UNIT-IV

Nondestructive Insulation Test Techniques

One of the possible testing procedure is to over-stress insulation with high a.c. and/ or d.c. or surge voltages. However, the disadvantage of the technique is that during the process of testing the equipment may be damaged if the insulation is faulty. For this reason, following non-destructive testing methods that permit early detection for insulation faults are used:

(*i*) Measurement of the insulation resistance under d.c. voltages.

(*ii*) Determination of loss factor tan δ and the capacitance C.

(*iii*) Measurement of partial discharges.

LOSS IN A DIELECTRIC

An ideal dielectric is loss-free and if its relative permittivity is ε_r, its permittivity is given by

$\varepsilon=\varepsilon_o\varepsilon_r$

and ε also known as the dielectric constant is a real number. A real dielectric is always associated with

loss. The following are the mechanisms which lead to the loss:

(*i*) Conduction loss P_c by ionic or electronic conduction. The dielectric, has σ as conductivity.

(*ii*) Polarization loss P_p by orientation boundary layer or deformation polarization.

(*iii*) Ionisation loss P_i by partial discharges internal or external zones.

Fig. 6.1 shows an equivalent circuit of a dielectric with loss due to conduction, polarization and partial discharges. An ideal dielectric can be represented by a pure capacitor $C1$, conduction losses can be taken into account by a resistor R_0 (σ) in parallel. Polarization losses produce a real component of the displacement current which is simulated by resistor $R1$. Pulse partial discharges are simulated by right hand branch. $C3$ is the capacitance of the void and S is the spark gap which fires during PD discharge and the repeated recharging of $C3$ is effected either by a resistor $R2$ or a capacitor $C2$.

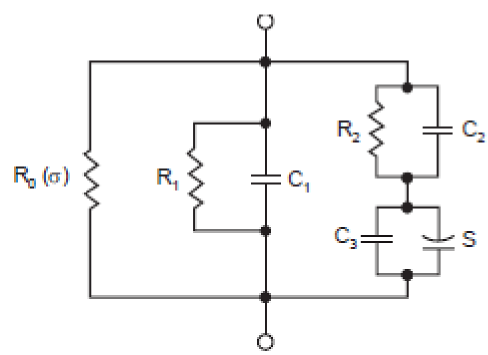

Fig. Equivalent circuit of a dielectric

MEASUREMENT OF RESISTIVITY:

When a dielectric is subjected to a steady state static electric field E the current density J_c is given by

$$J_c = \sigma E$$

Assuming a cuboid of the insulating material with thickness d and area A, then

Current $I = J_c A$ and power loss $= VI$

$$= VJ_c A = V\sigma EA = V\sigma \frac{V}{d} A.\frac{d}{d} = \frac{V}{d}\sigma\frac{V}{d} A.d = \sigma E^2.\text{ Volume.}$$

Therefore, specific dielectric loss $= \sigma E^2$ Watts/m^3.

The conductivity of the insulating materials viz liquid and solid depends upon the temperature and the moisture contents. The leakage resistance $R0$ (σ) of an insulating material is determined by measuring the current when a constant d.c. voltage is applied. Since the current is a function of time as different mechanisms are operating simultaneously. So to measure only the conduction current it is better to measure the current about 1 min after the voltage is switched on. For simple geometries of the specimen (cuboid or cube) specific resistivity ($p = 1/\sigma$) can be calculated from the leakage resistance measured. If I is the conduction current measure and V the voltage applied, the leakage resistance is given by

$$R = \frac{V}{I} = \rho\frac{d}{A}$$

where d is the thickness of the specimen and A is the area of section.

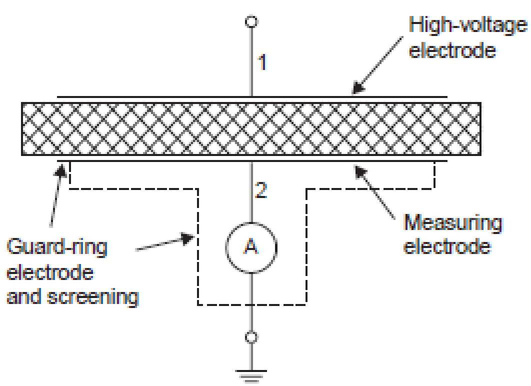

Fig. Electrode arrangement to measure the specific resistivity of an insulation specimen

Fig. 6.2. shows a simple arrangement for measurement of resistivity of the insulating material. The d.c. voltage of 100 volt or 1000 volt is applied between electrode 1 and the earth. The measuring electrode 2 is earthed through a sensitive ammeter. The third electrode known as guard ring electrode surrounds the measuring electrode and is directly connected to ground so as to eliminate boundary field effects and surface currents. The width of the guard electrode should be at least twice the thickness of the specimen and the unguarded electrode (1) must extend to the outer edge of the guard electrode. The gap between electrode 2 and 3 should be as small as possible. A thin metallic foil usually of aluminium or lead of about 20 µm thickness is placed between the electrodes and specimen for better contact. The specific conductivity for most of the insulating material lies in the range of 10–16 to 10–10 S/cm, which gives currents to be measured of these speciemen to be of the order of picoampers or nanoamperes.

The measuring leads should be appropriately and carefully screened. The measurement of conduction current using d.c. voltage not only provides information regarding specific resistivity of the material but it gives an idea of health of the insulating material. If conduction currents are large, the insulating properties of the material are lost. This method, therefore, has proved very good in the insulation control of large electrical machines during their period of operation.

