CMR INSTITUTE OF TECHNOLOGY

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Internal Test3 –January 2022

Sub:	High Voltage Engineering							Code:	18EE56
Date:	27/01/2022	Duration:	90 mins	Max Marks:	50	Sem:	**VB**	Branch:	EEE

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

		Marks	OBE CO	OBE RBT
1.	What are partial discharges? How are they detected using balance detection method?	[2+8]	CO6	L2

- 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**
- If the sites of partial discharges can be located inside an equipment, like in a power cable or a transformer, it gives valuable information to the insulation engineer about the regions of greater stress and imperfections in the fabrication.

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.**

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.

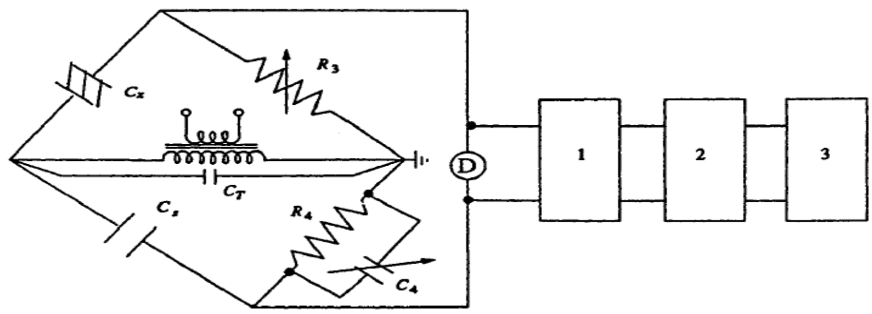
Any external interference from outside is balanced out, and only internally (test piece) generated pulses are detected.

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.

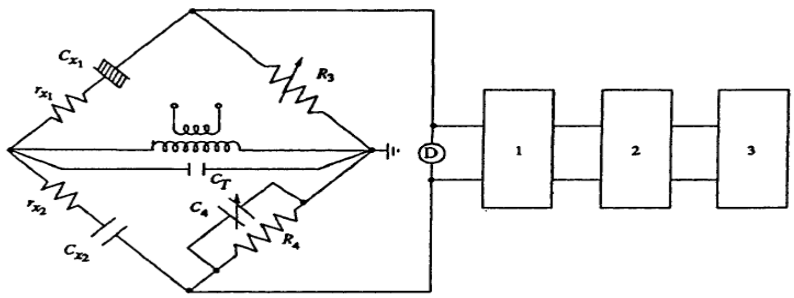
The disadvantage is that if two discharges occur in both the samples simultaneously, they cancel out, but this is very rare.

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

2.	What are the causes for switching and power frequency over voltages? How are they controlled in power systems?	[5+5]	CO5	L2

- Causes 5 Marks
- How to control minimum 3 points with explanation 5 Marks

The power frequency overvoltages occur in large power systems and they are of much
concern in EHV systems, i.e. systems of 400 kV and above. The main causes for power frequency and its harmonic overvoltages are

(a) sudden loss of loads:

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) disconnection of inductive loads or connection of capacitive loads,
(c) Ferranti effect, unsymmetrical faults:

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

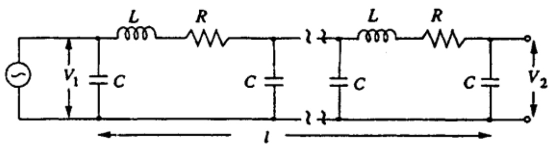
$$\approx \left[\frac{(R + j\,\omega L)\,(G + j\,\omega C)}{LC}\right]^{1/2}$$

$\approx$ 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



L, R and C — Inductance, resistance and capacitance per unit length of the line

l — Length of the line

Fig. 8.17 Typical uncompensated long transmission line

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.

