CMR INSTITUTE OF TECHNOLOGY	USN	

Internal Assesment Test - III

Sub:	POWER SYSTEM PROTECTION							Code:	18EE72
Date:		Duration:	90 mins	Max Marks:	50	Sem:	7th(A & B)	Branch:	EEE

Answer Any FIVE FULL Questions

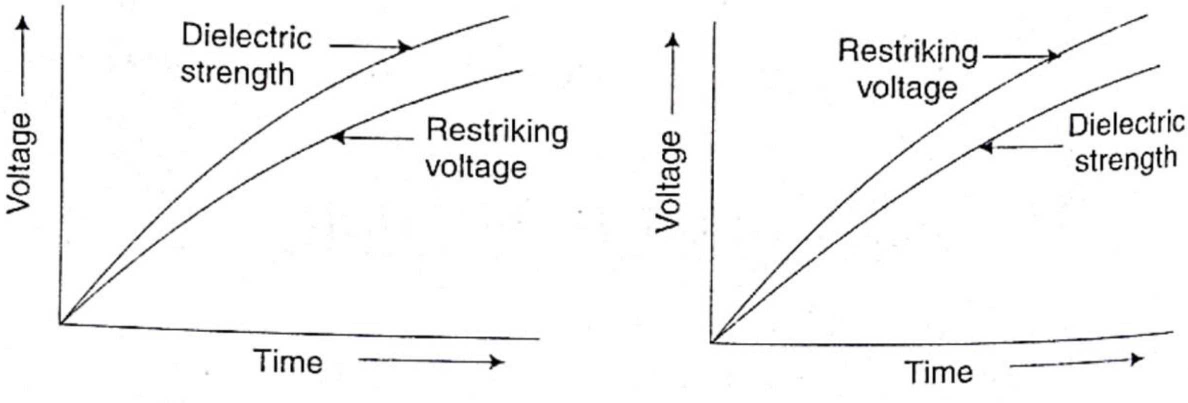
		Marks	OBE	
			CO	RBT
1a	Explain the recovery rate theory and energy balance theory of arc interruption in a circuit breaker.	[6]	CO4	L2
1b	Explain the interruption of capacitive current in the circuit breaker with a neat sketch and waveform.	[4]	CO4	L2
2a	Explain the working of axial blast circuit breaker with the help of neat sketch.	[6]	CO4	L2
2b	What are the advantages and disadvantages of SF6 circuit breaker?	[4]	CO4	L2
3a	A 132kV system, the reactance and capacitance up to the location of the circuit breaker is 3 ohms and 0.05μF, respectively. Calculate the following (a) The frequency of transient oscillation (b) The maximum value of restriking voltage across the contacts of the circuit breaker (c) The maximum value of RRRV	[6]	CO4	L3
3b	Explain the working of ‘HVDC’ circuit breaker with a schematic diagram.	[4]	CO4	L2
4	Define following terms: (a) Breaking capacity (b) Making capacity (c) Short-time capacity (d) Rated Voltage, Current & Frequency (e) Rated operating Duty	[10]	CO4	L1
5a	Explain the direct testing of circuit breaker with a neat sketch.	[6]	CO4	L3
5b	Explain the phenomenon of current chopping in a circuit breaker.	[4]	CO2	L2
6a	Explain the phenomena of lightning with the help of relevant diagrams.	[5]	CO5	L2
6b	Explain the construction and working of ‘Klydonograph’.	[5]	CO5	L2
7a	Describe the construction and working of the HRC cartridge fuse.	[5]	CO5	L2
7b	Explain the working of Expulsion type Lightning Arrester with the help of relevant diagram.	[5]	CO5	L2

Solution

Q.1.a

Recovery Rate Theory

The arc is a column of ionised gases. To extinguish the arc, the electrons and ions are to be removed from the gap immediately after the current reaches a natural zero. Ions and electrons can be removed either by recombining them into neutral molecules or by sweeping them away by inserting insulating medium (gas or liquid) into the gap. The arc is interrupted if ions are removed from the gap at a rate faster than the rate of ionisation. In this method, the rate at which the gap recovers its dielectric strength is compared with the rate at which the gap recovers its dielectric strength is compared with the rate at which the restriking voltage (transient voltage) across the gap rises. If the dielectric strength increases more rapidly than the restriking voltage, the arc is extinguished. If the restriking voltage rises more rapidly than the dielectric strength, the ionisation persists and breakdown of the gap occurs, resulting in an arc for another half cycle. Figure 14.5 explains the principle of recovery rate theory.



