CBCS SCHEME

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18EE72

Seventh Semester B.E. Degree Examination, Jan./Feb. 2023
Power System Protection

Time: 3 hrs. Max. Marks: 100

Note: ***Answer any FIVE full questions, choosing ONE full question from each module.***

Module-1

1 a. Explain various zones of protection of a power system with the help of schematic diagram. **(06 Marks)**

b. Explain various methods of backup protection. **(06 Marks)**

c. Derive an expression for torque produced by an induction relay. **(08 Marks)**

OR

2 a. Give the comparison of electromagnetic relays and Numerical relays. **(05 Marks)**

b. Explain the operation of induction cup type relay with the help of neat diagram. **(07 Marks)**

c. Explain the various time – current characteristics of over current relays. **(08 Marks)**

Module-2

3 a. Give notes on protection of parallel feeders. **(05 Marks)**

b. Explain the working of static impedance relay using Amplitude and phase comparator with the help of relevant diagram. **(08 Marks)**

c. Explain the working of directional Earth fault Relay with the help of neat diagram. **(07 Marks)**

OR

4 a. Fig Q4(a), show distance protection for a section of power system. The I zone setting at A and B is 150Ω.

i) What will be impedance seen by the relay at A for a fault at F_1? Will the relay at A operate before the circuit breaker at B has tripped?

ii) Will the relay at B trip for a fault at F_1 before the circuit breaker at A has tripped?

iii) If the circuit breaker C_2 fails for a fault at F_2, will the fault be cleared by relays at A and B?

iv) How will the fault at F_2 be cleared?

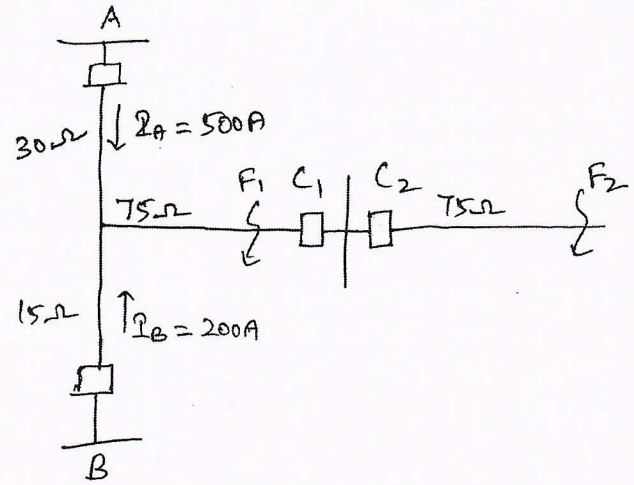

Fig Q4(a) **(08 Marks)**

Important Note : 1. On completing your answers, compulsorily draw diagonal cross lines on the remaining blank pages.
2. Any revealing of identification, appeal to evaluator and /or equations written eg, 42+8 = 50, will be treated as malpractice.

b. Write a notes on Reach of a Distance Relays. (04 Marks)

c. Explain in detail with the help of block diagram
   i) Static definite time overcurrent Relay
   ii) Static Inverse – time overcurrent relay (08 Marks)

Module-3

5 a. What are the different operating schemes used in wire pilot protection? Explain in detail about circulating current scheme and opposed voltage scheme. (08 Marks)

b. Explain the working of Buchholz's relay with the help of neat diagram. (05 Marks)

c. An 11kV, 100MVA alternator is grounded through a resistance of 5Ω. The C.T.S have a ratio 1000/5. The relay is set to operate when there is an out of balance current of 1A. What percentage of the generator winding will be protected by the percentage differential scheme of protection? (07 Marks)

OR

6 a. Write a note on :
   i) Stator – overheating protection of Generators.
   ii) Protection of Transformer against magnetizing inrush current. (08 Marks)

b. Explain the working of biased (or) percentage differential relay with the help of neat schematic diagram and Derive its operating condition. (08 Marks)

c. Give notes on Frame leakage protection. (04 Marks)

Module-4

7 a. Define: i) Restriking voltage ii) Recovery voltage.
Derive the expression for Restriking voltage and Rate of Rise of Ristriking Voltage (RRRV). (10 Marks)

b. With the help of neat diagram, explain the working of cross – blast and Axial-blast circuit breakers. (10 Marks)

OR

8 a. Write notes on :
   i) Recovery rate theory
   ii) Energy balance theory of arc interruption in a circuit breaker. (10 Marks)

b. With a neat circuit diagram, explain the synthetic testing of a circuit breaker. (06 Marks)

c. Describe the current chopping phenomenon in a circuit breaker. (04 Marks)

Module-5

9 a. What are the components of CRS? Briefly describe their functions. (08 Marks)

b. Explain the construction and working of HRC cartridge fuse. (06 Marks)

c. With a neat diagram, explain the construction and working of 'klydonograph'. (06 Marks)

OR

10 a. Explain the lighting phenomena with the help of relevant diagrams. (08 Marks)

b. With the help of neat diagram, explain the working of Rod gap and Arcing horn to protect against Travelling waves. (08 Marks)

c. Define : i) Fuse ii) Fusing factor. (04 Marks)

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Solution of VTU Question Paper Jan/Feb-2023

Power System Protection [18EE72]

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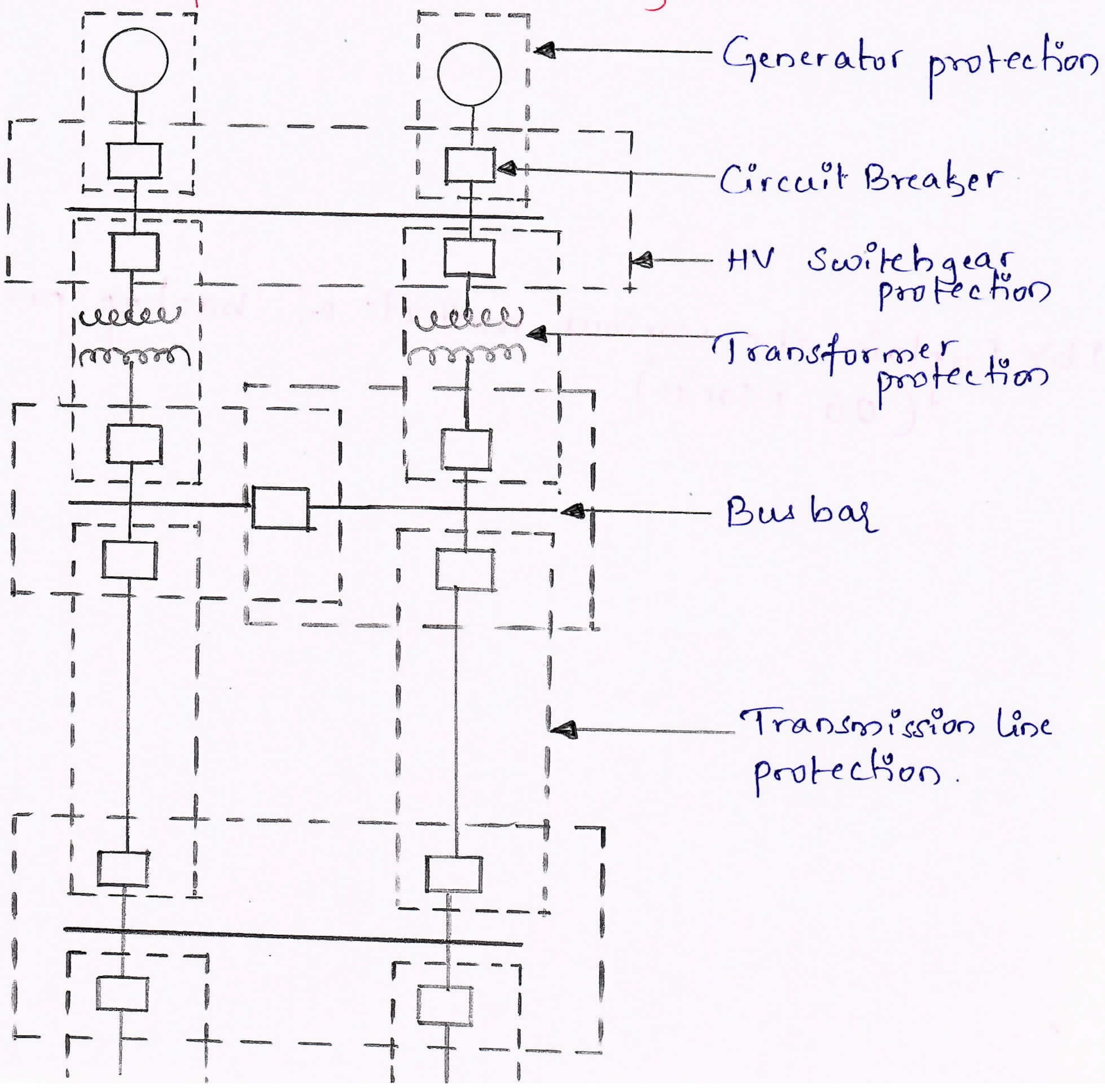
Module-01

1. a) Explain various zones of protection of power system with the help of schematic diagram. (06 Marks)



A power system contains generators, transformers, busbar, transmission & distribution lines etc., There is a separate protective scheme for each piece of equipment of power system such as generator protection, transformer protection, transmission line protection etc., The power system is divided into no. of zones of protection. The protective zones are planned in such a way that the entire power system is collectively covered by them & no part of the power system is left unprotected.

Adjacent protective zones must overlap each other, failing which a fault on boundry of a zone may not lie in any of the zones and hence no circuit breaker would trip. Thus overlapping between adjacent zones is unavoidable. If a fault occurs in the overlapping zone in a properly protected scheme, more circuit breakers than the minimum necessary to isolate the faulty element of the system would trip.

1b) Explain the various methods of backup protection. (06 Marks)

There are 3 types of backup protection.

1) Remote backup :

When backup relays are located at a neighbouring station, they backup the entire primary protective scheme which includes relays, CB, CT, PT & other elements. It is the cheapest and simplest form of back-up protection & widely used scheme for transmission lines.

2) Relay backup :

This is kind of local backup in which additional relay is provided for backup protection. It trips the same CB if primary relay fails & this operation takes place without delay. Though such backup is costly, it can be recommended where a remote backup is not possible. They should be supplied from separate CT and PT's.

3) Breaker Backup :

This type of backup is necessary for a busbar system where a no. of CB are connected to it. When a protective relay operates in response to a fault but CB fails to trip, the fault is treated as Busbar fault. In such situation it becomes necessary that all other CB on that busbar should trip. After a time delay the main relay closes the contact of the backup relay which trips all other CB on the bus if the proper breaker does not trip within a specified time after its trip coil is energized.

