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Internal Test3 –November 2018

Sub:	High Voltage Engineering								Code:	15EE73
Date:	19/11 /2018	Duration:	90 mins	Max Marks:	50	Sem:	VII		Branch:	EEE

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

		Marks	OBE	
			CO	RBT
1.	Explain with suitable figures the principles and functioning of (a) expulsion gaps, (b) protector tubes.	[5+5]	CO5	L2
2.	What are the mechanisms by which lightning strokes develop and induce overvoltages on overhead power lines?	[10]	CO5	L2
3.	What are partial discharges? How are they detected using straight detection and blance detection?	[2+8]	CO6	L2
4.	What are the causes for switching and power frequency overvoltages? How are they controlled in power systems?	[5+5]	CO5	L2
5.	What is a surge diverter? Explain its function as a shunt protective device.	[3+7]	CO6	L2
6a.	A resistance divider of 1400 kV (impulse) has a high voltage arm of 16 kilo-ohms and a low voltage arm consisting 16 members of 250 ohms, 2 watt resistors in parallel. The divider is connected to a CRO through a cable of surge impedance 75 ohms and is terminated at the other end through a 75 ohm resistor. Calculate the exact divider ratio.	[5]	CO4	L3
6b.	A 3-phase single circuit transmission line is 400 km long. If the line is rated for 220 kV and has the parameters, R = 0.1 ohms/km, L = 1.26 mH/km, C = 0.009 μF/km, and G =0, find (a) the surge impedance and (b) the velocity of propagation neglecting the resistance of the line. If a surge of 150 kV and infinitely long tail strikes at one end of the line, what is the time taken for the surge to travel to the other end of the line?	[5]	CO5	L3
7.	With the help of a diagram of Schering Bridge explain how capacitance and tan δ can be measured?	[7+3]	CO6	L2
8.	Provide the schematic arrangements of an impulse potential divider with an oscilloscope connected for measuring impulse voltages. Explain the arrangement used to minimize the error.	[6+4]	CO4	L3

1a) Protective Devices

In regions where lightning strokes are intensive or heavy, the overhead lines within these zones are fitted with shunt protected devices.

On the line itself two devices known as expulsion gaps and protector tubes are used. **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 breakover due to overvoltages.

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.

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.

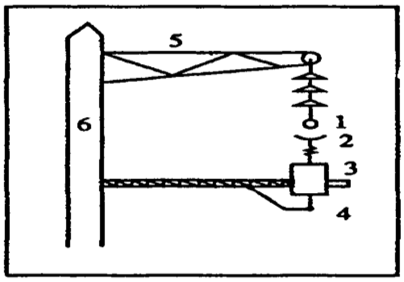
The hollow gap in the expulsion tube is replaced by a nonlinear element which offers a very high impedance at low currents but has low impedance for high or lightning currents. When an overvoltage occurs and the spark gap breaksdown, the current is limited both by its own resistance and the tower footing 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

2. **Mechanism of Lightning Strokes**

When the electric Held intensity at some point in the charge concentrated cloud exceeds the breakdown value of the moist ionized air (= 10 kV/cm), **an electric streamer with plasma** starts towards the ground with a **velocity of about 1/10 times** that of the light, but may progress only about 50 m or so before it comes to a halt emitting a bright flash of light The halt may be due to insufficient build-up of electric charge at its head and not sufficient to maintain the necessary field gradient for further progress of the streamer. But after a short interval of about 1OO μs, the streamer again starts out repeating its performance. The total time required for such a stepped leader to reach the ground may be 20 ms. The path may be quite lustruous, depending on the local conditions in air as well as the electric field gradients. Branches from the initial leader may also be formed. Since the progress of this leader stroke is by a series of jumps, it is referred as stepped leader.

The lightning stroke and the electrical discharges due to lightning are explained based on the **"streamer" or "kanel" theory for spark discharges in long gaps with non-uniform electric fields**.

The lightning consists of few separate discharges starting from a leader discharge and culminates in return strokes or main discharges.

After the leader touches the ground, the return stroke follows. As the leader moves towards the ground, positive charge is directly accumulated under the head of the stroke or canal. By the time the stroke reaches the ground or comes sufficiently near the ground, the electrical field intensity on the ground side is sufficiently large to build up the path.