(a) Arc extinguishes

(b) Arc does not extinguish

Fig. 14.5 *Recovery rate theory*

Energy Balance Theory

The space between the contacts contains some ionised gas immediately after current zero and hence, it has a finite post-zero resistance. At the current zero moment, power is zero because restricking voltage is zero. When the arc is finally extinguished, the power again becomes zero, the gap is fully de-ionised and its resistance is infinitely high. In between these two limits, first the power increases, reaches a maximum value, then decreases and finally reaches zero value as shown in Fig. 14.6. Due to the rise of restriking voltage and associated current, energy is generated in the space between the contacts. The energy appears in the form of heat. The circuit breaker is designed to remove this generated heat as early as possible by cooling the gap, giving a blast of air or flow of oil at high velocity and pressure. If the rate of removal of heat is faster than the rate of heat generation the arc is extinguished. If the rate of heat generation is more than the rate of heat dissipation, the space breaks down again resulting in an arc for another half cycle.

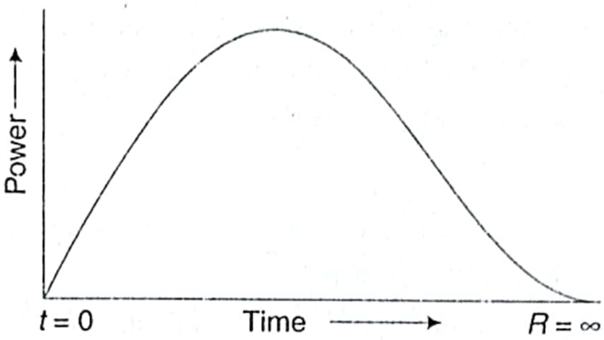
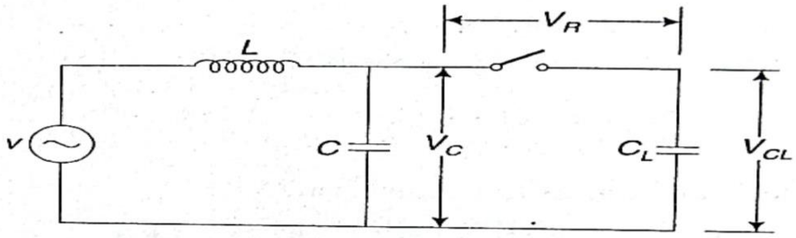
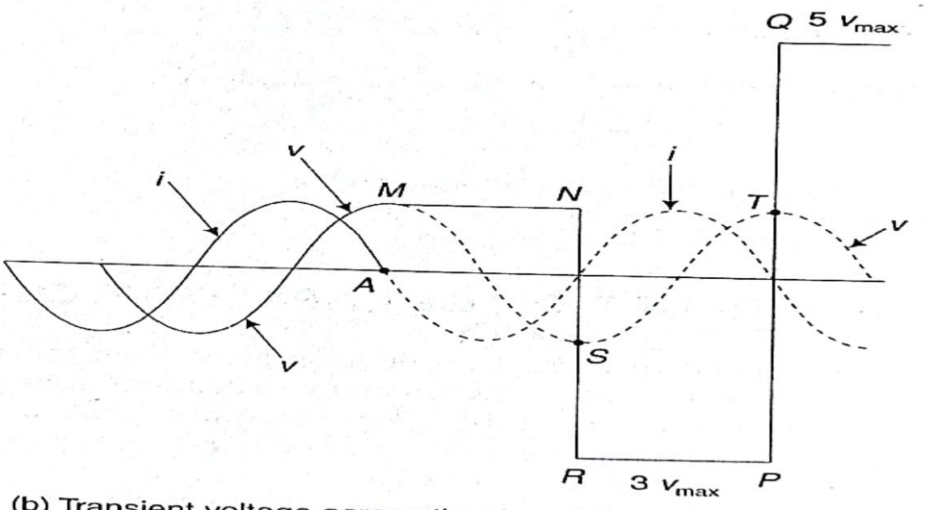


Fig. 14.6 *Energy balance theory*

Q.2.a



(a) Electrical circuit of a simple power system



(b) Transient voltage across the gap of the circuit breaker

Fig. 14.13 *Interruption of capacitive current*

Q.2.b

14.13.4 Advantages of SF_6 Circuit Breakers

(i) Low gas velocities and pressures employed in the SF_6 circuit breakers prevent current chopping and capacitive currents are interrupted without restriking.

(ii) These circuit breakers are compact, and have smaller overall dimensions and shorter contact gaps. They have less number of interrupters and require less mantenance.

(iii) Since the gas is non-inflammable, and chemically stable and the products of decomposition are not explosive, there is no danger of fire or explosion.

(iv) Since the same gas is recirculated in the circuit, the requirement of SF_6 gas is small.

(v) The operation of the circuit breaker is noiseless because there is no exhaust to atmosphere as in case of air blast circuit breakers

(vi) Because of excellent arc quenching properties of SF_6, the arcing time is very short and hence the contact erosion is less. The contacts can be run at higher temperatures without deterioration.