MEASUREMENT OF DIELECTRIC CONSTANT AND LOSS FACTOR

Dielectric loss and equivalent circuit

In case of time varying electric fields, the current density J_c using Amperes law is given by

$$J_c = \sigma E + \frac{\partial D}{\partial t} = \sigma E + \varepsilon \frac{\partial E}{\partial t}$$

For harmonically varying fields

$$E = E_m e^{j\omega t}$$

$$\frac{\partial E}{\partial t} = jE_m \omega e^{j\omega t} = j\,\omega E$$

Therefore,

$$J_c = \sigma E + j\,\omega\,\varepsilon E$$
$$= (\sigma + j\,\omega\,\varepsilon)E$$

In general, in addition to conduction losses, ionization and polarization losses also occur and, therefore, the dielectric constant $\varepsilon = \varepsilon_0\,\varepsilon_r$ is no longer a real quantity rather it is a

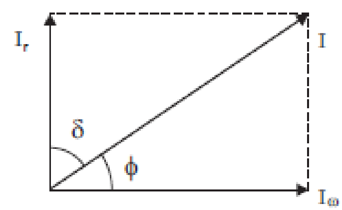

Fig. 6.3 Phasor diagram for a real dielectric material

complex quantity. By definition, the dissipation factor $\tan \delta$ is the ratio of real component of current I_ω to the reactive component I_r (Fig. 6.3).

$$\tan \delta = \frac{I_\omega}{I_r} = \frac{p_{\text{did}}}{P_r}$$

Here δ is the angle between the reactive component of current and the total current flowing through the dielectric at fundamental frequency. When δ is very small $\tan \delta = \delta$ when δ is expressed in radians and $\tan \delta = \sin \delta = \sin (90 - \phi) = \cos \phi$ *i.e.,* $\tan \delta$ then equals the power factor of the dielectric material.

As mentioned earlier, the dielectric loss consists of three components corresponding to the three loss mechanism.

$$P_{\text{diel}} = P_c + P_p + P_i$$

and for each of these an individual dissipation factor can be given such that

$$\tan \delta = \tan \delta_c + \tan \delta_p + \tan \delta_i$$

If only conduction losses occur then

$$P_{\text{diel}} = P_c = \sigma E^2 \, Ad = V^2 \omega \, C \tan \delta = \frac{V^2 \omega \, \varepsilon_0 \, \varepsilon_r A}{d} \tan \delta$$

or
$$\sigma E^2 = \frac{V^2}{d^2} \omega \varepsilon_0 \varepsilon_r \, \tan \delta = E^2 \, \omega \varepsilon_0 \varepsilon_r \tan \delta$$

or
$$\tan \delta = \frac{\sigma}{\omega \varepsilon_0 \, \varepsilon_r}$$

This shows that the dissipation factor due to conduction loss alone is inversely proportional to the frequency and can, therefore, be neglected at higher frequencies. However, for supply frequency each loss component will have considerable magnitude.

In order to include all losses, it is customary to refer the existence of a loss current in addition to the charging current by introducing complex permittivity.

$$\varepsilon^* = \varepsilon' - j \, \varepsilon''$$

and the total current I is expressed as

$$I = (j \, \omega \varepsilon' + \omega \varepsilon'') \frac{C_0}{\varepsilon_0} V$$

where C_0 is the capacitance without dielectric material.

or
$$I = j \, \omega \, C_0 \varepsilon_r^* \, . \, V$$

where
$$\varepsilon_r^* = \frac{(\varepsilon' - j \, \varepsilon'')}{\varepsilon_0} = \varepsilon'_r - j \, \varepsilon_r''$$

ε_r^* is called the complex relative permittivity or complex dielectric constant, ε' and ε_r' are called the permittivity and relative permittivity and ε'' and ε_r'' are called the loss factor and relative loss factor respectively.

The loss tangent

$$\tan \delta = \frac{\varepsilon''}{\varepsilon'} = \frac{\varepsilon_r''}{\varepsilon_r'}$$

The product of the angular frequency and ε'' is equivalent to the dielectric conductivity σ'' *i.e.*, $\sigma'' = \omega\varepsilon''$.

The dielectric conductivity takes into account all the three power dissipative processes including the one which is frequency dependent. Fig. 6.4 shows two equivalent circuits representing the electrical behaviour of insulating materials under a.c. voltages, losses have been simulated by resistances.

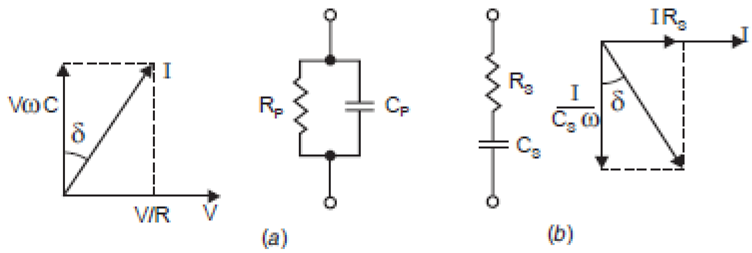

Fig. 6.4 Equivalent circuits for an insulating material

Normally the angle between *V* and the total current in a pure capacitor is 90°. Due to losses, this angle is less than 90°. Therefore, δ is the angle by which the voltage and charging current fall short of the 90° displacement.

