CBCS SCHEME

15EE73

USN 1CR15EE028

Seventh Semester B.E. Degree Examination, Dec.2018/Jan.2019
High Voltage Engineering

Time: 3 hrs. Max. Marks: 80

Note: Answer any FIVE full questions, choosing one full question from each module.

Module-1

1 a. Explain the current growth in the presence of secondary processes. **(08 Marks)**
b. Classify the breakdown mechanism in liquids and explain any one mechanism. **(08 Marks)**

OR

2 a. Classify the breakdown mechanism in solids and explain any one mechanism. **(10 Marks)**
b. In an experiment in a certain gas it was found that the steady state current is 5.5×10^{-8} A at a distance of 0.4cm between the plane electrodes. Keeping the field constant and reducing the distance to 0.1cm result in a current of 5.5×10^{-9}A. Calculate Townsend's primary ionization coefficient α. **(06 Marks)**

Module-2

3 a. What are the different forms of high voltage and mention their applications. **(06 Marks)**
b. Explain with schematic diagram the Marx circuit of multistage impulse generator incorporating the series and wave tail resistances within the generator. **(10 Marks)**

OR

4 a. With a neat sketch, explain Cockcroft Walton voltage multiplier circuit and also draw the voltage waveforms across the first and last capacitors of the cascaded voltage multiplier circuit. **(10 Marks)**
b. How a full impulse wave is characterized? Explain. **(06 Marks)**

Module-3

5 a. What are the factors influencing the spark over voltage of spheregaps? Explain any two factors. **(08 Marks)**
b. Determine the breakdown voltage for air gaps 2mm and 15mm lengths under uniform field and standard atmospheric conditions. Also determine the voltage is the atmospheric pressure is 750mm Hg and temperature 35°C **(08 Marks)**

OR

6 a. Draw Chubb – Fortescue circuit for measurement of peak value of a.c voltages. Discuss its advantages over other methods. **(08 Marks)**
b. What is Rogowski coil? Explain with a neat diagram its principle of operation for measurement of high impulse currents. **(08 Marks)**

Module-4

7 a. Explain the different theories of charge formation in the clouds. **(08 Marks)**
b. What are the different methods employed for lighting protection of over head lines? Explain them. **(08 Marks)**

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

OR

8 a. A 3-phse single circuit transmission line is 400km long. If the line is rated for 220kV and has parameters, R = 0.1Ω/km, L = 1.26mH/km, C = 0.009, μF/km and G = 0. Find (i) The surge impedance and (ii) The velocity of propagation neglecting the resistance of the line if a surge of 150kV and infinitely long tail strikes at one end of the line, what is the time taken for the surge to travel to the other end of the line? **(08 Marks)**

b. Write a note on surge diverters. **(08 Marks)**

Module-5

9 a. With a neat circuit diagram, explain the balanced detection method using Schering bridge. **(08 Marks)**

b. Explain the operation of Schering bridge for three terminal measurements with Wagner's earthling device. **(08 Marks)**

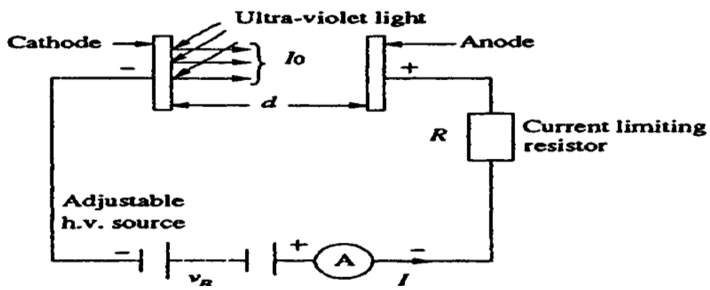
OR

10 a. A 33 kV, 50Hz, high voltage Schering bridge is used to test a sample of insulation. The various arms have the following parameters on balance. The standard capacitance 500pF, the resistive branch 500 ohms and branch with parallel combination R and C, has 180Ω and 0.15μF. Determine the value of capacitance of this sample, its parallel equivalent loss resistance, The pF and power loss under these conditions. **(08 Marks)**

b. Explain the methods to determine the large capacitance using shunt arrangement. **(08 Marks)**

* * * * *

1A



Townsend's Current Growth Theory.

Ref to fig ①, let us assume that n_0 e s are emitted from Cathode. When one e collide a neutral particle, a +ve ion and an e are f

This is called ionizing collision.

Let α be avg no. of ionizing collision made by an e / cm travel in the direction o the fld (α depends on gas pre p and E/P, and called T's first ionization coeff). At distance x from cathode, let no. of electro be n_x. When these n_x es travel a further distance of dx, they give rise to $\alpha n_x dx$

At $x = 0$, $n_x = n_0$ —— 1)

Also $\frac{dn_x}{dx} = \alpha n_x$ or $n_x = n_0 \exp(\alpha x)$.

Then no. of e reaching anode ($x = d$) will

$$n_d = n_0 \exp(\alpha d) \quad —— (3)$$

Number of new es created, on avg by each e is

$$\frac{n_d - n_0}{n_0} = \exp(\alpha d) - 1 \quad —— (4)$$

∴ Avg current in gap, which is equal to no. of es travelling per second will be.

$$I = I_0 \exp(\alpha d) \quad — (5)$$

where Io is initial current at the cathode.

Current Growth In The Presence of 2ndary Processes

Single avalanche process becomes complete when initial sets es reaches anode. Since amplification of es [exp (αd)] is occuring in fld, probability of additional new es being liberated in gap by other mechanisms ↑ and these new es create further avalanches. Other mechanisms are

i) +ve ions liberated may have sufficient energy to cause liberations of es from the cathode when they impinge on it

ii) Excited mols or atoms in avalanches may emits photons and this will lead to emission of es by photo- emission.

iii) Meta stable particle may diffuse back causing e emission.

e s produced by these process are called 2ndary emission.

★ 2ndary ionization coeff γ is defined as net number of 2ndary es produced by per incident +ve ions photon, excited particle or metastable particle and total value of γ is sum of individual coeffs due to 3 diff processes. $\gamma = \gamma_1 + \gamma_2 + \gamma_3$

$\gamma \rightarrow$ T's 2ndary ionization coeff and function of P and E/P.

Following T's procedure of current growth

let us assume,

n_0' = no. of 2ndary es produced due to 2ndary processes

$n_0'' \rightarrow$ total no. of es leaving cathode

$$n_0'' = n_0 + n_0' \quad \text{--- (1)}$$

Total no. of es n reaching anode becomes

$$n = n_0'' \exp(\alpha d) = (n_0 + n_0')\exp(\alpha d)$$

and $n_0' = \gamma [n - (n_0 + n_0')]$

Eliminating n_0' $\quad n = \dfrac{n_0 \exp(\alpha d)}{1 - \gamma[\exp(\alpha d) - 1]}$

$$I = \frac{I_0 \exp(\alpha d}{1 - \gamma \left[\exp(\alpha d) - 1\right]}$$

Townsend's Criterion for Breakdown

Above eqn. gives total avg current in a gap before occurance of breakdown. As d ↑, denominator of eqn tends to zero and at some critical distance $d = d_s$ $1 - \gamma\left[\exp(\alpha d) - 1\right] = 0$.

for values $d < d_s$ $I \simeq I_0$ and external source for supply of I_0 is removed, I becomes zero.

If $d = d_s$, $I \to \infty$ and current will be limited only by resis of power supply and ext ckt.