Hence, the positive charge returns to the cloud neutralizing the negative charge, and hence a heavy current flows through the path. The velocity of the return or main stroke ranges from 0.05 to 0,5 times the velocity of light, and currents will be of the order of 1000 to 250,000 A.

The return strokes vanish before they reached the cloud, suggesting that the charge involved is that conferred to the stroke itself.

After the completion of the return stroke, a much smaller current of 100 to 1000 A may continue to flow which persists approximately 20 ms. Due to these currents the initial breakdown points in the cloud are considerably reduced and discharges concentrate towards this point . Therefore, additional reservoirs of charge become available due to penetration of a cloud mass known as preferred paths and lead to repeated strokes. The leader strokes of the repeated strokes progress with much less velocity («1% of that of light) and do not branch. This stroke is called continuous leader, and return stroke for this leader follows with much less current. The interval between the repeated strokes may be from 0.6 ms to 500 ms with an average of 30 ms. Multiple strokes may last for 1 s. The total duration of the lightning may be more than 1 s.

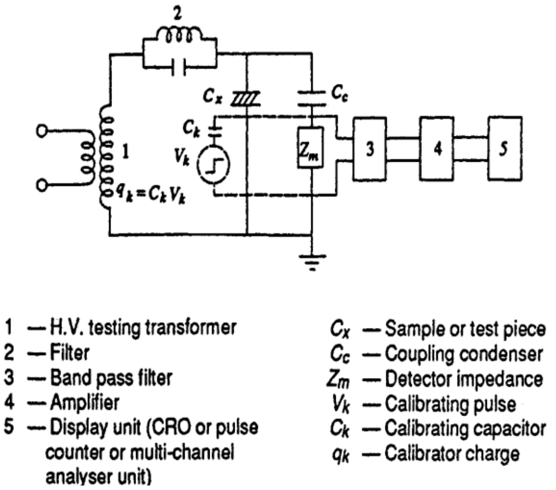
The current from the ground by the main return stroke may have a peak value of 250,000 A and and rates of rise may be as high as 100 kA/μ s or 1011 A/s.

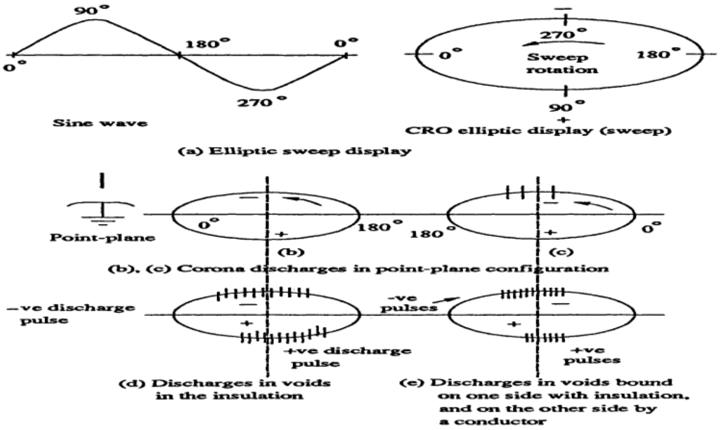
Important parameters : the time intervals between successive strokes, the number of successive strokes, the du ration of lightning discharges the discharge current, the rate of rise of current, and wavefront and wave tail times and their probability distribution

3. It was observed that the dissipation factor (tan δ) was voltage dependent and hence became a criterion for the monitoring of the high voltage insulation weak points in an insulation like voids, cracks, and other imperfections lead to internal or intermittent discharges in the insulation.

- These imperfections being small were not revealed in capacitance measurements but were revealed as power loss components in contributing for an increase in the dissipation factor.
- In modern terminology these are designated as "**partial discharges"** which in course of time reduce the strength of insulation leading to a total or **partial failure or breakdown of the insulation**
- **Discharge Detection Using Straight Detectors**
- 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.

