Solution of High Voltage Engineering Question Paper March 2021

Module 1

1. (a)**Desired Properties of Gaseous dielectric**

- High dielectric strength
- High thermal stability
- Chemical inertness
- Non – inflammability
- Good heat transfer capability
- Low cost

Examples of gaseous dielectric : Air, SF_6, Vacuum

----------------(6 Marks)

(b)**Expression for current in the air gap, $I = I_0 e^{\alpha d}$, considering Townsend's first ionization coefficient**

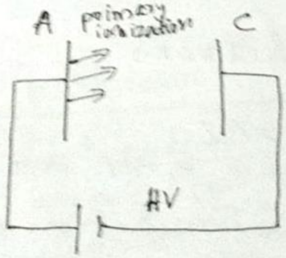
Classification of Secondary Ionization process

1) Electron emission due to positive ion impact
2) Electron emission due to photons
3) Electron emission due to metastable and neutral atoms.

Townsend's Theory

- Mainly used for Analysis of Ionization process. Put forward by Towsends (scientist). It predicts the probability of secondary electron formation.

When a high voltage is applied to a ~~gase~~ system of electrodes, small amount of current flows through the gaseous dielectric The dielectric medium becomes a conducting medium. This small amount of current value is calculated with the help of Townsend's theory.



Consider Anode and Cathode with a high voltage applied across them. Then primary ionization process occurs and electrons and positive ions are formed. when 'n' electrons moves towards further distance dx and give rises to $\underline{\alpha n dx}$ electrons.

where 'α' be the average no: of ionizing collisions made by an electron per cm travel in the direction of electric field

As part of primary ionization process, electrons are directed towards anode and positive ions are directed towards cathode.

$\therefore$ No: of electrons generated, $dn = \alpha n\, dx$

$$\therefore \frac{dn}{n} = \alpha\, dx \rightarrow ①$$

Integrating ① both sides, $\int \frac{dn}{n} = \int \alpha\, dx$

$$\therefore \ln(n) = \alpha x + A \rightarrow ②$$
$$= \alpha x + A \rightarrow ②$$

A - Integration constant

Applying initial conditions,

When $x = 0, \quad n = n_0$

$$\therefore \ln(n_0) = A \rightarrow ③$$

Substituting ③ in ② we get,

$$\therefore \ln(n) = \alpha x + \ln(n_0)$$

$$\ln(n) - \ln(n_0) = \alpha x$$

$$\ln(a) - \ln(b) = \ln\left(\frac{a}{b}\right)$$

$$\therefore \ln\left(\frac{n}{n_0}\right) = \alpha x$$

Applying exponential terms on L.H.S and R.H.S.

$$e^{\ln\left(\frac{n}{n_0}\right)} = e^{\alpha x} \qquad \text{Since } \left(e^{\ln(x)} = x\right)$$

$$\frac{n}{n_0} = e^{\alpha x}$$

$$\therefore \underline{\underline{n = n_0 e^{\alpha x}}}$$

n = no: of electrons

n_0 = Initial value of formation of number of electrons

Motion of electrons is called electric current.

$\therefore I = I_0 e^{\alpha x}$ (In terms of current)

where α = Townsend's primary ionization coefficient.

α is defined as average number of ionization made by an electrons per cm towards the direction of electric field.

α - depends on gaseous pressure

$$\alpha \propto \frac{E}{P}$$

E = Electric field

P = Pressure

$I = I_0 e^{\alpha x}$ → is known as Townsend's current growth equation (by considering primary ionization

Here I = total current that will be formed in the gaseous medium

I_0 = initial value of current

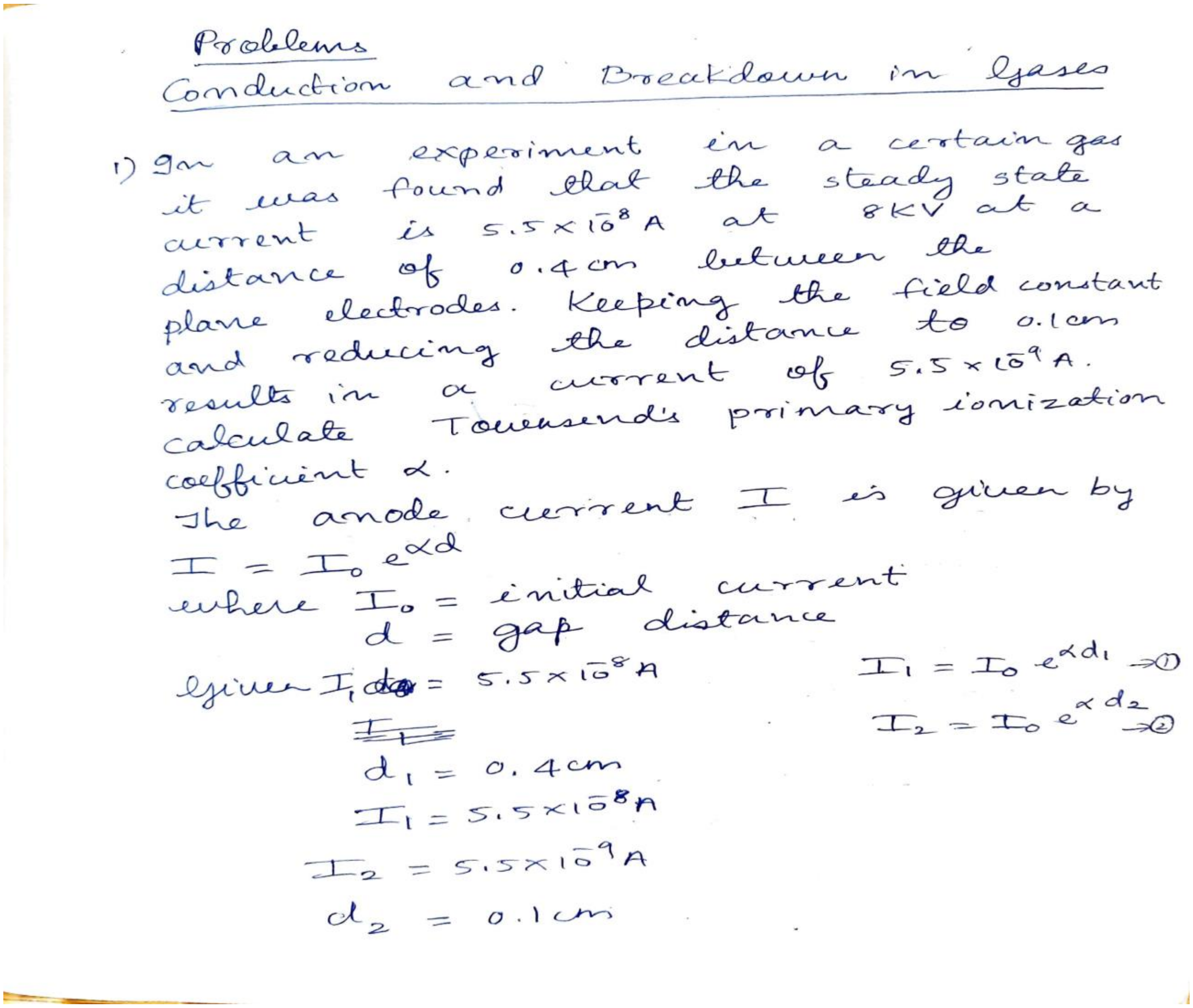
α = Townsend's primary ionization coefficient

x = distance between the cathode and anode

This is Townsend's theory of primary ionization.

------------------------------(8 Marks)

(c)



Problems

Conduction and Breakdown in Gases

1) In an experiment in a certain gas it was found that the steady state current is 5.5×10^{-8} A at 8KV at a distance of 0.4 cm between the plane electrodes. Keeping the field constant and reducing the distance to 0.1 cm results in a current of 5.5×10^{-9} A. calculate Townsend's primary ionization coefficient α.