(vii) Because of inertness of the SF_6 gas, the contact corrosion is very small. Hence contacts do not suffer oxidation.

(viii) The sealed construction of the circuit breaker avoids the contamination by moisture, dust, sand etc. Hence the performance of the circuit breaker is not affected by the atmospheric conditions.

(ix) Tracking or insulation breakdown is eliminated, because there are no carbon deposits following an arcing inside the system.

(x) Because of the excellent insulating properties of the SF_6, contact gap is drastically reduced.

(xi) As these circuit breakers are totally enclosed and sealed from atmosphere, they are particularly suitable for use in such environments where explosion hazards exist.

14.13.5 Disadvantages of SF_6 Circuit Breakers

(i) Problems of perfect sealing. There may be leakage of SF_6 gas because of imperfect joints.

(ii) SF_6 gas is suffocating to some extent. In case of leakage in the breaker tank, SF_6 gas may lead to suffocation of the operating personnel.

(iii) Arced SF_6 gas is poisonous and should not be inhaled or let out.

(iv) Influx of moisture in the breaker is very harmful to SF_6 circuit breaker. There are several cases of failures because of it.

(v) There is necessity of mechanism of higher energy level for puffer-types SF_6 circuit breakers. Lower speeds due to friction, misalignment can cause failure of the breaker.

(vi) Internal parts should be cleaned thoroughly during periodic maintenance under clean and dry environment.

(vii) Special facilities are required for transporting the gas, transferring the gas and maintaining the quality of the gas. The performance and reliability of the SF_6 circuit breaker is affected due to deterioration of quality of the gas.

Q.3.a

a) frequency of transient oscillation

$$L = \frac{R}{2\pi f}$$

$$L = \frac{3}{2\pi \times 50} = 0.00954 H.$$

$$f_n = \frac{1}{2\pi\sqrt{LC}} = 7.290 kHz$$

b) The restriking voltage

$$V_C = E[1 - \cos\omega_n t]$$

The maximum voltage is

$= 2$ peak

$$= 2 \times \frac{132}{\sqrt{3}} \times \sqrt{2} = 215.55 kV$$

c) The maximum value of RRRV

$= \omega_n E_{peak}$

$= 2\pi f_n \times E_{peak}$

$= 4.93418 kV/\mu s.$

Q.3.b

Fig. 14.27 *Artificial current zeros in dc*

Figure 14.28 shows the schematic diagram of a HVDC circuit breaker. It consists of a main circuit breaker MCB and a circuit to produce artificial current zero and to suppress transient voltage. The main circuit breaker MCB may either be an SF_6 or vacuum circuit breaker. R and C are connected in parallel with the main circuit breaker to reduce dv/dt after the final current zero. L is a saturable reactor in series with the main circuit breaker. It is used to reduce dI/dt before current zero. C_p and L_p are connected in parallel to produce artificial current zero after the separation of the contacts in the main circuit breaker MCB. A non-linear resistor is used to suppress the transient overvoltage which may be produced across the contacts of the main circuit breaker.

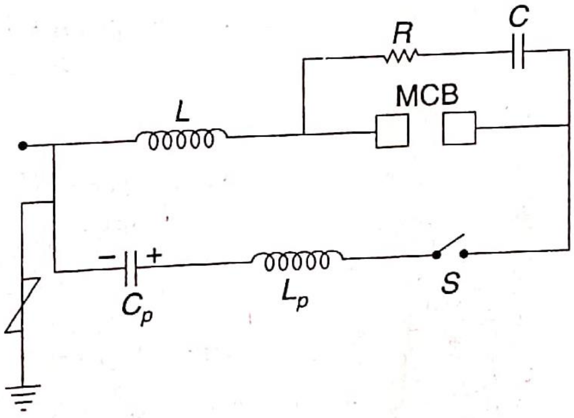


Fig. 14.28 *HVDC circuit breaker*

Switch S, which is a triggered vacuum gap, is switched immediately after the opening of the contacts of the main circuit breaker. The capacitor C_p is precharged in the direction as shown in the figure. When S is closed, the precharged capacitor C_p discharges through the main circuit breaker and sends a current in opposition to the main circuit current. This will force the main circuit current to become zero with a few oscillations. The arc is interrupted at a current zero.

Q.4

a.

14.18.1 Breaking Capacity

The breaking capacity of a circuit breaker is of two types.

(i) Symmetrical breaking capacity
(ii) Asymmetrical breaking capacity

Symmetrical Breaking Capacity

It is the rms value of the ac component of the fault current that the circuit breaker is capable of breaking under specified conditions of recovery voltage.

Asymmetrical Breaking Capacity

It is the rms value of the total current comprising of both ac and dc components of the fault current that the circuit breaker can break under specified conditions of recovery voltage.