This condition is called T's breakdown criterion and can be written as $\gamma\left[\exp(\alpha d) - 1\right] = 1$

Normally $\exp(\alpha d)$ is very large and above eqn. reduces to

$$\gamma \exp(\alpha d) = 1$$

For a given gap spacing and at a given pressure the value of V (voltage) which gives values of α and γ satisfying breakdown criterion is called spark breakdown voltage V_S and corresponding distance d_s is called sparking distance.

T's mechanism explain phenomenon of breakdown only at low pre, corresponding to $p \times d$ (gas pre & gap distance) values of 1000 torr-cm and below.

1B

Several theories have been proposed to explain the breakdown in liquids,

- (a) **Electronic Breakdown**
- (b) **Suspended Particle Mechanism**
- (c) ***Cavitations and Bubble Mechanism***
- (d) **Stressed Oil Volume Mechanism**

Suspended Particle Theory

- In commercial liquids, the presence of solid impurities cannot be avoided.
- These impurities will be present as fibrous or as dispersed solid particles.
- The permittivity of these particles (**$\varepsilon 1$**) will be different from the permittivity of the liquid (**$\varepsilon 2$**).

- If we consider these impurities to be spherical particles of radius r, and if the applied field is E, then the particles experience a force F, where

- $$F = r^3 \frac{\varepsilon_1 - \varepsilon_2}{\varepsilon_1 + 2\varepsilon_2} E \cdot \frac{dE}{dx}$$

- this force is directed towards a place of higher stress if ε1 > ε2 and towards a place of lower stress if ε1 < ε2 when ε1 is the permittivity of gas bubbles.

- The force given above increases as the permittivity of the suspended particles (ε1) increases. If ε1 → ∞

- $$F = r^3 \frac{1 - \varepsilon_2/\varepsilon_1}{1 + 2\varepsilon_2/\varepsilon_1} E \frac{dE}{dx}$$ Let $\varepsilon_1 \to \infty$ $$F = r^3 E \cdot \frac{dE}{dx}$$

- Force will tend the particle to move towards the strongest region of the field.

- In a uniform electric field which usually can be developed by a small sphere gap, the field is the strongest in the uniform field region**. Here *dE/dx* → *0 so that the force on the particle is zero and the particle* remains in equilibrium**.

- Particles will be dragged into the uniform field region.

- Permittivity of the particles is higher than that of the liquid, the presence of particle in the uniform field region will cause flux concentration at its surface.

- Other particles if present will be attracted towards the higher flux concentration.

- The movement of the particle under the influence of electric field is opposed by the viscous force posed by the liquid and since the particles are moving into the region of high stress, diffusion must also be taken into account.

- We know that the viscous force is given by (Stoke's relation)

- **Fv= 6πηrv**

- where η is the viscosity of liquid, r the radius of the particle and v the velocity of the particle.

- Equating the electrical force with the viscous force we have

- $$6\pi\eta r v = r^3 E \frac{dE}{dx} \quad \text{or} \quad v = \frac{r^2 E}{6\pi\eta} \frac{dE}{dx}$$

- However, if the diffusion process is included, the drift velocity due to diffusion will be given by

$$v_d = -\frac{D}{N}\frac{dN}{dx} = -\frac{KT}{6\pi\eta r}\frac{dN}{Ndx}$$

-
- where D = KT/6πηr a relation known as Stokes-Einstein relation. Here K is Boltzmann's constant and T the absolute temperature.
- At any instant of time, the particle should have one velocity and, therefore, equation
- $v = v_d$
- We have

$$-\frac{KT}{6\pi\eta r}\cdot\frac{dN}{Ndx} = \frac{r^2 E}{6\pi\eta}\cdot\frac{dE}{dx}$$

$$\frac{KT}{r}\frac{dN}{N} = -r^2 E\, dE$$

$$\frac{KT}{r}\ln N = -\frac{r^2 E^2}{2}$$

- It is clear that the breakdown strength E depends upon the concentration of particles N, radius r of particle, viscosity η of liquid and temperature T of the liquid. It has been found that liquid with solid impurities has lower dielectric strength as compared to its pure form. Larger the size of the particles impurity the lower the overall dielectric strength of the liquid containing the impurity.
- If there is only a single conducting particle between the electrodes, it will give rise to local field enhancement depending on its shape.
- If this field exceeds the breakdown strength of the liquid, local breakdown will occur near the particle, and this will result
- in the formation of gas bubbles which may lead to the breakdown of the liquid.
- The values of the breakdown strength of liquids containing solid impurities was found to be much less than the values for pure liquids.
- The impurity particles reduce the breakdown strength, and it was also observed that the larger the size of the particles the lower were the breakdown strengths

2A The various breakdown mechanisms in solid dielectric can be classified as follows:

(a) intrinsic or ionic breakdown,

(b) electromechanical breakdown,

(c) failure due to treeing and tracking,

(d) thermal breakdown,

(e) electrochemical breakdown, and

(J) breakdown due to internal discharges.

ELECTROMECHANICAL BREAKDOWN

- When solid dielectrics are subjected to high electric fields, failure occurs due to electrostatic compressive forces which can exceed the mechanical compressive strength.
- If the thickness of the specimen is *d0 and is compressed to* a thickness *d under an applied voltage V, then the electrically developed compressive stress is in equilibrium*

$$\varepsilon_0 \varepsilon_r \frac{V^2}{2d^2} = Y \ln\left[\frac{d_0}{d}\right]$$

where *Y is the Young's modulus.*

Usually, mechanical instability occurs when

$$V^2 = d^2\left[\frac{2Y}{\varepsilon_0 \varepsilon_r}\right]\ln\left[\frac{d_0}{d}\right]$$

Substituting this in above equation the highest apparent electric stress before breakdown,

$$d/d_0 = 0.6 \text{ or } d_0/d = 1.67$$

- The above equation is only approximate as *Y depends on the mechanical stress.*
- When the material is subjected to high stresses the theory of elasticity does not hold good, and plastic deformation has to be considered

$$E_{max} = \frac{V}{d_0} = 0.6\left[\frac{Y}{\varepsilon_0 \varepsilon_r}\right]^{\frac{1}{2}}$$

2B

Solution: The current at the anode I is given by

$$I = I_0 \exp(\alpha\, d)$$

where I_0 is the initial current and d is the gap distance.
Given,

$$d_1 = 0.4 \text{ cm} \qquad d_2 = 0.1 \text{ cm}$$

$$I_1 = 5.5 \times 10^{-8} A \quad I_2 = 5.5 \times 10^{-9} A$$

$$\frac{I_1}{I_2} = \exp \alpha(d_1 - d_2)$$

i.e., $$10 = \exp(\alpha \times 0.3)$$

i.e., $$0.3\alpha = \ln(10)$$

∴ $$\alpha = 7.676/\text{cm . torr}$$

3A

Important application of h.v . In modern time h.vs are used for a wide variety of applications covering power systems, industry and research laboratories. Such appl. have become essential to sustain modern civilization. H.vs are applied in a) laboratories in nuclear research, b) in particle accelerators and c) Van de Graaff generators.

d) For transmission of large bulks of power over long distances, h.vs are indispensable.

e) Voltages upto 100 kV are used in electrostatic precipitators, in automobile ignition coils etc,

f) X-ray equipment for medical and industrial appl. also uses h.v.

g) Modern h.v test laboratories employ voltages upto 6 MV or more.