The anode current I is given by

$I = I_0 e^{\alpha d}$

where I_0 = initial current

d = gap distance

Given I_1 ~~d~~ $= 5.5 \times 10^{-8}$ A

~~I_1~~

$d_1 = 0.4$ cm

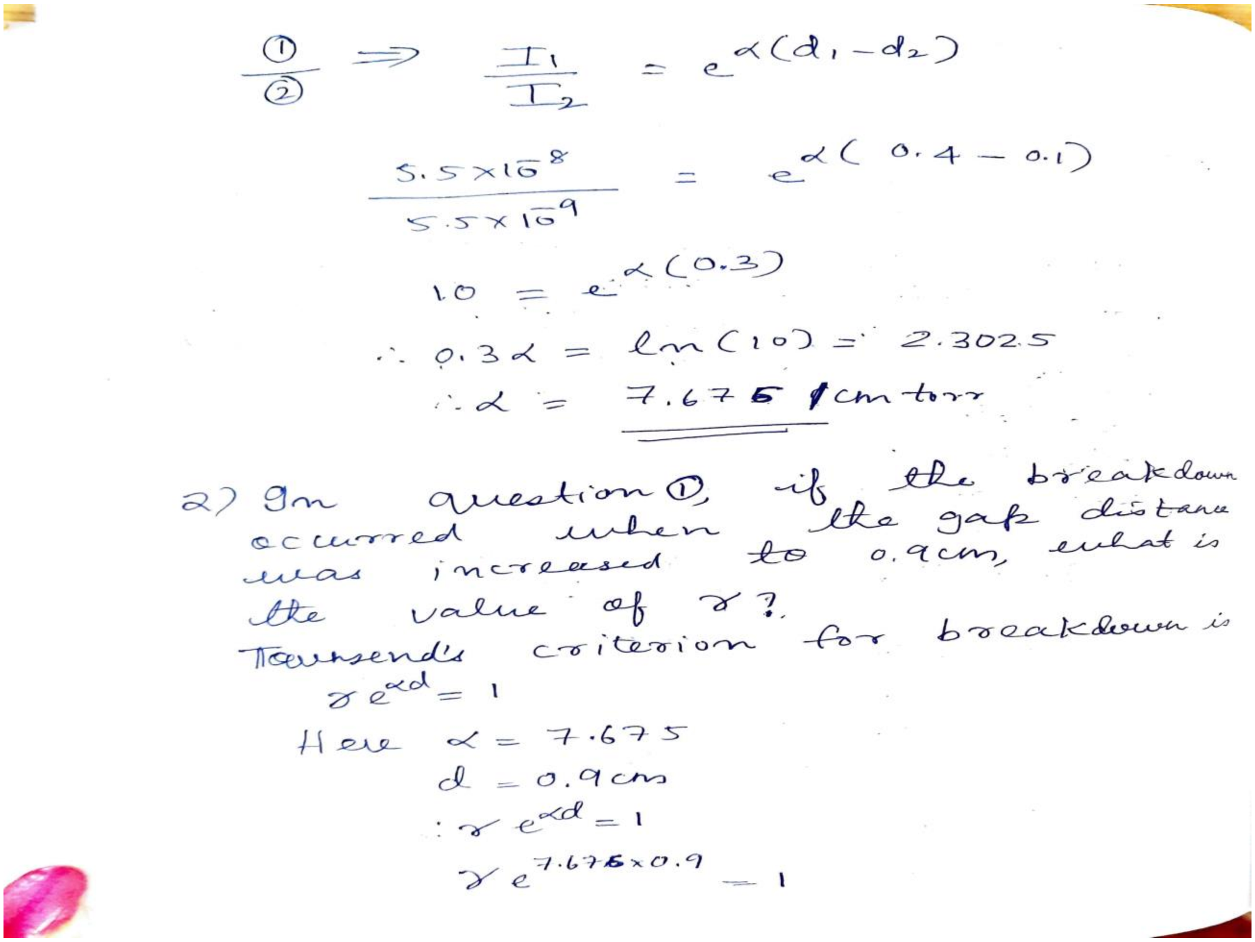
$I_1 = 5.5 \times 10^{-8}$ A

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

$d_2 = 0.1$ cm

$I_1 = I_0 e^{\alpha d_1} \rightarrow ①$

$I_2 = I_0 e^{\alpha d_2} \rightarrow ②$



$$\frac{①}{②} \Rightarrow \frac{I_1}{I_2} = e^{\alpha(d_1 - d_2)}$$

$$\frac{5.5\times10^{-8}}{5.5\times10^{-9}} = e^{\alpha(0.4-0.1)}$$

$$10 = e^{\alpha(0.3)}$$

$$\therefore 0.3\alpha = \ln(10) = 2.3025$$

$$\therefore \alpha = \underline{\underline{7.675 \text{ /cm torr}}}$$

2) In question ①, if the breakdown occurred when the gap distance was increased to 0.9cm, what is the value of γ?

Townsend's criterion for breakdown is

$$\gamma e^{\alpha d} = 1$$

Here $\alpha = 7.675$

$d = 0.9\text{cm}$

$$\therefore \gamma e^{\alpha d} = 1$$

$$\gamma e^{7.675\times0.9} = 1$$

------------------------------(6 Marks)

2. (a)**State and explain Paschen's Law**

Application of Streamer Theory

1) Ozone (O_3) production
2) Air and water purification
3) Plasma medicine

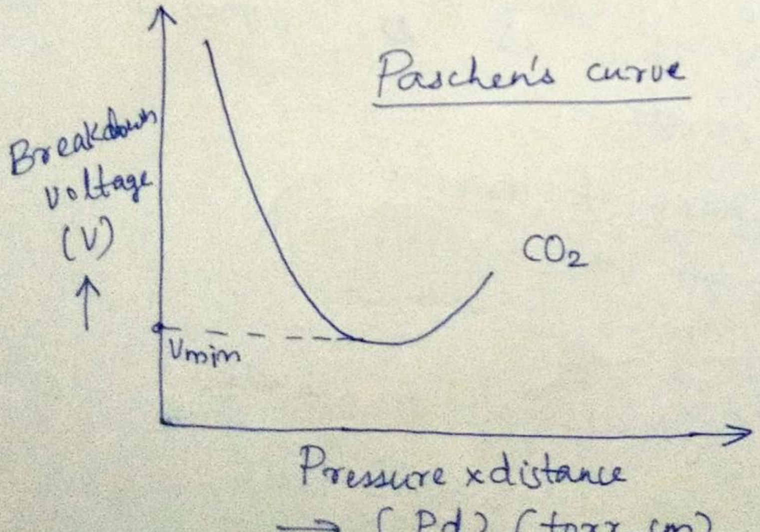
Derivation of Paschen's law

Paschen's Law

1) Paschen studied breakdown voltage of different gaseous dielectric material - SF_6, vacuum, CO_2. Here the pressure and distance is varied
2) He found that breakdown voltage is a function of product of pressure and distance.

$\therefore$ Breakdown voltage, $\underline{\underline{V = f(Pd)}}$

This law is called Paschen's law for gaseous dielectric.



Derive an expression for Paschen's Law

Townsend's current growth equation,

$$I = \frac{I_0 e^{\alpha d}}{1 - \gamma\left[e^{\alpha d} - 1\right]}$$

α – Townsend's primary ionization coefficient

γ – Townsend's secondary ionization coefficient

Applying break down condition,

$\therefore$ Equate denominator to zero

$$1 - \gamma\left[e^{\alpha d} - 1\right] = 0$$

$$\therefore \gamma\left[e^{\alpha d} - 1\right] = 1 \rightarrow ①$$

Then Express α and γ in terms of Electric field (E) and Pressure (P)

$$\frac{\alpha}{P} = f_1\left(\frac{E}{P}\right) = f_1\left[\frac{V}{Pd}\right] \rightarrow ②$$

$E = \frac{V}{d}$ = Volt per distance

$$\gamma = f_2\left(\frac{E}{P}\right) = f_2\left(\frac{V}{Pd}\right) \rightarrow ③$$

Substitute ② and ③ in ①

$$\therefore f_2\left(\frac{V}{Pd}\right)\left[e^{Pf_1\left(\frac{V}{Pd}\right)d} - 1\right] = 1 \rightarrow ④$$

$$\therefore \underline{\underline{V = f(Pd)}}$$

$\therefore$ Voltage is a function of Pressure and distance.