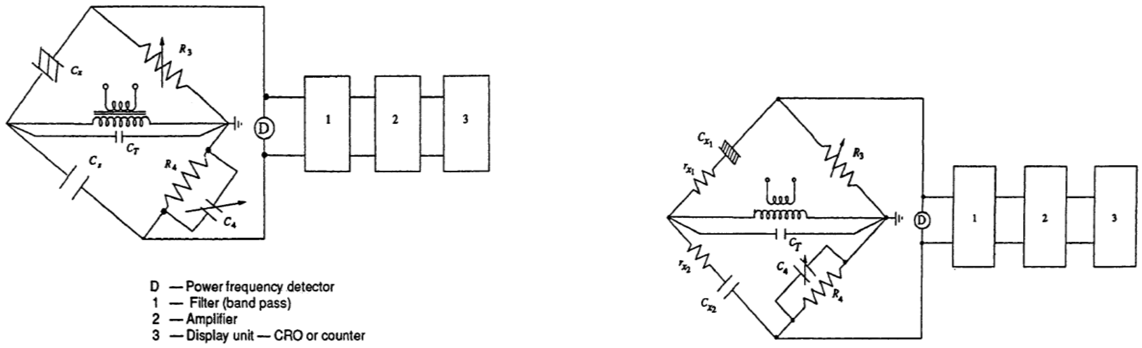
- The signal developed across the impedance Zm is passed through a band pass filter and amplifier and displayed on a CRO or counted by a pulse counter multi-channel analyzer unit.





- 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.
- **Balanced Detection Method**
- In the straight detection method, the external disturbances are not fully rejected.
- The filter used to block the noise sources may not be effective.
- The Schering bridge employed for the tan δ measurement is sometimes used.
- In this method, the test object is not grounded.
- A **modification** to the Schering bridge detector is **the differential discharge detector,** given by Kreuger.
- Both the schemes are given in Fig. 9.23.
- The bridges are tuned and balanced at 50 Hz.
- A filter is used across the detector terminals to block the 50 Hz components present
- Signals in the range from 5 to 50 kHz are allowed to pass through the filter and amplified.
- The CRO gives the display of the pulse pattern.
- Any external interference from outside is balanced out, and only internally (test piece) generated pulses are detected.
- In the modified scheme, another test sample called dummy sample is used in the place of the standard condenser.
- The capacitance and tan δ of the dummy sample are made approximately equal, but need not be equal.

- **The disadvantage is that if two discharges occur in both the samples**
- **simultaneously, they cancel out, but this is very rare.**
- The main advantage of the second method is its capacity for better rejection of external noise and use of the wide frequency band with belter resolution of the individual pulses.



D — Power frequency detector
1 — Filter (band pass)
2 — Amplifier
3 — Display unit — CRO or counter

(a) Balanced detector using Schering bridge

(b) Differential detector

Fig. 9.23 Balanced discharge detector schemes

4. The making and breaking of electric circuits with switchgear may result in abnormal over voltages in power systems having large inductances and capacitances.

- 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 summarised 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.
.

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 overvoltages

- The measures taken to control or reduce the overvoltages are
  - (i) one step or multi-step energization of lines by pre_insertion of resistors,
  - (ii) phase controlled closing of circuit breakers with proper sensors,
  - (iii) drainage of trapped charges on long lines before the reclosing of the lines, and
  - (iv) limiting the over voltages by using surge diverters.

Power Frequency Overvoltages in Power Systems
The main causes for power frequency and its harmonic overvoltages are
(a) sudden loss of loads,
(b) disconnection of inductive loads or connection of capacitive loads,
(c) Ferranti effect, unsymmetrical faults, and
(d) saturation in transformers, etc.

Overvoltages 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 overvoltages due to series capacitors with shunt reactors or transformers.

The duration of these overvoltages may be from one to two cycles to a few seconds depending on the overvoltage protection employed.

(a) Sudden Load Rejection

Sudden load rejection on large power systems causes the **speeding up of** generator **prime movers**. The **speed governors** and **automatic voltage regulators** will intervene to restore normal conditions. But **initially** both the **frequency** and **voltage increase**.

The approximate voltage rise, neglecting losses, etc. may be taken as

$$v = \frac{f}{f_0} E' \left[\left(1 - \frac{f}{f_0} \right) \frac{x_s}{x_c} \right]$$

where xs is the reactance of the generator (« the sum of the transient reactances of the generator and the transformer), xc is the capacitive reactance of the line at open end at increased frequency, E’ the voltage generated before the over-speeding and load rejection, f is the instantaneous increased frequency, and fo is the normal frequency

(b) Ferranti Effect

Long uncompensated transmission lines exhibit voltage rise at the receiving end. The voltage rise at the receiving end *V2 is approximately given by*

$$V_2 = \frac{V_1}{\cos \beta l}$$

where, V_1 = sending end voltage,

l = length of the line,

β = phase constant of the line

$\approx \left[\frac{(R + j\omega L)(G + j\omega C)}{LC} \right]^{1/2}$

$\approx$ about 6° per 100 km line at 50 Hz frequency.