1 c) Derive an expression for torque produced by an induction relay. (08 marks)

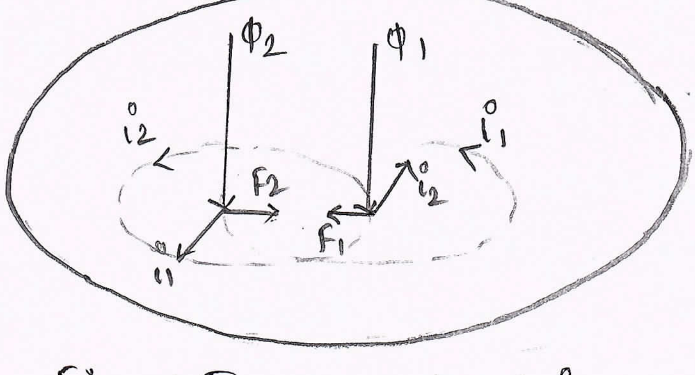


Fig 1: Torque produced in an induction relay.

Fig. 1 shows how force is produced in a rotor which is cut by ϕ_1 & ϕ_2 which are alternating quantities & can be expressed as follows.

$\phi_1 = \phi_{1m} \sin \omega t$ $\qquad$ $\phi_2 = \phi_{2m} \sin(\omega t + \theta)$

Voltages induced in the rotor are,

$$e_1 \propto \frac{d\phi_1}{dt} \propto \phi_{1m} \cdot \cos \omega t$$

$$e_2 \propto \frac{d\phi_2}{dt} \propto \phi_{2m} \cos(\omega t + \theta)$$

It is assumed that the eddy currents in the rotor are in phase with their voltages.

$$i_1 \propto \phi_{1m} \cos \omega t$$

$$i_2 \propto \phi_{2m} \cos(\omega t + \theta)$$

The forces produced are,

$$F_1 \propto \phi_1 i_2$$

$$\propto \phi_{1m} \sin \omega t \cdot \phi_{2m} \cos(\omega t + \theta)$$

$$\propto \phi_{1m} \phi_{2m} \cos(\omega t + \theta) \cdot \sin \omega t$$

$$F_2 \propto \phi_2 i_1$$

$$\propto \phi_{2m} \sin(\omega t + \theta) \cdot \phi_{1m} \cos \omega t$$

$$\propto \phi_{1m} \phi_{2m} \sin(\omega t + \theta) \cdot \cos \omega t$$

As these forces are in opposition, the resultant force is, $F = F_2 - F_1$

$$F \propto \phi_{1m} \phi_{2m} [\sin(\omega t + \theta) \cos \omega t - \cos(\omega t + \theta) \cdot \sin \omega t]$$

$$\propto \phi_{1m} \phi_{2m} \sin \theta.$$

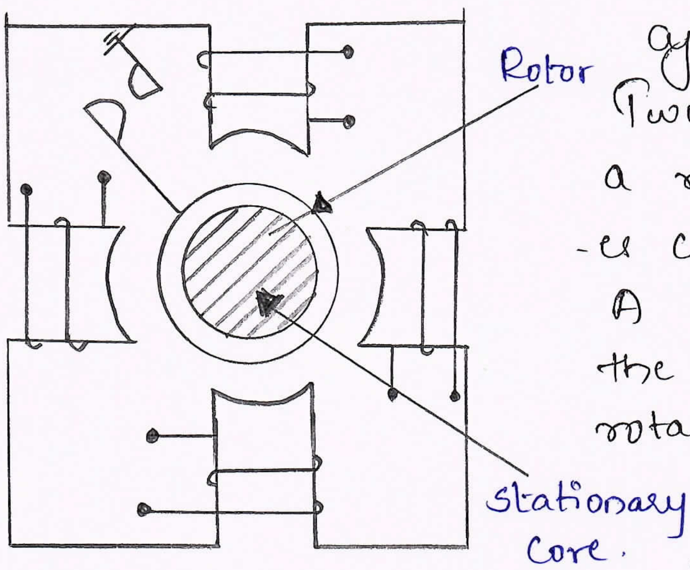
$$\therefore \quad F = K \phi_1 \phi_2 \sin \theta.$$

If the same current produces ϕ_1 & ϕ_2 the force produced is $F = K I^2 \sin \theta$

2 a) Give the comparison of electromagnetic relays & numerical relays. (05 marks)

	Feature	Electromechanical Relay.	Numerical Relay.
1.	Size	Bigger	Compact
2.	Characteristics	Fixed	Selectable
3.	Flexibility	No flexibility	Flexibility due to programmabilit
4.	Accuracy	±5% or more	±2%
5.	Speed of operation	Slow	Fast.

2 b) Explain the operation of induction cup type relay with the help of neat diagram. (07 marks)



The rotor is a hollow cylinder (inverted cup). Two pairs of coils, produce a rotating field which induces current in the rotor. A torque is produced due to the interaction between the rotating flux & the induced current, which causes rotation.

The magnetic system is more efficient & hence magnetic leakage in the magnetic circuit is minimum. This type of magnetic system also reduces the resistance of the induced current path in the rotor.

Due to low weight of the rotor & efficient magnetic system its torque per VA is about three times that of an induction disc type construction. It possesses high sensitivity, high speed & produces a steady non-vibrating torque. Its operating time is of the order of 0.01 sec. Thus with its high torque/inertia ratio, it is suitable for higher speeds of operation.

Q2c) Explain the various time-current characteristics of over current relays. (08 Marks)

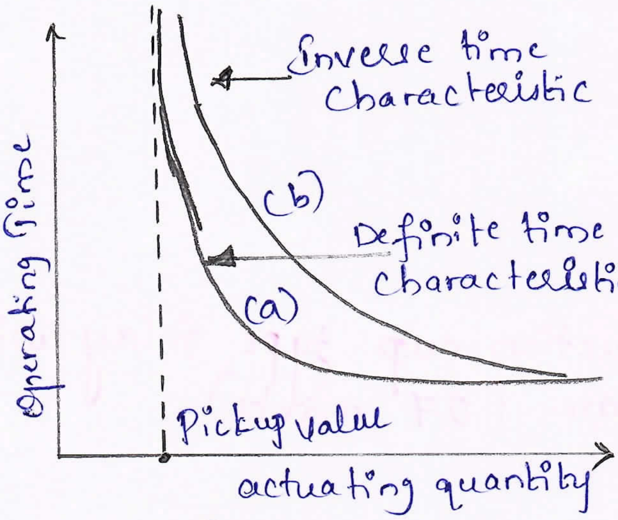


Fig. 1

1) Definite-time OC relay.

This relay operates after a predetermined time when the current exceeds its pickup value. In curve (a) of fig 1, the operating time is constant, irrespective of the magnitude of the current above the pickup value. The desired definite operating time can be set with the help of an intentional time delay mechanism provided in the relaying unit.

2) Instantaneous OC relay.

An instantaneous relay operates in a definite time when the current exceeds its pick-up value. The operating time is constant irrespective of magnitude of the current as shown in fig. 1 curve (a). There is no intentional time delay. It operates in 0.1 sec or less.

3) Inverse - time over - current relay.

It operates when the current exceeds its pick-up value. The operating time depends on the magnitude of the operating current. The operating time decreases as the current increases as shown in Fig 1. curve (b)

4) Inverse Definite Minimum Time Overcurrent (IDMT) Relay:

This type of a relay gives an inverse - time current characteristics at lower values of fault current & definite time - current characteristic at higher values of the fault current as shown in Fig 2. IDMT relays are widely used for the protection of distribution lines.

5) Very Inverse - time OC relay.

Its time current characteristics lies between an IDMT & extremely inverse characteristic as shown in Fig. 2. Its recommended standard time - current characteristic is $t = 13.5/(I-1)$

The general expression is given by $t = \frac{K}{I^n - 1}$

where value of 'n' lies between 1.02 & 2.

These are particularly effective with ground faults because of their steep characteristic.

6) Extremely Inverse - time OC relay:

The electromechanical relay which gives the steepest time - current characteristic is an extremely inverse relay. These are very suitable for protection of machines against overheating.

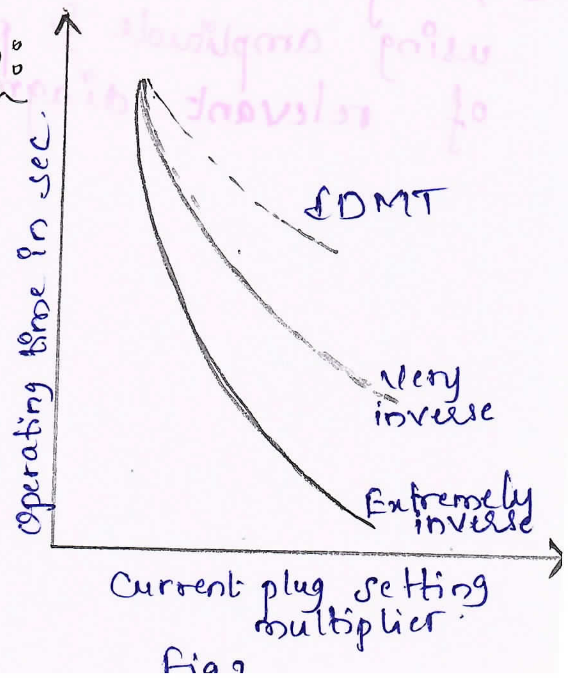
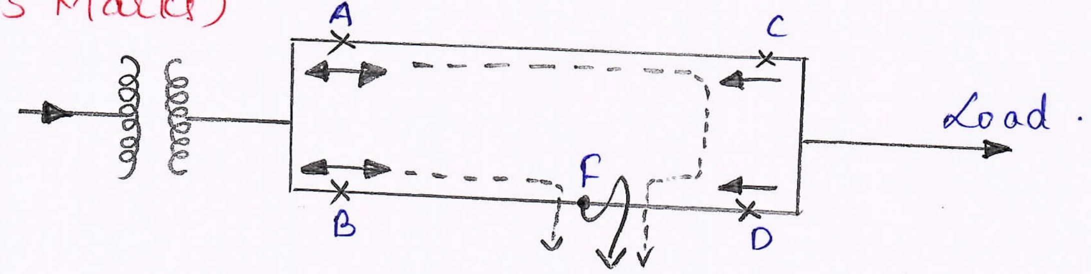


Fig 2

Module - 02

3a) Give a notes on protection of parallel feeders. (05 Marks)



Above figure shows an overcurrent protective scheme for parallel feeders. At the sending end of feeder A & B non-directional relays (⟷) & at the other end of feeder C & D directional relays (⟵) are used. If fault occurs at F, the directional relay at D trips as the direction of current is reversed. The relay at C does not trip as the current flows in the normal direction. The relay at B trips for faults at F. Thus the faulty feeder is isolated & supply of healthy feeder is maintained.

3b) Explain the working of static impedance relay using amplitude & phase comparator with the help of relevant diagram. (08 Marks)

Static impedance relay using an amplitude comparator:

Rectifier bridge comparator is used to realise an impedance relay characteristic. Since it is an amplitude comparator I is compared with V. I is operating quantity & V is restraining quantity. As the bridge is current comparator, it is supplied with operating current I_o & restraining current I_r

as shown in fig 1. I_0 is proportional to load current I & I_r is proportional to system voltage V.

