CMR INSTITUTE OF TECHNOLOGY

USN | | | | | | | | | |

Internal Test 4 –February 2022

Sub:	High Voltage Engineering							Code:	18EE56
Date:	3/02/2022	Duration:	90 mins	Max Marks:	50	Sem:	**VA**	Branch:	EEE

Note: Answer any FIVE full questions with neat diagram wherever necessary.

		Marks	OBE	
			CO	RBT
1.	Describe the Generating voltmeter used for measuring high voltages with a neat diagram. Mention its advantages and disadvantages.	[10]	CO6	L1
2.	Explain the principle of operation and construction of an electrostatic voltmeter used for the measurement of high voltage. What are the limitations?	[10]	CO6	L1
3.	Summarize the features of (a)Series resistance with micro-ammeter (b)Chubb-Fortesque method	[10]	CO4	L2
4.	Explain Sphere gap method of measuring high voltage	[10]	CO4	L1
5	Explain the different theories of charge formation in clouds	[10]	CO5	L1
6	Write short notes on : (a)Expulsion gaps (b)Protector tubes	[10]	CO5	L2
7(a)	Explain Resistance potential divider	[5]	CO4	L1
7(b)	A Generating voltmeter is required to measure voltage between 15 kV to 250 kV. If the indicating meter reads a minimum current of 2 µA and maximum of 35 µA, determine the capacitance of the Generating voltmeter. Assume that the speed of driving synchronous motor is 1500 rpm.	[5]	CO4	L3
8	Explain the causes for switching and power frequency over voltages? How are they controlled in power systems?	[10]	CO5	L1

Solution of High Voltage Engineering – IAT4

1 **Generating Voltmeter**

When the **source loading** is not permitted or when direct connection to the high voltage source is to be avoided, the generating principle is employed for the measurement of high voltages

- **Principle:** A generating voltmeter is a variable capacitor electrostatic voltage generator which generates current proportional to the voltage to be measured.
- Similar to electrostatic voltmeter the generating voltmeter provides loss free measurement of d.c. and a.c. voltages.
- The device is driven by an external constant speed motor and does not absorb power or energy from the voltage measuring source.

- It is a device used to measure loss free AC voltage
- It has high input impedance
- There is no direct connection to the High Voltage(HV)
- It is also known as 'Variable capacitor electrostatic voltmeter'
- This device is driven by external synchronous motor
- Device generates current which is proportional to the applied HV

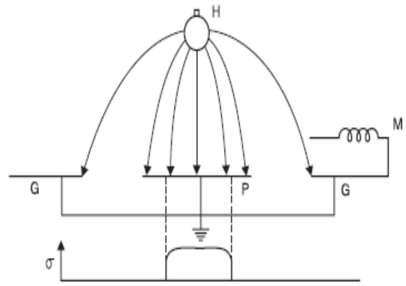


Fig. 4.8 Principle of generating voltmeter

$$i(t) = \frac{dq(t)}{dt} = \frac{d}{dt}\left[\int \sigma(a)da\right]$$

- The principle of operation explained with the help of Fig.
- **Construction:**
- H is a high voltage electrode
- the earthed electrode is subdivided into a sensing or pick up electrode P, a guard electrode G and a movable electrode M, all of which are at the same potential.
- The high voltage electrode H develops an electric field between itself and the electrodes P, G and M.
- The field lines are shown in Fig. 4.8.
- The **electric field density σ** is also shown.
- If electrode M is fixed and the voltage **V** is changed, the field density σ would change and thus a current **i (t)** would flow between P and the ground.

