designs are based on intensive development tests (Ref. Ch. 10).

## 12.4. CAUSES OF FAILURE OF INSULATION

(*A*) **Tracking of Solid Insulators.** Tracking is formation of premanent conducting path along the surface of insulator. The following are the causes :

— Degradation of surface glaze by sparking.
— Presence of conduction film along the surface of insulator due to moisture, dirt, layer, etc.
— Mechanism of sparking along the surface arising due to breaking of leakage currents along the surface.

To prevent tracking the insulators should be dry, surface condition should be undamaged and clean. Insulators should be cleaned regularly.

(*B*) **Breakdown by discharge in solid Insulating Material.** The discharge occurs on the surface or within the insulator wherever the stresses exceed breakdown value. The surface discharge is caused by higher stresses, than permitted by the surface. The discharges within the insulator are caused by cavities, poor design/manufacture, presence of moisture.

The high voltage tests cause a harmful effect on the insulators. Though high voltage tests are intended to detect defects, the insulator suffers higher stresses during such tests and becomes weaker. Hence HV tests should be applied only when necessary, unnecessary, tests should be avoided.

(*C*) **Thermal Breakdown.** Heat is generated in the electrically stressed insulation, due to dielectric loss and conduction currents. Heat is imparted to insulation by the neighbouring current carrying parts. Heat is lost by the insulators by conduction, convection and radiation. Special cooling facility is provide wherever necessary. Resistivity of some dielectric materials decreases with

* Supply connection should be preferably to upper terminal and not to Lower terminal Isolators should be switched open after switching off the breaker.

increase in temperature whereas the loss angle increases. Thermal equilibrium implies a stable temperature at which the heat lost is equal to heat gained. If thermal stability is lost (say to inadequate cooling), the temperature rises indefinitely, leading to insulation failure.

Increasing the thickness of insulation indefinitely does not prevent insulation failure caused by thermal effects.

(*D*) **Failure of Electrical Insulation caused by Chemical Deterioration.** Some organic insulating materials show slow instability which increases with time and temperature. Paper loses its mechanical strength within a few days at temperature of the order of 150°C, even if it is protected from moisture and air. Oxygen and moisture cause rapid deterioration at such temperatures.

Moisture causes deterioration of transformer oil and other insulating materials whether solid/liquid/gaseous. Moisture has created special problems in $SF_6$ equipment. The moisture gets condensed on insulator surface and cause flashover.

At temperatures of 400—500°C, mica products slowly deteriorates, both electrically and mechanically.

(*E*) **Effect of Oxygen and Humidity.** Some organic and inorganic materials oxidise in presence of oxygen, ozone, particularly when exposed to light. Polythelene oxidises when exposed to bright sun-light. Rubber oxidises and cracks when exposed to light. Epoxy insulators are not suitable for outdoor use.

Some materials absorb moisture and lose electrical and mechanical strength under humid conditions due to hydrolysis. Polythelene, cellulose esters, other polysters are typical examples of such materials.

(*F*) **Incompatibility of Dielectric Materials.** Incompatibility means not suitable to be used together. Some dielectric materials are not suitable in particular assemblies because of their incompatibility with surrounding substance. For example, some synthetic materials deteriorate rapidly when placed adjacent to current carrying copper at temperature of about 80°C.

(*G*) **Electro-chemical Deterioration.** In some insulating materials, the impurities get dissociated under electric stresses, causing ionization of the material. Thereby the material deteriorates.

(*H*) **In Presence of Arc.** The insulating gas/oil used for arc extinction gets decomposed in presence of arc. Though the products of decomposition recombine after arc extinction, some remainder remains. Thereby the insulating properties of the dielectric arc affected.

(*I*) **Breakdown in Gaseous Medium.** When the dielectric stresses at sharp points increases above the limiting withstand value the internal flash-over can occur between the live point and earth or between live points. (Ref. Sec. 7.4 (*vii*)).