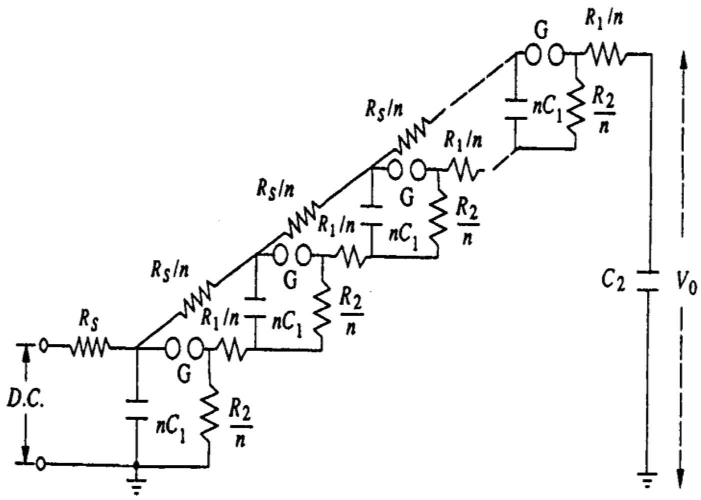
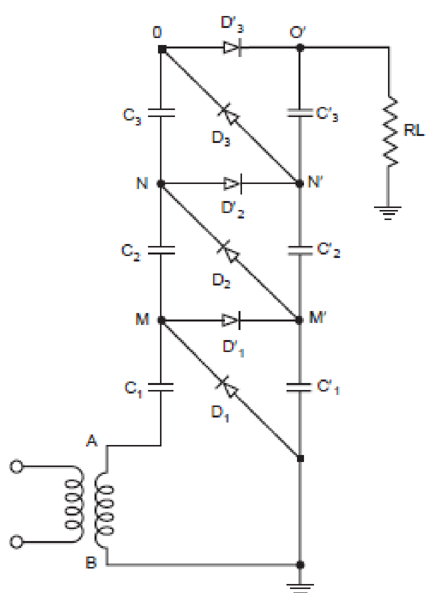


Fig. 6.17b Multistage impulse generator incorporating the series and wave tail resistances within the generator

- The schematic diagram of Marx circuit and its modification are shown in Figs. Usually the charging resistance is chosen to limit the charging current to about 50 to 100 mA, and the generator capacitance *C* is chosen such that the product CRs is about 10 s to 1 min. The gap spacing is chosen such that the breakdown voltage of the gap G is greater than the charging voltage V.all the capacitances are charged to the voltage V in about 1 minute. When the impulse generator is to be discharged, the gaps G are made to spark over simultaneously by some external means. all the capacitors C get connected in series and discharge into the load capacitance or the test object .The discharge time constant CR1/n (for n stages) will be very very small (microseconds), compared to the charging time constant CRs which will be few seconds. Hence, no discharge takes place through the charging resistors Rs. the modified Marx circuit is shown, wherein the resistances R1 and R2 are incorporated inside the unit.
- R1 is divided into n parts equal t oR1/n and put in series with the gap G.
- R2 is also divided into n parts and arranged across each capacitor unit after the gap G.
- This arrangement saves space, and also the cost is reduced.
- But, in case the waveshape is to be varied widely, the variation becomes difficult.
- The additional advantages gained by distributing R1 and R2 inside the unit are that the control resistors are smaller in size and the efficiency (Vo/nV) is high
- Impulse generators are nominally rated by the total voltage (nominal), the number of stages, and the gross energy stored.

- The nominal output voltage is the number of stages multiplied by the charging voltage.
- The nominal energy stored is given by $\frac{1}{2}C_1V^2$
- \- where C1 = *C/n (the discharge capacitance) and V is the nominal maximum* voltage (n times charging voltage).
- The waveform of either polarity can be obtained by suitably changing the charging unit polarity.

4A



Cockroft and Walton suggested an improvement over the circuit developed by Greinacher for

producing high D.C. voltages. Fig. 2.3. shows a multistage single phase cascade circuit of the Cockroft-

Walton type. *No Load Operation*: The portion ABM'MA is exactly indentical to Greinarcher voltage doubler circuit and the voltage across *C* becomes 2*Vmax*when *M* attains a voltage 2*Vmax.*

During the next half cycle when *B* becomes positive with respect to *A,* potential of *M* falls and, therefore, potential of *N* also falls becoming less than potential at *M*′ hence *C*2 is charged through *D*2. Next half cycle *A* becomes more positive and potential of *M* and *N* rise thus charging *C*′2 through *D*′2. Finally all the capacitors *C*′1, *C*′2, *C*′3, *C*1, *C*2, and C3 are charged. The voltage across the column of capacitors consisting of *C*1, *C*2, *C*3, keeps on oscillating as the supply voltage alternates. This column, therefore, is known as *oscillating column*. However, the voltage across the capacitances *C*′1, *C*′2, *C*′3, remains constant and is known as *smoothening column*. The voltages at *M*′, *N*′, and *O*′ are 2 *Vmax* 4 *Vmax* and 6 *Vmax.* Therefore, voltage across all the capacitors is 2 *Vmax* except for *C*1 where it is *Vmax* only. The total output voltage is 2*n V*max where *n* is the number of stages. Thus, the use of multistages arranged in the manner shown enables very high voltage to be obtained. The equal stress of the elements (both capacitors and diodes) used is very helpful and promotes a modular design of such generators. *Generator Loaded*: When the generator is loaded, the output voltage will never reach the value 2*n Vmax*. Also, the output wave will consist of ripples on the voltage. Thus, we have to deal with two quantities, the voltage drop Δ*V* and the ripple δ*V*.

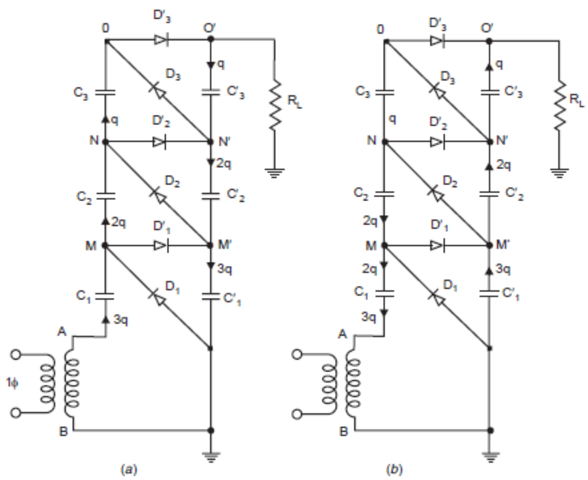


Fig. 2.4 (*a*) Charging of smoothening Column (*b*) Charging of oscillating column