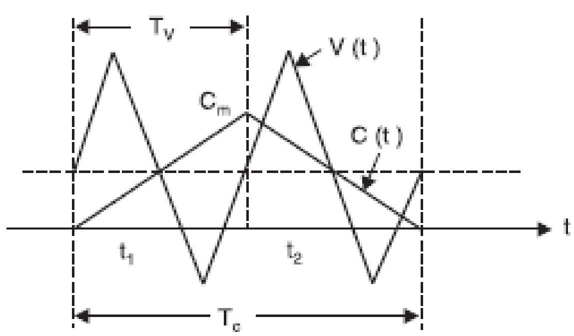


Fig. 4.9 Capacitance and voltage variation

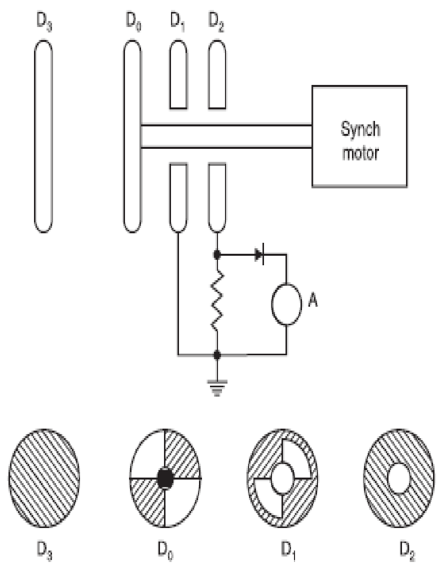


Fig. 4.10 Schematic diagram of generating voltmeter

- Fig. 4.10 shows a schematic diagram of a generating voltmeter which employs rotating vanes for variation of capacitance.
- The high voltage electrode is connected to a disc electrode *D3 which is* kept at a fixed distance on the axis of the other low voltage electrodes *D2, D1, and D0.*
- *The rotor D0 is* driven at a constant speed by a synchronous motor at a suitable speed.
- The rotor vanes of *D0 cause* periodic change in capacitance between the insulated disc *D2 and the high voltage electrode D3.*
- *The* number and shape of vanes are so designed that a suitable variation of capacitance (sinusoidal or linear) is achieved.
- The a.c. current is rectified and is measured using moving coil meters.
- If the current is small an amplifier may be used before the current is measured.

Advantages

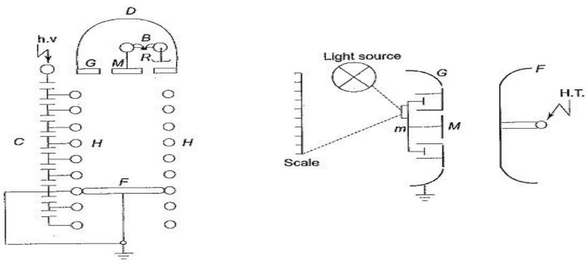
- Scale is linear and can be extrapolated
- Source loading is practically zero
- No direct connection to the high voltage electrode.

Disadvantages

- They require calibration
- Careful construction is needed and is a cumbersome instrument requiring an auxiliary drive, and
- Disturbance in position and mounting of the electrodes make the calibration invalid.

---------------------------(10 Marks)

2 **Electrostatic Voltmeter**



(a) Absolute electrostatic voltmeter (b) Light beam arrangement

Fig. 7.14 Electrostatic voltmeter

Schematic diagram of an absolute electrostatic voltmeter is shown :

- The hemispherical metal dome D encloses a sensitive balance B which measures the force of attraction between the movable disc M, which hangs from one of its arms and the lower plate F.
- The movable electrode M hangs with a clearance of above 0.01 cm, in a central opening in the upper plate which serves as a guard ring.
- The diameter of each of the plates is 1 metre.
- Light reflected from a mirror carried by the balance beam serves to magnify its motion and to indicate to the operator at a safe distance when a condition of equilibrium is reached.
- As the spacing between the two electrodes is large (about 100 cms for a voltage of about 300 kV), the uniformity of the electric field is maintained by the guard rings G which surround the space between the discs M and F.
- The guard rings G are maintained at a constant potential in space by a capacitance divider ensuring a uniform spatial potential distribution.
- When voltages in the range 10 to 100 kV are measured, the accuracy is of the order of 0.01 per cent.