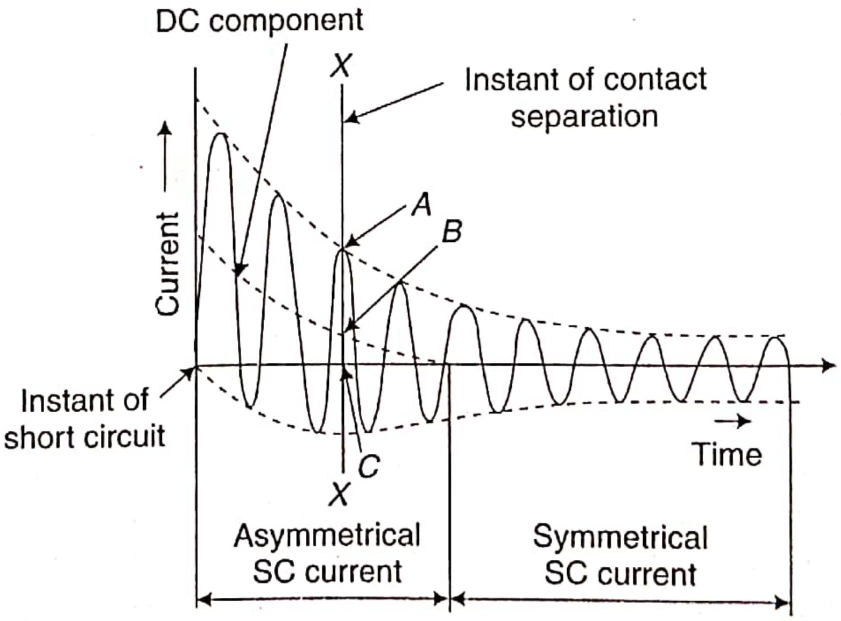


Fig. 14.29 *Short-circuit current waveform*

b.

14.18.2 Making Capacity

The possiblity of a circuit breaker to be closed on short-circuit is also considered. The rated making current is defined as the peak value of the current (including the dc component) in the first cycle at which a circuit breaker can be closed onto a short-circuit. I_p in Fig. 14.29 is the making current. The capacity of a circuit breaker to be closed onto a short-circuit depends upon its ability to withstand the effects of electromagnetic forces.

$$\text{Making current} = \sqrt{2} \times 1.8 \times \text{symmetrical breaking current.}$$

The multiplication by $\sqrt{2}$ is to obtain the peak value and again by 1.8 to take the dc component into account.

$$\begin{aligned}\text{Making capacity} &= \sqrt{2} \times 1.8 \times \text{symmetrical breaking capacity}\\ &= 2.55 \times \text{symmetrical breaking capacity.}\end{aligned}$$

c.

14.18.3 Short-time Current Rating

The short-time current rating is based on thermal and mechanical limitations. The circuit breaker must be capable of carrying short-circuit current for a short period while another circuit breaker (in series) is clearing the fault. The rated short-time current is the rms value (total current, both ac and dc components) of the current that the circuit breaker can carry safely for a specified short period. According to British standard, the time is 3 seconds if the ratio of symmetrical breaking current to rated normal current is equal to or less than 40 and 1 second if this ratio is more than 40. According to ASA there are two short-time ratings, one is the current which the circuit breaker can withstand for 1 second or less. Another is rated 4-second current which is the current that the circuit breaker can withstand for a period longer than 1 second but not more than 4 seconds.

d.

14.18.4 Rated Voltage, Current and Frequency

In a power system, the voltage level at all points is not the same. It varies, depending upon the system operating conditions. Due to this reason manufacturers have specified a rated maximum voltage at which the operation of the circuit breaker is guaranteed. The specified voltage is somewhat higher than the rated nominal voltage.

The rated current is the rms value of the current that a circuit breaker can carry continuously without any temperature rise in excess of its specified limit.

The rated frequency is also mentioned by the manufacture. It is the frequency at which the circuit breaker has been designed to operate. The standard frequency is 50 Hz. If a circuit breaker is to be used at a frequency other than its rated frequency, its effects should be taken into consideration.

e.

14.18.5 Rated Operating Duty

The operating duty of a circuit breaker prescribes its operations which can be performed at stated time intervals. For the circuit breakers which are not meant for autoreclosing, there are two alternative operating duties as given below:

(i) $O - t - CO - t' - CO$

(ii) $O - t'' - CO$

where O denotes opening operation, CO denotes closing operation followed by opening without any intentional time lag, and t, t' and t'' are time intervals between successive operations. According to IEC, the value of t and t' is 3 minutes and t'' is 15 seconds.

For circuit breakers with auto-reclosing, the operating duty is as follows.

$O - Dt - CO$, where Dt is the dead time of the circuit breaker, which is expressed in cycle.

According to B.S.S. there is only one operating duty for the circuit breakers not intended for auto-reclosing. It is written as follows.