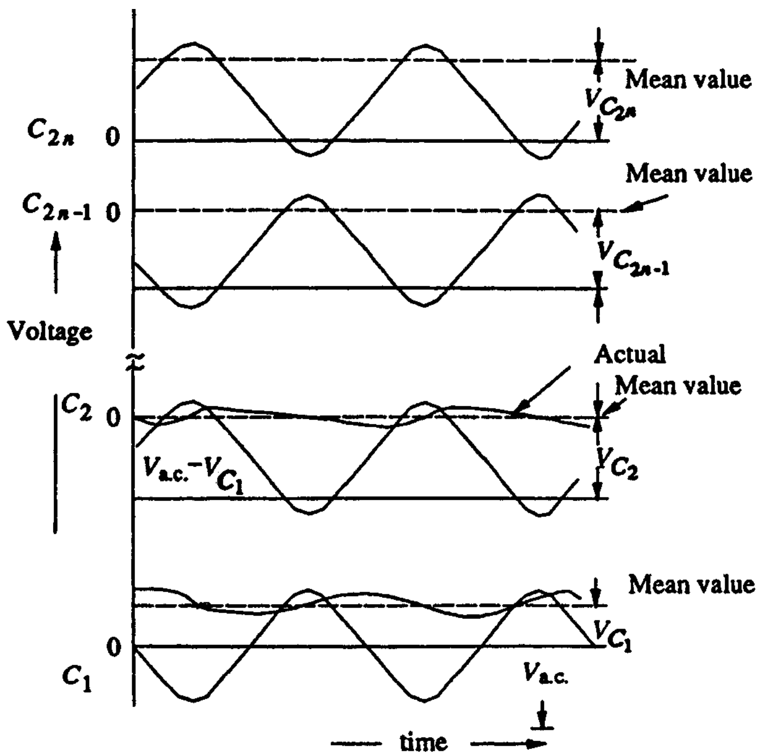


Fig. 6.4d Voltage waveforms across the first and the last capacitors of the cascaded voltage multiplier circuit shown in Fig. 6.4(b)

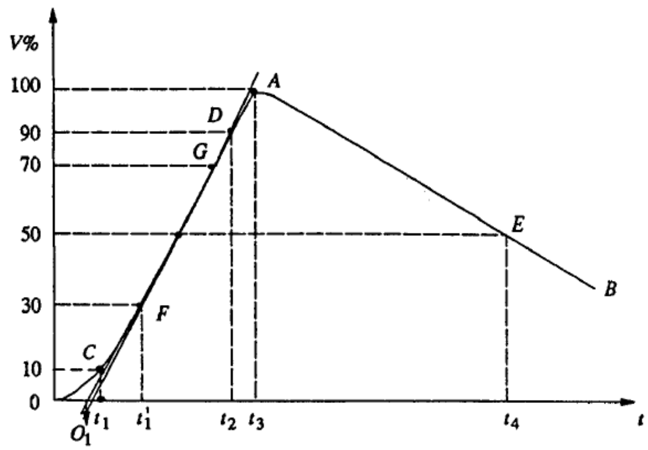


Fig. 6.14 Impulse waveform and its definitions

Impulse waves are specified by defining their **rise or front time**, **fall or tail time to 50% peak value**, and the value of **the peak voltage**.

Thus 1.2/50 µs, 1000 kV wave represents an impulse voltage wave with a front time of 1.2 (is, fall time to 50% peak value of 50 µs and a peak value of 1000 kV.

When impulse waveshapes are recorded, the initial portion of the wave will not be clearly defined or sometimes will be missing.

Moreover, due to disturbances it may contain superimposed oscillations in the rising portion.

Referring to the waveshape in Fig. 6.14, the peak value A is fixed and referred to as 100% value.

The points corresponding to 10% and 90% of the peak values are located in the front portion (points C and D). The line joining these points is extended to cut the time axis at o1. o1 is taken as the virtual origin. 1.25 times the interval between times t1 and t2 corresponding to points C and D (projections on the time axis) is defined as the **front time, i.e. 1.25 (o1t2 – o1t1).** The point E is located on the wave tail corresponding to 50% of the peak value, and its projection on the time axis is t4. 0t4 is defined as the fall or tail time. In case the point C is not clear or missing from the waveshape record, the point corresponding to 30% peak value F is taken and its projection t‘1 is located on time axis. The wavefront time in that case will be defined as 1.67 (01t3 – o1t’1), The tolerances that can be allowed in the front and tail times are respectively ± 30% and ± 20%. Indian standard specifications define **1.2/50 µS** wave to be the standard impulse. The tolerance allowed in the peak value is **± 3%.**

Various factors that affect the sparkover voltage of a sphere gap are:

(i) nearby earthed objects,

(ii) atmospheric conditions and humidity,

(iii) irradiation, and

(i v) polarity and rise time of voltage waveforms

- **Effect of nearby earthed objects**
- The effect of nearby earthed objects was investigated by Kuffel by enclosing the earthed sphere inside an earthed cylinder.
- It was observed that the sparkover voltage is reduced.
- The reduction was observed to be

$$\Delta V = m \log (B/D) + C$$

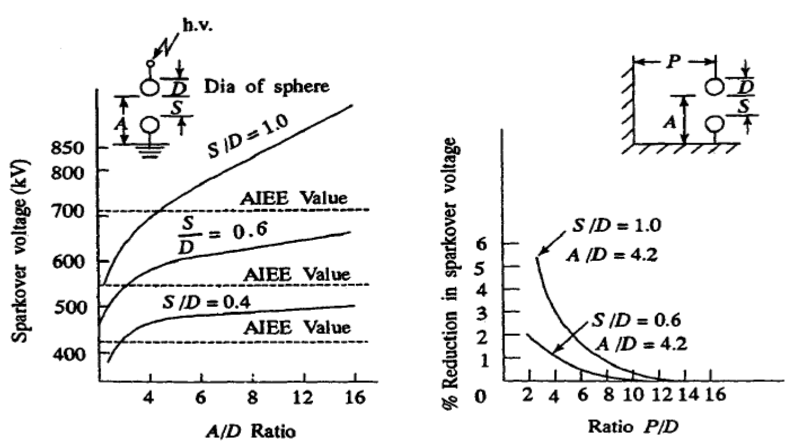
where,

$\Delta V =$ percentage reduction,

$B =$ diameter of earthed enclosing cylinder,

$D =$ diameter of the spheres,

$S =$ spacing, and m and C are constants.



(a) (b)

(ii) Effect of atmospheric conditions

- The sparkover voltage of a spark gap depends on the air density which varies with the changes in both temperature and pressure.
- Let sparkover voltage = ***V** under test* conditions of temperature ***T** and pressure **p** torr*
- *sparkover voltage =V0* under standard conditions of temperature *T = 2O°C and pressure p = 760 torr, then V=kV0*
- where *k is a function of the air density factor d, given by*

$$d = \frac{p}{760}\left(\frac{293}{273+T}\right)$$

5B

Solution: According to empirical formula which holds good at standard atmospheric conditions

$$V_b = 24.22\ S + 6.08\sqrt{S}$$

where S is the gap length in cms.

(*i*) When $S = 0.2$ cm

$$V = 24.22 \times 0.2 + 6.08\sqrt{0.2} = 7.56 \text{ kV} \quad \textbf{Ans.}$$

(*ii*) When $S = 1.5$ cms

$$V_b = 24.22 \times 1.5 + 6.08\sqrt{1.5} = 36.33 + 7.446 = 43.776 \text{ kV} \quad \textbf{Ans.}$$

The air density correction factor

$$= \frac{3.92\ b}{273 + t} = \frac{3.92 \times 75}{273 + 35} = 0.9545 \quad \textbf{Ans.}$$

Therefore, voltage for 2 mm gap will be 7.216 kV and for 15 mm gap it will be 41.78 kV.