(d) saturation in transformers, etc :

- 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:

- 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.
- The applied step at the first instance is only 0.5 per unit.
- When the resistor is short circuited, a voltage step equal to the instantaneous voltage drop enters the line.
- If the resistor is kept for a duration larger than 5ms (for 50 Hz sine wave = 1/4 cycle duration), it can be shown from successive reflections and transmissions, that the overvoltage may reach as high as 1.2 p.u. for a line length of 500 km.
- But for conventional opening of the breaker, the resistors have too high an ohmic value to be effective for resistance closing.

(b) phase controlled closing of circuit breakers:

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 charges before reclosing:

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) use of shunt reactors:

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.

(e) Limiting the switching and power frequency over voltages by using surge diverters

3. What is a surge diverter? Explain its function as a shunt protective device. [3+7] CO5 L2

- Definition 3 Marks
- Diagram 3 Marks
- Explanation of working with graph 4 Marks

Surge diverters or lightning arresters are devices used at sub-stations and at line terminations to discharge the lightning overvoltages and short duration switching surges.
These are usually mounted at the line end at the nearest point to the sub-station.
They have a flashover voltage higher than that of any other insulation or apparatus at the sub-station. These are capable of discharging 10 to 20 kA of long duration surges (8/20 μ s) and 100 to 250 kA of the short duration surge currents (1/5 *μs).*

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

$$I = kV^a$$

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

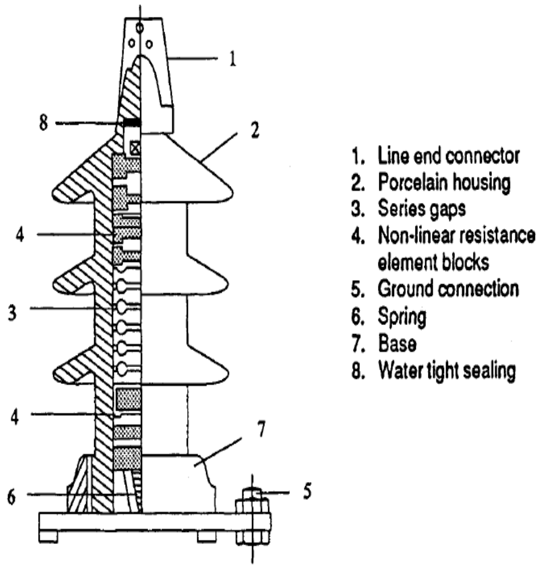
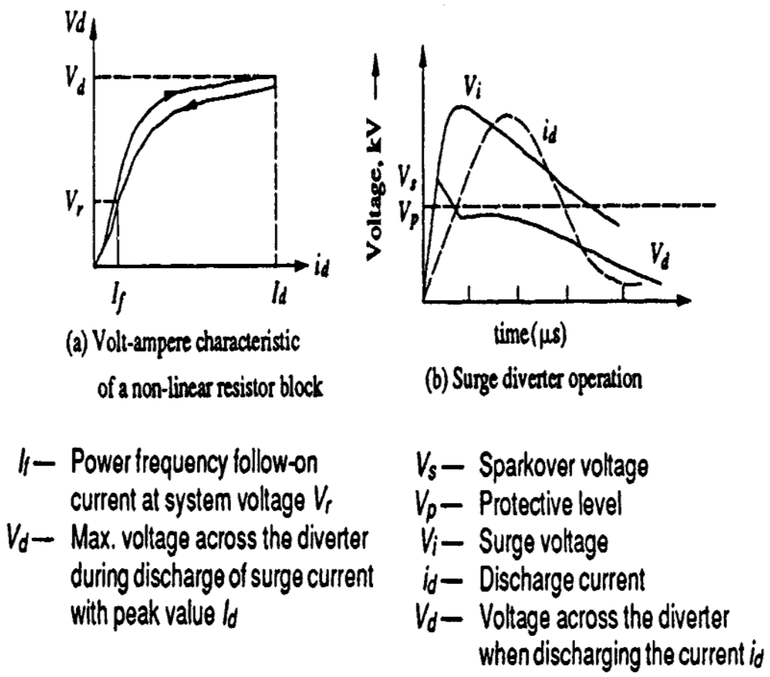
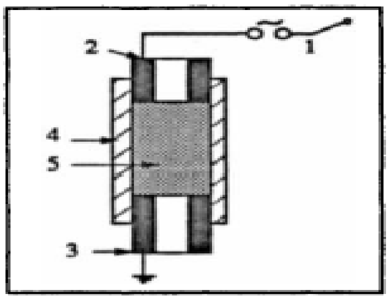