---------------------(6 Marks)

(b)(i)**Streamer breakdown**

- This is similar to breakdown in gases due to cumulative ionization. Conduction electrons gain sufficient energy above a certain critical electric field and cause liberation of electrons from the lattice atoms by collisions.
- Under uniform field conditions, if the electrodes are embedded in the specimen, breakdown will occur when an electron avalanche bridges the electrode gap.
- An electron within the dielectric, starting from the cathode will drift towards the anode and during this motion gains energy from the field and loses it during collisions.
- When the energy gained by an electron exceeds the lattice ionization potential, an additional electron will be liberated due to collision of the first electron.
- This process repeats itself resulting in the formation of an electron avalanche.
- Breakdown will occur, when the avalanche exceeds a certain critical size.
- In practice, breakdown does not occur by the formation of a single avalanche itself, but occurs as a result of many avalanches formed within the dielectric and extending step by step through the entire thickness of the material

- This can be readily demonstrated in a laboratory by applying an impulse voltage between point-plane electrodes with point embedded in a transparent solid dielectric such as perspex.

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 d_0 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

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

-----------------------------(14 Marks)

Module 2

3(a)**Need of Generation of very high voltages in the laboratory**

Applications of High Voltage Engineering

- ⦿ Power system
- ⦿ Industries
- ⦿ Research Labs

Power System

- ⦿ HVAC Power Transmission
- ⦿ Transmission losses can be reduced
- ⦿ Transmission efficiency can be improved

Industries

- ⦿ Uses Electrostatic Precipitator(ESP) for pollution control

- Used to minimize air pollution
- Can be connected to chimneys of different industries
- Pollutant particles can be filtered out
- Electrostatic painting is applicable for painting electrical and mechanical machines
- Electrostatic printing is applicable for the design of Printed Circuit Boards(PCBs)

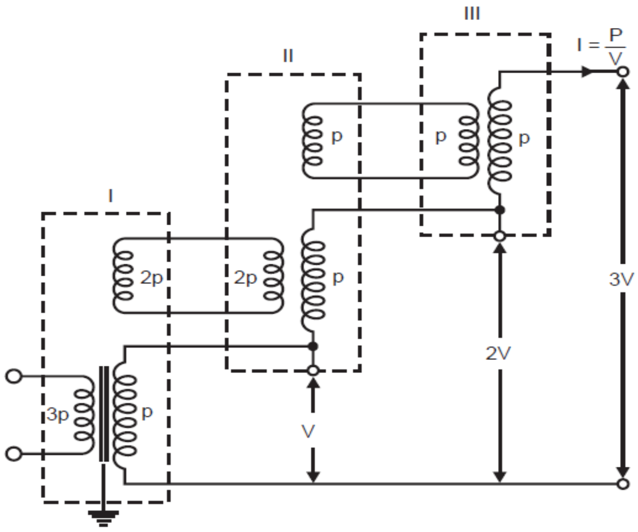
Research Labs

Van de Graff Generator

- Mainly used for nuclear physics applications
- It can accelerate the speed of moving particles
- It can be employed in nuclear power stations

--------------------(6 Marks)

(b)**Cascade Transformers for generation of HVAC(3 stages)**



- For voltages higher than 400 KV, it is desired to cascade two or more transformers depending upon the voltage requirements
- With this, the weight of the whole unit is subdivided into single units and, therefore, transport and erection becomes easier.
- Also the transformer cost for a given voltage may be reduced, since cascaded units need not individually possess the expensive and heavy insulation required in single stage transformers for high voltages exceeding 345 kV.
- It is found that the cost of insulation for such voltages for a single unit becomes proportional to square of operating voltage.
- The primary of the first stage transformer is connected to a low voltage supply.
- A voltage is available across the secondary of this transformer.
- The tertiary winding (excitation winding) of first stage has the same number of turns as the primary winding, and feeds the primary of the second stage transformer
- The potential of the tertiary is fixed to the potential V of the secondary winding
- The secondary winding of the second stage transformer is connected in series with the secondary winding of the first stage transformer
- Accordingly a voltage of 2V is available between the ground and the terminal of secondary of the second stage transformer

- Similarly, the stage-III transformer is connected in series with the second stage transformer
- With this the output voltage between ground and the third stage transformer, secondary is 3V
- The individual stages except the upper most must have three-winding transformers. The upper most, however, will be a two winding transformer
- The metal tank construction of transformers and the secondary winding is not divided
- Here the low voltage terminal of the secondary winding is connected to the tank
- The tank of stage-I transformer is earthed
- The tanks of stage-II and stage-III transformers have potentials of V and 2V, respectively above earth and, therefore, these must be insulated from the earth with suitable solid insulation
- Through HT bushings, the leads from the tertiary winding and the HV winding are brought out to be connected to the next stage transformer
- If the high voltage windings are of mid-point potential type, the tanks are held at 0.5 V, 1.5 V and 2.5 V, respectively.
- This connection results in a cheaper construction and the high voltage insulation now needs to be designed for V/2 from its tank potential.

◆ The main disadvantage of cascading the transformers is that the lower stages of the primaries of the transformers are loaded more as compared with the upper stages.

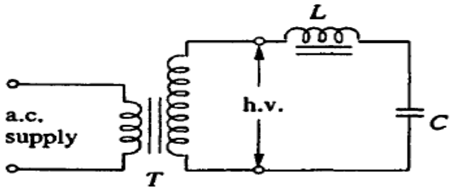
------------------------(8 Marks)

(c)**Principle of operation of a Resonant Transformer**

◎ A resonant transformer is a transformer in which one or both windings has a capacitor across it and functions as a tuned circuit.

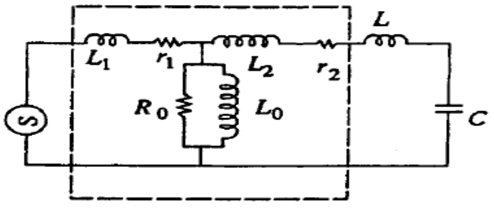
◎ Used at radio frequencies, resonant transformers can function as high Q factor band pass filters.

Resonant Transformer



(a)

Fig. 6.12a Transformer



(b)

Fig. 6.12b Equivalent circuit

T — Testing transformer
L — Choke
C — Capacitance of h.v. terminal and test object
L_0 — Magnetizing inductance

L_1, L_2 — Leakage inductances of the transformer
r_1, r_2 — Resistances of the windings
R_0 — Resistance due to core loss

The equivalent circuit of a high voltage testing transformer consists of the following :

◎ Leakage reactance of the windings

◎ Winding resistances

◎ Magnetizing reactance

◎ Shunt capacitance across the output terminal due to the bushing of the high voltage terminal and also that of the test object

◎

It is possible to have series resonance at power frequency if,

- w (L1 + L2) = 1 / wC
- In that current will be controlled by resistance of the circuit
- Magnitude of voltage across the test object

$$V_C = \left|\frac{-jVX_C}{R+j\,(X_L-X_C)}\right| = \frac{V}{R}X_C = \frac{V}{\omega CR}$$

- Factor Xc/R = 1 / wCR is the Q factor of the circuit
- It gives magnitude of voltage multiplication across the test object under resonance condition
- Input voltage required for excitation is reduced by factor 1/Q
- Output KVA required reduced by 1/Q

---------------------(6 Marks)

4(a)**Marx circuit arrangement for multistage impulse generator**

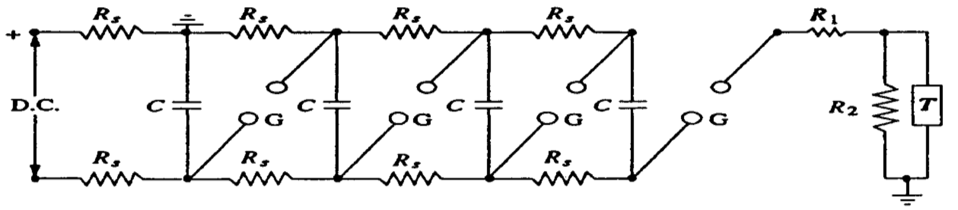
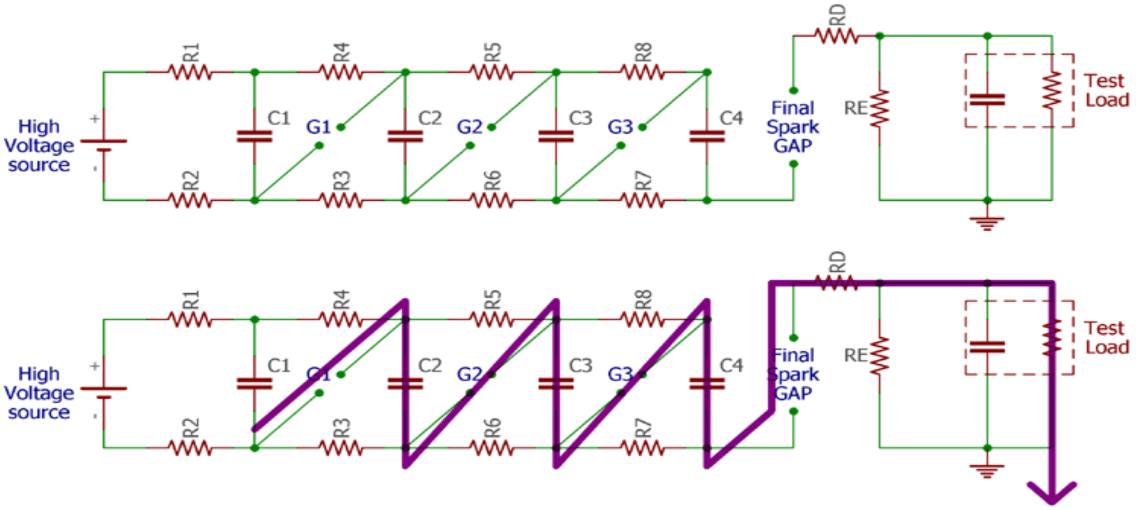