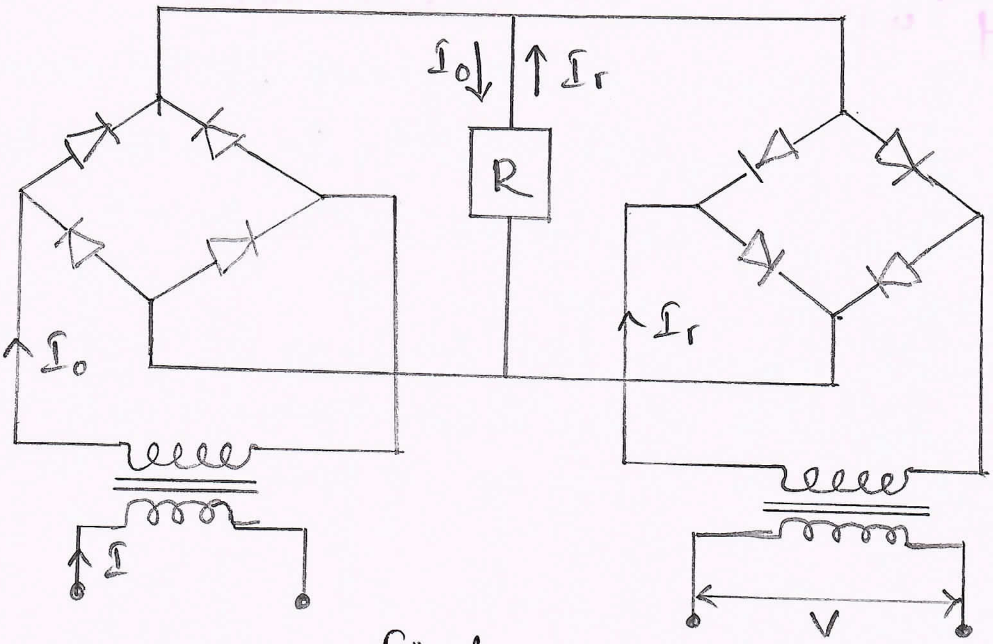


fig. 1.

Static impedance Relay using phase comparator.

An impedance relay characteristic can be realised using phase comparator. The radius of the circle Z_r. Fig. 2(a) shows phasor diagram showing V, I, IR_r, IX_r & IZ_r. In this diagram I has been taken as the reference. Resultant phasor is shown in fig 2(b)

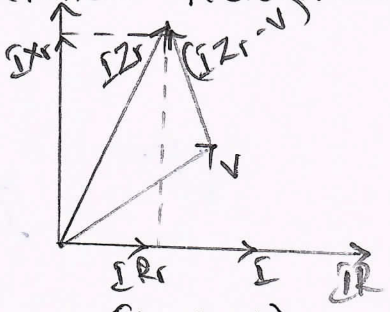


Fig 2(a)

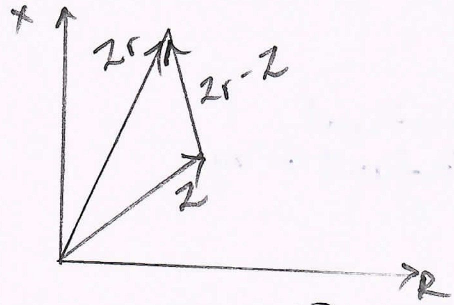


Fig 2(b)

In fig 3, a circle with radius Z_r is drawn. NM is diameter of circle. The angle between $(Z_r + Z)$ & $(Z_r - Z)$ is θ. If point P lies within the circle, θ is less than 90°. If P falls outside the circle θ is greater than 90°.

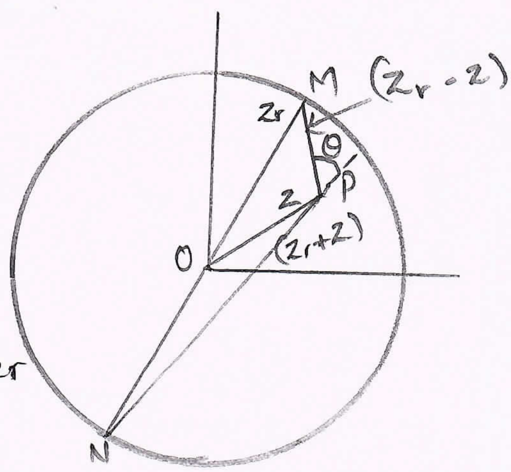


Fig. 3

To realise an impedance relay characteristic, phase angle θ is compared with ±90°. If θ is less than ±90°, the point lies within the characteristic circle.

3c) Explain the working of directional earth fault relay with the help of neat diagram (07 Marks)

For the protection against ground faults, directional overcurrent relay is required. It contains two elements, a directional element & an IDMT element.

The directional element has two coils, one coil is energized by current & the other by voltage. The current coil is energised by residual current & potential coil by residual voltage as shown in below figure (a)

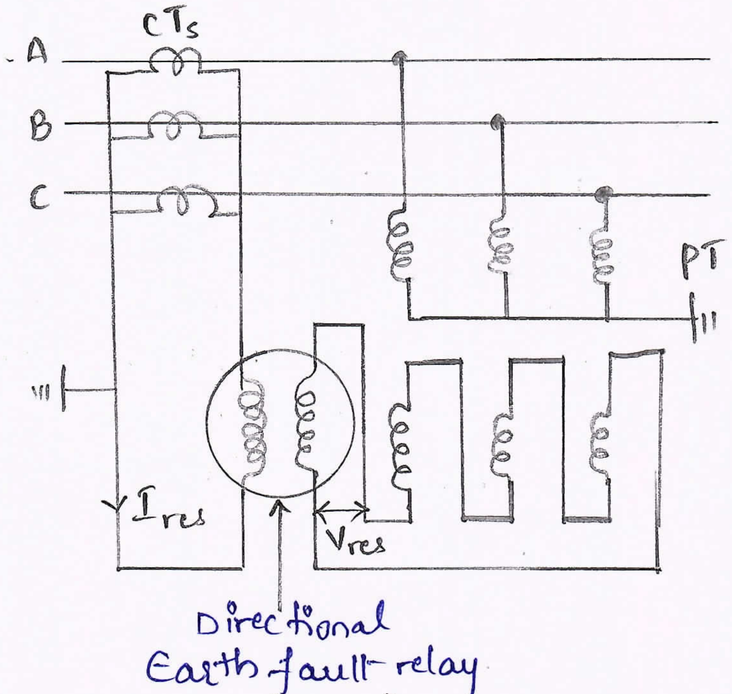


Fig (a)

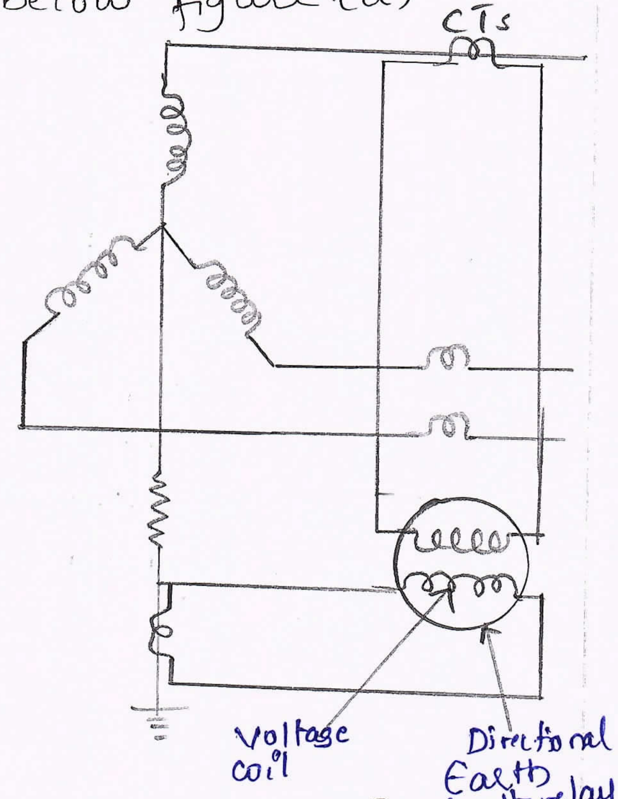


Fig (b)

If the neutral of an alternator or transformer is grounded, connections are made as shown in fig b.
The IDMT element has plug setting of 20% to 80%.

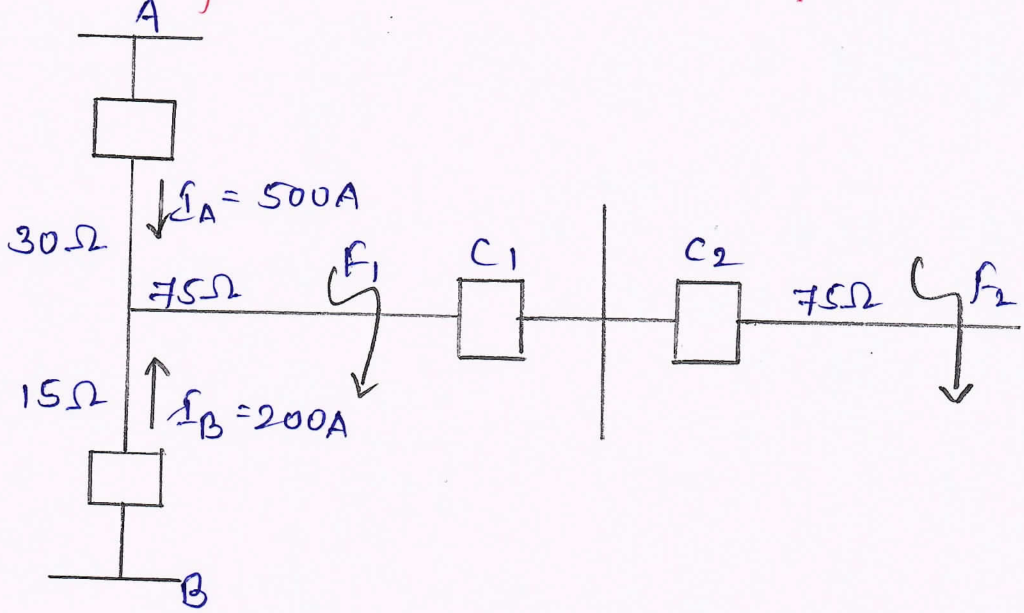
4 a) Fig Q4(a) shows distance protection for a section of power system. The I zone setting at A & B is 150Ω.

i) What will be impedance seen by the relay at A for a fault at F_1? Will the relay at A operate before the CB at B has tripped?

ii) Will the relay at B trip for fault at F_1 before the CB at A has tripped?

iii) If the CB C_2 fails for a fault at F_2, will the fault be cleared by relays at A & B?

iv) How will the fault at F_2 be cleared? (08 Marks)



i) For a fault at F_1, the voltage drop from A to F_1

$= 500 \times 30 + (500 + 200) \times 75$

The impedance seen by the relay at A

$$= \frac{500 \times 30 + (500 + 200) \times 75}{500} = 135\,\Omega.$$

The setting of the distance relay at A = 150Ω.