For the parallel circuit the dissipation factor is given by

$$\tan\delta = \frac{1}{\omega C_p R_p}$$

and for the series circuit

$$\tan\delta = \omega\, C_s R_s$$

For a fixed frequency, both the equivalents hold good and one can be obtained from the other. However, the frequency dependence is just the opposite in the two cases and this shows the limited validity of these equivalent circuits.

The information obtained from the measurement of tan δ and complex permittivity is an indication of the quality of the insulating material.

(*i*) If tan δ varies and changes abruptly with the application of high voltage, it shows inception of internal partial discharge.

(*ii*) The effect to frequency on the dielectric properties can be studied and the band of frequencies where dispersion occurs *i.e.*, where that permittivity reduces with rise in frequency can be obtained.

HIGH VOLTAGE SCHERING BRIDGE:

The bridge is widely used for capacity and dielectric loss measurement of all kinds of capacitances, for instance cables, insulators and liquid insulating materials. We know that most of the high voltage equipments have low capacitance and low loss factor. This bridge is then more suitable for measurement of such small capacitance equipments as the bridge uses either high voltage or high frequency supply. If measurements for such low capacity equipments is carried out at low voltage, the results so obtained are not accurate.

Fig. shows a high voltage schering bridge where the specimen has been represented by a parallel combination of R_p and C_p.

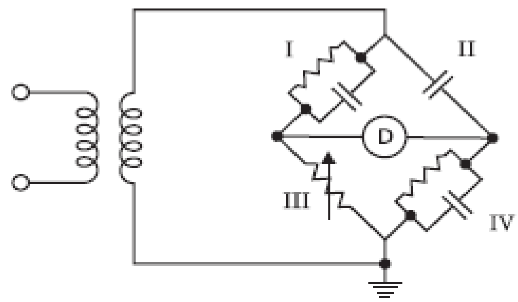

Fig. 6.5 Basic high voltage schering bridge

The special features of the bridge are:

1. High voltage supply, consists of a high voltage transformer with regulation, protective circuitry and special screening. The input voltage is 220 volt and output continuously variable between 0 and 10 kV. The maximum current is 100 mA and it is of 1 kVA capacity.
2. Screened standard capacitor C_s of 100 $pF \pm 5\%$, 10 kV max and dissipation factor tan $\delta = 10^{-5}$. It is a gas-filled capacitor having negligible loss factor over a wide range of frequency.
3. The impedances of arms I and II are very large and, therefore, current drawn by these arms is small from the source and a sensitive detector is required for obtaining balance. Also, since the impedance of arm I and II are very large as compared to III and IV, the detector and the impedances in arm III and IV are at a potential of only a few volts (10 to 20 volts) above earth even when the supply voltage is 10 kV, except of course, in case of breakdown of one of the capacitors of arm I or II in which case the potential will be that of supply voltage. Spark gaps are, therefore, provided to spark over whenever the voltage across arm III or IV exceeds 100 volt so as to provide personnel safety and safety for the null detector.
4. *Null Detector:* An oscilloscope is used as a null detector. The γ-plates are supplied with the bridge voltage V_{ab} and the x-plates with the supply voltage V. If V_{ab} has phase difference with respect to V, an ellipse will appear on the screen (Fig. 6.6). However, if magnitude balance is not reached, an inclined straight line will be observed on the screen. The information about the phase is obtained from the area of the eclipse and the one about the magnitude from the inclination angle. Fig. 6.6*a* shows that both magnitude and phase are balanced and this represents the null point condition. Fig. (6.6*c*) and (*d*) shows that only phase and amplitude respectively are balanced.

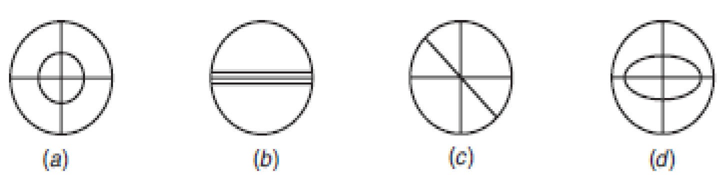

Fig. Indications on null detector

The handling of bridge keys allows to meet directly both the phase and the magnitude conditions in a single attempt. A time consuming iterative procedure being used earlier is
thus avoided and also with this a very high order of accuracy in the measurement is achieved.

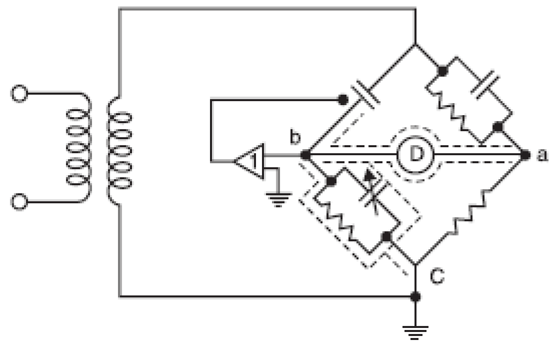

Fig. . Automatic Wagner earth or automatic guard potential regulator

The high accuracy is obtained as these null oscilloscopes are equipped with a γ– amplifier of automatically controlled gain. If the impedances are far away from the balance point, the whole screen is used. For nearly obtained balance, it is still almost fully used. As *Vab* becomes smaller, by approaching the balance point, the gain increases automatically only for deviations very close to balance, the ellipse area shrinks to a horizontal line.