ω = angular frequency for a line

R — Resistance per unit length C — Capacitance per unit length

L — Inductance per unit length G — Leakage conductance per unit length

Considering that the line capacitance is concentrated at the middle of the line, under open circuit conditions at the receiving end, the line charging current

$I_C \approx j\omega C V_1 = \frac{V_1}{X_C}$ and the voltage $V_2 \approx V_1 \left[1 - \frac{X_L}{2X_C} \right]$ where, X_L = line inductive reactance, and

X_C = line capacitive reactance.

(c)Ground Faults and Their Effects

Single line to ground faults cause rise in voltages in other healthy phases. Usually, with solidly grounded systems, the increases in voltage (phase to ground value) will be less than the line-to-line voltage. With effectively grounded systems, i.e. with

$$\frac{X_0}{X_1} \leq 3.0 \text{ and } \frac{R_0}{X_1} \leq 1.0$$

(where, R0 and X0 are zero sequence resistance and reactance and X1 is the positive sequence reactance of the system), the rise in voltage of the healthy phases does not usually exceed 1.4 per unit.

(d)Saturation Effects

- When voltages above the rated value are applied to transformers, their magnetizing currents (no load currents also) increase rapidly and may be about the full rated current for 50% overvoltage.
- These magnetizing currents are not sinusoidal in nature but are of a peaky waveform.
- The third, fifth, and seventh harmonic contents may be 65%, 35%, and 25% of the exciting current of the fundamental frequency corresponding to an overvoltage of 1.2 p.u.
- For third and its multiple harmonics, zero sequence impedance values are effective, and delta connected windings suppress them.
- But the shunt connected capacitors and line capacitances can form resonant circuits and cause high third harmonic overvoltages.

- When such overvoltages are added, the voltage rise in the lines may be significant. For higher harmonics a series resonance between the transformer inductance and the line capacitance can occur which may produce even higher voltages.

Control of Overvoltages Due to Switching

The overvoltages 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, and
(e) limiting switching surges by suitable surge diverters

(a) Insertion of Resistors

- It is normal and a common practice to insert resistances in series with circuit breaker contacts when switching on but short circuiting them after a few cycles.
- This will reduce the transients occurring due to switching.
- The voltage step applied is first reduced to Z0(R + Z0) per unit where Z0 is the surge impedance of the line.
- It is reflected from the far end unchanged and again reflected back from the near end with reflection factor (R – Z0)/(R+ Z0) per unit.

If R = Z0, there is no reflection from the far end.

(b) Phase Controlled Switching

Overvoltages can be avoided by controlling the exact instances of the closing of the three phases separately. But this necessitates the use of complicated controlling equipment and therefore is not adopted.

(c) Drainage of Trapped Charge

When lines are suddenly switching off, "electric charge" may be left on capacitors and line conductors. This charge will normally leak through the leakage path of the insulators, etc.
Conventional potential transformers (magnetic) may also help the drainage of the charge.
An effective way to reduce the trapped charges during the lead time before reclosing is by temporary insertion of resistors to ground or in series with shunt reactors and removing before the closure of the switches.

(d) Shunt Resistors

Normally all EHV lines will have shunt reactors to limit the voltage rise due to the Ferranti effect.
They also help in reducing surges caused due to sudden energizing.
However, shunt reactors cannot drain the trapped charge but will give rise to oscillations with the capacitance of the system.
Since the compensation given by the reactors will be less than 100%, the frequency of oscillation will be less than the power frequency and overvoltages produced may be as high as 1.2 p.u.
Resistors in series with these reactors will suppress the oscillations and limit the over voltages.
Limiting the switching and power frequency over voltages by using surge diverters.

5. Surge Diverters

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

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

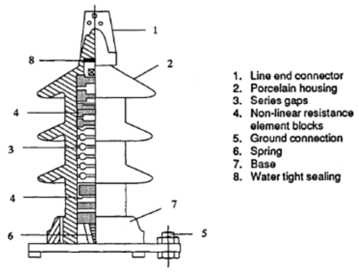


Fig. 8.23 Non-linear element surge diverter

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

The lighter designs operate for smaller duration of currents, while the heavy *duty* surge diverters with assisted or active gaps are designed for high currents and long duration surges.