Fig. 8.23 Non-linear element surge diverter

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 horn 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.  **Fig. 8.24 Characteristics of a surge diverter**			
4.	Explain with suitable figures the principles and functioning of (a) expulsion gaps. (b) protector tubes. (a) Expulsion Graph • Diagram 2 Marks • Explanation 3 Marks 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.	[5+5]	CO5	L2

The gas thus produced, being a mixture of water vapour and the decomposed fibre product, drive away the arc products and ionized air.
When the follow-on power frequency current passes through zero value, the arc is extinguished and the path becomes open circuited.
Meanwhile the insulation recovers its dielectric strength, and the normal conditions are established.
The lightning and follow-up power frequency currents together can last for 2 to 3 half cycles only. Therefore, generally no disturbance in the network is produced.
For 132 or 220 kV lines, the maximum current rating may be about 7,500 A.



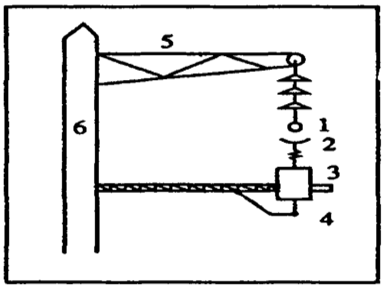
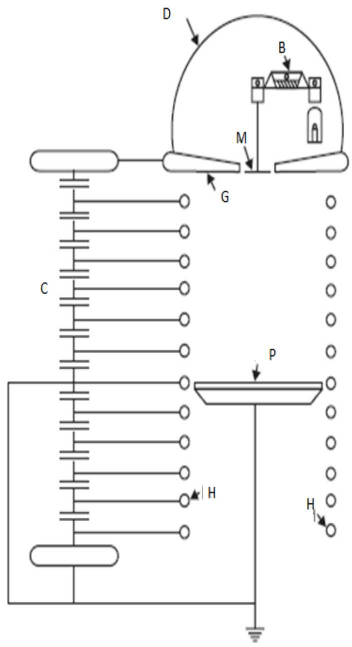
1. External series gap
2. Upper electrode
3. Ground electrode
4. Fibre tube
5. Hollow space

Fig. 8.20a Expulsion gap

(b) protector tubes

- Diagram 2 Marks
- Explanation 3 Marks

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. 8.2Ob.
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**			
5.	Explain the principle of operation and construction of an electrostatic voltmeter used for the measurement of high voltage. What are the limitations? • Principle of operation 4 marks • Construction and diagram 2+2 Marks • Limitations 2 Marks  Fig. 4.7 Schematic diagram of electrostatic voltmeter D–Metal Dome M-mounting Plate G –guard plate P –Fixed Plate H- Guard loop or ring B-Balance C-Capacitance Divider W Balancing Weight • Fig. shows a schematic diagram of an absolute electrostatic voltmeter. • The hemispherical metal dome *D encloses a sensitive balance B which measures the force of attraction between the movable* disc which hangs from one of its arms and the lower plate *P*. • *The movable electrode M hangs with a* clearance of above 0.01 cm, in a central opening in the upper plate which serves as a guard ring. • Light reflected from a mirror carried by the balance beam serves to magnify its motion and to indicate to the operator at a safe distance when a condition	[4+4+2]	CO4	L2

of equilibrium is reached.