Fig. 6.17a Schematic diagram of Marx circuit arrangement for multistage impulse generator

C — Capacitance of the generator
Rs — Charging resistors
G — Spark gap
R1, R2 — Wave shaping resistors
T — Test object



Impulse Voltage Generator

- The generator capacitance C1 is to be first charged and then discharged into the wave shaping circuits.
- A single capacitor C1 may be used for voltages up to 200 kV.
- Beyond this voltage, a single capacitor and its charging unit may be too costly, size becomes very large.
- The cost and size of the impulse generator increases at a rate of the square or cube of the voltage rating.
- Producing very high voltages, a bank of capacitors are charged in parallel and then discharged in series.

- ⦿ The arrangement for charging the capacitors in parallel and then connecting them in series for discharging was originally proposed by Marx.
- ⦿ Modified Marx circuits are used for the multistage impulse generators.

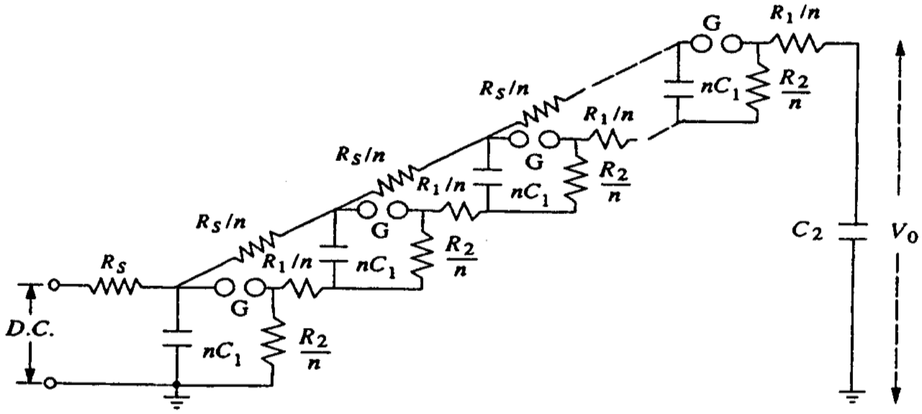


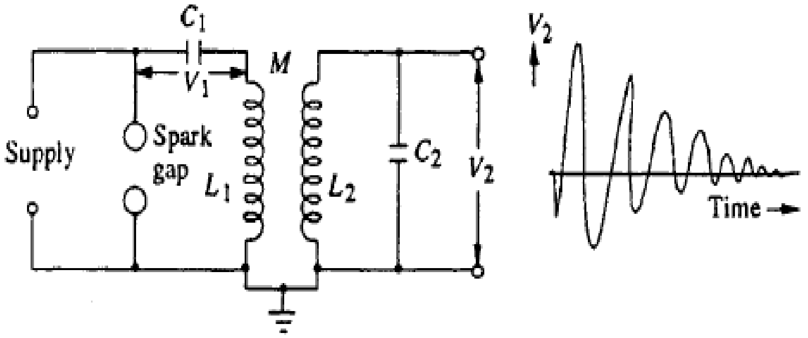
Fig. 6.17b Multistage impulse generator incorporating the series and wave tail resistances within the generator

-------------------------------(8 Marks)

(b)**Tesla coil : Generation of damped high frequency oscillations**

- The commonly used high frequency resonant transformer is the Tesla coil
- Doubly tuned resonant circuit
- The primary voltage rating is 10 kV
- The secondary may be rated to as high as 500 to 1000 kV.
- The primary is fed from a d.c. or a.c. supply through the condenser Ci.

- A spark gap G connected across the primary is triggered at the desired voltage V1 which induces a high self-excitation in the secondary.
- The primary and the secondary windings (L1)and (L2) are wound on an insulated former with no core (air-cored) and are immersed in oil.
- The windings are tuned to a frequency of 10 to 100 kHz by means of the condensers C1 and C2



(a) Equivalent circuit (b) Output waveform

Tesla coil Equivalent circuit and its waveform

- Output voltage V_2 is a function of L_1, L_2, C_1, C_2, M.
- Winding resistances will be small, contribute only for damping of the oscillations.
- Neglecting the winding resistances.
- Let the condenser C_1 be charged to a voltage V_1 when the spark gap is triggered.
- Let a current i_1 flow through the primary winding L_1 and produce a current i_2 through L_2 and C_2

-----------------(6 Marks)

(c)

4) A Cockroft-Walton type voltage multiplier has 8 stages with capacitances, all equal to 0.05μF. The supply transformer secondary voltage is 125 kV at a frequency of 150 Hz. If the load current to be supplied is 5mA, find (a) % Ripple (b) the regulation (c) the optimum number of stages for minimum regulation or voltage drop.

~~(a)~~ No: of stages, $n = 8$

Capacitance, $C = 0.05\,\mu F$

Secondary voltage $= 125\,kV$

frequency, $f = 150\,Hz$

Load current, $I = 5\,mA$

(a) Ripple voltage, $\delta V = \frac{I}{fC} \frac{n(n+1)}{2}$

$$= \frac{5\times10^{-3}\,(8)(9)}{150\times0.05\times10^{-6}\times2}$$

$$= \underline{\underline{24\,kV}}$$

$$\%\,\text{Ripple} = \frac{\delta V\times100}{2nV_{max}} = \frac{24\times100}{2\times8\times125}$$

$$= 1.2\%$$

(b) Voltage drop, $\delta V = \frac{I}{fC}\left[\frac{2}{3}n^3 + \frac{n^2}{2} - \frac{n}{6}\right]$

$$= \frac{5\times10^{-3}}{150\times0.05\times10^{-6}}\left[\frac{2}{3}\times8^3 + \frac{8^2}{2} - \frac{8}{6}\right]$$

$$= 666.67\left[341.33 + 32 - 1.33\right]$$

$$= \underline{\underline{248\ kV}}$$

$$\%\ \text{regulation} = \frac{V\times100}{2nV_{max}} = \frac{248}{2\times8\times125}$$

$$= \underline{\underline{0.124\times100}}$$

$$= \underline{\underline{12.4\%}}$$

(C) Optimum number of stages

$$n_{optimum} = \sqrt{\frac{V_{max} f C}{I}}$$

$$= \sqrt{\frac{125\times150\times0.05\times10^{-6}\times10^{3}}{5\times10^{-3}}}$$

--------------(6 Marks)

Module 3

5(a)**Principle of operation of an Electrostatic voltmeter for measurement of very high AC and DC voltages**

- 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*

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

- Now force *F between the plates is defined as the derivative of stored electric energy along the* field direction *i.e.*,

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

- 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

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

- Since the two plates are oppositely charged, there is always force of attraction between the plates.
- If the voltage is time dependant, the force developed is also time dependant. In such a case the mean value of force is used to measure the voltage.

$$F = \frac{1}{T}\int_0^T F(t)dt = \frac{1}{T}\int\frac{1}{2}\varepsilon\frac{V^2(t)}{d^2}A\,dt = \frac{1}{2}\frac{\varepsilon A}{d^2}\cdot\frac{1}{T}\int V^2(t)dt = \frac{1}{2}\varepsilon A\frac{V_{rms}^2}{d^2}$$

- Electrostatic voltmeters measure the force based on the above equations and are arranged such that one of the plates is rigidly fixed whereas the other is allowed to move.