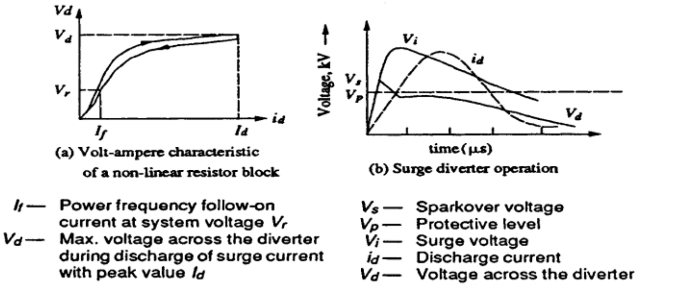
The lighter design arresters can interrupt 100 to 300 A of power frequency follow-on current and about 5000 A of surge currents.

If the current is to be more and has to be exceeded, the number of series elements has to be increased or some other method to limit the current has to be used. In heavy duty arresters, the gaps are so arranged that the arc burns in the magnetic field of the coils excited by power frequency follow-on currents.

During lightning discharges, a high voltage is induced in the coil by the steep front of the surge, and sparking occurs in an auxiliary gap.

For power frequency follow-on currents, the auxiliary gap is extinguished, as sufficient voltage will not be present across the auxiliary gap to maintain an arc. The main gap arcs occur in the magnetic field of the coils. The magnetic field, aided by the born shaped main gap electrodes, elongates the arc and quenches it rapidly. The follow-on current is limited by the voltage drop across the arc and the resistance element. During surge discharge the lightning protective level becomes low.

Sometimes, it is possible to limit the power frequency and other overvoltages after a certain number of cycles using surge diverters. The permissible voltage and duration depend on the thermal capacity of the diverter. The rated diverter voltage is normally chosen so that it is not less than the power frequency overvoltage expected (line to ground) at the point of installation, under any faulty or abnormal operating condition.



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

(b) Surge diverter operation

I_f — Power frequency follow-on current at system voltage V_r
V_d — Max. voltage across the diverter during discharge of surge current with peak value I_d

V_s — Sparkover voltage
V_p — Protective level
V_i — Surge voltage
i_d — Discharge current
V_d — Voltage across the diverter when discharging the current i_d

Fig. 8.24 Characteristics of a surge diverter

Protection of Lines with Surge Dlverters

Since surge diverters are devices that provide low resistance paths for overvoltages through an alternate ground path, their operating characteristic and application is of importance.

The spark gap inside the diverter acts as a fast acting switch while non-linear diverter elements provide the low impedance ground path.

The arrester voltage at its terminal when connected to a "line of surge impedance Z to ground, is given as

$$V = [2(R+r)/(R+r+Z)]\,u(t)$$

Z is the line surge impedance,
R is the resistance of the non-linear element,
r is the ground to earth resistance, and
$u(t)$ is the surge voltage.

The Thevinin equivalent circuit for the diverter is shown in Fig. 8.26.