Therefore, the relay at A will see the fault at F_1 & trip before the circuit breaker at B has tripped.

ii) The voltage from B to F_1 for fault at F_1.

$= 200 \times 15 + (200 + 500) \times 75$ V.

The impedance measured by relay at B

$$= \frac{200 \times 15 + (200 + 500) \times 75}{200} = 277.5 \Omega.$$

Therefore, the relay at B will not trip before the CB at A has tripped.

When the CB at A has tripped, the relay at B will measure the impedance $= (15 + 75) = 90 \Omega$ & trip.

iii) For fault at F_2 the impedance measured by the relay at A $= \frac{(500 \times 30) + (500 + 200) \times (75 + 75)}{500}$

$= 240 \Omega$.

The relay at A will not operate.

For a fault at F_2, the impedance measured by the relay at B

$$= \frac{(200 \times 15) + (200 + 500) \times (75 + 75)}{200}$$

$= 540 \Omega$.

The relay at B will not see the fault at F_2.

iv) The fault at F_2 will be cleared by back-up protection.

4b) Write a note on reach of distance relays. (04 marks)

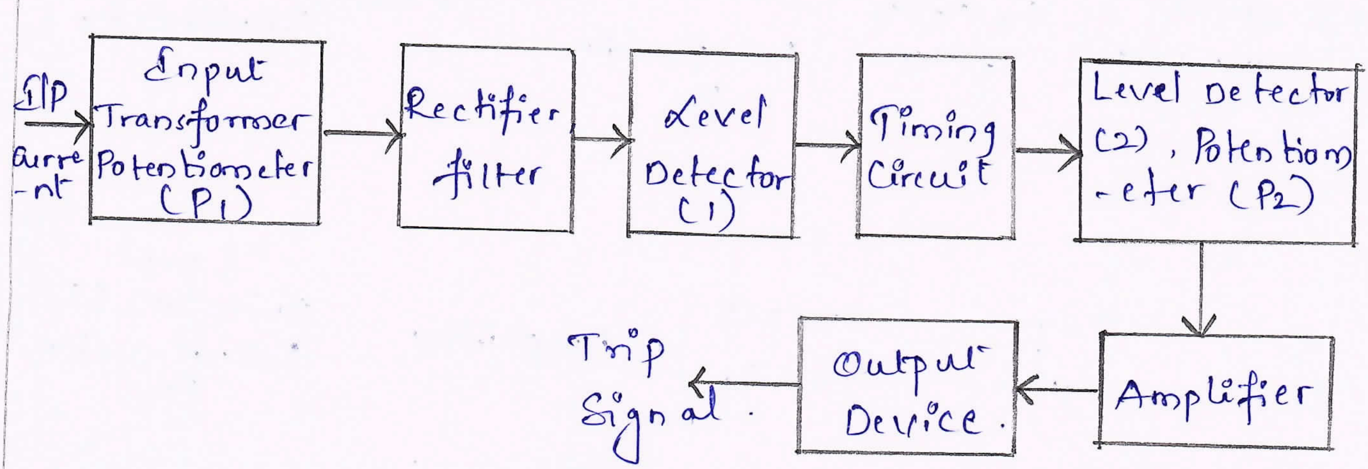
A distance relay operates when the impedance as seen by the relay is less than a preset value. This preset impedance or corresponding distance is called reach of the relay. Distance relays have under reaching & over reaching tendencies depending on the fault conditions.

When a distance relay fails to operate even when the fault point is within its reach, but it is at the far end of the protected line is called under reach. The main reason for under-reach is the presence of arc resistance in the fault which makes impedance seen by the relay as more than the actual impedance of the line upto the fault point.

The tendency of distance relay to operate even when a fault point is beyond its preset reach is known as over-reach. The reason for overreach of relay is presence of dc offset in the fault current wave, which makes impedance seen by the relay as smaller than the actual impedance of the line upto the fault point.

4c) Explain in detail with the help of block diagram
i) Static definite time overcurrent relay.
ii) Static inverse time overcurrent relay.
(08 Marks)

* Static definite-time overcurrent relay.



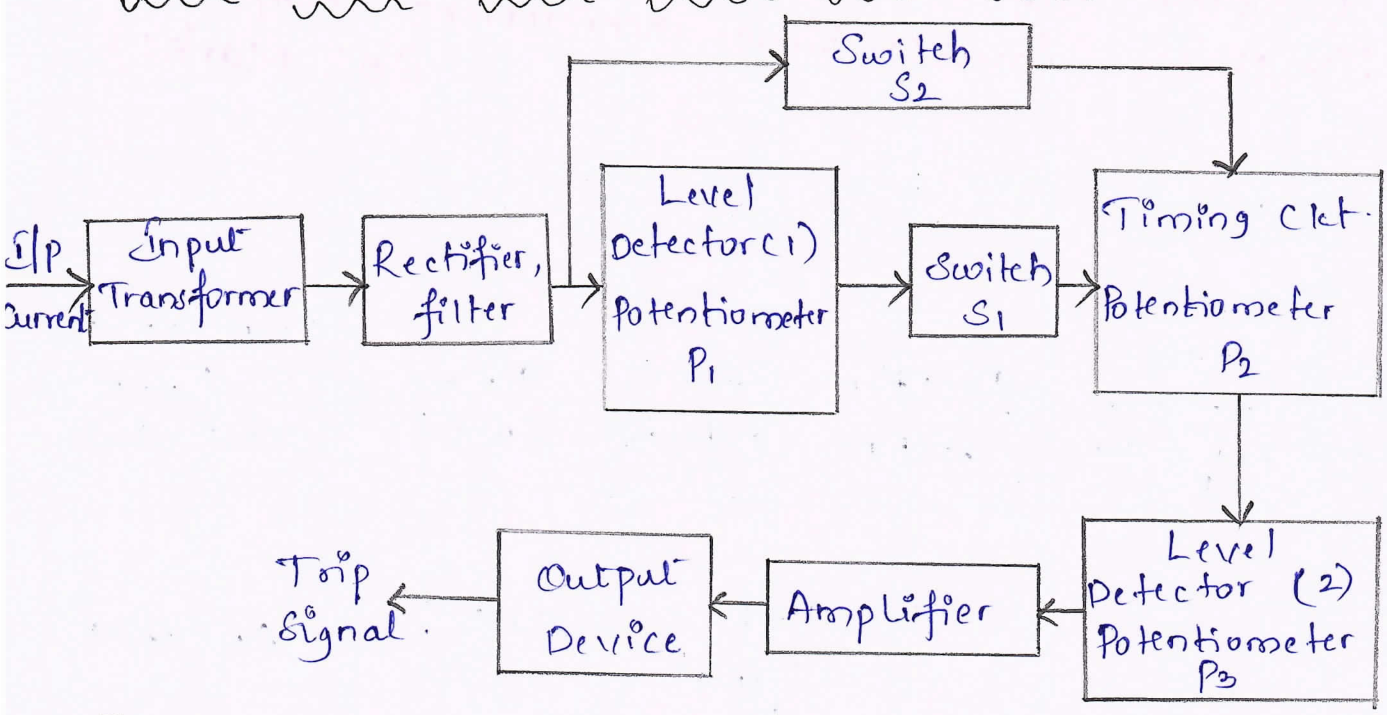
The input current signal derived from the main CT is converted to a proportional voltage signal by i/p transformer & then rectified, filtered & compared with the preset threshold value of the level detector (1).

If the voltage exceeds the preset threshold value, level detector gives an output voltage, thereby charging the capacitor C of the RC timing circuit starts. As soon as the voltage across the capacitor exceeds the preset threshold value (V_T) of level detector (2), a signal through the amplifier is given to the output device which issues the trip signal. Potentiometers P_1 & P_2 are used for current setting & time setting respectively.

If V_T is threshold value of the level detector, the time T_C required to reach this voltage depends upon the charging time of the capacitor C of the RC timing circuit given by,

$$T_C = RC \log_e \left[\frac{V}{V - V_T} \right]$$

* Static Inverse Time Overcurrent Relay.



The current signal is converted to proportional voltage signal by the input transformer & then rectified, filtered & compared with reference voltage of the level detector (1) set by potentiometer (P_1). Under normal condition, ie when the input current is low, switch S_1 is ON, short circuiting the capacitor C of the RC timing circuit &

switch S_2 is OFF. As soon as input voltage exceeds the preset reference voltage of the level detector (1), switch S_1 is OFF & S_2 is switched ON & charging of capacitor C of the timing circuit & starts from a voltage proportional to current. When the voltage across capacitor C of timing circuit exceeds the reference voltage of the level detector (2) as set by potentiometer P_3, a signal is given to the output device through an amplifier & finally output device issues the trip signal.

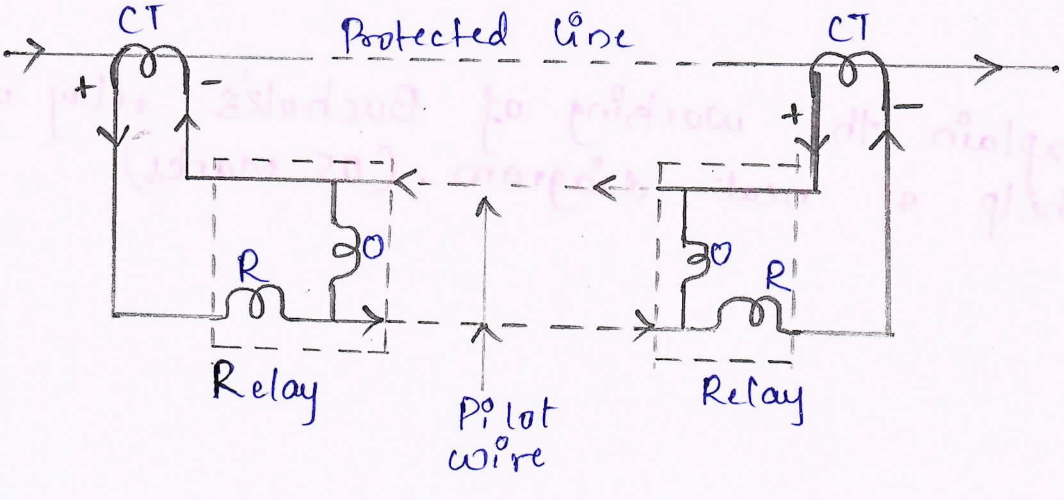
Module - 03

5 a) What are the different operating schemes used in wire pilot protection? Explain in detail about circulating current scheme & opposed voltage scheme. (08 Marks)