- With this the electric field gets disturbed.
- For this reason, the movable electrode is allowed to move by not more than a fraction of a millimetre to a few millimetres even for high voltages so that the change in electric field is negligibly small.
- As the force is proportional to square of *Vrms, the meter can be used both for a.c. and d.c. voltage* measurement

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

(b)**Principle of operation of a 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

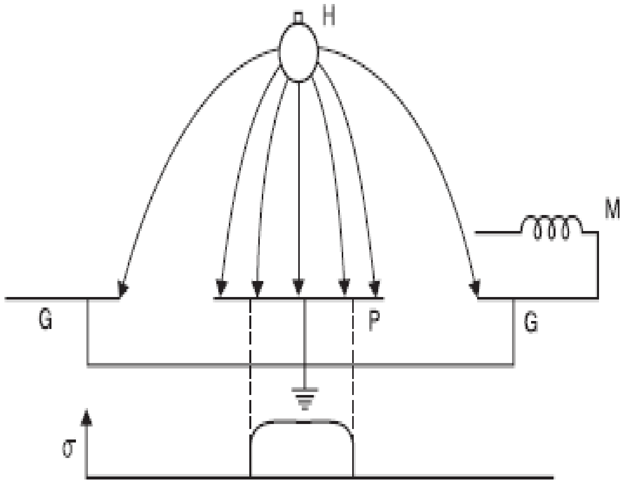


Fig. 4.8 Principle of generating voltmeter

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

- σ (a) is the electric field density or charge density along some path and is assumed constant over the differential area da of the pick up electrode.
- In this case σ (a) is a function of time also and $\int$ da the area of the pick up electrode P exposed to the electric field.
- If the voltage V to be measured is constant (d.c voltage), a current i(t) will flow only if it is moved i.e. now σ (a) will not be function of time but the charge q is changing because the area of the pick up electrode exposed to the electric field is changing.
- The current i(t) is given by

$$i(t) = \frac{d}{dt}\int_{A(t)} \sigma(a)da = \varepsilon \frac{d}{dt}\int_{A(t)} E(a)da$$

- where **σ (a) = εE(a**) and ε is the permittivity of the medium between the high voltage electrode and the grounded electrode.
- The integral boundary denotes the time varying exposed area.
- The high voltage electrode and the grounded electrode in fact constitute a capacitance system.
- The capacitance is, however, a function of time as the area A varies with time and, therefore, the charge q(t) is given as :

$$q(t) = C(t)V(t)$$

$$i(t) = \frac{dq}{dt}$$

$$C(t)\frac{dV(t)}{dt} + V(t)\frac{dC(t)}{dt}$$

For d.c. voltages $\frac{dV(t)}{dt} = 0$

Hence $i(t) = V\frac{dC(t)}{dt}$

If the capacitance varies linearly with time and reaches its peak value C_m is time $T_c/2$ and again reduces to zero linearly in time $T_c/2$, the capacitance is given as

$$C(t) = 2\frac{C_m}{T_c}t$$

For a constant speed of n rpm of synchronous motor which is varying the capacitance, time T_c is given by $T_c = 60/n$.

Therefore $I = 2C_m V\frac{n}{60} = \frac{n}{30}C_m V$

If the capacitance C varies sinusoidally between the limits C_0 and $(C_0 + C_m)$ then

$$C = C_0 + C_m \sin wt$$

and the current i is then given as

$$i(t) = i_m \cos wt \text{ where } i_m = VC_m\omega$$

Advantages

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

Limitations

- 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.

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6(a)Chubb and Fortescue circuit for the measurement of peak value of AC voltages

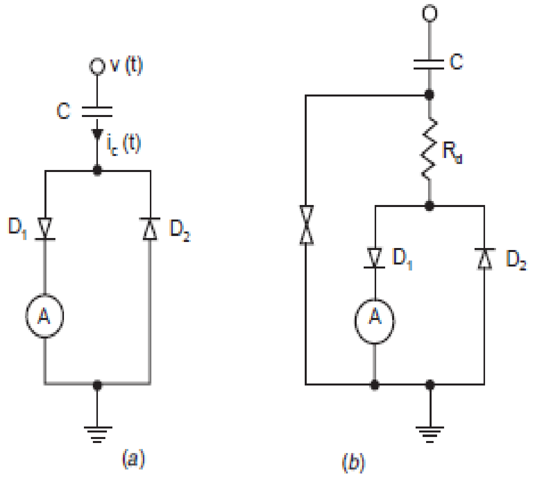
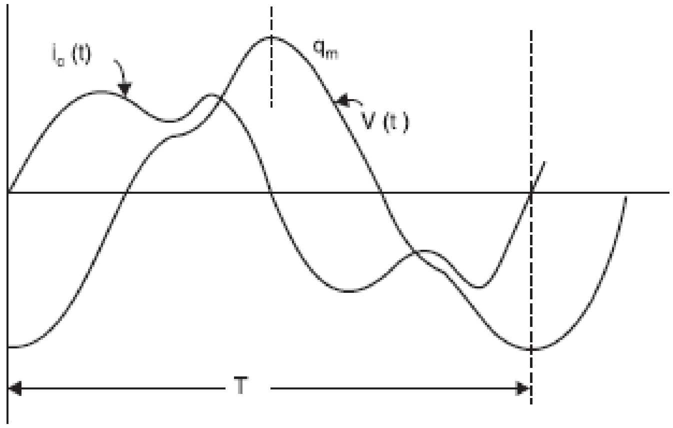


Fig. 4.11 (*a*) Basic circuit (*b*) Modified circuit

- **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, 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.

------------------------(8 Marks)

(b)**Factors influencing the spark over voltages of sphere gaps**

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

- nearby earthed objects,
- atmospheric conditions and humidity,
- irradiation,
- 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.

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 *:*

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

Influence of Humidity

- Kuffel has studied the effect of the humidity on the breakdown voltage by using spheres of 2 cms to 25 cms diameters and uniform field electrodes.
- The effect was found to be maximum in the region 0.4 mm Hg. and thereafter the change was decreased.
- Between 4–17 mm Hg. the relation between breakdown voltage and humidity was practically linear for spacing less than that which gave the maximum humidity effect.
- Fig. 4.4 shows the effect of humidity on the breakdown voltage of a 25 cm diameter sphere with spacing of 1 cm when a.c. and d.c voltages are applied.

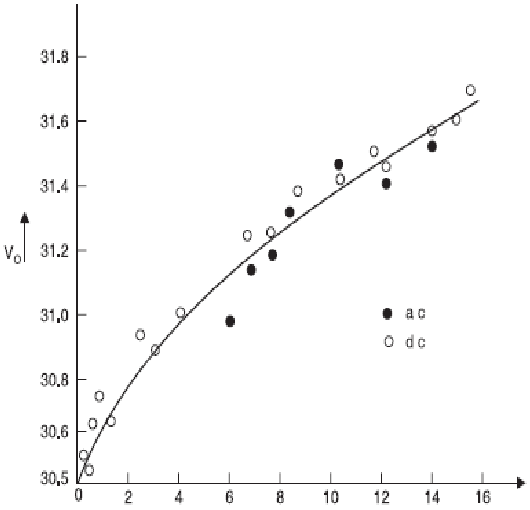


Fig. 4.4 Breakdown voltage humidity relation for a.c. and d.c. for 1.0 cm gap between 25 cms diameter spheres

Influence of dust particles

- When a dust particle is floating between the gap this results into erratic breakdown in homogeneous or slightly inhomogenous electrode configurations.

- When the dust particle comes in contact with one electrode under the application of d.c. voltage, it gets charged to the polarity of the electrode and gets attracted by the opposite electrode due to the field forces and the breakdown is triggered shortly before arrival.

Effect of Irradiation

- Illumination of sphere gaps with ultra-violet or x-rays aids easy ionization in gaps.
- The effect of irradiation is pronounced for small gap spacings.
- A reduction of about 20% in sparkover voltage was observed for spacings of 0.1 D to 0.3 D for a 1.3 cm sphere gap with d.c. voltages.