Principle of operation

- The electric field according to Coulomb is the field of forces. The electric field is produced by voltage and, therefore, if the field force could be measured, the voltage can also be measured.
- The voltmeters are used for the measurement of high a.c. and d.c. voltages. The measurement of voltages lower than about 50 volt is, however, not possible, as the forces become too small.
- When a voltage is applied to a parallel plate electrode arrangement, an electric field is set up between the plates.
- It is possible to have uniform electric field between the plates with suitable arrangement of the plates.
- The field is uniform, normal to the two plates and directed towards the negative plate.
- If A is the area of the plate and E is the electric field intensity between the plates ε the permittivity of the medium between the plates, we know that the energy density of the electric field between the plates is given as,
- $$W_d = \frac{1}{2}\varepsilon E^2$$
- Consider a differential volume between the plates and parallel to the plates with area *A and* thickness *dx, the energy content in this differential volume Adx is*
- Now force *F between the plates is defined as the derivative of stored electric energy along the* field direction *i.e.,*

$$dW = W_d\, A dx = \frac{1}{2} \varepsilon E^2\ A dx$$

$$F = \frac{dW}{dx} = \frac{1}{2} \varepsilon\ E^2 A$$

- Now $E = V/d$ *where V is the voltage to be measured and d the distance of separation between the* plates. Therefore, the expression for force

$$F = \frac{1}{2} \varepsilon \frac{V^2 A}{d^2}$$

Demerits of Electrostatic Voltmeter :

- Not used for small voltage as operating force becomes less.
- Expensive, larger size, not robust.
- Non uniform scale.
- Humidity effects on resistance and consumption increase.
- Not suitable for very high frequency above few MHz.

---------------------(10 Marks)

3(a) Series Resistance Microammeter

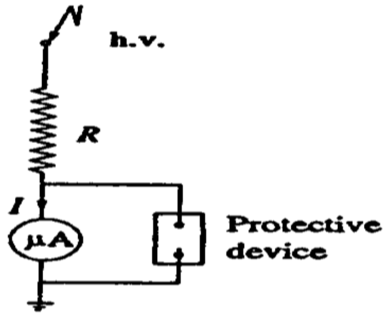


Fig. 7.1 **Series resistance micrometer**

- High d.c. voltages are usually measured by connecting a very high resistance (few hundreds of megaohms) in series with a microammeter as shown in Fig. 7. 1 .
- Only the current I flowing through the large calibrated resistance R is measured by the moving coil microammeter.
- The voltage of the source is given by $V = I R$
- The voltage drop in the meter is negligible, as the impedance of the meter is only few ohms compared to few hundred mega-ohms of the series resistance R.
- A protective device like a paper gap, a neon glow tube, or a zener diode with a suitable series resistance is connected across the meter as a protection against high voltages in case the series resistance R fails or flashes over.
- The ohmic value of the series resistance R is chosen such that a current **of one to ten microamperes is allowed for full-scale deflection.**

- The resistance is constructed from a large number of wire wound resistors in series. The voltage drop in each resistor element is chosen to avoid surface flashovers and discharges.
- Value of Iess than 5 kV/cm in air or less than 2 kV/cm in good oil is permissible.
- The resistor chain is provided with **corona free terminations.**

The limitations in the series resistance design are:

- power dissipation and source loading,
- temperature effects and long time stability,
- voltage dependence of resistive elements, and
- sensitivity to mechanical stresses.
- Series resistance meters are built for 500 kV d.c. with an accuracy better than 0.2%.