5. *Automatic Guard Potential Regulator:* While measuring capacitance and loss factors using a.c. bridges, the detrimental stray capacitances between bridge junctions and the ground adversely affect the measurements and are the source of error. Therefore, arrangements should be made to shield the measuring system so that these stray capacitances are either neutralised, balanced or eliminated by precise and rigorous calculations. Fig. 6.7 shows various stray capacitance associated with High Voltage Schering Bridge.

Automatic Wagner earth or automatic guard potential regulator:

The guard potential regulator keeps the shield potential at the same value as that of the detector diagonal terminals *a* and *b* for the bridge balance considered. Since potentials of
a, *b* and shield are held at the same value the stray capacitances are eliminated. During the process of balancing the bridge the points *a* and *b* attain different values of potential in magnitude and phase with respect to ground. As a result, the guard potential regulator should be able to adjust the voltage both in magnitude and phase. This is achieved with a voltage divider arrangement provided with coarse and fine controls, one of them fed with in-phase and the other quadrature component of voltage.

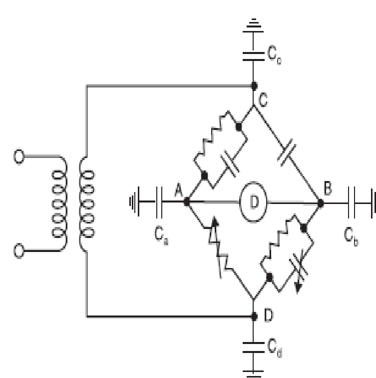

Fig. Schering bridge with stray capacitances

The control voltage is then the resultant of both components which can be adjusted either in positive or in negative polarity as desired. The comparison between the shielding potential adjusted by means of the Guard potential regulator and the bridge voltage is made in the null indicator oscilloscope as mentioned earlier. Modifying the potential, it is easy to bring the reading of the null detector to a horizontal straight line which shows a balance between the two voltages both in magnitude and phase.

Balancing the Bridge

For ready reference Fig. 6.5 is reproduced here and its phasor diagram under balanced condition is drawn in Fig. 6.10 (*b*)

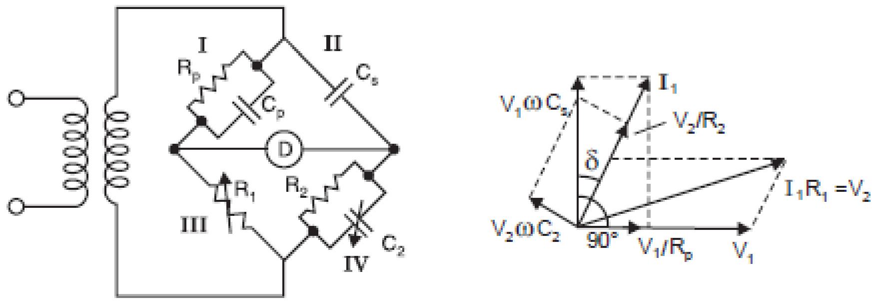

Fig. 6.10 (*a*) Schering bridge (*b*) Phasor diagram

The bridge is balanced by successive variation of R_1 and C_2 until on the oscilloscope (Detector) a horizontal straight line is observed:

At balance
$$\frac{Z_I}{Z_{II}} = \frac{Z_{III}}{Z_{IV}}$$

Now
$$Z_I = \frac{R_p}{1 + j\,\omega\,C_p R_p}$$

$$Z_{II} = \frac{1}{j\,\omega\,C_s}$$

$$Z_{III} = R_I \text{ and } Z_{IV} = \frac{R_2}{1 + j\,\omega\,C_2 R_2}$$

From balance equation we have

$$\frac{R_p}{R_1\,(1 + i\omega\,C_p R_p)} = \frac{1/j\,\omega\,C_s\,(1 + j\omega\,C_2 R_2)}{R_2}$$

or
$$\frac{R_p\,(1 - j\,\omega\,C_p R_p)}{R_1\left(1 + \omega^2 C_p^2 R_p^2\right)} = \frac{1 + j\,\omega\,C_2 R_2}{j\,\omega\,C_s R_2}$$

or
$$\frac{R_p}{R_1\left(1 + \omega^2 C_p^2 R_p^2\right)} - \frac{j\,\omega\,C_p R_p^2}{R_1\left(1 + \omega^2 C_p^2 R_p^2\right)} = -\frac{j}{\omega C_s R_2} + \frac{C_2}{C_s}$$

Equating real part, we have

$$\frac{R_p}{R_1\left(1 + \omega^2 C_p^2 R_p^2\right)} = \frac{C_2}{C_s}$$

and equating imaginary part, we have

$$\frac{\omega\,C_p R_p^2}{R_1\left(1 + \omega^2\,C_p^2 R_p^2\right)} = \frac{1}{\omega C_s R_2}$$

Now tan δ from the phasor diagram

$$\tan\delta = \frac{V_1/R_p}{V_1\omega C_p} = \frac{1}{\omega C_p R_p} = \frac{V_2\,\omega\,C_2}{V_2/R_2} = \omega C_2 R_2$$