- **Principle:** 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*

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

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. Thus

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

- 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

Limitation:

- the load inductance and the measuring system capacitance form a series resonance circuit, a limit is imposed on the frequency range.
- Difficult in construction

6	Write short notes on a) Rogogowsky coil, b) Magnetic Links.	[5+5]	CO4	L2

a) Rogogowsky coil

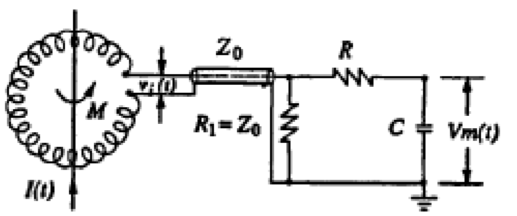
- Diagram and explanation 2 + 3 Marks

- If a coil is placed surrounding a current carrying conductor, the voltage signal induced in the coil is

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

- *Where* **M** *is the mutual inductance between the conductor* and the coil, and **I** is the current flowing in the conductor.
- Usually, the **coil is wound on a nonmagnetic former of toroidal shape** and is **coaxially placed surrounding the current carrying conducto**r.
- The **number of turns** on the coil is chosen to be **large**, to get enough signal induced.
- The coil is wound cross-wise to reduce the leakage inductance.
- Usually an integrating circuit (see Fig. 7.52) is employed to get the output signal voltage proportional to the current to be measured.
- The output voltage is given by

$$V_m(t) = \frac{1}{CR}\int_0^t v_i(t) = \frac{M}{CR} I(t)$$



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

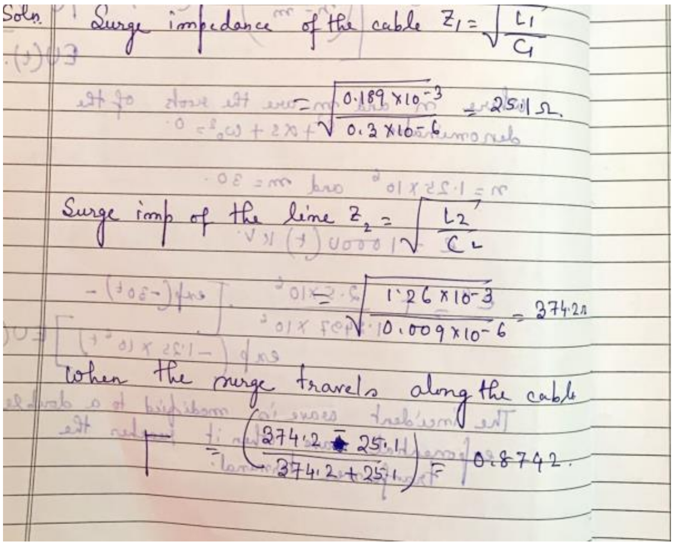
Fig. 7.52 Rogowski coil for high impulse current measurements

b) Magnetic Links

- Explanation 5 Marks

- **Remanence** or **remanent magnetization** or **residual magnetism** is the **magnetization** left behind in **a** ferromagnetic material (such as iron) after **an** external **magnetic** field is removed.
- Magnetic links are short high retentivity steel strips arranged on a circular wheel or drum.
- These strips have the property that the **remanent magnetism** for a current pulse of *0.5/5 µs is same as that caused by a d.c. current of the same value.*
- *Hence, these* can be used for measurement of peak value of impulse currents.
- The strips will be kept at a known distance from the current carrying conductor and parallel to it.
- The remanent magnetism is then measured in the laboratory from which the peak value of the current can be estimated.
- These are useful for field measurements, mainly for estimating the lightning

	currents on the transmission lines and towers. • By using a number of links, accurate measurement of the peak value, polarity, and the percentage oscillations in lightning currents can be made.			
7	An underground cable of inductance 0.189 mH/km and of capacitance 0.3 µF/km is connected to an overhead line having an inductance of 1.26 mH/km and capacitance of 0.009 µF/km. Calculate the transmitted and reflected voltage and current waves at the junction, if a surge of 200 kV travels to the junction, along the cable. • Calculation of Z1 and Z2 3 Marks • Reflection Coefficient 2 Marks • Transmitted voltage and current 2.5 Marks • Reflected voltage and current 2.5 Marks	[10]	CO5	L3