$B - 3 - MB - 3 - MB$, where B denotes breaking and MB denotes making followed by breaking without any intentional time delay. Three is the time interval in minutes.

For circuit breakers with auto-reclosing, the operating duty is written as

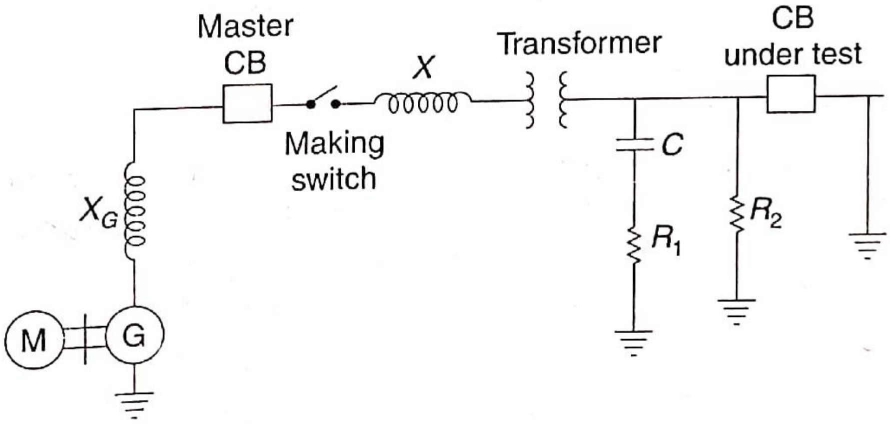
$$B - Dt - MB$$

Dt is the dead time and it is expressed in cycles.

Q.5.a.

14.19.3 Direct Testing

In direct testing, the circuit breaker is tested under the conditions which actually exist on power systems. It is subjected to restriking voltage which is expected in practical situations. Figure 14.30 shows an arrangement for direct testing. The reactor X is to control short-circuit current. C, R_1 and R_2 are to adjust transient restriking voltage. Short-circuit tests to be performed are as follows.



Q.5.b

14.7 CURRENT CHOPPING

When low inductive current is being interrupted and the arc quenching force of the circuit breaker is more than necessary to interrupt a low magnitude of current, the current will be interrupted before its natural zero instant. In such a situation, the energy stored in the magnetic field appears in the form of high voltage across the stray capacitance, which will cause restriking of the arc. The energy stored in the magnetic field is ½ $L\,i^2$, if i is the instantaneous value of the current which is interrupted. This will appear in the form of electrostatic energy equal to ½ Cv^2. As these two energies are equal, they can be related as follows.

$$\frac{1}{2}Li^2 = \frac{1}{2}Cv^2$$

$$\therefore \qquad v = i\sqrt{L/C} \qquad (14.19)$$

Figure 14.12 shows the current chopping phenomenon. If the value of v is more than the withstanding capacity of the gap between the contacts, the arc appears again. Since the quenching force is more, the current is again chopped. This phenomenon continues till the value of v becomes less than the withstanding capacity of the gap. The theoretical value of v is called the prospective value of the voltage.

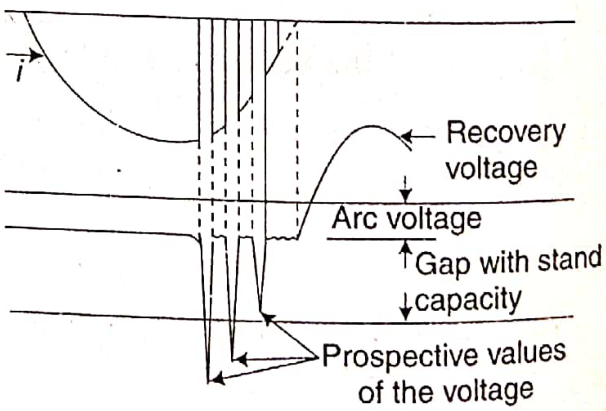


Fig. 14.12 *Current chopping*

Q.6.a

16.2 LIGHTNING PHENOMENA

The discharge of the charged cloud to the ground is called lightning phenomenon. A lightning discharge through air occurs when a cloud is raised to such a high potential with respect to the ground (or to a nearby cloud) that the air breaks down and the insulating property of the surrounding air is destroyed. This raising of potential is caused by frictional effects due to atmospheric disturbances (e.g., thunderstorms) acting on the particles forming the cloud. The cloud and the ground form two plates of a gigantic capacitor whose dielectric medium is air. During thunderstorms, positive and negative charges are separated by the movement of air currents forming ice crystals in the upper layer of cloud and rain in the lower part. The cloud becomes negatively charged and has a larger layer of positive charge at its top. As the separation of charge proceeds in the cloud, the potential difference between concentrations of charges increases and the vertical electric field along the cloud also increases. The total potential difference between the two