Effect of Polarity and waveform

- It has been observed that the spark over voltages for positive and negative polarity impulses are different.
- Experimental investigation showed that for sphere gaps of 6.25 to 25 cm diameter, the difference between positive and negative d.c. voltages is not more than 1%.
- For smaller sphere gaps (2 cm diameter and less) the difference was about 8% between negative and positive impulses of 1/50 µs waveform.

-----------------------(6 Marks)

(c)**Working of Rogowski coil for high impulse current measurement**

- Rogowski coil is used to measure impulse currents, high speed currents and AC currents with power frequency

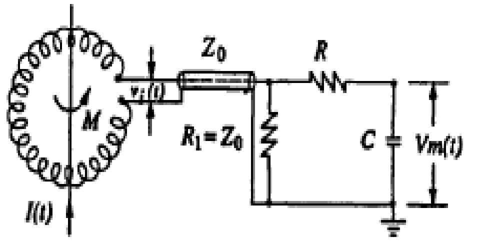
- It was developed by Walte Rogowski
- It consists of a helical coil of wire which is wrapped around a straight conductor whose current has to be measured
- If a coil is placed surrounding a current carrying conductor, the voltage signal induced in the coil is

$$v_i(t) = M\,dI(t)/dt$$

- 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 conductor.
- 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 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

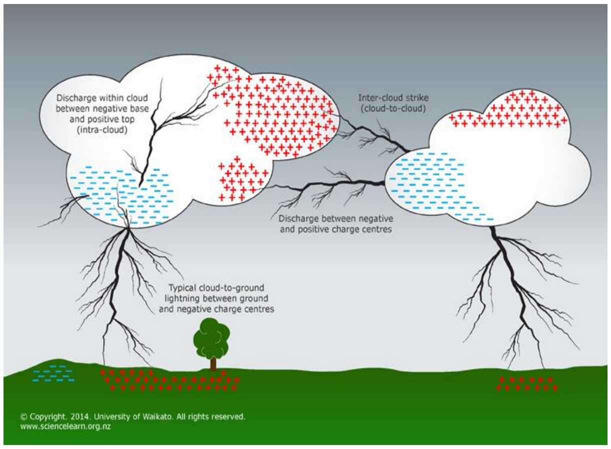
Fig. 7.52 Rogowski coil for high impulse current measurements

- Rogowski coils with electronic or active integrator circuits have large band 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.

---------------------------(6 Marks)

Module 4

7(a)**Different theories of charge formation in clouds**



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- 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.

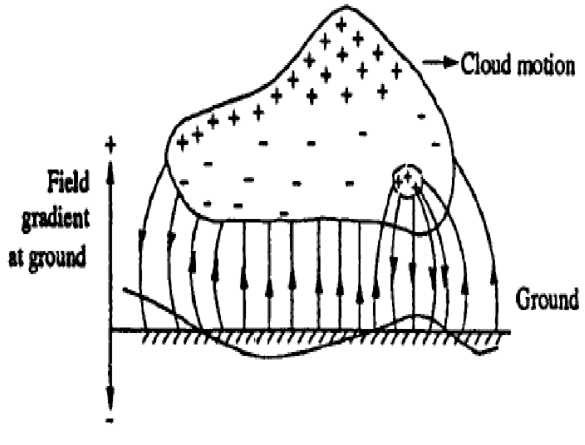


Fig. 8.1 Probable field gradient near the ground corresponding to the probable charge distribution in a cloud

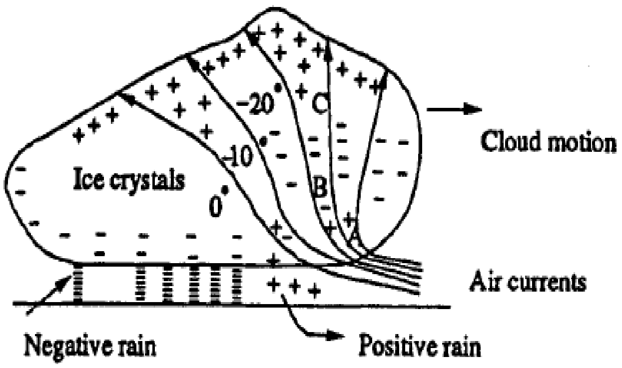


Fig. 8.2 Cloud model according to Simpson's theory

- 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 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)

(b)**Function of a Surge Arrester as a Shunt protective device**

- 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 given as follows :
- $I = kV^a$
- 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.

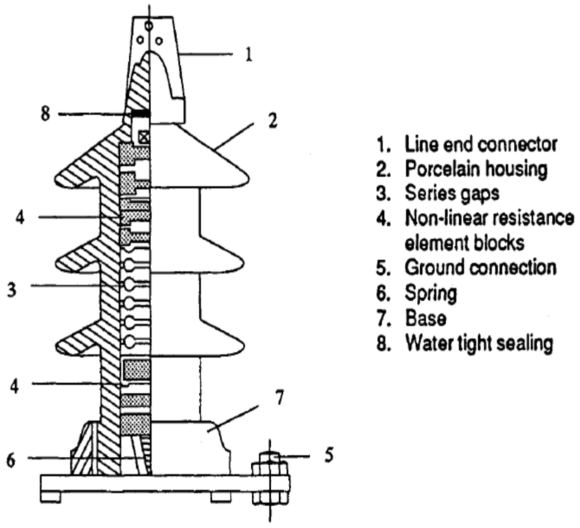
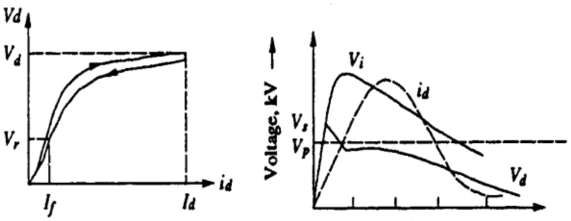


Fig. 8.23 Non-linear element surge diverter

- 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 over voltages 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

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

8(a)(i)**Rod Gaps**

- A much simpler and effective protective device is a rod-gap
- However, it does not meet the complete requirement.
- The sparkover voltage of a rod gap depends on the atmospheric conditions.
- A typical volt-time characteristic of a 67 cm-rod gap is shown in Fig. with its protective margin.
- There is no current limiting device provided so as to limit the current after sparkover, and hence a series resistance is often used.
- Without a series resistance, the sparking current may be very high and the applied impulse voltage suddenly collapses to zero thus creating a steep step voltage, which sometimes proves to be very dangerous to the apparatus to be protected, such as transformer or the machine windings.

- Nevertheless, rod gaps do provide efficient protection where thunderstorm activity is less and the lines are protected by ground wires.

(ii)**Ground wires for the protection of overhead lines**

- 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. 8.19.

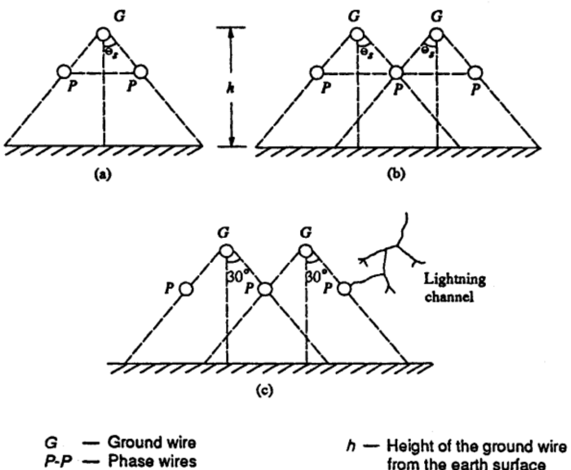
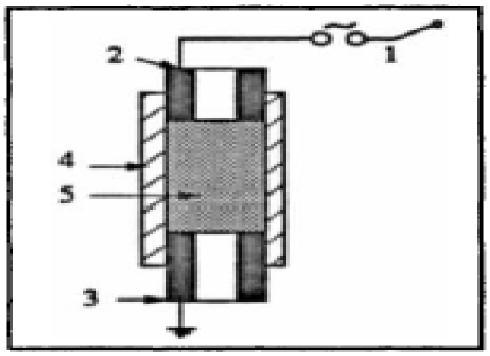


Fig. 8.19 Shielding arrangement of overhead lines by ground wires

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

(b)(i)**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.