## 12.5. PURPOSE OF H.V. TESTING OF CIRCUIT-BREAKERS

A circuit-breaker connected in the system is subjected to high voltage transients due to switching and lighting. The insulation of circuit-breaker should not fail due to such voltage surges. The characteristics of the circuit-breaker insulation are specified by standards. These characteristics should be proved by conducting high voltages tests. According to the standard specifications, certain type tests and certain routine tests should be performed on circuit-breakers. The standards pertaining to H.V. testing cover the following aspects :

(1) To define the insulation characteristics of circuit-breakers.

(2) To standardize the insulation levels.

(3) To specify the tests intended to verify insulation level and conditions under which the test are made.

(4) To specify the markings on the rating plates of circuit-breakers indicating their insulation levels.

International Electrotechnical Commission (I.E.C.) and standards institutions like Indian Bureau of Standards, specify, standards covering the above aspects. The manufacturer normally conducts the type tests and routine tests in accordance with the above standards. The following description is based on I.E.C. Publication 56-4 on alternating current circuit-breakers and refers to circuit breakers for rated voltage above 1000 V.



## 12.6. TESTS ON A HIGH VOLTAGE CIRCUIT-BREAKERS

The insulation level (Refer Sec. 12.7) of a circuit-Breaker is verified by means of type test and routing tests.

Type tests are conducted on one or first few circuit-breakers of each type to prove the characteristics of that type. Routine tests are conducted on each circuit-breaker.

High voltage tests on circuit-breakers are the following :

**Type tests.** (*a*) Impulse voltage dry withstand test.

(*b*) One minute power frequency voltages dry withstand tests.

(*c*) One minute power frequency voltage wet withstand tests.

(For outdoor circuit-breaker only). Routine tests comprise one minute power frequency voltage dry withstand tests.

All the above mentioned tests are made on complete circuit-breaker.

### Application of Test Voltage

The impulse test voltage and power frequency test voltage are applied as follows :

(*A*) **With breaker closed.** Between terminals of each pole in turn and the frame of the circuit-breaker ; the terminals of all the other poles being connected to the frame of the circuit-breaker and earthed.

**Table 12.1. Power Frequency Voltage Withstand test and Impulse Voltage Withstand Test For Voltages upto 72.5 kV (Reference (Values)***

| *Circuit Breaker Rated Insulation Level* | | *One Minute Power Frequency Withstand Voltage* | |
|---|---|---|---|
| *Rated voltage of Circuit-Breakers kV (r.m.s.)* | *Standard impulse withstand voltage positive or negative polarity kV (peak)* | *For type tests kV (r.m.s.)* | *For routine test kV (r.m.s.)* |
| 3.6 | 45 | 21 | 16 |
| 7.2 | 60 | 27 | 22 |
| 12 | 75 | 35 | 28 |
| 17.5 | 95 | 45 | 38 |
| 24 | 125 | 55 | 50 |
| 36 | 170 | 75 | 70 |
| 52 | 250 | 105 | 110 |
| 72.5 | 325 | 140 | 140 |

**Table 12.2 (Above 72.5 kV Reference Values)***

| *Circuit Breaker Rated Insulation Level* | | | *One Minute Power Frequency Voltage withstand* | |
|---|---|---|---|---|
| *Standard Impulse Withstand Voltage* | | | *For type and Routine Tests* | |
| *Rated voltage kV (r.m.s)* | *Full insulation kV (peak)* | *Reduced insulation kV (peak)* | *Full insulation kV (r.m.s.)* | *Reduced insulation kV. (r.m.s).* |
| 100 | 450 | 380 | 185 | 150 |
| 123 | 550 | 450 | 230 | 185 |
| 145 | 650 | 550 | 275 | 230 |
| 170 | 750 | 650 | 325 | 275 |
| 245 | 1050 | 900 | 460 | 395 |
| 300 | — | 1050 | — | 460 |
| 420 | — | 1425 | — | 680 |

* These values are for familiarity. (Ref. Sec. 3.19.2)

(*B*) **With breaker open.** (*i*) Between the terminals of all the poles of the circuit-breaker connected together and frame of the circuit breaker.

(*ii*) Between one terminal of each pole and the other terminal of the same pole connected of the frame of the circuit-breaker. In multipole circuit-breaker the corresponding terminals of each pole are connected in parallel.