Also
$$\cos\delta = \frac{V_1\omega C_p}{V_1\sqrt{\left(1/R_p^2\right) + \omega^2 C_p^2}}$$

or
$$\cos^2\delta = \frac{\omega^2 C_p^2 R_p^2}{1+\omega^2 C_p^2 R_p^2}$$

or
$$\frac{\omega C_p R_p}{1+\omega^2 C_p^2 R_p^2} = \cos^2\delta\,.\,\frac{1}{\omega\,C_p R_p} = \frac{R_1}{\omega\,C_s R_2 R_p}$$

or
$$C_p = \cos^2\delta\; C_s\,\frac{R_2}{R_1}$$

Since δ is usually very small cos δ = 1

Therefore
$$C_p \approx C_s\,\frac{R_2}{R_1}$$

and
$$\tan\delta_p = \omega\,C_2 R_2$$

and since
$$\frac{1}{\omega\,C_p R_p} = \omega\,C_2 R_2$$

or
$$\omega^2 C_p R_p C_2 R_2 = 1$$

or
$$R_p = \frac{1}{\omega^2 R_2 C_2 C_p} \approx \frac{R_1}{\omega^2 R_2 C_2 C_s R_2} \approx \frac{R_1}{\omega^2 C_2 C_s R_2^2}$$

If, however, the specimen is replaced by *a* series equivalent circuit, then at balance

$$Z_I = R_s - \frac{j}{\omega C_s}$$

and the equation becomes

$$\frac{R_s - j/\omega\,C_s}{R_1} = \frac{1 + j\,\omega\,C_2 R_2}{j\,\omega\,C_s' R_2}$$

and the equation becomes

$$\frac{R_s - j/\omega\,C_s}{R_1} = \frac{1 + j\,\omega\,C_2 R_2}{j\,\omega\,C_s' R_2}$$

or
$$\frac{R_s}{R_1} - \frac{j}{\omega\,C_s R_1} = -\frac{j}{\omega C_s' R_2} + \frac{C_2}{C_s'}$$

Equating real parts, we have

$$\frac{R_s}{R_1} = \frac{C_2}{C_s'}$$

or
$$R_s = R_1\,\frac{C_2}{C_s'}$$

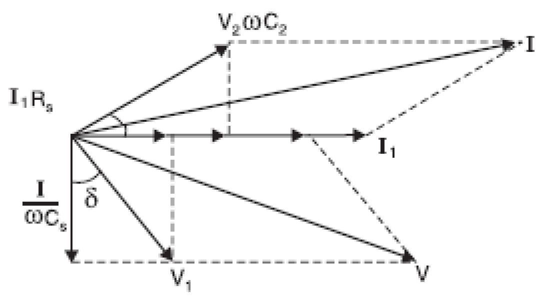

Fig. 6.11 Phasor diagram of S.B. for series equivalent of specimen

Similarly equating imaginary part, we have

$$\omega C_s R_1 = \omega C_s' R_2$$

or
$$C_s = C_s' \frac{R_2}{R_1}$$

To find out tan δ, we draw the phasor diagram of the bridge circuit (Fig. 6.11).

$$\tan \delta_s = \frac{I_1 R_s}{I_1/\omega C_s} = \omega C_s R_s$$

MEASUREMENT OF LARGE CAPACITANCE

In order to measure a large capacitance, the resistance R_1 should be able to carry large value of current and resistance R_1 should be of low value. To achieve this, a shunt of S ohm is connected across R_1 as shown in Fig. 6.12. It is desirable to connect a fixed resistance R in series with variable resistance R_1 so as to protect R_1 from excessive current, should it accidentally be set to a very low value.

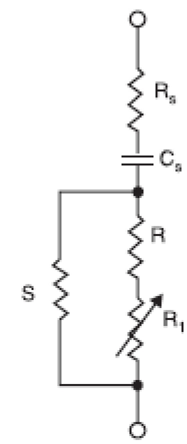

Fig. 6.12 Shunt arrangement for measurement of large capacitance

We know that under balanced condition for series equivalent representation of specimen

$$C_s = C_s' \frac{R_2}{R_1}$$

But here R_1 is to be replaced by the equivalent of $(R + R_1) \parallel S$.

or
$$\frac{(R + R_1)\, S}{R + R_1 + S}$$

or
$$\frac{1}{R_{eq}} = \frac{R + R_1 + S}{(R + R_1)\, S}$$

Therefore,
$$C_s = C_s' R_2 \cdot \frac{R + R_1 + S}{(R + R_1) S} \cdot \frac{R_1}{R_1} = C_s' \frac{R_2}{R_1} \cdot \frac{R_1\,(R + R_1 + S)}{(R + R_1)\, S}$$

usually $R << R_1$

Therefore
$$C_s = C_s' \frac{R_2}{R_1} \frac{R_1\,(R + R_1 + S)}{R_1 S} = C_s' \frac{R_2}{R_1} \left[\frac{R}{S} + \frac{R_1}{S} + 1 \right]$$

and
$$\tan \delta = \omega\, C_s' R_2 . R/R_1$$

If circuit elements of Schering bridge are suitably designed, the bridge principle can be used upto to 100 kHz of frequency. However, common schering bridge can be used upto about 10 kHz only.

SCHERING BRIDGE METHOD FOR GROUNDED TEST SPECIMEN:

A dielectric material which is to be tested, one side of this is usually grounded *e.g.* underground cables or bushings with flanges grounded to the tank of a transformer etc. There are two well known methods used for such measurement. One is the inversion of a Schering bridge shown in Fig. 6.13 with the operator, ratio arms and null detector inside a Faraday Cage at high potential. The system requires the cage to be insulated for the full test voltage and with suitable design may be used upto maximum voltage available. However, there are difficulties in inverting physically the standard capacitor and it becomes necessary to mount it on a platform insulated for full voltage.