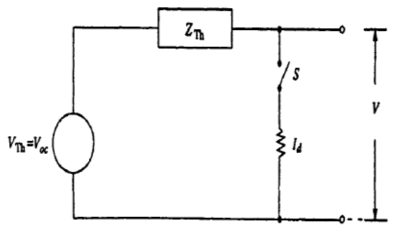


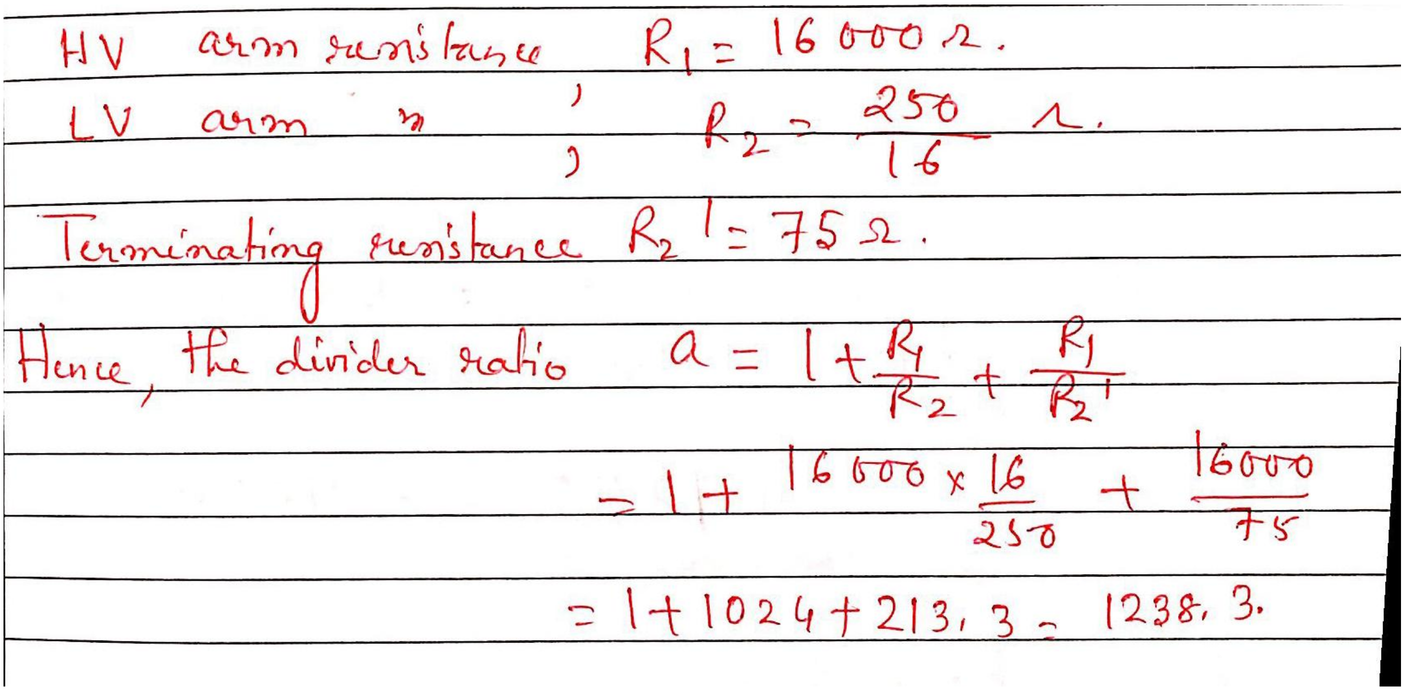
Fig. 8.26 Equivalent circuit of a surge diverter

The switch S is open for voltages less than the sparkover voltage of the surge diverter Vs, while it is closed for voltage magnitudes greater than Vs.

The closing of the switch is represented by injecting a voltage cancellation wave having a negative amplitude equal to the potential difference between the voltage that appears when the switch is open Voc, and the voltage developed across the impedance of the device after the switch is closed.

ZTh is the impedance of the system viewed from the terminals of the protective device.

6a



HV arm resistance $R_1 = 16000\ \Omega$.

LV arm " , $R_2 = \frac{250}{16}\ \Omega$.