(b)**The Chubb Fortesque method**

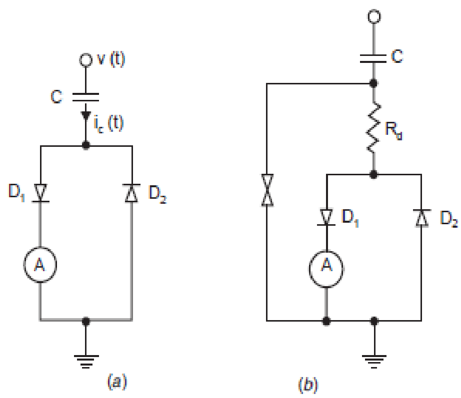
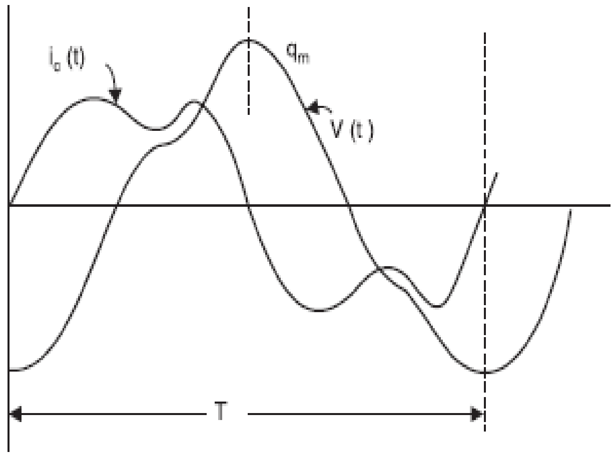


Fig. 4.11 (a) Basic circuit (b) Modified circuit

- **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. 4.11 (a).
- 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 pre discharges, 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

$$I = \frac{1}{T}\int_{t_1}^{t_2} C\frac{dv(t)}{dt}\,.\,dt = \frac{C}{T}\,.\,2V_m = 2V_m fC \text{ or } V_m = \frac{I}{2fC}$$

- 

--------------------(10 Marks)

4 **Sphere gap method of measuring high voltage**

- Sphere gap is by now considered as one of the standard methods for the measurement of peak value of d.c, a.c and impulse voltages and is used for checking the voltmeters and other voltage measuring devices used in high voltage test circuits.
- Two identical metallic spheres separated by certain distance form a sphere gap.
- The sphere gap can be used for measurement of impulse voltage of either polarity provided that the impulse is of a standard wave form and has wave front time at least 1 micro sec. and wave tail time of 5 micro sec.
- The gap length between the sphere should not exceed a sphere radius.
- If these conditions are satisfied and the specifications regarding the shape, mounting, clearances of the spheres are met, the results obtained by the use of sphere gaps are reliable to within ±3%.
- In standard specification that in places where the availability of ultraviolet radiation is low, irradiation of the gap by radioactive or other ionizing media should be used when voltages of magnitude less than 50 kV are being measured or where higher voltages with accurate results are to be obtained
- The spheres should be so made that their surfaces are smooth and their curvatures as uniform as possible.
- For smaller size, the spheres are placed in horizontal configuration whereas large sizes (diameters), the spheres are mounted with the axis of the sphere gaps vertical and the lower sphere is grounded.
- In either case, it is important that the spheres should be so placed that the space between spheres is free from external electric fields and from bodies which may affect the field between the spheres