6A **THE CHUBB-FORTESCUE METHOD**

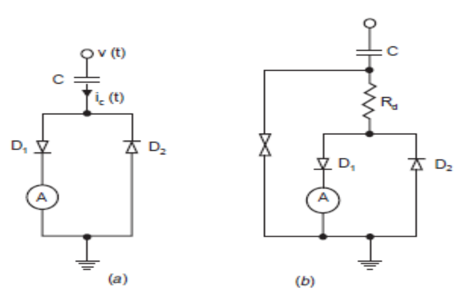
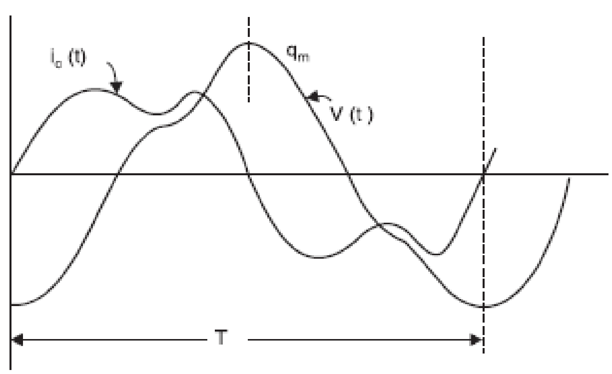


Fig. 4.11 (*a*) Basic circuit (*b*) Modified circuit

- **Chubb and Fortescue** suggested a simple and accurate method of measuring **peak value of a.c. voltages.**

- The basic circuit consists of a standard capacitor, two diodes and a current integrating ammeter (MC ammeter) as shown in Fig.
- The displacement current ic(t), Fig. 4.12 is given by the rate of change of the charge and hence the voltage V(t) to be measured flows through the high voltage capacitor C and is subdivided into positive and negative components by the back to back connected diodes.
- The voltage drop across these diodes can be neglected (1 V for Si Diodes) as compared with the voltage to be measured.
- The measuring instrument (M.C. ammeter) is included in one of the branches.
- The ammeter reads the mean value of the current.
- The relation is similar to the one obtained in case of generating voltmeters.
- An increased current would be obtained if the current reaches zero more than once during one half cycle.
- This means the wave shapes of the voltage would contain more than one maxima per half cycle.
- The standard a.c. voltages for testing should not contain any harmonics and, therefore, there could be very short and rapid voltages caused by the heavy predischarges, within the test circuit which could introduce errors in measurements.
- To eliminate this problem filtering of a.c. voltage is carried out by introducing a damping resistor in between the capacitor and the diode circuit, Fig. 4.11 (*b).*
- $$I = \frac{1}{T}\int_{t_1}^{t_2} C\frac{dv(t)}{dt}\,.\,dt = \frac{C}{T}\,.\,2V_m = 2V_m fC \text{ or } V_m = \frac{I}{2fC}$$

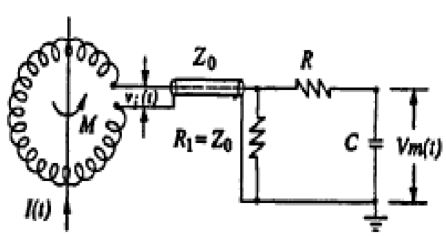


Also, if full wave rectifier is used instead of the half wave as shown in Fig. 4.11, the factor 2 in the denominator of the above equation should be replaced by 4.

Since the frequency f, the capacitance C and current I can be measured accurately, the measurement of symmetrical a.c. voltages using Chubb and Fortescue method is quite accurate and it can be used for calibration of other peak voltage measuring devices.

6B **Measurement of High Impulse Currents Using Magnetic Potentiometers (Rogowski Coils)**

- If a coil is placed surrounding a current carrying conductor, the voltage signal induced in the coil is $v_i(t) = M dI(t)/dt$
- *Where* **M** *is the mutual inductance between the conductor* and the coil, and **I** is the current flowing in the conductor.
- Usually, the **coil is wound on a nonmagnetic former of toroidal shape** and is **coaxially placed surrounding the current carrying conducto**r.
- The **number of turns** on the coil is chosen to be **large**, to get enough signal induced.
- The coil is wound cross-wise to reduce the leakage inductance.
- Usually an integrating circuit (see Fig. 7.52) is employed to get the output signal voltage proportional to the current to be measured.
- The output voltage is given by $$V_m(t) = \frac{1}{CR}\int_0^t v_i(t) = \frac{M}{CR} I(t)$$



$V_i(t)$ — Induced voltage in the coil $= M\frac{d[I(t)]}{dt}$
Z_0 — Coaxial cable of surge impedance Z_0
R-C — Integrating network

- **Fig. 7.52** Rogowski coil for high impulse current measurements

- Rogowski coils with electronic or active integrator circuits have large and widths (about 100 MHz).

- At frequencies greater than 100 MHz the response is affected by the skin effect, the capacitance distributed per unit length along the coil, and due to the electromagnetic interferences.
- However, miniature probes having nanosecond response time are made using very few turns of copper strips for UHF measurements.

7A **Charge Formation in the Clouds**

- The factors that contribute to the formation or accumulation of charge in the clouds are too many and uncertain. During thunderstorms, **positive and negative charges** become **separated** by the heavy **air currents with ice crystals** in the upper part and rain in the lower parts of the cloud. This charge separation depends on the height of the clouds, which range from 200 to 10,000 m, with their charge centres probably at a distance of about 300 to 2000 m. The volume of the clouds that participate in lightning flashover are uncertain, but the charge inside the cloud may be as high as 1 to 100 C.Clouds may have a **potential** as high as **10^7 to 10^8 V** with **field gradients** ranging from **100 V/cm** within the cloud to as high as **10 kV/cm** at the initial discharge point .The **energies** associated with the cloud discharges can be as high **as 250 kWh**. It is believed that the **upper regions** of the cloud are usually **positively charged**, whereas **the lower region** and the base are predominantly **negative** except the local region, **near** the **base** and the **head**, which is **positive**. The maximum gradient reached at the ground level due to a charged cloud may be as high as 300 V/cm, while the fair weather gradients are about 1 V/cm. A probable charge distribution model is given in Fig. 8.1 with the corresponding field gradients near the ground.

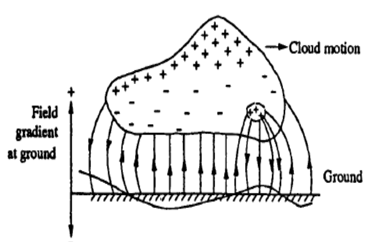


Fig. 8.1 Probable field gradient near the ground corresponding to the probable charge distribution in a cloud

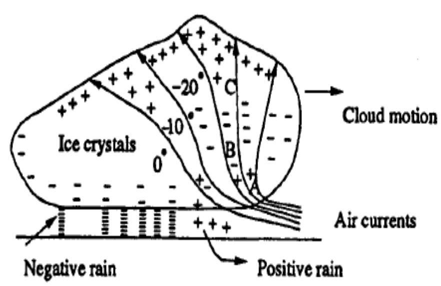


Fig. 8.2 Cloud model according to Simpson's theory

- According to **the Simpson's theory** (Fig. 8.2) there are **three essential regions** in the cloud to be considered for charge formation.
- Below region A, air currents travel above 800 cm/s, and no raindrops fall through.
- In region A, air velocity is high enough to break the falling raindrops causing a positive charge spray in the cloud and negative charge in the air.