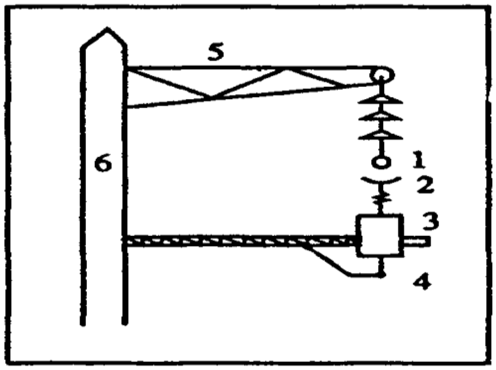
1. External series gap
2. Upper electrode
3. Ground electrode
4. Fibre tube
5. Hollow space

Fig. 8.20a Expulsion gap

(ii)**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)

Module 5

9(a)**Measuring capacitance and tan delta using 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.

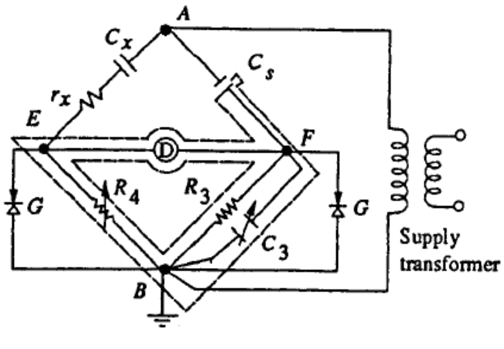
Balance is obtained when

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

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

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

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

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.
- R4 will be a decade box with 5 to 6 decade dials.
- The maximum value of R4 is limited *to 10^4 Ω and the* lowest value will not be less than 0.01 Ω

This range adequately takes care of the errors due to contact resistances as well as the stray capacitance effects across *R4* which are usually very small.

It is important to see that the resistances are pure and not reactive and the standard capacitor has negligible tan δ (air or gas Filled capacitor is used).

- The arrangement shown in Fig. is suitable when the test specimen is not grounded.
- The standard condenser Cs is usually a three terminal condenser.
- The low voltage arms of the bridge (R4 and R3 C3) and the detector are enclosed in grounded shielded boxes to avoid stray capacitances during the measurements.
- The detector is either a vibration galvanometer or in modern bridges a tuned electronic null detector of high sensitivity.
- The protective gaps G are so arranged that the low voltage arms

are protected from high voltages in case the test objects fail.

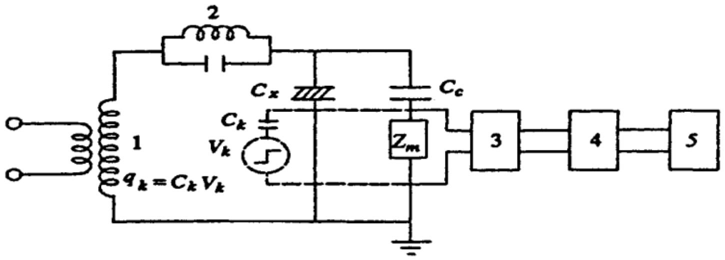
- The impedances of the low voltage arms are such that the voltage drop across EB or FB does not exceed 10 to 20 V.
- The arms will be usually rated for a maximum instantaneous voltage of 100 V.

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

(b)**Method of discharge detection using straight detector method**

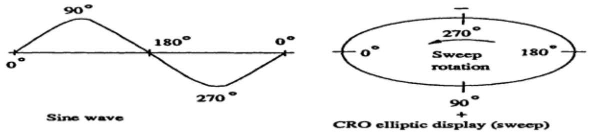
- The circuit arrangement shown in Fig. 9.21 gives a simplified circuit for detecting "partial discharges".

- The high voltage transformer shown is free from internal discharges.
- A resonant filter is used to prevent any pulses starting from the capacitance of the windings and bushings of the transformer.
- Cx is the test object, Cc is the coupling capacitor, and Zm is a detection impedance.
- The signal developed across the impedance Zm is passed through a band pass filter and amplifier and displayed on a CRO or counted by a pulse counter multi-channel analyzer unit.

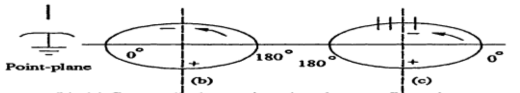


1 — H.V. testing transformer
2 — Filter
3 — Band pass filter
4 — Amplifier
5 — Display unit (CRO or pulse counter or multi-channel analyser unit)

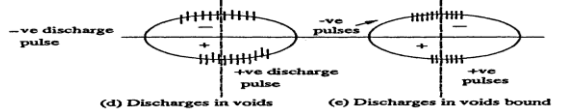
C_x — Sample or test piece
C_c — Coupling condenser
Z_m — Detector impedance
V_k — Calibrating pulse
C_k — Calibrating capacitor
q_k — Calibrator charge



(a) Elliptic sweep display



(b), (c) Corona discharges in point-plane configuration



(d) Discharges in voids in the insulation

(e) Discharges in voids bound on one side with insulation, and on the other side by a conductor

- The discharge pattern displayed on the CRO screen of a partial discharge detector with an elliptical display is shown.
- The sinusoidal voltage and the corresponding ellipse pattern of the discharge are shown in Fig. 9.22a and a single corona pulse in a point-plane spark gap geometry is shown in Figs. 9.22b and c.
- When the voltage applied is greater than that of the critical inception voltage, multiple pulses appear (see Fig. 9.22c), and all the pulses are of equal magnitude.
- A typical discharge pattern in cavities inside the insulation is shown in Fig. 9.22d.
- This pattern of discharge appears on the quadrants of the ellipse which correspond to the test voltage rising from zero to the maximum, either positively or negatively.
- The discharges usually start near the peaks of the test voltage but spread towards the zero value as the test voltage is increased beyond the inception level.
- The number and magnitude of the discharges on both the positive and negative cycles are approximately the same.
- A typical discharge pattern from a void bounded on one side by the insulation and the other side by a conductor is shown in Fig. 9.22c.
- This pattern of discharge is common in insulated cables (like polyethylene and XLPE cables) when the discharge is made up of a large number of pulses of small magnitude on the positive cycle and a much smaller number of large magnitude pulses on the negative half-cycle

- In the narrow band detection scheme Zm is a parallel L -C circuit tuned to 500 kHz.
- The bandpass filter has a bandwidth of about ± 10 kHz. The pulses after amplification are displayed in an elliptical time base of a CRO, and the resolution for the pulses is about 35 per quadrant

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

10(a)**Tests on Transformers and Impulse Testing of Transformers**

- Transformers are very important and costly apparatus in power systems.
- Great care has to be exercised to see that the transformers are not damaged due to transient over voltages of either lightning or power frequency.
- Hence, overvoltage tests become very important in the testing of transformers.

Induced Over voltage Test

- Transformers are tested for over voltages by exciting the secondary of the transformer from a high frequency a.c. source (100 to 400 Hz) to about twice the rated voltage.
- This reduces the core saturation and also limits the charging current necessary in large power transformers.
- The insulation withstand strength can also be checked.

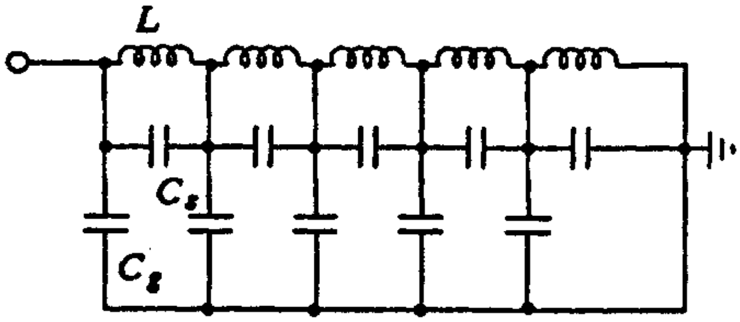
Partial Discharge Tests

- Partial discharge tests on the windings are done to assess the discharge magnitudes and the radio interference levels .

- The transformer is connected in a manner similar to any other equipment and the discharge measurements are made.
- The location of the fault or void is sometimes done by using the travelling wave technique similar to that for cables.
- So far, no method has been standardized as to where the discharge is to be measured.
- Multi-terminal partial discharge measurements are recommended.
- Under the application of power frequency voltage, the discharge magnitudes greater than 10^4 pico coulomb are considered to be severe, and the transformer insulation should be such that the discharge magnitude will be far below this value.