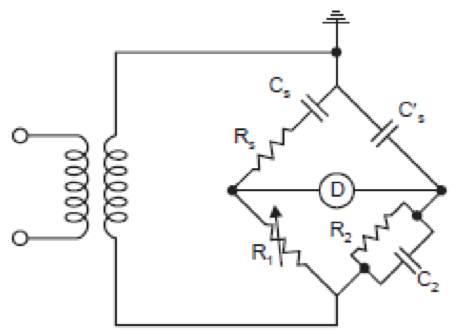

Fig. 6.13 Inverted Schering bridge

Second method requires grounding of detector as shown in Fig. 6.14. In this arrangement, stray capacitances of the high voltage terminal C_q and of the source, leads etc. come in parallel with the test object. Hence, balancing is carried out in two steps: First step: The test specimen is disconnected and the capacitance C_q and loss factor tan δ_q are measured. Second step: The test object is connected in the bridge and new balance is obtained. The second balance gives net capacitance of the parallel combination *i.e.*,

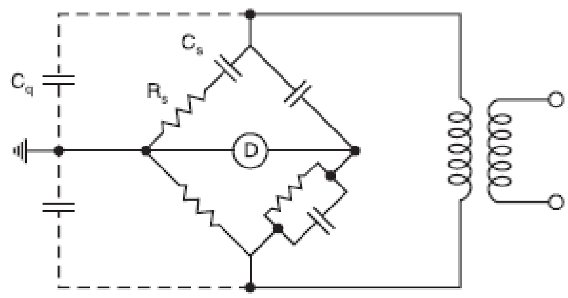

Fig. 6.14 Grounded specimen

$$C_s' = C_s + C_q$$

and $$\tan \delta_q' = \frac{C_s \tan \delta_s + C_q \tan \delta_q}{C_s + C_q}$$

Hence the capacitance and loss factor of the specimen are

$$C_s = C_s'' - C_q$$

and $$\tan \delta_s = \frac{C_s'' \tan \delta'' - C_q \tan \delta_q}{C_s}$$

If the stray capacitances are large as compared to the capacitance of the specimen, the accuracy of measurement is poor.

SCHERING BRIDGE FOR MEASUREMENT OF HIGH LOSS FACTOR

If the loss factor tan δ of a specimen is large, the bridge arm containing resistance *R*2 is modified. Resistance *R*2 is made as a slide wire along with a decade resistor and a fixed capacitance *C*2 is connected across the resistance *R*2 as shown in Fig. 6.15 (*a*). This modification can be used for test specimen having loss factor of the order of 1.0. If it is more than one and upto 10 or greater *C*2, *R*2 arm is not made a parallel combination, rather it is made a series combination as shown in Fig. 6.15 (*b*) Here, of course *R*2 is made variable.

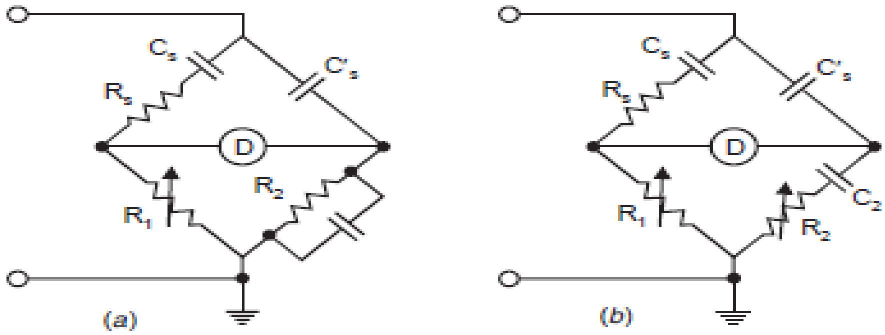

Fig. 6.15 Schering bridges for large loss factor

PARTIAL DISCHARGES:

Partial discharge is defined as localised discharge process in which the distance between two electrodes is only partially bridged *i.e.*, the insulation between the electrodes is partially punctured. Partial discharges may originate directly at one of the electrodes or occur in a cavity in the dielectric. Some of the typical partial discharges are: (*i*) Corona or gas discharge. These occur due to non-uniform field on sharp edges of the conductor subjected to high voltage especially when the insulation provided is air or gas or liquid Fig. 6.18 (*a*). (*ii*) Surface discharges and discharges in laminated materials on the interfaces of different dielectric material such as gas/solid interface as gas gets over stressed εr times the stress on the solid material (where εr is the relative permittivity of solid material) and ionization of gas results Fig. 6.18 (*b*) and (*c*). (*iii*) Cavity discharges: When cavities are formed in solid or liquid insulating materials the gas in the cavity is over stressed and discharges are formed Fig. 6.18 (*d*) (*iv*). Treeing Channels: High intensity fields are produced in an insulating material at its sharp edges and this deteriorates the insulating material. The continuous partial discharges so produced are known as Treeing Channels Fig. 6.18 (*e*).

External Partial Discharge
External partial discharge is the process which occurs external to the equipment e.g. on overhead lines, on armature etc.