Soln. Surge impedance of the cable $Z_1 = \sqrt{\frac{L_1}{C_1}}$

$= \sqrt{\frac{0.189\times10^{-3}}{0.3\times10^{-6}}} = 25.1\,\Omega$

Surge imp of the line $Z_2 = \sqrt{\frac{L_2}{C_L}}$

$= \sqrt{\frac{1.26\times10^{-3}}{0.009\times10^{-6}}} = 374.2\,\Omega$

When the surge travels along the cable

$\Gamma = \left(\frac{374.2 - 25.1}{374.2 + 25.1}\right) = 0.8742.$

	The reflected wave $e' = \Gamma e$ $= 0.8742 \times 200$ kV $= 174.84$ kV. The transmitted wave $e'' = (1+\Gamma)e$ $= 1.8742 \times 200$ kV $= 374.84$ kV. reflected current wave $I' = \frac{e'}{Z_1} = \frac{174.84 \times 10^3}{25.1} = 6.97$ kA. The transmitted current wave, $I'' = \frac{e''}{Z_2} = \frac{374.84 \times 10^3}{374.20} = 1.002$ kA When the wave travels along the line $\Gamma = \frac{(25.1 - 374.2)}{(25.1 + 374.2)} = -0.8742$. ∴ reflected wave $- e' = \Gamma e = -174.84$ kV. The transmitted wave $e'' = (1+\Gamma)e = (1 - 0.8742) \times 200$ $= 25.16$ kV.			
8a	A generating voltmeter has to be designed so that it can have a range from 20 to 200 kV d.c. If the indicating meter reads a minimum current of 2 µA and maximum current of 25 µA, what should the capacitance of the generating voltmeter be? • Calculation of C= 3 Marks • Verification with upper current limit 2 Marks Ans. Let the angular speed of synchronous motor be = 1500 rpm. $I_{rms} = \frac{V C_m \omega}{\sqrt{2}}$ $2 \times 10^{-6} = \frac{20 \times C_m \times 1000 \times 2\pi \times 1500}{\sqrt{2} \times 60}$ $C_m = (2 \times 10^{-6} \times \sqrt{2} \times 60)/(20 \times 1000 \times 2\pi \times 1500)$ $= 9.00 \times 10^{-13}$ F. At 200 kV the current indicated will be $2 \times \frac{200}{20} = 20\,\mu A$ which is less than 25 µA. $\therefore C_m = 9.00 \times 10^{-3}$ F.	[5]	CO4	L3

8 b.	Discuss any two factors affecting the spark over voltage of sphere gap.	[5]	CO4	L2

- Each point carries 2.5 Marks

Effect of nearby earthed objects

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

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

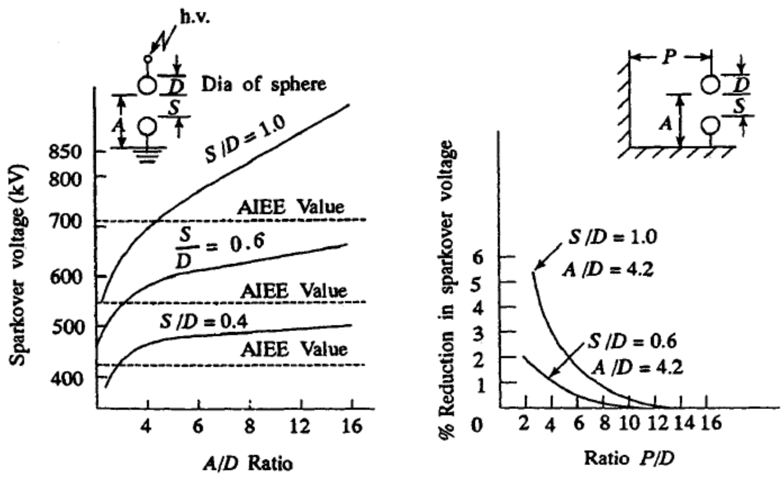
where,

$\Delta V =$ percentage reduction,

$B =$ diameter of earthed enclosing cylinder,

$D =$ diameter of the spheres,

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



(a) (b)

) **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*

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