Operating schemes used in wire pilot protection are,

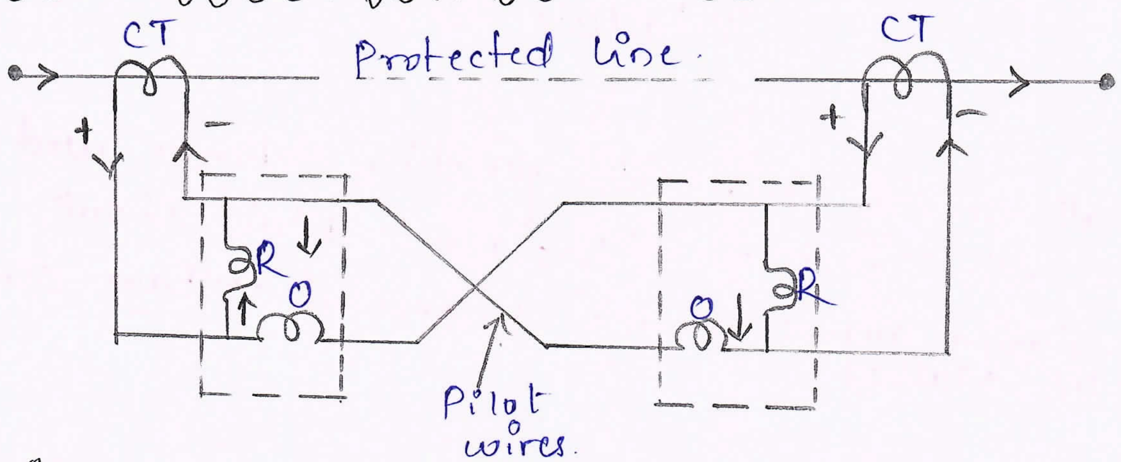
1) Circulating current scheme
2) Balanced voltage (Opposed voltage) scheme
3) Transley scheme
4) Transley S protection
5) Half-~~way~~ wave comparison scheme.

* Circulating Current Scheme.



In this scheme, current circulates normally through the terminal CT & pilot wires. Under normal conditions & in case of external faults, current does not flow through the operating coil. In case of internal faults, the polarity of the remote end CT is reversed & hence current flows through the operating coil of the relay. This scheme is suitable for pilot loop resistance upto 1000Ω & inter-core capacitance upto 2.5μf.

* Balanced voltage (opposed voltage) scheme.

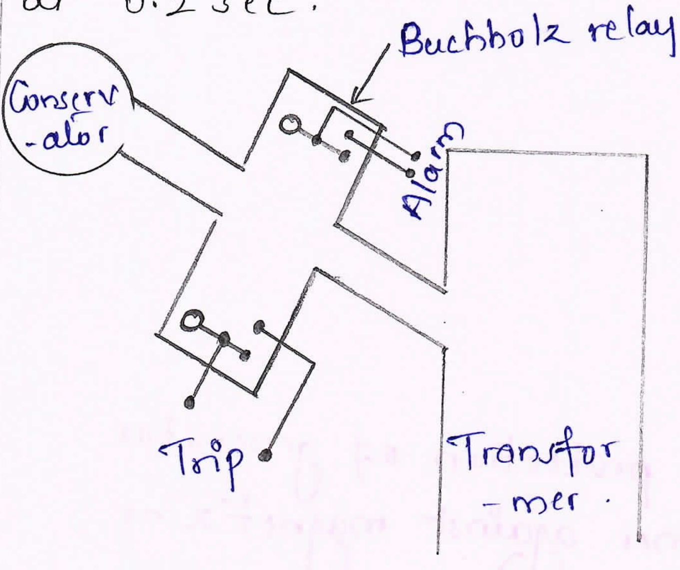


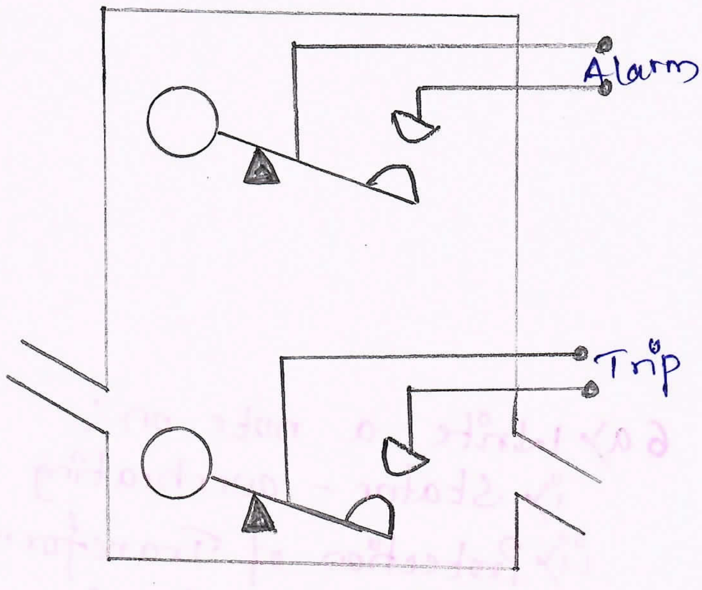
In this scheme operating coil is of the relay is placed in series with pilot wire & hence current does not flow through the pilot wires under normal conditions & external faults. In case of internal faults, polarity of the remote end CT is reversed & hence current flows through the pilot wires & operating coils of relays. This scheme is suitable for 7/0.029 pilot loops upto 400Ω.

5b> Explain the working of Bucholz relay with the help of neat diagrams. (05 Marks)

Buchholz relay is gas actuated relay used to detect incipient faults which are initially minor but may cause ~~minor~~ major faults in due course of time.

When fault develops slowly, it produces heat thereby decomposing solid or liquid insulating material in the transformer which produces inflammable gases.
There is a chamber to accomodate Buchholz relay in between transformer tank & conservator as shown in fig
When gas accumulates, the oil level falls down & thus float also comes down. It causes an alarm to sound & alert the operator. For reliable operation mercury switch is used with float.
When oil level falls because of gas accumulation, the bucket is filled up with oil. The accumulated gas can be drawn off through the petcock via a pipe for analysis to know the type of fault.
If there is severe fault, large volume of gases are produced which causes the lower float to operate & finally trips the CB of the transformer.
The Buchholz relay is slow operating device, the minimum operating time is 0.1 sec and average time is 0.2 sec.





5c) A 11kV, 100 MVA alternator is grounded through a resistance of 5Ω. The CTs have a ratio 1000/5. The relay is set to operate when there is an out of balance current of 1 A. What percentage of the generator winding will be protected by the percentage differential scheme of protection? (07 Marks)

Primary earth-fault current at which relay operates

$$= \frac{1000}{5} \times 1 = 200 \text{ A}.$$

Suppose p % of the winding from the neutral remains unprotected.

$$\text{The fault current} = \frac{p}{100} \times \frac{11 \times 10^3}{\sqrt{3} \times 5}$$

For the operation of the relay, the fault current must be greater than the relay pick-up current.

$$\frac{p}{100} \times \frac{11 \times 10^3}{\sqrt{3} \times 5} > \frac{1000}{5} \times 1 \quad \text{or} \quad p > 15.75$$

This means that 15.75% of the winding from the neutral is not protected. In other words, $100 - p = 100 - 15.75 = 84.25\%$ of the winding from the terminal is protected.

6a) Write a note on:
i) Stator - overheating protection of generator.
ii) Protection of Transformer against magnetizing inrush current. (08 Marks)

* Stator - overheating protection of generator.

Overheating of the stator may be caused by the failure of the cooling system, overloading or core faults like short-circuited laminations & failure of core bolt insulation. Two methods have been used to detect overheating of large generators (above 2MW)

In one method, inlet & outlet temperature of the cooling medium which may be hydrogen/water are compared for detecting overheating.

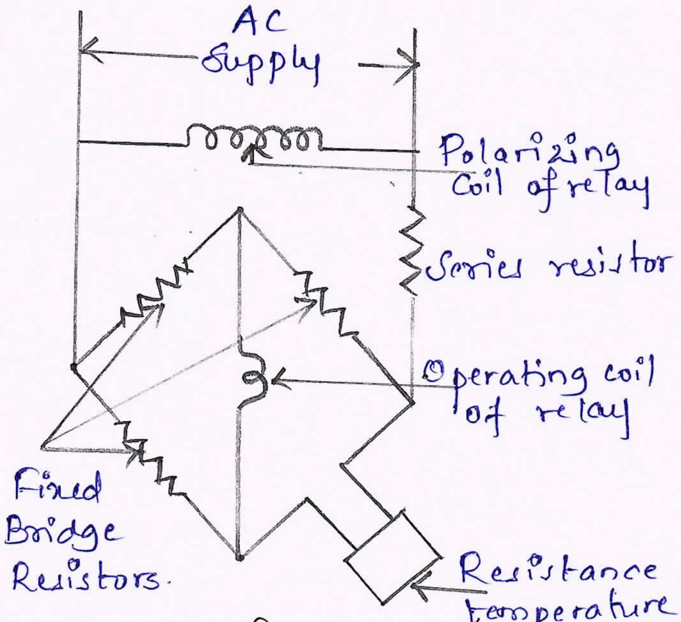


fig 1.

In the other method shown in fig 1, temperature sensing element are embedded in the stator slots to sense the temperature. When temperature exceeds certain preset max. temperature limit, relay sounds an alarm.
The scheme employs temperature detector unit, relay & wheatstone bridge.

* Protection of transformer against magnetising inrush current.