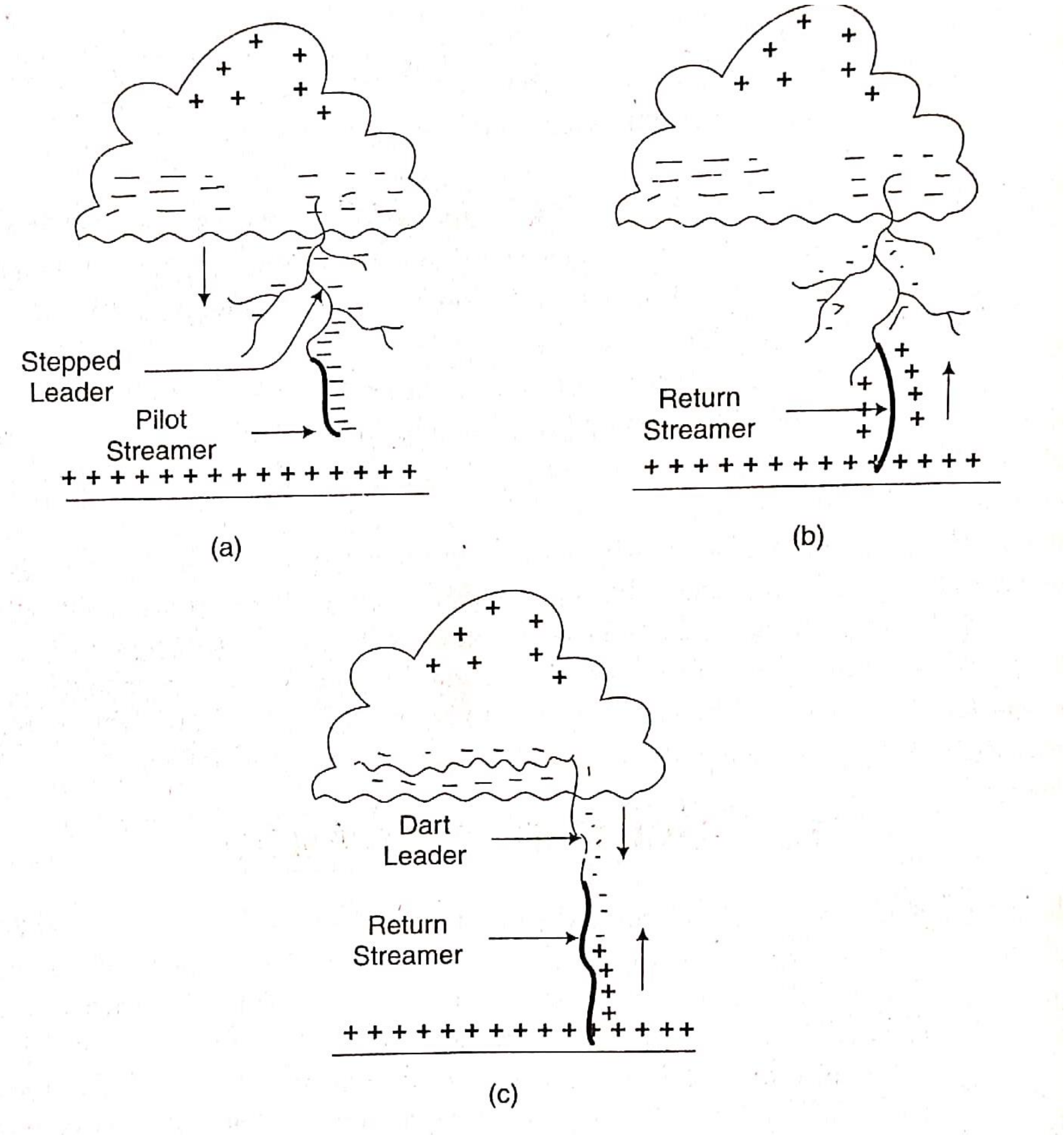


Fig. 16.1 *Lightning mechanism*

- The lightning is initiated with a flow of electrons from the base of the cloud towards the ground (stepped leader)
- When the leader gets close to the ground a flow of positive charges surges upwards.
- When they meet a strong current (return stroke) transfers a charge between the cloud and the ground.
- The process can be repeated several times in the same channel (dart leader, return stroke…)

Q.6.b

16.5.1 Klydonograph

The klydonograph is an instrument for the measurement of surge voltage on transmission lines caused by lightning. It measures voltage by means of Lichtenberg figures, when suitably coupled to the line whose surge voltage is to be measured. The klydonograph contains a rounded electrode connected to the line whose surge voltage is to be measured. The electrode rests on the emulsion side of a photographic film or plate, which in turn rests on the smooth surface of an insulating plate made of homogeneous insulating material, backed by a metal plate electrode as shown in Fig. 16.4.