- The spray is blown upwards, but as the velocity of air decreases, the positively charged water drops recombine with the larger drops and fall again. Thus region A, eventually becomes **predominantly positively charged**, while **region B** above it, becomes **negatively charged** by air currents. In the **upper regions in the cloud, the temperature is low (below freezing point) and only ice crystals exist .**The **impact of air** on these crystals makes them **negatively charged**, thus the distribution of the charge within the cloud becomes as shown in Fig. 8.2**Reynolds and Mason** proposed modification, according to which the thunder clouds are developed at heights 1 to 2 km above the ground level and may extend up to 12 to 14 km above the ground. For thunder clouds and charge formation **air currents, moisture and specific temperature range** are required.The **air currents** controlled by the **temperature gradient** move upwards carrying **moisture** and **water droplets**. The temperature is O^{0}C at about 4 km from the ground and may reach - 5O^{0}C at about 12 km height. But water droplets do not freeze as soon as the temperature is O^{0}C. They freeze below - 4O^{0}C only as solid particles on which crystalline ice patterns develop and grow. The larger the number of solid sites or nuclei present, the higher is the temperature (> -4O^{0}C) at which the ice crystals grow.
- Thus in clouds, the effective freezing temperature range is around - 33^{0}C to - 4O^{0}C.The water droplets in the thunder cloud are blown up by air currents and get super cooled over a range of heights and temperatures. When such freezing occurs, the crystals grow into large masses and due to their weight and gravitational force start moving downwards. Thus, a thunder cloud consists of supercooled water droplets moving upwards and large hail stones moving downwards. When the upward moving super cooled water droplets act on cooler hail stone, it freezes partially, i.e. the outer layer of the water droplets freezes forming a shell with water inside. When the process of cooling extends to inside warmer water in the core, it expands, thereby splintering and spraying the frozen ice shell. The splinters being fine in size are moved up by the air currents and carry a net positive charge to the upper region of the cloud.
- The hail stones that travel downwards carry an equivalent negative charge to the lower regions of the cloud and thus negative charge builds up in the bottom side of the cloud .According to Mason, the ice splinters should carry only positive charge upwards. Water being ionic in nature has concentration of H+ and OH- ions. The ion density depends on the temperature.
- Thus, in an ice slab with upper and lower surfaces at temperatures *T1and T2 (T1 < T2), there will be a higher concentration of ions in the* lower region.
- However, since H+ ions are much lighter, they diffuse much faster all over the volume.
- Therefore, the lower portion which is warmer will have a net negative charge density, and hence the upper portion, i.e. cooler region will have a net positive charge density.
- Hence, it must be appreciated, that the outer shells of the freezed water droplets coming into contact with hail stones will be relatively cooler (than their inner core—warmer water) and therefore acquire a net positive charge.

- When the shell splinters, the charge carried by them in the upward direction is positive.
- According to the Reynold's theory, which is based on experimental results, the hail packets get negatively charged when impinged upon by warmer ice crystals.
- When the temperature conditions are reversed, the charging polarity reverses.
- However, the extent of the charging and consequently the rate of charge generation was found to disagree with the practical observations relating to thunder clouds.
- This type of phenomenon also occurs in thunder clouds.

7B ***Protection against Lightning Overvoltages***

Overvoltages due to lightning strokes can be avoided or minimized in practice by

(a) shielding the overhead lines by using ground wires above the phase wires,

(b) using ground rods and counter-poise wires, and

(c) including protective devices like expulsion gaps, protector tubes on the lines, and surge diverters at the line terminations and substations

a)Lightning Protection Using Shielded Wires or Ground Wires

Ground wire is a conductor run parallel to the main conductor of the transmission line supported on the same tower and earthed at every equally and regularly spaced towers. It is run above the main conductor of the line. The ground wire shields the transmission line conductor from induced charges, from clouds as well as from a lightning discharge. The arrangements of ground wires over the line conductor is shown in Fig. 8.19.The mechanism by which the line is protected may be explained as follows. If a positively charged cloud is assumed to be above the line, it induces a negative charge

on the portion below it, of the transmission line. With the ground wire present, both the ground wire and the line conductor get the induced charge. But the ground wire is earthed at regular intervals, and as such the induced charge is drained to the earth potential only;

the potential difference between the ground wire and the cloud and that between the ground wire and the transmission line wire will be in the inverse ratio of their respective capacitances [assuming the cloud to be a perfect conductor and the atmospheric medium (air) a dielectric]. As the ground wire is nearer to the line wire, the induced charge on it will be much less and hence the potential rise will be quite small. The effective protection or shielding given by the ground wire depends on the height of the ground wire above the ground *(H) and the protection or shielding angle* Θ_s (usually 30°) as shown in Fig.

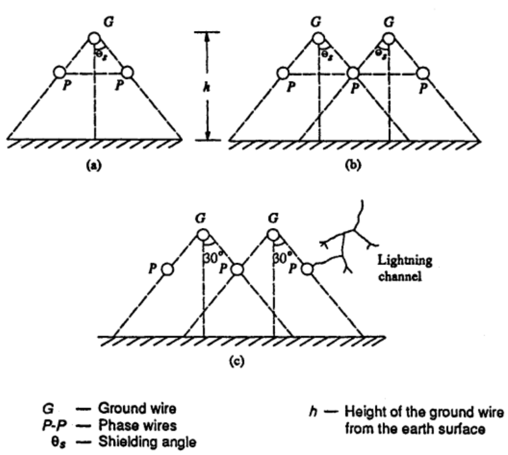


Fig. 8.19 Shielding arrangement of overhead lines by ground wires

b)Protection Using Ground Rods and Counter-Poise Wires

When a line is shielded, the lightning strikes either the tower or the ground wire. The path for drainage of the charge and lightning current is

(a) through the tower frame to ground,

(b) through the ground line in opposite directions from the point of striking.

Thus the ground wire reduces the instantaneous potential to which the tower top rises considerably, as the current path is in three directions.

The instantaneous potential to which tower top can rise is

$$V_T = \frac{I_0 Z_T}{\left(1 + \frac{Z_T}{Z_S}\right)}$$

where,

Z_T = surge impedance of the tower, and

Z_S = surge impedance of the ground wire.

If the surge impedance of the tower, which is the effective tower footing resistance, is reduced, the surge voltage developed is also reduced considerably.

This is accomplished by providing driven ground rods and counter-poise wires connected to tower legs at the tower foundation.

Ground rods are a number of rods of suitable dimension driven into the ground. In hard soils the rods may be much longer and can be driven to a more depth. They are usually made of galvanized iron or copper bearing steel. The spacings of the rods, the number of rods, and the depth to which they are driven depend on the desired tower footing resistance. The above effect is alternatively achieved by using **counter-poise** wires.

Counterpoise wires are wires buried in the ground at a depth of 0.5 to 1.0 m, running parallel to the transmission line conductors and connected to the tower legs. These are found to be more effective than driven rods and the surge impedance of the tower may be reduced to as low as 25Ω

. *The depth does not* materially affect the resistance of the counter-poise, and it is only necessary to bury it to a depth enough to prevent theft. It is desirable to use a larger number of parallel wires than a single wire. But it is difficult to lay counter-poise wires compared to ground or driven rods.

c) Protective Devices

In regions where lightning strokes are intensive or heavy, the overhead lines within these zones are fitted with shunt protected devices. On the line itself two devices known as expulsion gaps and protector tubes are used. Line terminations, junctions of lines, and sub-stations are usually fitted with surge diverters.