Internal Partial Discharge:
Internal paratial discharge is a process of electrical discharge which occurs inside a closed system (discharge in voids, treeing etc). This kind of classification is essential for the PD measuring system as external discharges can be nicely distinguished from internal discharges. Partial discharge measurement have been used to assess the life expectancy of insulating materials. Even though there is no well defined relationship, yet it gives sufficient idea of the insulating properties of the material. Partial discharges on insulation can be measured not only by electrical methods but by optical, acoustic and chemical method also. The measuring principles are based on energy conversion process associated with electrical discharges such as emission of electromagnetic waves, light, noise or formation of chemical compounds. The oldest and simplest but less sensitive is the method of listening to hissing sound coming out of partial discharge. A high value of loss factor tan δ is an indication of occurrence of

partial discharge in the material. This is also not a reliable measurement as the additional losses generated due to application of high voltage are localised and can be very small in comparison to the volume losses resulting from polarization process. Optical methods are used only for those materials which are transparent and thus not applicable for all materials. Acoustic detection methods using ultrasonic transducers have, however, been used with some success. The most modern and the most accurate methods are the electrical methods. The main objective here is to separate impulse currents associated with PD from any other phenomenon.

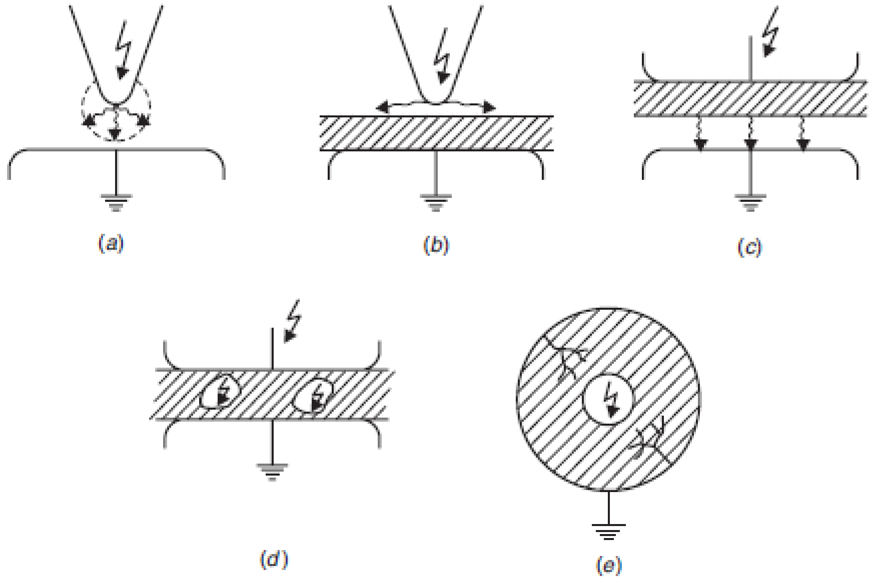

Fig. 6.18 Various partial discharges

The Partial Discharge Equivalent Circuit

If there are any partial discharges in a dielectric material, these can be measured only across its terminal. Fig. 6.19 shows a simple capacitor arrangement in which a gas filled void is present. The partial discharge in the void will take place as the electric stress in the void is ε_r times the stress in the rest of the material where ε_r is the relative permittivity of the material. Due to geometry of the material, various capacitances are formed as shown in Fig. 6.19 (*a*). Flux lines starting from electrode and terminating at the void will form one capacitance C_{b1} and similarly C_{b2} between electrode *B* and the cavity. C_c is the capacitance of the void. Similarly C_{a1} and C_{a2} are the capacitance of healthy portions of the dielectric on the two sides of the void. Fig. 6.19 (*b*) shows the equivalent of 6.19 (*a*) where $C_a = C_{a1} + C_{a2}$, and $C_b = C_{b1}C_{b2}/(C_{b1} + C_{b2})$ and C_c is the cavity capacitance. In general $C_a >> C_b >> C_c$.

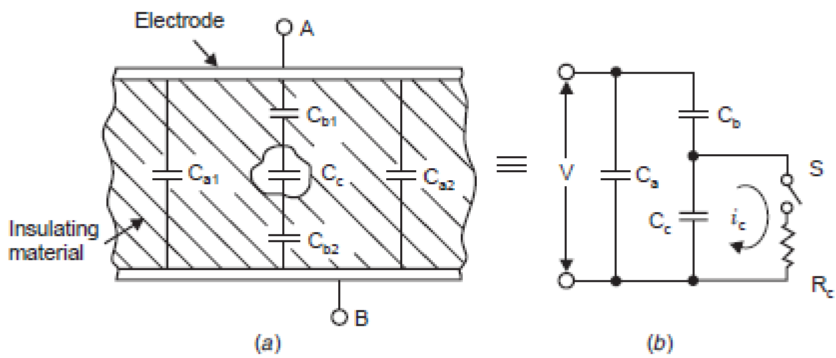

Fig. 6.19. (*a*) Dielectric material with a cavity (*b*) Equivalent circuit

Closing of switch *S* is equivalent to simulating partial discharge in the void as the voltage V_c across the void reaches breakdown voltage. The discharge results into a current $i_c(t)$ to flow. Resistor R_c simulates the finite value of current $i_c(t)$.

Suppose voltage V is applied across the electrode A and B and the sample is charged to this voltage and source is removed. The voltage V_c across the void is sufficient to breakdown the void. It is equivalent to closing switch S in Fig. 6.19 (b). As a result, the current $i_c(t)$ flows which releases a charge $\Delta q_c = \Delta V_c C_c$ which is dispersed in the dielectric material across the capacitance C_b and C_a. Here ΔV_c is the drop in the voltage V_c as a result of discharge. The equivalent circuit during redistribution of charge Δq_c is shown in Fig. 6.20.