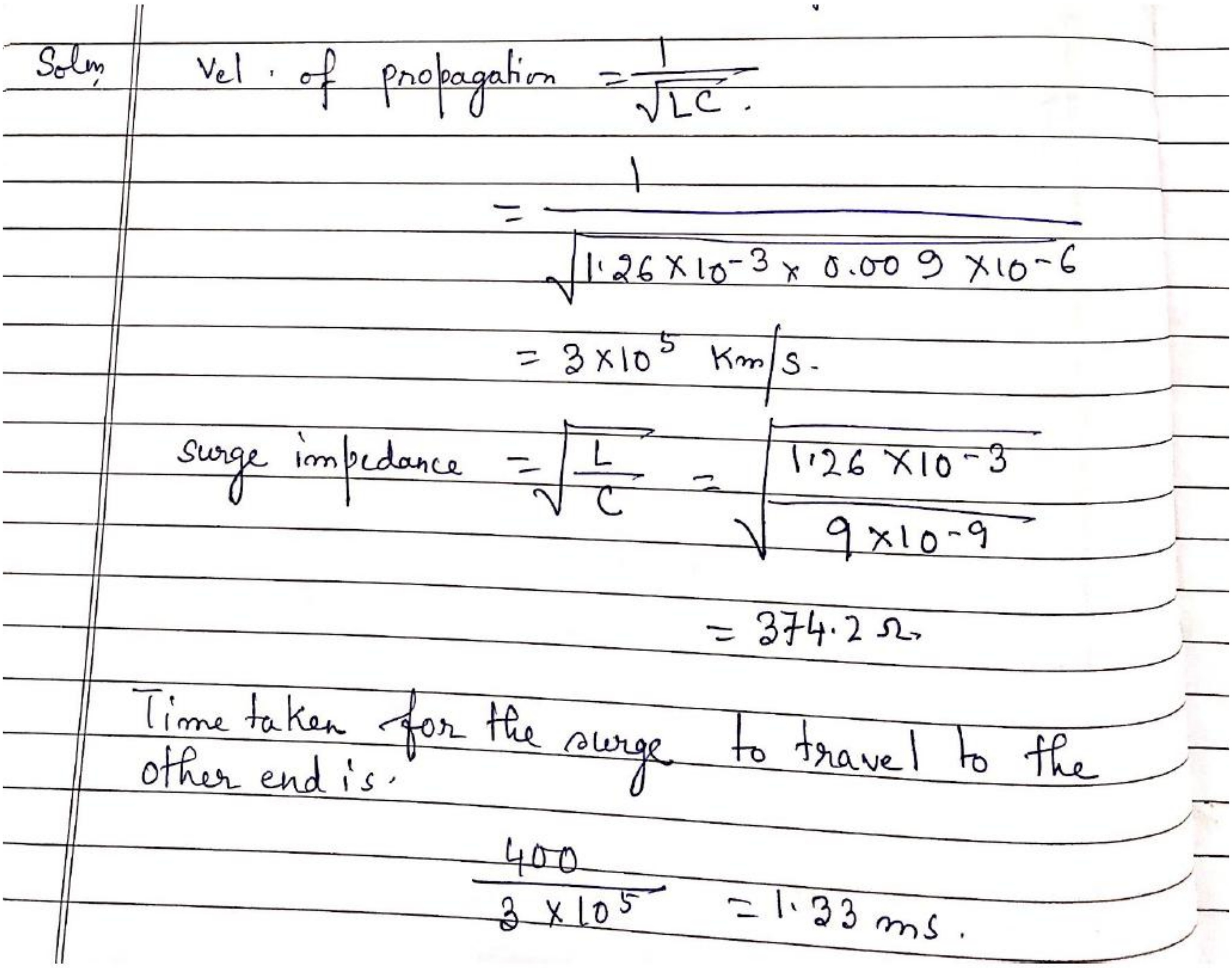
Terminating resistance $R_2' = 75\ \Omega$.

Hence, the divider ratio $a = 1 + \frac{R_1}{R_2} + \frac{R_1}{R_2'}$

$= 1 + \frac{16000 \times 16}{250} + \frac{16000}{75}$

$= 1 + 1024 + 213.3 = 1238.3.$

6b



Soln, Vel. of propagation $= \frac{1}{\sqrt{LC}}$.

$$= \frac{1}{\sqrt{1{\cdot}26 \times 10^{-3} \times 0.009 \times 10^{-6}}}$$

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

surge impedance $= \sqrt{\frac{L}{C}} = \sqrt{\frac{1{\cdot}26 \times 10^{-3}}{9 \times 10^{-9}}}$

$$= 374.2\,\Omega.$$

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

$$\frac{400}{3 \times 10^{5}} = 1{\cdot}33 \text{ ms}.$$

7 **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.

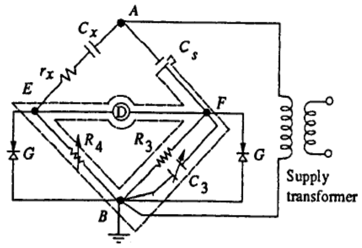
The standard capacitor is shown as Cs which will usually have a capacitance of 50 to 500 µF.
The variable arms are R4 and C3 /R3.
Balance is obtained when

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

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

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

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 loss angle, $\tan\delta_x = \omega C_x R_x$

$= \omega C_3 R_3$

- 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.

- **SOURCES OF ERROR:**
- For a very accurate measurement of the dissipation factor at **power frequency**, the **stray and grounded capacitances** should be eliminated and the **indirect capacitive** and **inductive coupling** of the arms are to be **minimized** to a level lower than the accuracy of the bridge arms.