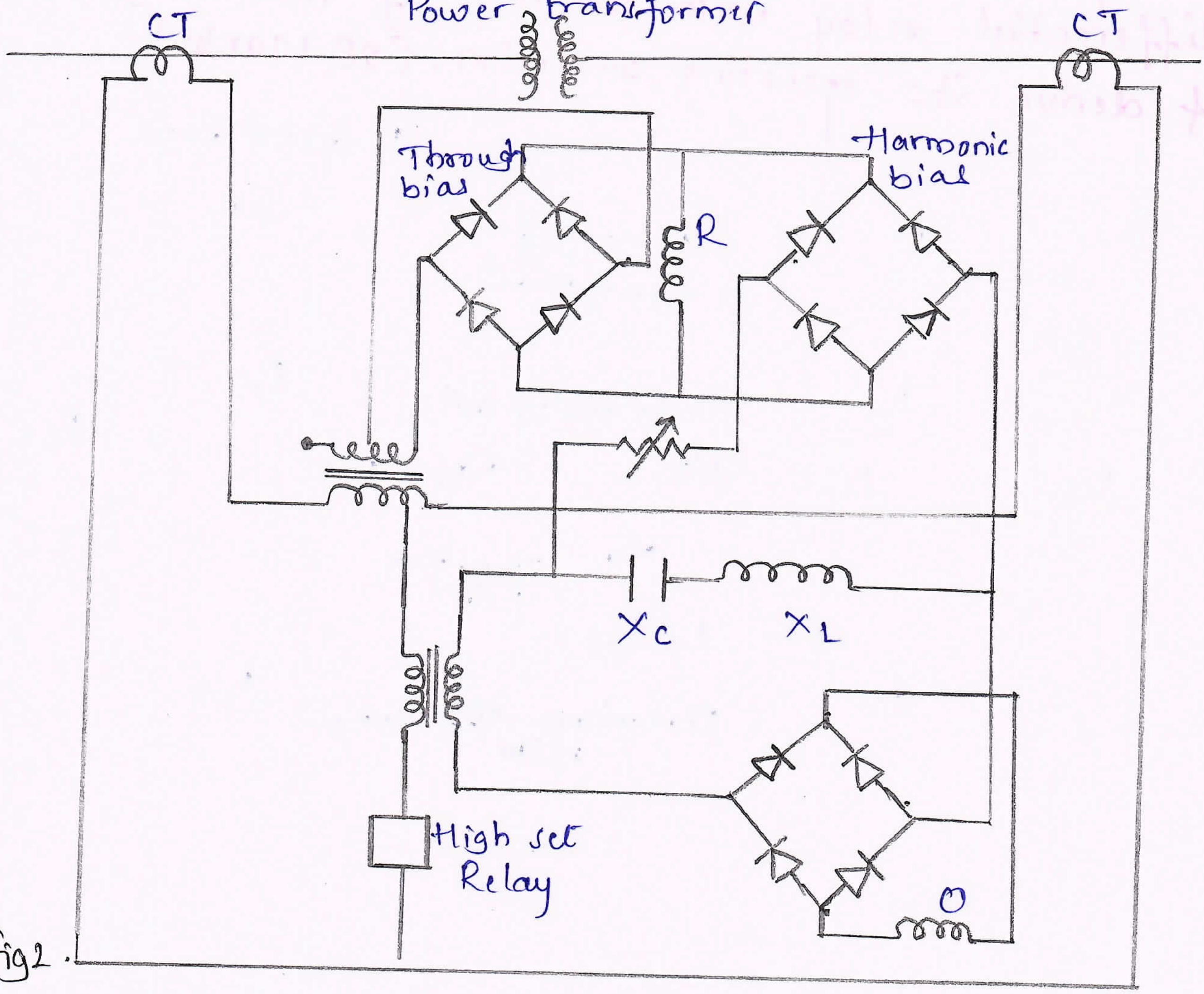
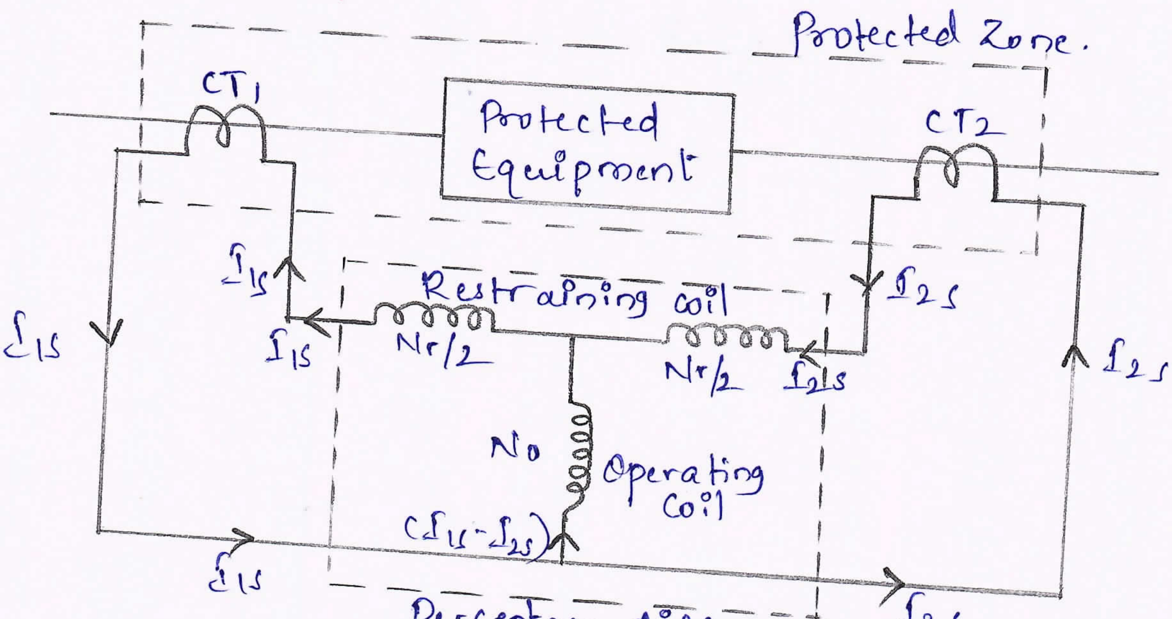


Fig2.

When an unloaded transformer is switched on, it draws a large initial magnetising current which may be several times the rated current of the transformer. This initial magnetising current is called magnetizing inrush current. fig 2. shows a high speed biased differential scheme incorporating a harmonic restraint feature.

The relay of this scheme is made insensitive to magnetising inrush current. The operating principle is to filter out the harmonics from the differential current, rectify them & add them to the percentage restraint. The tuned circuit $X_C X_L$ allows only current of fundamental frequency to flow through the operating coil. The relay is adjusted so as not to operate when the second harmonic exceeds 15% of fundamental current. The minimum operating time is about 2 cycles.

6b) Explain the working of biased or percentage differential relay with the help of neat diagram & derive its operating condition. (08 Marks)



Percentage differential relay

The relay has two coils namely restraining & operating coil. which are producing restraining torque & operating torque respectively. When operating torque exceeds restraining torque, the relay operates.

* Operating condition.

As the torque is proportional to the ampere-turns (AT), the relay will operate when

$$AT_0 > AT_r$$

Ampere turns of the left hand section of restraining coil $= N_r/2 \cdot I_{1S}$

Ampere turns of the right hand section of restraining coil $= N_r/2 \cdot I_{2S}$

Total ampere-turns of restraining coil,

$$AT_r = \frac{N_r}{2}\left[I_{1S} + I_{2S}\right] = N_r \cdot \left[\frac{I_{1S} + I_{2S}}{2}\right]$$

Thus it can be assumed that the entire N_r turns of the restraining coil carries a current $\left[\frac{I_{1S} + I_{2S}}{2}\right]$ which is average of the secondary currents of the two CTs known as through current or restraining current I_r.

The ampere turns of the operating coil

$$AT_0 = N_0\left(I_{1S} - I_{2S}\right)$$

Neglecting spring restrain, the relay will operate when

$$AT_0 > AT_r$$

ie

$$N_0\left(I_{1S} - I_{2S}\right) > N_r \cdot I_r$$

$$\left(I_{1S} - I_{2S}\right) > \frac{N_r}{N_0} \cdot I_r$$

or

$$\boxed{I_d > K \cdot I_r}$$

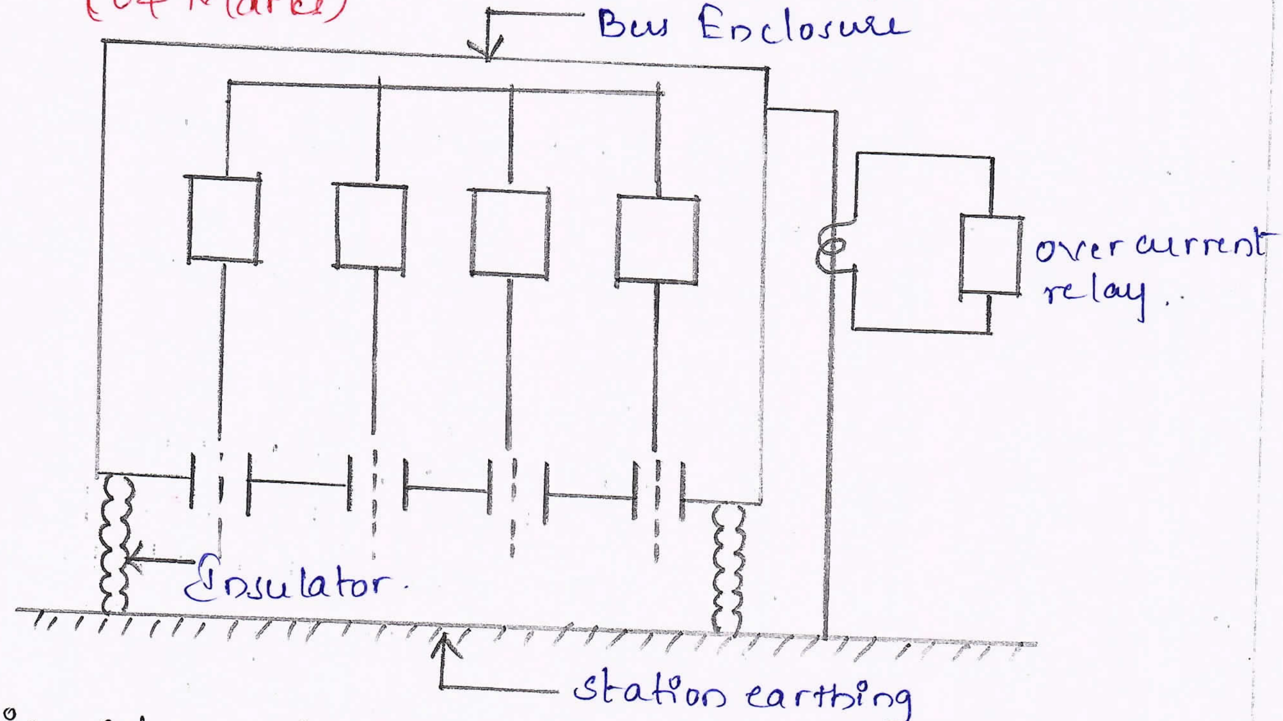
where, I_d - differential current through operating coil.

$K = N_r/N_0$ - slope or bias expressed as % value.

Under normal & external fault conditions,
$AT_r > AT_o$ hence relay is inoperative.

Under internal fault conditions, $AT_o > AT_r$ & hence relay operates.

6 c) Give notes on frame leakage protection. (04 Marks)



This scheme is more favoured for indoor rather than outdoor installations. & applicable to metal clad type switchgear installations.
The frame work is insulated from the ground. The insulation is light anything over 10Ω is acceptable. This is most effective in case of isolated phase construction type switchgear installations in which all faults involves ground. To avoid undesired operation of the relay due to spurious currents, a check relay energised from a CT connected in a neutral of the system is employed. An instantaneous overcurrent relay is used in this scheme, if a neutral check relay is incorporated. If neutral check relay is not employed then an inverse time delay relay should be used.

Module - 04

7a) Define : i) Restriking Voltage ii) Recovery Voltage
Derive the expression for restriking voltage & Rate of Rise of Restriking voltage (RRRV). (10 Marks)

i) Restriking Voltage : The transient voltage which appears across the breaker contacts at the instant of arc being extinguished.

ii) Recovery Voltage : The power frequency rms voltage which appears across the breaker contacts after the arc is finally extinguished & transient oscillations die out.

* Expression for Restriking Voltage and RRRV.