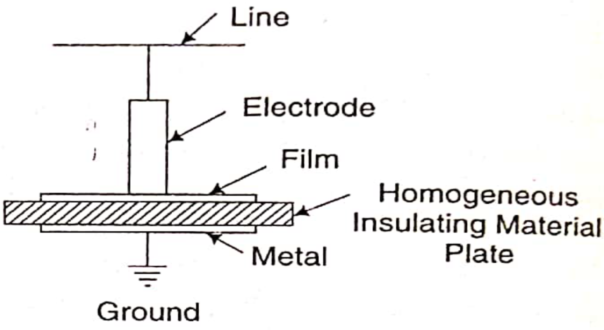


Fig. 16.4 *Klydonograph*

The photographic plate or the film is turned or moved by a clockwork mechanism for bringing in the element of time. Three assemblies are generally placed in the same box, for simultaneously measuring the voltages on the three phases of a transmission line.

With this arrangement, a positive Lichtenberg figure is produced by a positive surge, and a negative Lichtenberg figure by a negative surge, as illustrated in Fig.16.5. Positive Lichtenberg figures are found to be superior to the negative ones for voltage measurement purpose, since they are much larger than the negative figures for the same voltage, as shown in Fig. 16.5. Diameter of positive Lichtenberg figure is a

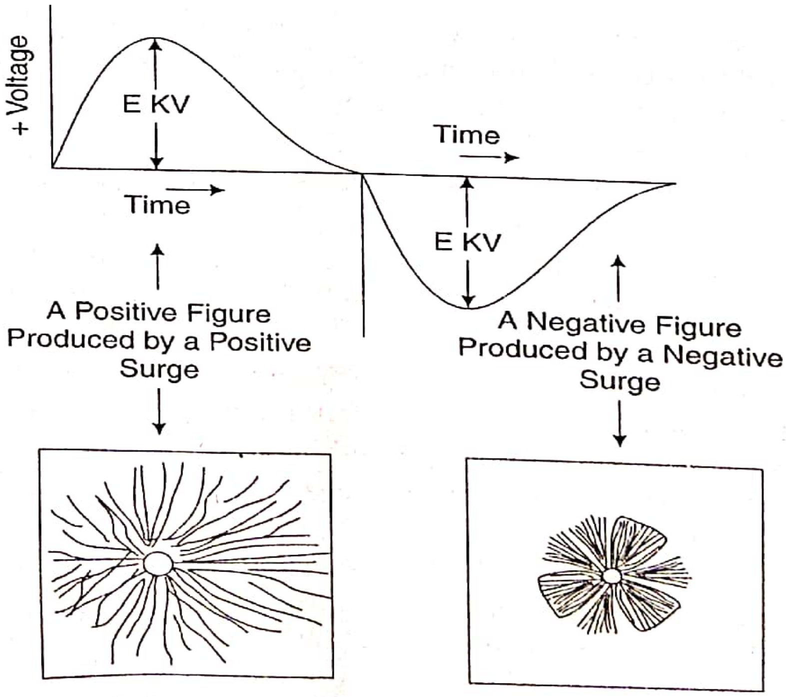


Fig. 16.5 *Positive and negative Lichtenberg figures produces by positive and negative surge voltages of same magnitude and wave shape*

Q.7.a

15·4·4 High Rupturing Capacity (HRC) Cartridge Fuse

The HRC fuses cope with increasing rupturing capacity on the distribution system and overcome the serious disadvantages suffered by the semi-enclosed rewirable fuses.

In an HRC fuse, the fuse element surrounded by an inert arc quenching medium is completely enclosed in an outer body of ceramic material having good mechanical strength. The unit in which the fuse element is enclosed is called 'fuse link'. The fuse link is replaced when it blows off. In its simplest form (Fig. 15.5), an HRC fuse consists of a cylindrical body of ceramic material usually steatite, pure silver (or bimetalic) element, pure quartz powder, brass end-caps and copper contact blades. The fuse element is fitted inside the ceramic body and the space within the body surrounding the clement is completely filled with pure powdered quartz. The ends of the fuse element arc connected to the metal end-caps which are screwed to the ceramic body by means of special forged screws. End contacts (contact blades) are welded to the metal end-caps. The contact blades arc bolted on the stationary contacts on the panel.