**Test Voltages.** Test voltages are specified by standards. Examples are given in Table 12.1 and 12.2.

## 12.7. SOME TERMS AND DEFINITIONS. (Ref. Sec. 3.19. 1/2. Ref. Fig. 12.1)

1. *Creepage Distance.* Shortest distance between two conducting parts along the surface of the insulating material.

2. *Clearance.* Shortest distance between two conducting parts along a stretched string.

3. *Clearance between Open Contacts.* Gap between open contacts.

4. *Clearance to earth.* Clearance between conductor and nearest earthed part.

5. *Clearance between poles.* Shortest distance between conducting parts of adjacent poles of the same breaker.

6. Amplitude Factor $= \dfrac{\text{Highest peak value of overvoltage}}{\text{Amplitude of power frequency recovery voltage}}$

7. *Insulation level of circuit-breaker.* It is the combination of rated voltage, the corresponding impulse withstand voltage and corresponding power frequency withstand voltage, which together characterize the insulation of the circuit breaker as regards its ability to withstand the electrical stresses. For the sake of convenience the rated insulation level of a circuit-breaker is designated by the rated voltage and impulse withstand voltage. BIL refers to Basic insulation level or Basic impulse level.

8. *Power frequency withstand voltage of circuit-breaker.* It is r.m.s. value of alternating voltage wave of power frequency (50 c/s) which the insulation of the circuit-breaker should withstand under specified conditions of test. (Ref. Sec. 3.19.2)

9. *Ground Clearance.* Distance between ground and the highest earthed point on equipment. (Ref. Fig. 12.1—Safe height).

10. *Impulse withstand voltage.* It is the amplitude of the standard voltage wave which the insulation of the circuit-breaker can withstand under specified test conditions.

11. *Indoor circuit-breaker.* It is the circuit-breaker which is designed for installation within a building or house such that it is projected from rains snow, abnormal dirt etc.

12. *Outdoor Circuit-Breaker.* It is designed such it can be installed under the open sky. It should withstand rains snow, dew, atmospheric dust deposits etc.

Ambient conditions for test :

Temperature 20°C.

Pressure 750 mm of mercury (at 0°C).

For other temperatures and pressures the specified test voltage, should be multiplied by a factor $k$ given by

$$k = \frac{0.386b}{273 + t}$$

where $b$ = pressure of air in mm of mercury

$t$ = temperature in °C



## 12.8. IMPULSE VOLTAGE TESTS AND STANDARDS IMPULSE WAVES

This test is necessary for all indoor and outdoor breakers. The test is carried out as follows. Standard impulse wave of specified amplitude is applied five times in succession. If flash-over or puncture of insulators does not occur, the circuit-breaker is considered to have passed the test. If puncture occurs or if on two or more applied test wave flash-over occurs, the circuit-breaker is considered to have failed the test. During the test some waves should be applied with several of polarity.

The impulse voltage wave is generated in an Impulse Voltage Generator. During the test one terminal of the impulse generator is connected to the terminal of the circuit-breaker pole. The other terminal is connected to the earth and the frame of the circuit-breaker.

The peak value and wave shape of the test voltage is recorded by means of Cathode Ray Oscillograph with a calibrated voltages divider.

Voltage divider is used to reduce the voltage for measurement.

**Impulse Voltage.** An impulse voltage is characterized by

(*a*) Polarity

(*b*) Peak value.

(*c*) Virtual front $T_1$

(*d*) Virtual half time $T_2$

(*e*) Virtual time chopping $T_c$.

**Standard lightning Impulse** is a full impulse having a front time 1.2 m-sec and time to half value of 50 µ-sec. It is 1.2/50 impulse (Fig. 12.2).