Impulse Testing of Transformers

- The purpose of the impulse tests is to determine the ability of the insulation of the transformers to withstand the transient voltages due to lightning, etc.
- Since the transients are impulses of short rise time, the voltage distribution along the transformer winding will not be uniform.
- The equivalent circuit of a transformer winding for impulses is shown in Fig.
- If an impulse wave is applied to such a network the voltage distribution along the element will be uneven, and oscillations will be set in producing voltages much higher than applied voltage.

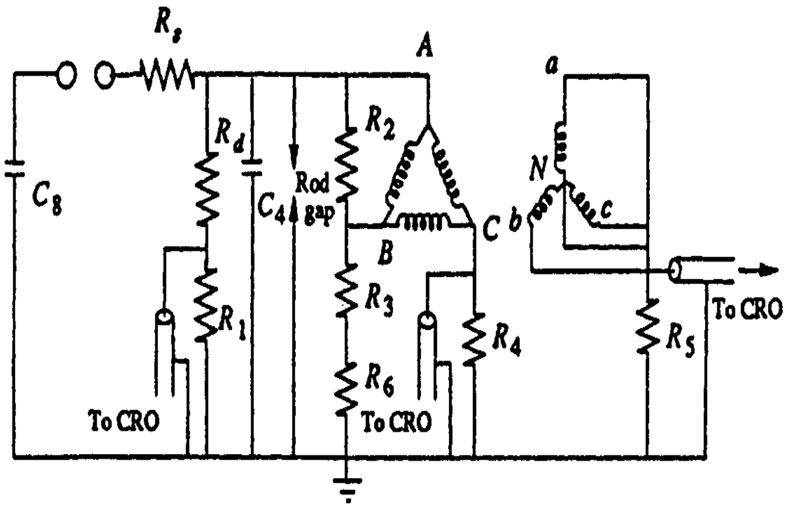


L — Inductance (series)
C_s — Series capacitance
C_g — Shunt capacitance to ground

Equivalent circuit of a Transformer

- Impulse testing of transformers is done using both the full wave and the chopped wave of the standard impulse, produced by a rod gap with a chopping time of 3 to 6 μs.
- To prevent large over voltages being induced in the windings not under test, they are short circuited and connected to ground.
- But the short circuiting reduces the impedance of the transformer and hence poses problems in adjusting the standard waveshape of the impulse generators.
- It also reduces the sensitivity of detection.

Arrangement of Transformer for Impulse Testing



Impulse testing is done in the following sequence:

(*i*) applying impulse voltage of magnitude 75% of the Basic Impulse Level (BIL) of the transformer under test,

(*ii*) one full wave ovltage of 100% BIL,

(*iii*) two chopped waves of 100% BIL,

(*iv*) one full wave of 100% BIL, and

(*v*) one full wave of 75% BIL.

It is very important to see that the grounding is proper and the windings not under test

Detection and Location of fault during Impulse Testing

- General observations: The fault can be located by general observations like noise in the tank or smoke or bubbles in breather.
- Voltage oscillogram method : Fault or failure appears as a partial or complete collapse of the applied voltage wave.
- The sensitivity of this method is low and does not detect faults which occur on less than 5% of the winding.

Other methods are:

- Neutral current method :
- Transferred surge current method:

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(b)(i)**Testing of Isolators and Circuit breakers**

- An isolator or a disconnector is a mechanical switching device, which provides in the open position, an isolating distance in accordance with special requirements.
- An isolator is capable of opening and closing a circuit when either negligible current is broken or made or when no significant change in the voltage across the terminals of each of the poles of the isolator occurs.
- It is also capable of carrying currents under normal circuit conditions, and carrying for a specified time, currents under abnormal conditions such as those of a short circuit

Electrical Isolator

Electrical Isolation Switch

Circuit Breaker

Testing of circuit breakers is intended to evaluate :

(a) the constructional and operational

characteristics,

(b) the electrical characteristics of the circuit

which the switch or the breaker has to

interrupt or make.

The different characteristics of a circuit breaker or a switch may be summarized as per the following groups **:**

- The electrical characteristics which determine the arcing voltage, the current chopping characteristics, the residual current, the rate of decrease of conductance of the arc space and the plasma, and the shunting effects in interruption.
- Other physical characteristics including the media in which the arc is extinguished, the pressure developed or impressed at the point of interruption, the speed of the contact travel, the number of breaks, the size of the arcing chamber, and the materials and configuration of the circuit interruption.

The characteristics of the circuit include :

- degree of electrical loading,
- normally generated or applied voltage,
- type of fault in the system which the breaker has to clear,

time of interruption, time constant,

- natural frequency and the power factor of the circuit,

- rate of rise of recovery voltage, the restriking voltage,
- decrease in the a.c. component of the short circuit current,

and the degree of asymmetry and the d.c. component of the short circuit current,

To assess the above factors, the main tests conducted on the circuit breakers and isolator switches are :

- dielectric tests or overvoltage tests
- temperature rise tests
- mechanical tests
- short circuit tests

Dielectric tests consist of overvoltage withstand tests of power frequency, lightning and switching impulse voltages.

(ii)**Insulators**

The tests are as (i) type tests, and (ii) the routine tests.

- Type tests to prove or check the design features and the quality.
- The routine tests to check the quality of the individual test piece.
- Type tests are done on samples when new designs or design changes are introduced,
- The routine tests are done to ensure the reliability of the individual test objects and quality and consistency of the materials used in their manufacture.

High voltage tests include

(i) the power frequency tests,

(ii) impulse tests.

All the insulators are tested for both categories of test.

Power frequency tests

(a)Dry and Wet Flashover Tests :

- In these tests the a.c. voltage of power frequency is applied across the insulator and increased at a uniform rate of about 2 per cent per second of 75% of the estimated test voltage, to such a value that a breakdown occurs along the surface of the insulator.
- If the test is conducted under normal conditions without

any rain or precipitation, it is called "dry flashover test".

- If the test is done under conditions of rain, it is called "wet

flashover test”

b) **Wet and Dry Withstand Tests (One Minute):**

- In these tests, the voltage specified in the relevant specification is applied under dry or wet conditions for a period of one minute with an insulator mounted as in service conditions.
- The test piece should withstand the specified voltage.

(a)Impulse Withstand Voltage Test :

- This test is done by applying standard impulse voltage of specified value under dry conditions with both positive and negative polarities of the wave.

- If five consecutive waves do not cause a flashover or puncture, the insulator is deemed to have passed the test.
- If two applications cause flashover, the object is deemed to have failed.
- If there is only one failure, additional ten applications of the voltage wave are made.
- If the test object has withstood the subsequent applications, it is said to have passed the test.

b)Impulse Flashover Test

- The test is done as above with the specified voltage.
- Usually, the probability of failure is determined for 40% and 60% failure values or 20% and 80% failure values, since it is difficult to adjust the test voltage for the exact 50% flashover values.
- The average value of the upper and the lower limits is taken.
- The insulator surface should not be damaged by these tests, but slight marking on its surface or chipping off of the cement is allowed.

c)Pollution Testing

Because of the problem of pollution of outdoor electrical insulation and consequent problems of the maintenance of electrical power systems, pollution testing is gaining importance.

The normal types of pollution are :

- Dust, micro-organisms, bird secretions, flies, etc.,
- Industrial pollution like smoke, petroleum vapours, dust, and other deposits,
- Coastal pollution in which corrosive and hygroscopic salt layers are deposited on the insulator surfaces,
- Desert pollution in which sand storms cause deposition of sand and dust layers,
- Ice and fog deposits at high altitudes and in polar countries.

Effect of Pollution:

- Pollutions cause corrosion, non-uniform gradients along the insulator strings and surface of insulators and also cause deterioration of the material.

  Pollution causes partial discharges and radio interference.
- Pollution testing is important for extra high voltage systems.
- There is no standard pollution test available.
- The popular test that is normally done is the salt fog test.
- The maximum normal withstand voltage is applied on the insulator and then artificial salt fog is created around the insulator by jets of salt water and compressed air.
- If the flashover occurs within one hour, the test is repeated with fog of lower salinity, otherwise, with a fog of higher salinity.

- The maximum salinity at which the insulator withstands three out of four tests without flashover is taken as the representative figure.
- Much work is yet to be done to standardize the test procedures

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