8A

Solution : Velocity of propagation $= \frac{1}{\sqrt{LC}}$

$$= \frac{1}{\sqrt{1.26 \times 10^{-3} \times 0.009 \times 10^{-6}}}$$

$$= 3 \times 10^5 \text{ km/s}$$

Surge impedance $= \sqrt{\frac{L}{C}}$

$$= \sqrt{\frac{1.26 \times 10^{-3}}{9 \times 10^{-9}}}$$

$$= 374.2\ \Omega$$

Time taken for the surge to travel to the other end is

$$= \frac{400}{3 \times 10^5}$$

$$= 1.33 \text{ m s}$$

8B **Surge Diverters**

These are non-linear resistors in series with spark gaps which act as fast switches. A typical surge diverter or lightning arrester is shown in Fig. 8.23 and its characteristics are given in Fig. 8.24. A number of non-linear resistor elements made of silicon carbide are stacked one over the other into two or three sections. They are usually separated by spark gaps (see Fig. 8.23). the entire assembly is housed in a porcelain water-tight housing. The volt-ampere characteristic of a resistance element is of the form

$$I = kV^a$$

where, I= discharge current, V = applied voltage across the element, and k and a are constants depending on the material and dimensions of the element.

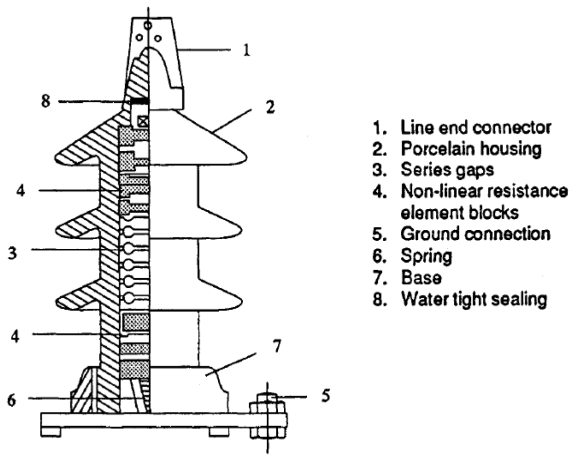


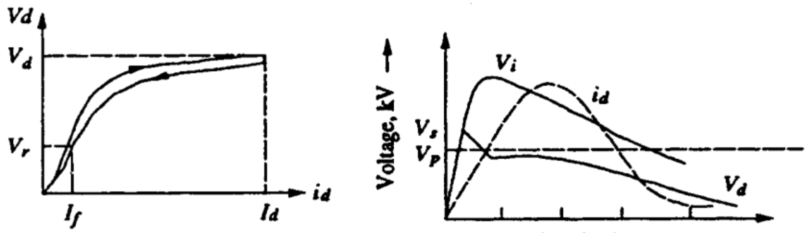
Fig. 8.23 Non-linear element surge diverter

When a surge voltage (Vi of Fig. 8.24b) is applied to the surge diverter, it breaks down giving the discharge current id and maintains a voltage Vd across it Thus, it provides a protection to the apparatus to be protected above the protective level *Vp* .

The lighter designs operate for smaller duration of currents, while the heavy *duty* surge diverters with assisted or active gaps are designed for high currents and long duration surges. The lighter design arresters can interrupt 100 to 300 A of power frequency follow-on current and about 5000 A of surge currents. If the current is to be more and has to be exceeded, the number of series elements has to be increased or some other method to limit the current has to be used. In heavy duty arresters, the gaps are so arranged that the arc burns in the magnetic field of the coils excited by power frequency follow-on currents. During lightning discharges, a high voltage is induced in the coil by the steep front of the surge, and sparking occurs in an auxiliary gap. For power frequency follow-on currents, the auxiliary gap is extinguished, as sufficient voltage will not be present across the auxiliary gap to maintain an arc.

The main gap arcs occur in the magnetic field of the coils. The magnetic field, aided by the born shaped main gap electrodes, elongates the arc and quenches it rapidly. The follow-on current is limited by the voltage drop across the arc and the resistance element. During surge discharge the lightning protective level becomes low. Sometimes, it is possible to limit the power frequency and other overvoltages after a certain number of cycles using surge diverters. The permissible voltage and duration depend on the thermal capacity of the diverter.

The rated diverter voltage is normally chosen so that it is not less than the power frequency overvoltage expected (line to ground) at the point of installation, under any faulty or abnormal operating condition.



(a) Volt-ampere characteristic of a non-linear resistor block

(b) Surge diverter operation

I_f — Power frequency follow-on current at system voltage V_r

V_d — Max. voltage across the diverter during discharge of surge current with peak value I_d

V_s — Sparkover voltage

V_p — Protective level

V_i — Surge voltage

i_d — Discharge current

V_d — Voltage across the diverter when discharging the current i_d

Fig. 8.24 Characteristics of a surge diverter

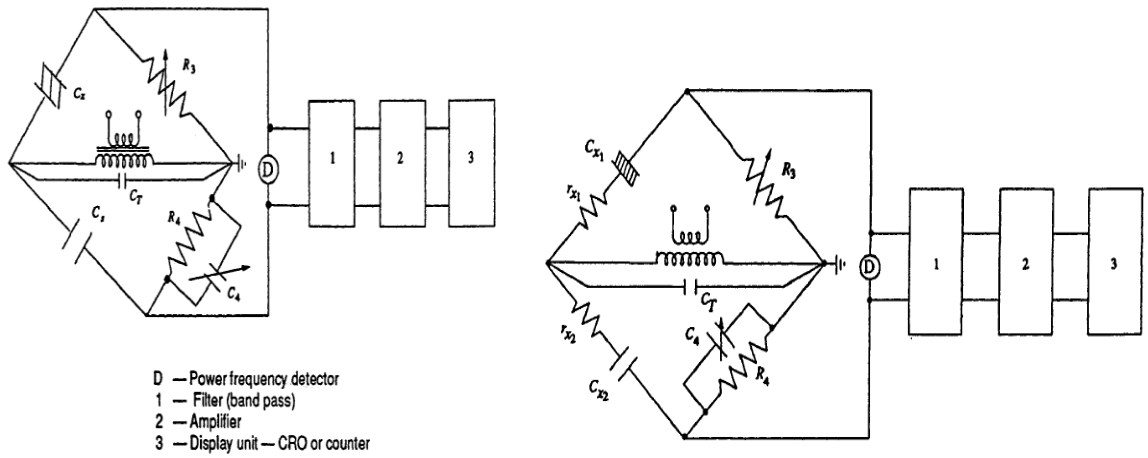
9A **Balanced Detection Method**

In the straight detection method, the external disturbances are not fully rejected. The filter used to block the noise sources may not be effective. The Schering bridge employed for the tan δ measurement is sometimes used. In this method, the test object is not grounded. A **modification** to the Schering bridge detector is **the differential discharge detector,** given by Kreuger.

Both the schemes are given in Fig. The bridges are tuned and balanced at 50 Hz. A filter is used across the detector terminals to block the 50 Hz components present Signals in the range from 5 to 50 kHz are allowed to pass through the filter and amplified. The CRO gives the display of the pulse pattern.

Any external interference from outside is balanced out, and only internally (test piece) generated pulses are detected. In the modified scheme, another test sample called dummy sample is used in the place of the standard condenser. The capacitance and tan δ of the dummy sample are made approximately equal, but need not be equal. **The disadvantage is that if two discharges occur in both the samples**

simultaneously, they cancel out, but this is very rare. The main advantage of the second method is its capacity for better rejection of external noise and use of the wide frequency band with belter resolution of the individual pulses.