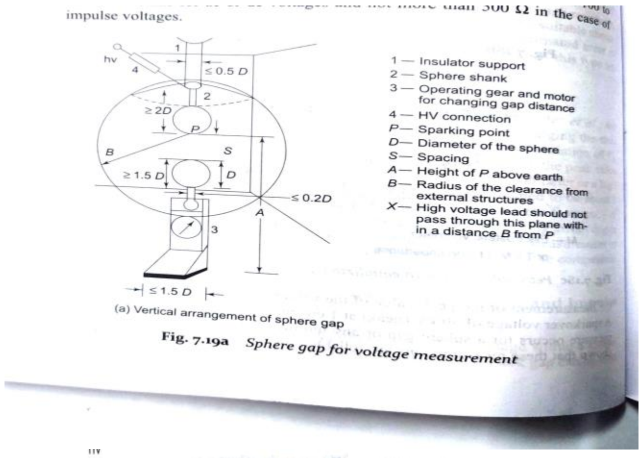


Fig. 7.19a Sphere gap for voltage measurement

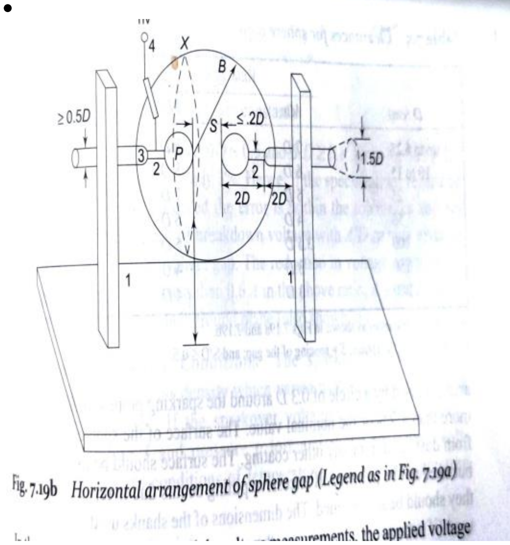
- 

Fig. 7.19b Horizontal arrangement of sphere gap (Legend as in Fig. 7.19a)

- For the measurement of a.c. or d.c. voltage, a reduced voltage is applied to begin with so that the switching transient does not flash over the sphere gap and then the voltage is increased gradually till the gap breaks down.
- Alternatively the voltage is applied across a relatively large gap and the spacing is then gradually decreased till the gap breaks down. Corresponding to this gap the value of peak voltage can be read out from the calibration tables.
- The calibration tables values correspond to 760 mm Hg pressure and 20°C temperature.
- Any deviation from the value, a correction factor will have to be used to get the correct value of the voltage being measured.
- For the measurement of 50% impulse disruptive discharge voltages, the spacing of the sphere gap or the charging voltage of the impulse generator is adjusted in steps of 3% of the expected disruptive voltage.
- Six applications of the impulse should be made at each step and the interval between two applications is 5 seconds.
- The value giving 50% probability to disruptive discharge is preferably obtained
- By interpolation between at least two gap or voltage settings, one resulting in two disruptive discharges or less out of six applications and the other in four disruptive discharges or more out of again six applications

- The breakdown voltage of a sphere gap increases with increase in pressure and decreases with increase in temperature.
- The value of disruptive voltages as given in Standard Tables correspond to 760 mm Hg pressure and 20°C.
- For small variation in temperatures and pressures, the disruptive voltage is closely proportional to the relative air density. The relative air density δ is given by :

$$\delta = \frac{293b}{760\,(273 + t)}$$

- Here b and t are the atmospheric conditions (pressure in mm of Hg and temperature in °C respectively) during measurement.
- Disruptive voltage V is given $V = K_d V_0$
- Here V0 is the disruptive voltage as given in the Standard Tables and Kd is a correction factor
- Kd is a slightly non-linear function of δ a result explained by Paschen's law.

Air density correction factor K_d

δ	0.70	0.75	0.8	0.85	0.90	0.95	1.0	1.05	1.10
K_d	0.72	0.76	0.81	0.86	0.90	0.95	1.0	1.05	1.09

------------------------(10 Marks)