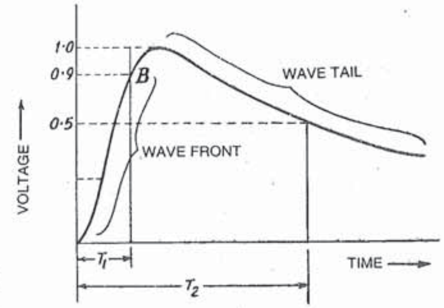
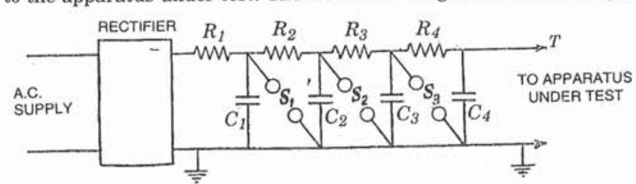



Fig. 12.2. Standard impulse wave.

**Standard switching impulse** wave is characterised by prolonged wave-front and wave tail. The typical switching impulse wave has front time of the order of 250 µs and half-time of 2500 µs. The permissible deviation in the crest value is of the order of 4 to 12%. The switching impulse wave has been specified for high voltage circuit-breaker rated 420 kV and above.

## 12.9. IMPULSE GENERATOR

In impulse tests impulse voltage wave having a steep wave front and flat wave tails and high amplitude are usually applied to called 'Mark Circuit'. (Ref. Fig. 12.3). Capacitors $C_1$, $C_2$.......are charged by the rectifier to certain voltage. When the gas $S$ is triggered by means of a spark the capacitors $C_1$, $C_2$........etc. discharge through series gap $S_1$, $S_2$ etc. and the impulse wave is applied to the apparatus under test. The total d.c. voltages is sum of voltages of capacitors.




$S_1, S_2, S_3$, = Sphere gaps
$C_1, C_2, C_3$, = Capacitors
$R_1, R_2, R_3, R_4$ = Resistors
$R$ - Rectifier

Fig. 12.3. Circuit of impulse generator.

## 12.10. TEST PLANT FOR POWER FREQUENCY TESTS

High voltage tests are conducted on electrical machines, switch gear, insulators, cables etc. These tests are conducted in high voltages tests laboratory. The equipment for conducting power frequency high voltage tests are the following :

(1) **Voltage source :** Single phase generator driven by a.c. motor. The terminal voltage can be varied widely changing the field current.

(2) **High voltage transformer :** These are single phase transformer units. For obtaining high voltage the units are connected in cascade.

(3) **Apparatus for voltage regulation :** During the test, the voltage is raised gradually. It is held at specified value for one minute.

(4) **Apparatus for voltage measurements :** Special methods are developed for high voltage-measurement. These include (*i*) sphere-gap, (*ii*) transformer ratio method, (*iii*) potential divider, (*iv*) methods of measuring peak voltage etc. Sphere gap is used for calibration of high voltage measurements.

(5) **Switchgear and protective relaying :** Safety device. Switchgear components include gate switch circuit-breaker etc.

In addition to the equipments (1) to (5) mentioned above, the following equipment is usually provided to conduct D.C. test, high frequency tests and impulse test.

(1) Instruments for measurements and record

(2) Devices to obtain high voltage D.C.

(3) Devices to obtain high frequency supply.

(4) Devices to obtain impulse wave.

(5) Equipment for testing dielectric oil, etc.

Fig. 12.4 gives a simplified diagram of H.V. testing circuit for power frequency test.

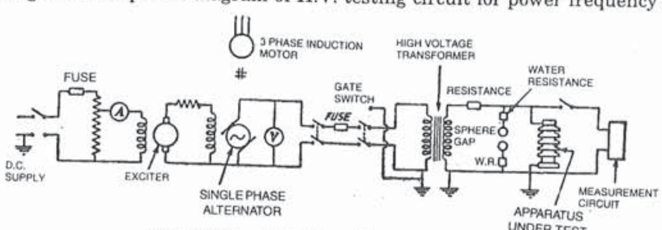



Fig. 12.4. Circuit for Power Frequency Voltage Test.