In this bridge the **main source** of **error** is the **ground capacitance** of the low voltage terminals of high voltage arms, i.e. the stray capacitances from *E* and *F to ground. These are* **eliminated** *by* **shielding** *the low voltage arms using doubly* shielded cables for connections and using the "**Wagner earthing device**". Compensation for the stray capacitances is given by providing a parallel *R-L circuit* across *R4.*

8. **Potential Dividers for Impulse Voltage Measurements**

- Potential or voltage dividers for high voltage impulse measurements, high frequency a.c. measurements, or for fast rising transient voltage measurements are usually either **resistive** or **capacitive** or **mixed element type.**
- The low voltage arm of the divider is usually connected to a fast recording oscillograph or a peak reading instrument through a delay cable.

- A schematic diagram of a potential divider with its terminating equipment is given in Fig. is usually a **resistor or a series of resistors in case of a resistance potential divider**, or **a single or a number of capacitors in case of a capacitance divider.**
- It can also be a combination of both resistors and capacitors.
- Z2 will be a resistor or a capacitor or an R-C impedance depending upon the type of the divider.
- Each element in the divider, in case of high voltage dividers, has a **self_resistance** or **capacitance**. In addition, the **resistive elements** have **residual inductances**, a **terminal stray capacitance** to **ground**, and **terminal to terminal capacitances**

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

- The attenuation factor of the divider or the voltage ratio is given by
- The divider element R2, in practice, is connected through the coaxial cable to the oscilloscope.
- The cable will generally have a surge impedance Z0 and this will come in parallel with the oscilloscope input impedance (Rm, Cm).
-
- the equivalent circuit of the divider with inductance neglected is of the form shown in Fig.
-

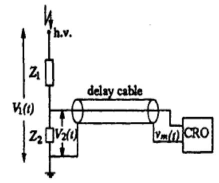
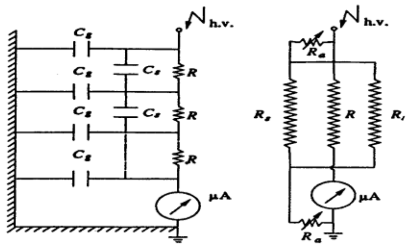


Fig. 7.23 Schematic diagram of a potential divider with a delay cable and oscilloscope



(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

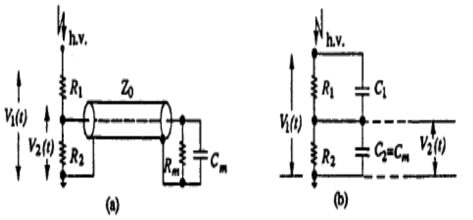
-
- When a step or fast rising voltage is applied at the high voltage terminal, the voltage developed across the element **Z2** will not have the true waveform as that of the applied voltage. The cable can also introduce distortion in the waveshape
- For high frequency and impulse voltages (since they also contain high frequency fundamental and harmonics), the ratio in the frequency domain will be given by

$$a = \frac{V_1}{V_2} = 1 + \frac{R_1}{(R_2/1 + j\omega R_2 C_m)}$$

-
- To avoid the frequency dependence of the voltage ratio a, the divider is compensated by adding an additional capacitance C1 across R1.
- The value of C1, to make the divider independent of the frequency, may be obtained from the relation,

$$\frac{R_1}{R_2} = \frac{C_m}{C_1}$$

- $R_1C_1 = R_2C_m$



Resistance potential divider with surge cable and oscilloscope terminations

Comepensated resistance potential divider

Fig. 7.24 a & b Resistance potential dividers

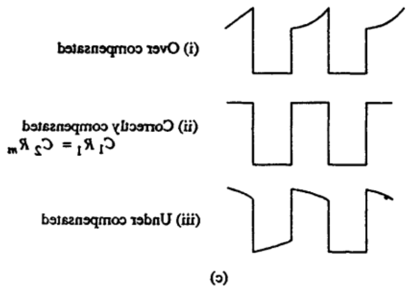


Fig. 7.24c Output of compensated resistance voltage divider for different degrees of compensation

- **meaning that the time constant of both the arms should be the same. This compensation is used for the construction of high voltage dividers and probes used with oscilloscopes**