5 **Different theories of charge formation in clouds**

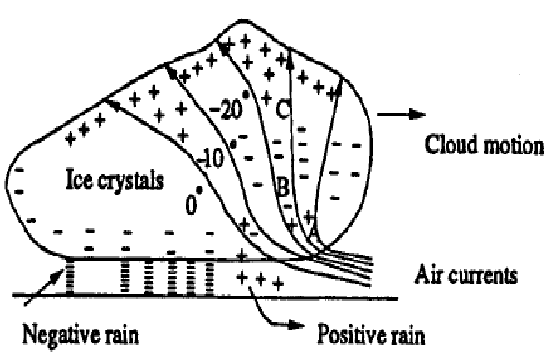


Fig. 8.2 Cloud model according to Simpson's theory

- 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

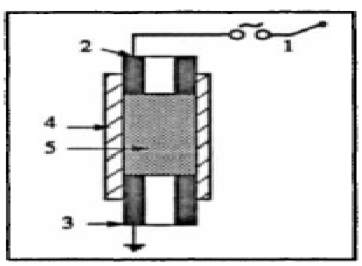
- The impact of air on these crystals makes them negatively charged, thus the distribution of the charge within the cloud becomes as shown in Fig.
- Reynolds and Mason proposed modification, according to which the thunder clouds are developed at heights 1 to 2 km above the ground level and may extend 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 0^0C at about 4 km from the ground and may reach - 50^0C at about 12 km height.
- But water droplets do not freeze as soon as the temperature is 0^0C. They freeze below - 40^0C 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 (> -40^0C) at which the ice crystals grow.
- Thus in clouds, the effective freezing temperature range is around - 33^0C to - 40^0C.
- 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 $T_1$and T_2 ($T_1 < T_2$), 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

-------------------(10 Marks)

6 (a)**Expulsion Gaps**

- Expulsion gap is a device which consists of a spark gap together with an arc quenching device which extinguishes the current arc when the gaps break over due to over voltages.
- A typical such arrangement is shown in Fig.
- This essentially consists of a rod gap in air in series with a second gap enclosed within a fibre tube.
- In the event of an overvoltage, both the spark gaps breakdown simultaneously.
- The current due to the overvoltage is limited only by the tower footing resistance and the surge impedance of the ground wires.
- The internal arc in the fibre tube due to lightning current vapourizes a small portion of the fibre material
- The gas thus produced, being a mixture of water vapour and the decomposed fibre product, drive away the arc products and ionized air.
- When the follow-on power frequency current passes through zero value, the arc is extinguished and the path becomes open circuited.
- Meanwhile the insulation recovers its dielectric strength, and the normal conditions are established.
- The lightning and follow-up power frequency currents together can last for 2 to 3 half cycles only.
- Therefore, generally no disturbance in the network is produced.
- For 132 or 220 kV lines, the maximum current rating may be about 7,500 A.



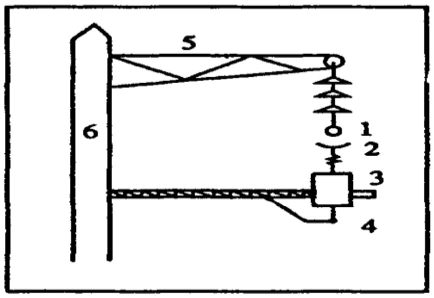
1. External series gap
2. Upper electrode
3. Ground electrode
4. Fibre tube
5. Hollow space

Fig. 8.20a Expulsion gap

(b) **Protector Tubes**

- A protector tube is similar to the expulsion gap in, construction and principle.
- It also consists of a rod or spark gap in air formed by the line conductor and its high voltage terminal.
- It is mounted underneath the line conductor on a tower.
- The arrangement is shown in Fig. 8.20b.
- The hollow gap in the expulsion tube is replaced by a nonlinear element which offers a very high impedance at low currents but has low impedance for high or lightning currents.
- When an overvoltage occurs and the spark gap breaksdown, the current is limited both by its own resistance and the tower footing resistance.

- The overvoltage on the line is reduced to the voltage drop across the protector tube.
- After the surge current is diverted and discharged to the ground, the follow-on normal power frequency current will be limited by its high resistance.
- After the current zero of power frequency, the spark gap recovers the insulation strength quickly.
- Usually, the flashover voltage of the protector tube is less than that of the line insulation, and hence it can discharge the lightning overvoltage effectively.