(a) Balanced detector using Schering bridge

(b) Differential detector

Fig. 9.23 Balanced discharge detector schemes

9B SCHERING BRIDGE

- In the power frequency range (25 to 100 Hz) Schering bridge is a very versatile and sensitive bridge and is readily suitable for high voltage measurements. The stress dependence of K' or εr and tanδ can be readily obtained with this bridge. The schematic diagram of the bridge is shown in Fig. The lossy capacitor or capacitor with the dielectric between electrodes is represented as an imperfect capacitor of capacitance Cx together with a resistance rx. The standard capacitor is shown as Cs which will usually have a capacitance of 50 to 500 µF. The variable arms are R4 and C3 /R3.

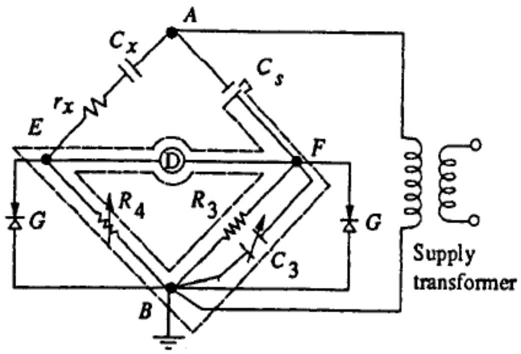
Balance is obtained when

$$\frac{Z_1}{Z_2} = \frac{Z_4}{Z_3}$$

where,

$$Z_1 = r_x + \frac{1}{j\omega C_x}, \qquad Z_2 = \frac{1}{j\omega C_s}$$

$$Z_3 = \frac{R_3}{1 + j\omega C_3 R_3}, \text{ and } Z_4 = R_4$$



- - - dotted line is the shielding arrangement. Shield is connected to B, the ground

Fig. 9.11 Schematic diagram of a Schering bridge

$$C_x = \frac{R_3}{R_4} C_s; \text{ and } r_x = \frac{C_3}{C_2} R_1$$

The loss angle, $\tan \delta_x = \omega C_x R_x$
$= \omega C_3 R_3$

Usually δ_x will be small at power frequencies for the common dielectrics so that

$$\cos \theta_x = \sin \delta_x = \delta_x = \tan \theta_x = \omega C_2 R_3 \qquad (9.17)$$

The lossy capacitor which is made as an equivalent C_x in series with r_x can be represented as a parallel combination of C_x and R_x where the parallel combination R_x is found to be

$$R_x = \frac{1}{\omega^2 C_x^2 r_x} \qquad (9.18)$$

with C_x having the same value.

- The normal method of balancing is **by fixing** the value of **R3** and **adjusting C3 and** ***R4***.
- C3 giving a direct reading of tan δ.
- *Earthing and Shielding*
- For two terminal measurements the bridge is grounded at its junction points. The supply ransformer, detector, and all the components of the bridge are enclosed in

- earthed shields. For three terminal measurements, it is necessary to avoid stray capacitances, for accurate measurements. Hence, a guard circuit and earthing device
- (known as Wagner's earthing device) are used. The bridge is balanced once with the
- ratio arms and again with the earthing device, alternately, so that no change in balance
- occurs. This ensures the elimination of stray ground capacitances and coupling. The
- schematic arrangement is shown in Fig. 9.17. The arms, containing *Ry* and *RwCw* are
- the Wagner earthing device arms. The bridge is first balanced with *R^ RB** Qv» and
- *CT* and later with /?v, *Rw,* C//, and Cj. The detector is alternately connected to either
- the earthing device or to the bridge arms *A* and *B.* The balance is achieved, when at
- either position the detector indicates the same null indication. This bridge can be extended to frequencies as high as 500 kHz beyond which the
- lead lengths and the residual inductances in various arms become too high to achieve
- proper balance. Hence, for higher frequencies other methods have to be adopted.

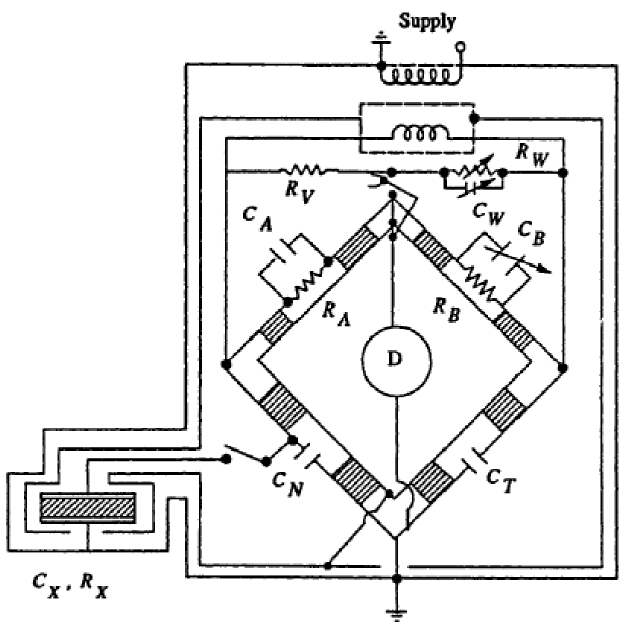


Fig. 9.17 Schering bridge for three terminal measurements with Wagner's earthing device

10A

10B Given $C_S = 500\,pf$

$R_1 = ~~800\Omega~~\ 500\Omega$

$R_2 = 180\,\Omega$

$C_2 = 0.15\,pf$

$C_P = C_S \frac{R_2}{R_1} = 500 \times 10^{-12} \times \frac{180}{500} = ~~112.5\,pf~~\ 180\,pf$

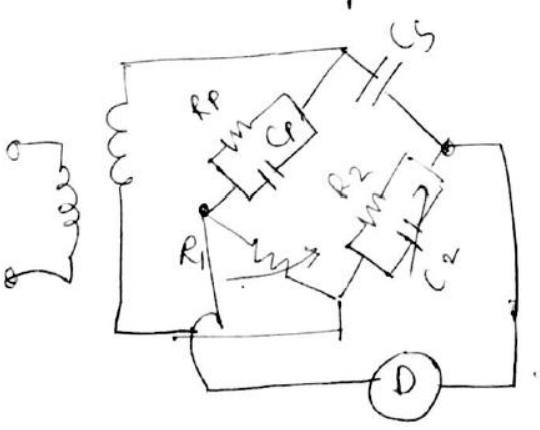
$R_P = \frac{R_1}{\omega^2 C_2 C_S R_2^2} = \frac{500}{314^2 \times 0.15 \times 10^{-6} \times 500 \times 10^{-12} \times 180^2}$

$= 2087\,M\Omega.$

$p.f = \tan\delta_P = \frac{1}{\omega C_P R_P} = \frac{1}{314 \times 180 \times 2087 \times 10^{6} \times 10^{-12}}$

$= 0.008478$

$\text{Power loss} = \frac{V^2}{R} = \frac{33^2 \times 10^6}{2087 \times 10^6} = 0.522\ \text{Watt}$



Schering Bridge

10B

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.

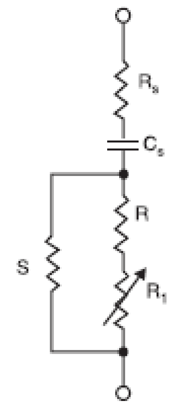


Fig. 6.12 Shunt arrangement for measurement of large capacitance

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.