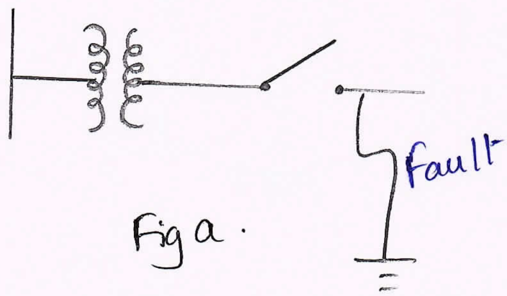


Fig a.

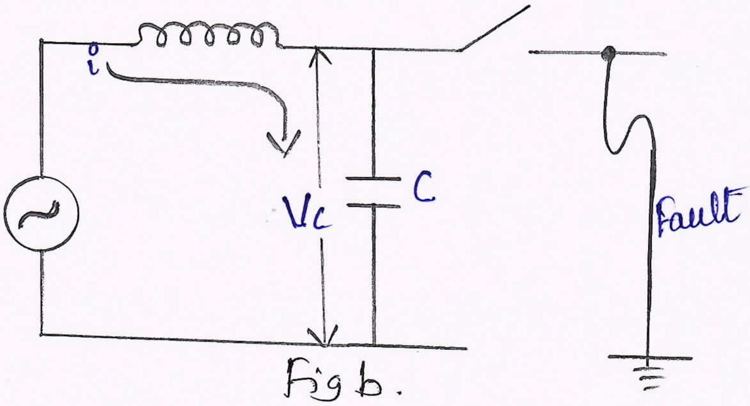


Fig b.

Fig (a) shows a short circuit (fault) on feeder beyond the location of the CB. Fig (b) shows an equivalent electrical circuit where L & C are the inductance & capacitance per phase of the system upto the point of CB location.

When the CB contacts are opened & arc is extinguished, the current i is diverted through the capacitance C, resulting in a transient condition. The inductance & capacitance forms a series oscillatory circuit.
The voltage across the capacitance which is restriking voltage, rises & oscillates. The natural frequency of oscillation is given by,

$$f_n = \frac{1}{2\pi\sqrt{LC}} \quad \text{--- (1)}$$

& the natural angular frequency is,

$$\omega_n = \frac{1}{\sqrt{LC}} \quad \text{--- (2)}$$

The mathematical expression for the transient condition is,

$$L.\frac{di}{dt} + \frac{1}{C}\int i.dt = V_m \cos \omega t \quad \text{--- (3)}$$

The change in the power frequency term is very little & hence negligible because $\cos \omega t = 1$.

Hence sinusoidally varying voltage $V_m \cos \omega t$ in eqn. (3) can be assumed to remain constant at V_m during transient period.

$$\therefore \quad L.\frac{di}{dt} + \frac{1}{C}\int i\,dt = V_m \quad \text{--- (4)}$$

WKT,

$$i = \frac{dq}{dt} = \frac{d.(CV_c)}{dt} \quad \text{--- (5)}$$

Therefore,

$$\frac{di}{dt} = \frac{d^2(CV_c)}{dt^2} = C.\frac{d^2V_c}{dt^2} \quad \text{--- (6)}$$

$$\frac{1}{C}\int i\,dt = \frac{q}{C} = V_c \quad \text{--- (7)}$$

Substituting these values in eqn. (4),

$$LC\frac{d^2V_c}{dt^2} + V_c = V_m \quad \text{--- (8)}$$

Taking Laplace transform on both sides of eqn. (8),

$$LC s^2 V_c(s) + V_c(s) = \frac{V_m}{s}$$

or

$$V_c(s) = \frac{V_m}{s[LCs^2+1]} = \frac{V_m}{LCs\left[s^2+\frac{1}{LC}\right]}$$

We have, $\omega_n = \frac{1}{\sqrt{LC}} \Rightarrow \frac{1}{LC} = \omega_n^2$

$$\therefore V_c(s) = \frac{\omega_n^2 V_m}{s[s^2+\omega_n^2]} = \frac{\omega_n V_m}{s}\left[\frac{\omega_n}{s^2+\omega_n^2}\right] \quad \text{--- (9)}$$

Taking inverse Laplace of eqn. (9),

$$V_c(t) = \omega_n V_m \int_0^t \sin \omega_n t$$

$$= \omega_n V_m \left[\frac{-\cos \omega_n t}{\omega_n} \right]_0^t$$

or $$\boxed{V_c(t) = V_m [1 - \cos \omega_n t]} \quad \text{——— (10)}$$

This is expression for restriking voltage.

The maximum value of restriking voltage occurs at $t = \pi/\omega_n$

∴ Maximum value of restriking voltage $= 2V_m$.

The Rate of Rise of Restriking Voltage is

$$RRRV = \frac{d}{dt}\left[V_m (1 - \cos \omega_n t) \right]$$

$$\boxed{RRRV = V_m \omega_n \sin \omega_n t}$$

Maximum value of RRRV is obtained at $\omega_n t = \pi/2$

∴ Maximum value of RRRV $= V_m \cdot \omega_n$

7 b) With the help of neat diagram explain working of cross-blast & axial blast circuit breakers. [10 Marks]

* Cross-blast CB:

In this CB, a high pressure blast of air is directed perpendicularly to the arc for its interruption. The arc is forced into a suitable chute. Sufficient lengthening of the arc is obtained, resulting in the introduction of appreciable resistance in the arc itself. These are suitable for interrupting high current (upto 100 kA) at comparatively lower voltages.

* **Axial-blast CB:**

In this CB, a high pressure blast of air is directed longitudinally i.e., in line with arc as shown in fig b. These CB are suitable for EHV & super high voltage application. This is because interrupting chambers can be fully enclosed in a porcelain tubes. Resistance switching is employed to reduce the transient overvoltages.

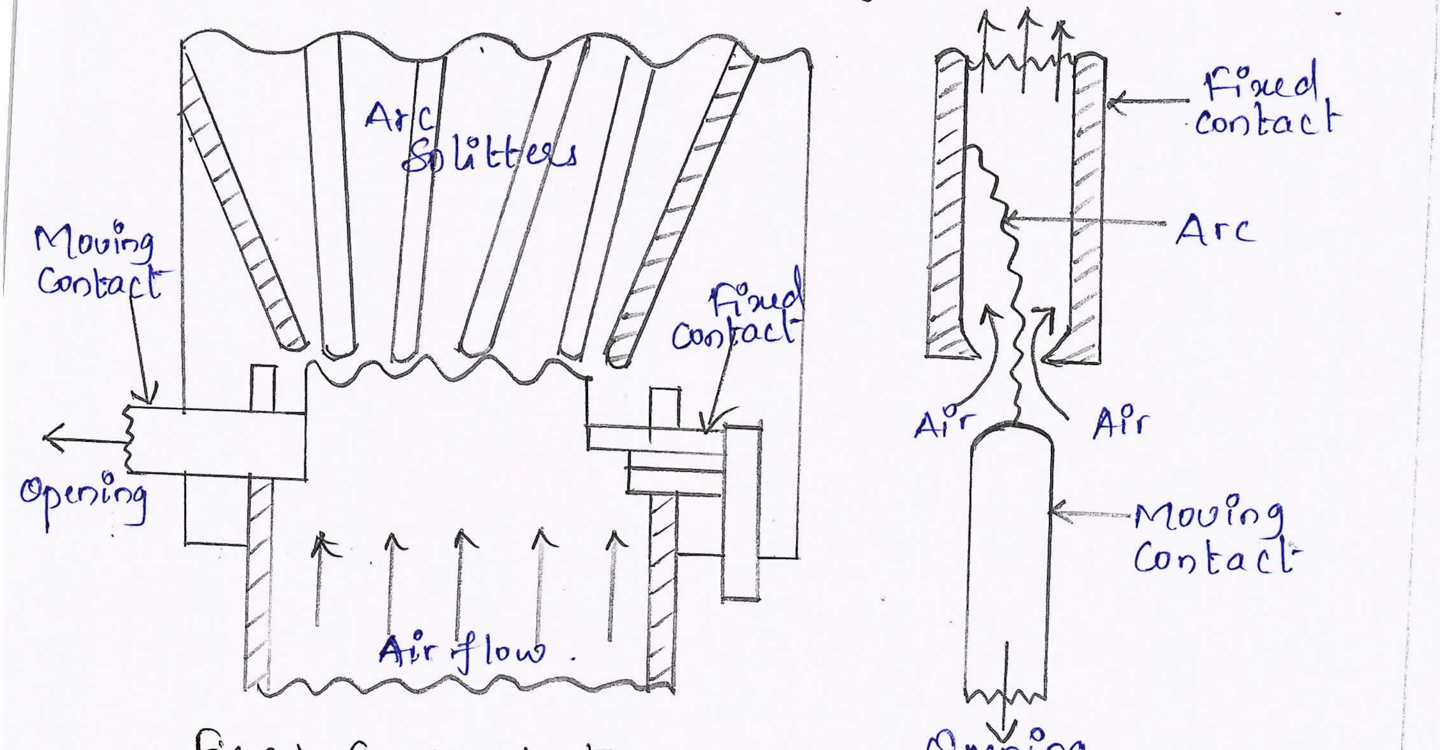


fig a: Cross blast

fig b: axial blast

8 a) Write notes on:

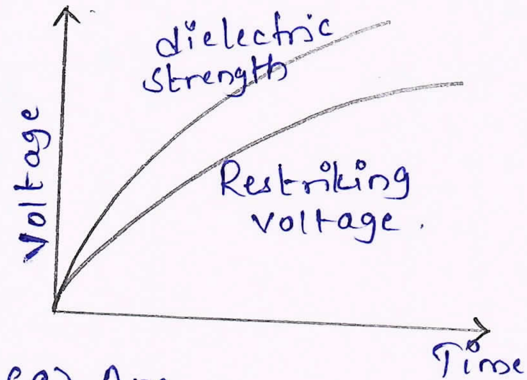
i) Recovery Rate theory

ii) Energy balance theory of arc interruption in a CB. (10 Marks)

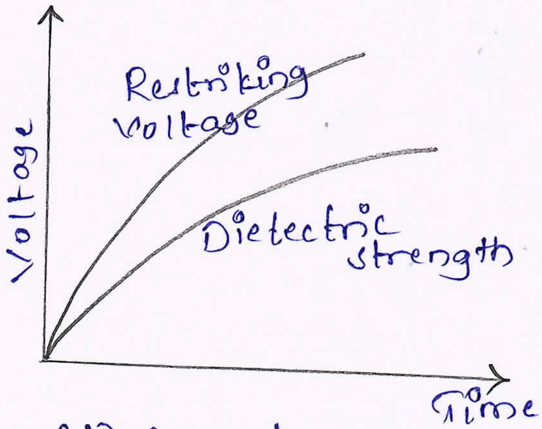
* **Recovery Rate Theory:**

In this theory, the rate at which the gap recovers its dielectric strength is compared with the rate at which the restriking 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 & breakdown of the gap occurs, resulting in an arc for another half-cycle.