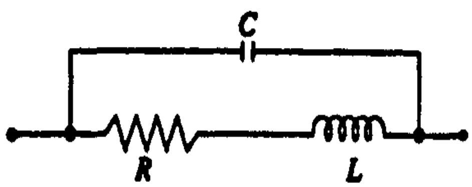


1. Line conductor on string insulator
2. Series gap
3. Protector tube
4. Ground connection
5. Cross arm
6. Tower body

Fig. 8.20b Protector tube mounting

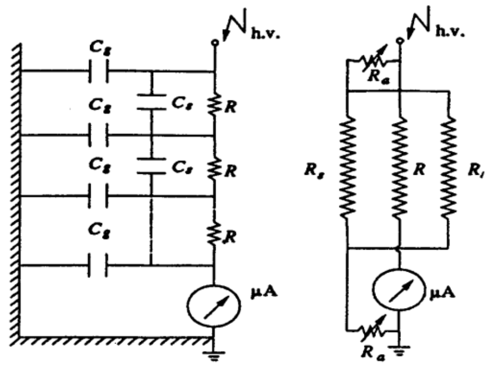
------------------(10 Marks)

7(a) **Resistance potential divider**



Lumped Circuit Equivalent of a Resistance element

- The equivalent circuit of the divider with inductance neglected is of the form shown in Fig..
- A capacitance potential divider also has the same equivalent circuit as in Fig. 7.7a, where Cs will be the capacitance of each elemental capacitor, Cg will be the terminal capacitance to ground, and R will be the equivalent leakage resistance and resistance due to dielectric loss in the element.
- When a step or fast rising voltage is applied at the high voltage terminal, the voltage developed across the element Z2 will not have the true waveform as that of the applied voltage. The cable can also introduce distortion in the waveshape.



(a) Extended series resistance with inductance neglected

C_g — Stray capacitance to ground
C_s — Winding capacitance

(b) Series resistance with guard and tuning resistances

R — Series resistor
R_s — Guard resistor
R_a — Tuning resistor

•

The following elements mainly constitute the different errors in the measurement:

- residual inductance in the elements;
- stray capacitance occurring

(a)between the elements,

(b) from sections and terminals of the elements to ground,

(c) from the high voltage lead to the elements or sections;

- impedance errors due to

(a) connecting leads between the divider and the test objects,

(b) ground return leads and extraneous current in ground leads

- parasitic oscillations due to lead and cable inductances and capacitance of high voltage terminal to ground.
- The effect to residual and lead inductances becomes pronounced when fast rising impulses of less than one microsecond are to be measured.
- The residual inductances damp and slow down the fast rising pulses.
- Secondly, the layout of the test objects, the impulse generator, and the ground leads also require special attention to minimize recording errors
- A simple resistance potential divider consists of two resistances R1 and R2 in series (R1» R2)
- The attenuation factor of the divider or the voltage ratio is given by :

$$a = \frac{V_1(t)}{V_2(t)} = 1 + \frac{R_1}{R_2}.$$

--------------------(5 Marks)

7(b)

$\therefore C_m = \dfrac{2\times10^{-6}\times\sqrt{2}}{314.1592\times10^{4}} = 9\times10^{-13} F$

$= 0.9\times10^{-12} F$

$= 0.9 pF$

At 200KV,

$I_{rms} = \dfrac{V C_m}{\sqrt{2}} W$

$= \dfrac{200\times10^{3}\times0.9\times10^{-12}\times157.08}{1.414}$

$= 1.999\times10^{-5} A = 19.99\times10^{-6} A = 19.99 \mu A$

2) A generating voltmeter is required to measure voltage between 15 KV to 250KV. If the indicating meter reads a minimum current of 2 μA and maximum of 35μA, determine the capacitance of the generating voltmeter. Assume that the speed of driving synchronous motor is 1500rpm.