**Description of Circuit.** Fig. 12.4 illustrates, the arrangement in a test circuit. The test voltage is obtained from a single phase a.c. generator driven by an induction motor. The terminal voltage can be varied widely by changing the field current. The generator voltage is stepped up by high voltage transformer. The test voltage is supplied to the apparatus under test. The sphere gap is connected in parallel with the test specimen. The voltmeter on generator side, *i.e.* L.T. side can be calibrated by means of sphere-gap. In addition instruments for measurements may be connected on H.T. side by means of potential divider. Resistances are connected in the H.T. side to limit the current after breakdown. Circuit-breaker opens and protects the circuit in case of breakdown.

## 12.11. H.V. TESTING TRANSFORMER

Such transformers are single phase units. For obtaining test voltages upto 500 kV, usually a single unit is used. For higher voltages of 1000 kV and upwards two or more transformers are



generally used and are connected in *Cascade.* This method is convenient because a single unit for very high voltage is very large and costly. Cascade condition gives flexible test conditions. Cascade connection is illustrated in Fig. 12.5.

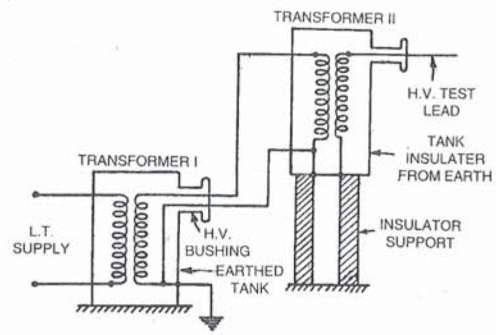



Fig. 12.5. Cascade connection of H.V. testing transformers.

Therefore, the insulation of H.V. Testing Transformer should be carefully proportioned. When the test specimen breaks down, the current is limited by insertion of water resistance in the circuit (Fig. 12.4). The kVA capacity of the testing transformers is relatively low (limited by 1 amp.) because current is relatively low.

Control of voltage is obtained by any one of the following methods :

(1) Variation of alternator field current.

(2) Tapped transformer.

(3) Resistance and inductance on supply side.

(4) Induction regulator.

The switchgear in the layout consists of main-switch circuit breaker, gate switch and is provided, with over-voltage relay, over current relay, interlocks, earthing facility and safety measures. The gate switch is placed ion the gate of screen enclosing the test field. It disconnects the supply to the transformer and earths the primary as soon as the gate is opened. Hence nobody can enter the test field when the HV transformer is energized.

The size and shape of conductor on test side-should be carefully designed so that no corona occurs. The diameters of conductors are at least 2.5 cm for 100 kV and 30 cm for 1000 kV to avoid corona under normal conditions and ample cleanness are provided.

## 12.12. SPHERE GAPS

**Purpose.** Sphere gaps are used for measurement of high voltages such as peak value of

(*i*) Power frequency alternating voltages.

(*ii*) Impulse voltage waves.

(*iii*) Direct voltages.

The procedure consists of establishing a relation between high voltage as measured by the sphere gap and indicating voltmeter, an oscillograph or device connected for voltage measurement. Under standard test conditions the voltage measured by sphere-gap can be derived from the spacing. It means from the known diameter of spheres, known test conditions and known spacing of gaps the peak value of disruptive discharge voltage can be derived from the standard table. From this value the other measuring instrument can be calibrated.

**Description.** Standard sphere-gap is a peak voltage measuring device constructed and arranged according to the rules specified by the standards, some of which are given below. Before conducting a test, the standards pertaining to High Voltage Testing Techniques and Sphere Gaps should be thoroughly studied. The sphere gap consists of two metal spheres of equal diameter (D) with their shanks, operating gear, insulating support, supporting frames, leads upto the point at which the voltage is to be measured. The standard values of diameter D recommended by I.E.C. Specification are the following twelves.

D = 2-5-6.25-10-12.5-15-25-50-75-100-150-200 cm (12 Standard Diameters)

One sphere is preferably connected directly to earth and the frame of the circuit-breaker. If resistance is connected in this circuit should be of a low value.

The other sphere is connected to high voltage conductor. The lead coming from high voltage transformer or impulse generator).