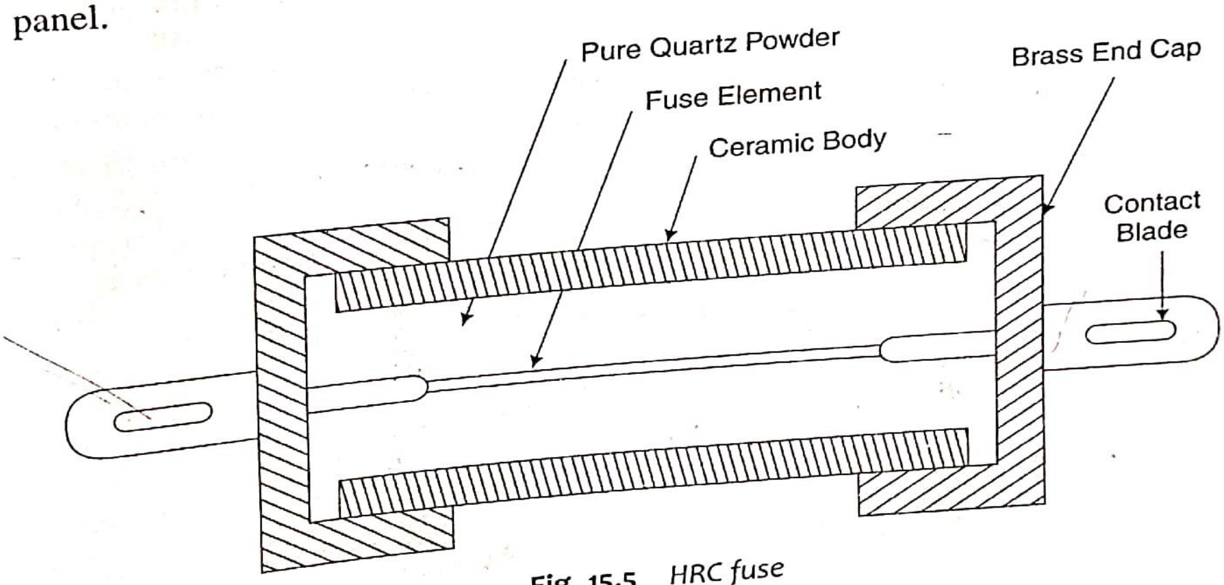


Fig. 15·5 *HRC fuse*

The fuse element is either pure silver or bimetalic in nature. Normally, the fuse element has two or more sections joined together by means of a tin joint. The fuse element in the form of a long cylindrical wire is not used, because after melting, it will form a string of droplets and an arc will be struck between each of the droplets. Later on these droplets will also evaporate and a long arc will be struck. The purpose of the tin joint is to prevent the formation of a long arc. As the melting point of tin is much lower than that of silver, tin will melt first under fault condition and the melting of tin will prevent silver from attaining a high temperature. The shape of the fuse element depends upon the characteristic desired.

Q7.b

(i) Expulsion type lightning arrester

This type of arrester is also known as Expulsion Gap or Protector Tube. It consists of a fibre tube with an electrode at each end. The lower electrode is solidly grounded. The upper electrode forms a series gap with the line conductor, as shown in Fig. 16.16. When a surge appears on the conductor, the series gap breaks down, resulting in formation of arc in the fibre tube between the two electrodes. The heat of the arc vaporises some of the fibre of the tube walls resulting in the generation of an inert gas. This gas is expelled violently through the arc so that arc is extinguished and the power frequency current is prevented from flowing after the surge discharge.

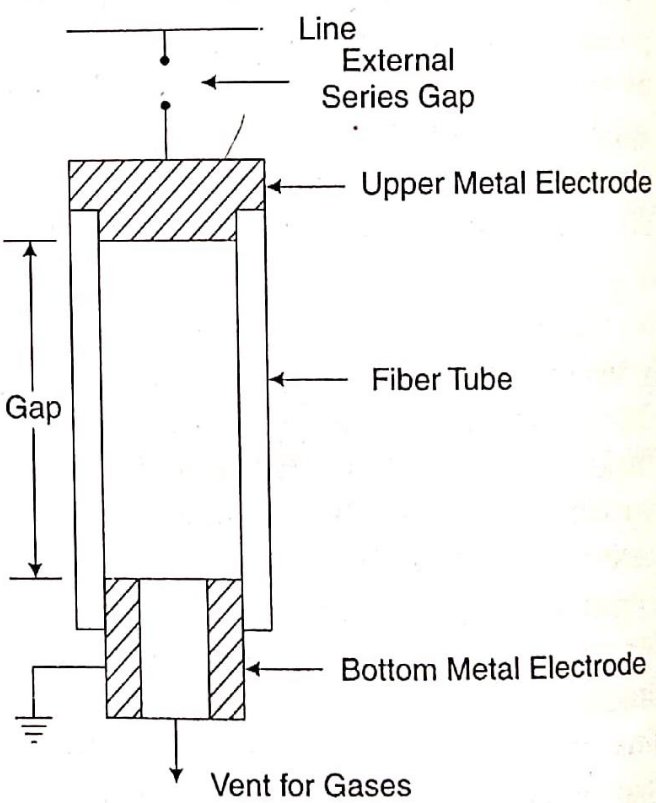


Fig. 16.16 *Expulsion type lightning arrester*