Generating Voltmeter

Voltage range is 15KV – 250KV

Minimum current read by the indicating meter = 2 μA

RMS value of current, $I_{RMS} = \dfrac{V C_m W}{\sqrt{2}}$

$N_s = 1500 rpm = n$

$\therefore W = \dfrac{2\pi n}{60} = \dfrac{2\pi\times1500}{60} = 157.079$

(2)

$$\therefore C_m = \frac{I_{RMS}\sqrt{2}}{V\omega} = \frac{2\times10^{-6}\times\sqrt{2}}{15\times10^{3}\times157.099}$$

$$= 1.2\times10^{-12}\,F = 1.2\,pF$$

At 250 kV, the current indicated will be given by

$$I_{RMS} = \frac{V C_m \omega}{\sqrt{2}} = \frac{250\times10^{3}\times1.2\times10^{-12}\times157.079}{\sqrt{2}}$$

$$= 3.33\times10^{-5}$$

$$= 33.3\times10^{-6}\,A$$

$$= 33.3\,\mu A$$

3) An absolute electrostatic voltmeter has ... diameter.

---------------------(5 Marks)

8 **Switching & Power frequency over voltages**

- The insulation has the lowest strength for switching surges with regard to long air gaps.
- Switching overvoltages are of relatively higher magnitudes as compared to the lightning overvoltages for UHV systems.
- Overvoltages are generated in EHV systems when there is a sudden release of internal energy stored either in the electrostatic form (in the capacitance) or in the electromagnetic form (in the inductance).
- The different situations under which this happens are summarized as :
- (i) Interruption of low inductive currents (current chopping) by high speed circuit breakers. This occurs when the transformers or reactors are switched off
- (ii) Interruption of small capacitive currents, such as switching off of unloaded lines etc.
- (iii) Ferro-resonance condition
- This may occur when poles of a circuit breaker do not close simultaneously
- (iv) Energization of long EHV or UHV lines.
- Transient over voltages in the above cases can be of the order of 2.0 to 3.3 p.u. and will have magnitudes of the order of 1200 kV to 2000 kV on 750 kV systems.
- The duration of these over voltages varies from 1 to 10 ms depending on the circuit parameters.
- It is seen that these are of comparable magnitude or are even higher than those that occur due to lightning.
- Sometimes the over voltages may last for several cycles.

- The other situations of switching that give rise to switching overvoltages of shorter duration (0.5 to 5 ms) and lower magnitudes (2.0 to 2.5 p.u.) are :
- (a) single pole closing of circuit breaker
- (b) interruption of fault current when the L-G or L-L fault is cleared
- (c) resistance switching used in circuit breakers
- (d) switching lines terminated by transformers
- (e) series capacitor compensated lines
- (f) sparking of the surge diverter located at the receiving end of the line to limit the lightning over voltages

The power frequency over voltages

- The power frequency over voltages occur in large power systems and they are of much concern in EHV systems, i.e. systems of 400 kV and above.
- The main causes for power frequency and its harmonic over voltages are
- (a) sudden loss of loads,
- (b) disconnection of inductive loads or connection of capacitive loads,
- (c) Ferranti effect, unsymmetrical faults
- (d) saturation in transformers, etc.
- Over voltages of power frequency harmonics and voltages with frequencies nearer to the operating frequency are caused during tap changing operations, by magnetic or ferro-resonance phenomenon in large power transformers, and by resonating over voltages due to series capacitors with shunt reactors or transformers.
- The duration of these over voltages may be from one to two cycles to a few seconds depending on the overvoltage protection employed.
- The over voltages due to switching and power frequency may be controlled by :
- (a) energization of transmission lines in one or more steps by inserting resistances and withdrawing them afterwards,
- (b) phase controlled closing of circuit breakers,
- (c) drainage of trapped charges before reclosing,
- (d) use of shunt reactors
- (e) limiting switching surges by suitable surge diverters

----------------------(10 Marks)