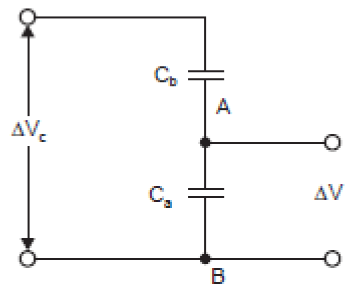

Fig. 6.20 Equivalent of 6.19 (a) after discharge

The voltage as measured across AB will be

$$\Delta V = \frac{C_b}{C_a + C_b} \Delta V_c = \frac{C_b}{C_a + C_b} \frac{\Delta q_c}{C_c}$$

Ordinarily ΔV_c is in kV whereas ΔV is a few volts since the ratio C_b/C_a is of the order of 10^{-4} to 10^{-3}. The voltage drop ΔV even though can be measured but as C_b and C_c are normally not known neither ΔV_c nor Δq_c can be obtained. Also since V is in kV and ΔV is in volts the ratio $\Delta V/V$ is very small $\approx 10^{-3}$, therefore the detection of $\Delta V/V$ is a tedious task.

The measurement of *PD current pulses provides important information concerning the discharge* processes in a test specimen.

The time response of an electric discharge depends mainly on the nature of fault and design of insulating material.

The shape of the circular current is an indication of the physical discharge process at the fault location in the test object.

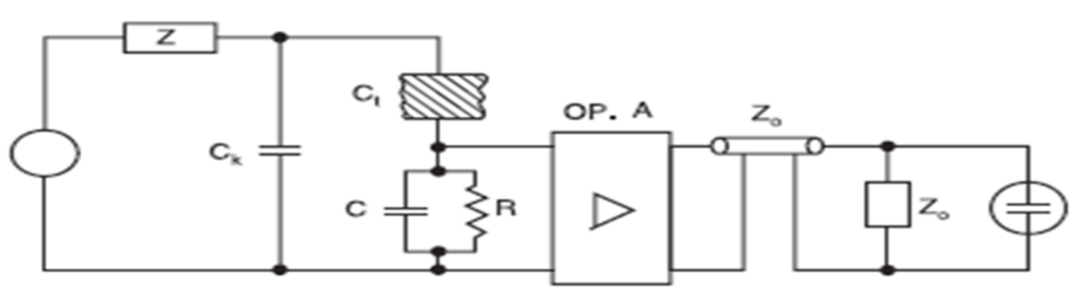

Fig. Principle of pulse current measurement

Here *C indicates the stray capacitance between the lead of Ct and the earth, the input capacitance* of the amplifier and other stray capacitances.

The function of the high pass amplifier is to suppress the power frequency displacement current *ik(t) and Ic(t) and to further amplify the short duration* current pulses.

Thus the delay cable is electrically disconnected from the resistance *R. Suppose during* a partial discharge a short duration pulse current δ (*t) is produced and results in apparent charge q on Ct* which will be redistributed between *Ct, C and Ck .*

Potential across C_t $= \dfrac{q}{C_t + \dfrac{CC_k}{C + C_k}}$

Therefore, voltage across C will be

$$v = \frac{q}{C_t + \dfrac{CC_k}{C + C_k}} \cdot \frac{C_k}{C + C_k} = \frac{q}{C_t\,(C + C_k) + CC_k} \cdot C_k$$

$$= \frac{qC_k}{CC_t + C_kC_t + CC_k} = \frac{q}{C + C_t\left(1 + \dfrac{C}{C_k}\right)}$$

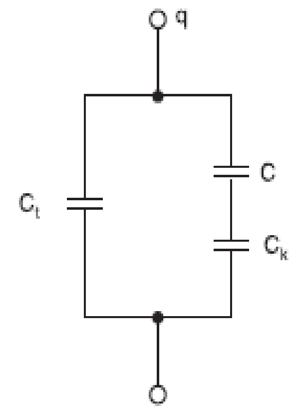

Fig. Equivalent of 6.23 after discharge

and because of resistance R the expression for voltage across R will be

$$v(t) = \frac{q}{C + C_t\left(1 + \dfrac{C}{C_k}\right)} e^{-t/\tau}$$

where
$$\tau = \left(C + \frac{C_tC_k}{C_t + C_k}\right)R$$

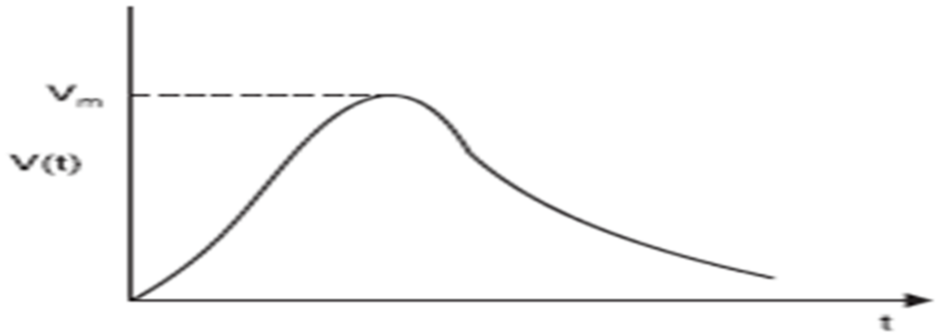

Fig. Wave shape of voltage across *R*

The voltage across the resistance *R indicates a* fast rise and is followed by an exponential decay with time constant τ.

The circuit elements have thus deferred the original current wave shape especially the wave tail side of the wave and therefore, the measurement of the pulse current *i(t) is a difficult task.*