**Measurement**

**Direct and Alternating Voltage.** The voltage with a low magnitude is applied so that the transient switching surge voltage should not cause disruptive discharge. The voltage is increased gradually so that the voltage at which the disruptive discharge occurs, can be read accurately on low voltage indicator. Alternatively a constant voltage is applied across the gap and the spacing between spheres slowly reduced until disruptive discharge occurs.

The final measurement should be the mean of three successive readings agreeing within 3%.

**Impulse voltages.** Impulses are obtained from impulse generator. The interval between application of impulses should be at least 5 seconds. The charging voltage or spacing of the gap is adjusted till 50% probability of disruptive discharge is obtained. To obtain 50% probability, final reading is obtained by interpolation between the readings obtained with either (1) Two gaps or (2) Two voltage settings.

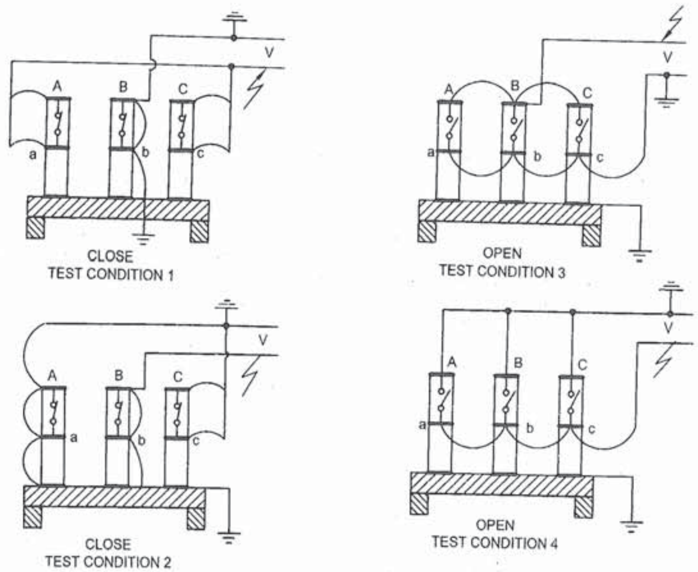



Fig. 12.6 Application of test voltage for power frequency tests and impulse test.

The readings should be such that in one case out of six applications of voltage 2 or less discharges occurs. In the second case out of 6 applied voltages 4 or more discharges occur.

**Transformer Ratio Method.** An indicating voltmeter is connected on L.T. side of high voltage testing transformer. The voltmeter is calibrated by means of sphere-gap connected on H.T. side. Once the voltmeter is calibrated, the voltage on L.T. side be measured by the same voltmeter and the voltage on H.T. side be obtained on multiplying with trans ratio.



**Potential Divider Methods.** In this method, capacitor potential divider (or resistance divider) is connected across the H.T. winding of high voltages testing transformer. The potential divider consists of several air capacitors in series. The voltage across one capacitor is a definite fraction of the total voltage. This smaller voltage is measured by means of electrostatic voltmeter.

**Summary**

High voltage circuit-breakers are subjected to type test and routine tests which include High Voltage tests :

(1) Impulse withstand test. (Standard Lightning Impulse)

(2) One minute power frequency voltage withstand test-dry.

(3) One minute power frequency voltage withstand test-wet.

(4) Impulse withstand test (Standard Switching Impulse-For 400 kV and above).

| *Test Condition No.* | *Circuit-breaker* | *Voltage applied to* | *Earthed connection to* |
|---|---|---|---|
| 1. | Close | Aa Cc | BbF |
| 2. | Close | Bb | Aa CcF |
| 3. | Open | ABC | abcf |
| 4. | Open | abc | ABCF |

**QUESTIONS**

1. State the difference between type tests and routine test. Why are high voltage tests necessary in case of high voltage circuit-breakers ?
2. What is the purpose of conducting high voltage tests on circuit-breaker through they are basically switching devices ?
3. Explain the methods of applying tests voltage in high voltage testing of circuit-breaker.
4. Define the 'insulation level' of a circuit-breaker.
5. Explain the procedure coducting power frequency voltages withstand test on a high voltage circuit-breaker.
6. Explain the procedure of impulse test on a high voltage circuit breaker.