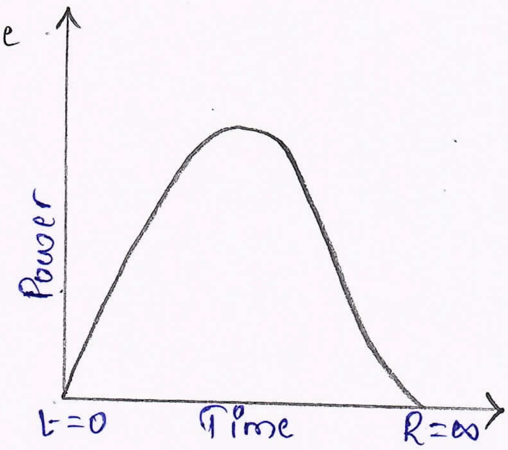
(a) Arc Extinguishes



(b) Arc does not extinguishes.

* Energy Balance Theory:

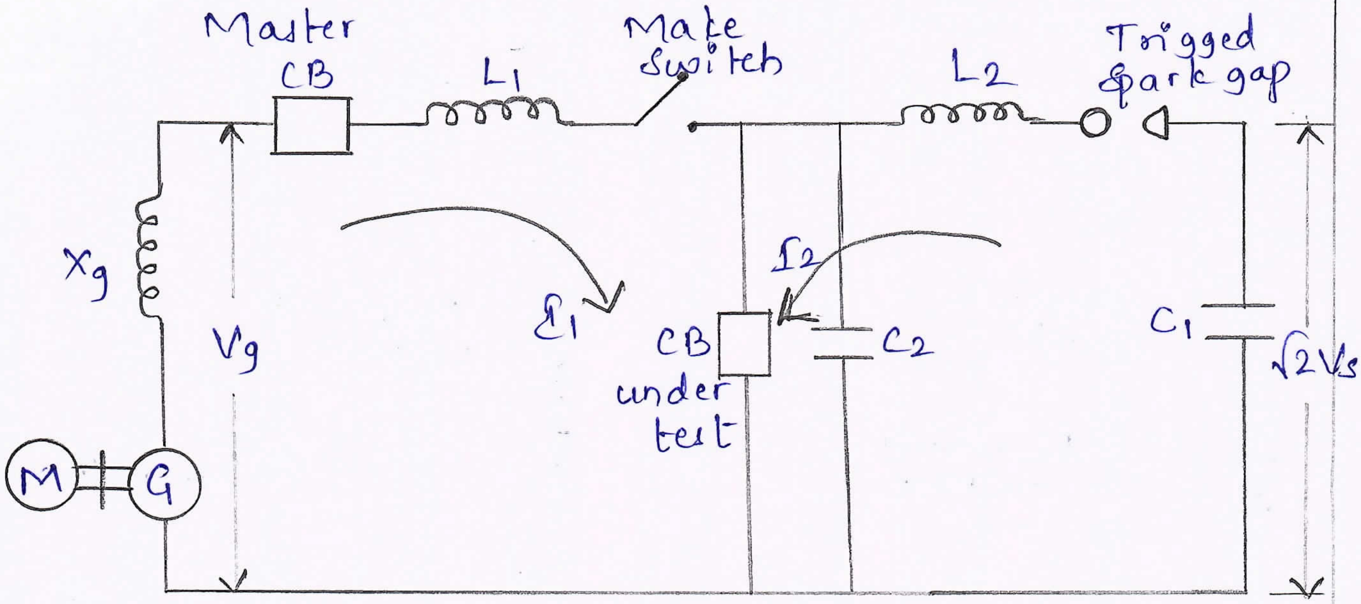
Due to the rise of restriking voltage & associated current, energy is generated in the space between the contacts. The energy appears in the form of heat. The CB is designed to remove this generated heat as easily as possible by cooling the gap, giving a blast of air or flow of oil at high velocity & 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.

8 b) With a neat circuit diagram, explain the synthetic testing of a circuit breaker. (06 Marks)

Fig. shows a circuit for synthetic testing ~~for~~ of parallel method.
The high current source is a motor driven generator. It injects a high short circuit current I_1 into the CB under test at a relatively reduced voltage V_g.



The inductance L_1 is to control the short circuit current. The master CB & CB under test are tripped before current I_1 reaches its natural zero. These CBs are fully opened by the time t_0. The capacitor C_1 is high voltage source to provide recovery voltage. It is charged prior to the test to a voltage $\sqrt{2}V_s$ which is equal to peak power frequency voltage which will appear across the contacts at the moment the CB under test interrupts the current.

L_2 & C_2 control transient recovery voltage & RRRV. The triggered spark gap is fired at t_1, slightly before the short circuit current I_1 reaches its natural zero. It is done to properly simulate the pre-current zero zone during the test.

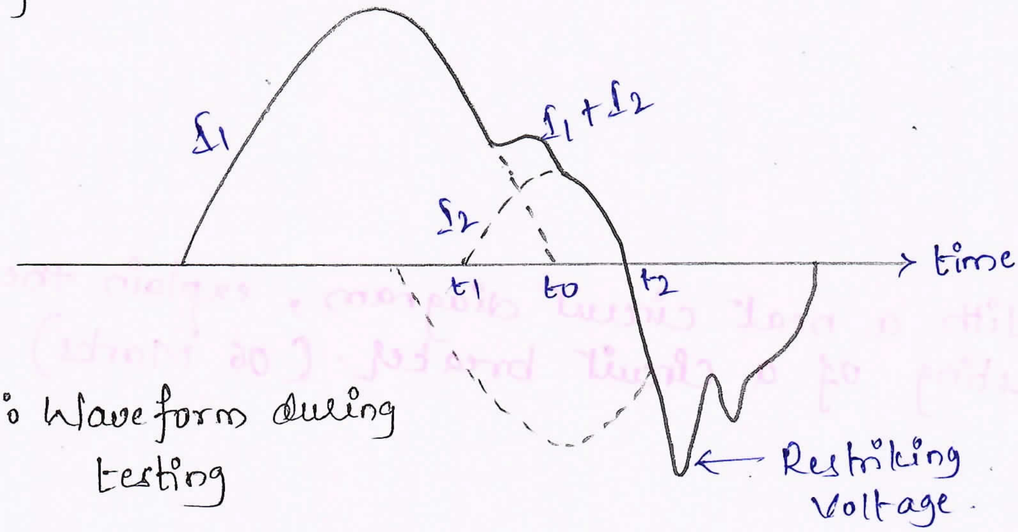


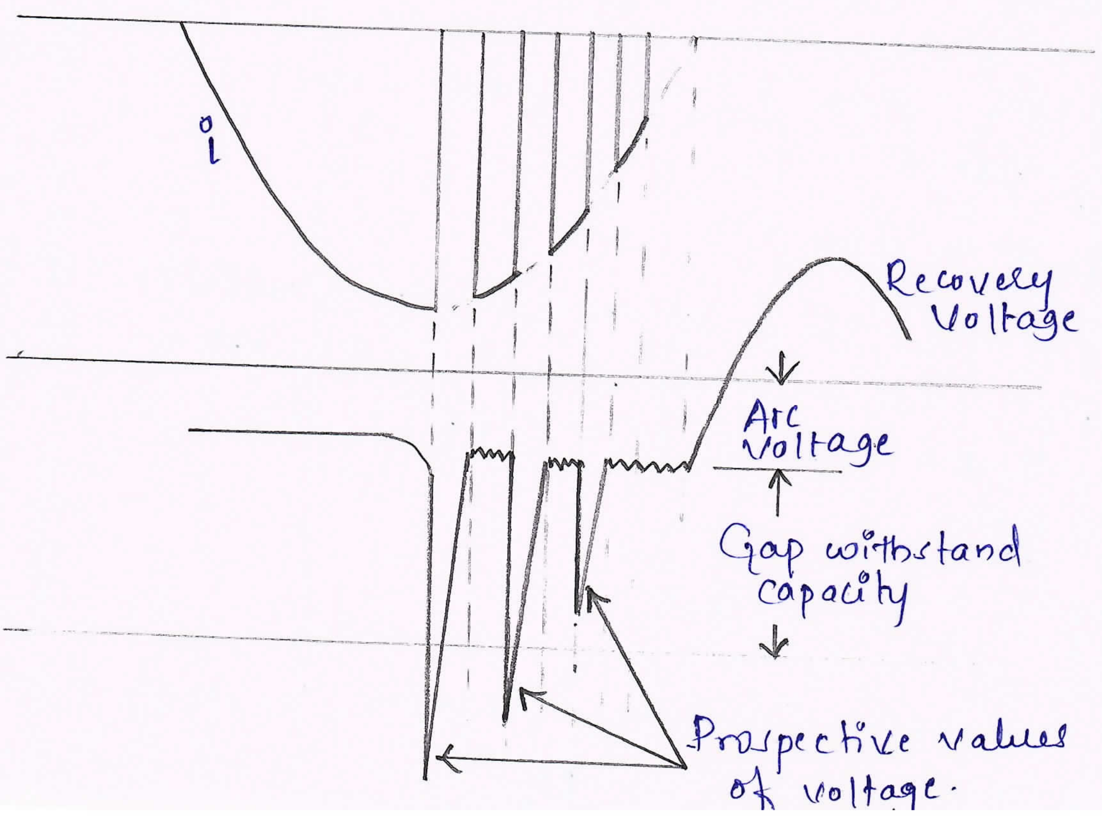
Fig: Waveform during testing

8 c) Describe the current chopping phenomenon in a circuit breaker. (04 Marks)

When low inductive current is being interrupted & the arc quenching force of the CB is more than necessary to interrupt a low magnitude of current, the current will be interrupted before its natural zero instant. In such 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 $\frac{1}{2}Li^2$, if i is instantaneous value of the current which is interrupted. This will appear in the form of electrostatic energy equal to $\frac{1}{2}CV^2$. As the two energies are equal, they can be treated as $\frac{1}{2}Li^2 = \frac{1}{2}CV^2$

$$\therefore V = i\sqrt{L/C}$$

If the value of ~~the~~ 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 gap as shown in fig.



Module-05

9 a) What are the components of CSR? Briefly describe their functions. (08 Marks)

* Components of CSR are,
  1) Busbars
  2) Isolator/disconnector.
  3) Circuit breaker
  4) Current transformer
  5) Earthing switch.

* **Busbars:**

In CSR (GIS) busbar is of different lengths to cater to the equipment of circuit. For optimal stress distribution purpose co-axial bus bars are used.
The main high voltage conductor made of aluminium or copper is centrally placed in a tubular metal enclosure & supported by the disc/post insulator at a uniform distance to maintain concentricity.

* **Isolators/Disconnector:**

Isolators are placed in series with circuit breaker to provide additional protection & physical isolation. Two isolators are used one on line side & other on feeder side. In GIS system motorised isolators are prefered.

* **Circuit Breaker:**

In CSR CB is of metal clad & utilises SF_6 gas both for insulations & fault interruption. SF_6 puffer type CB are preferred to accomplish fault current interruption.

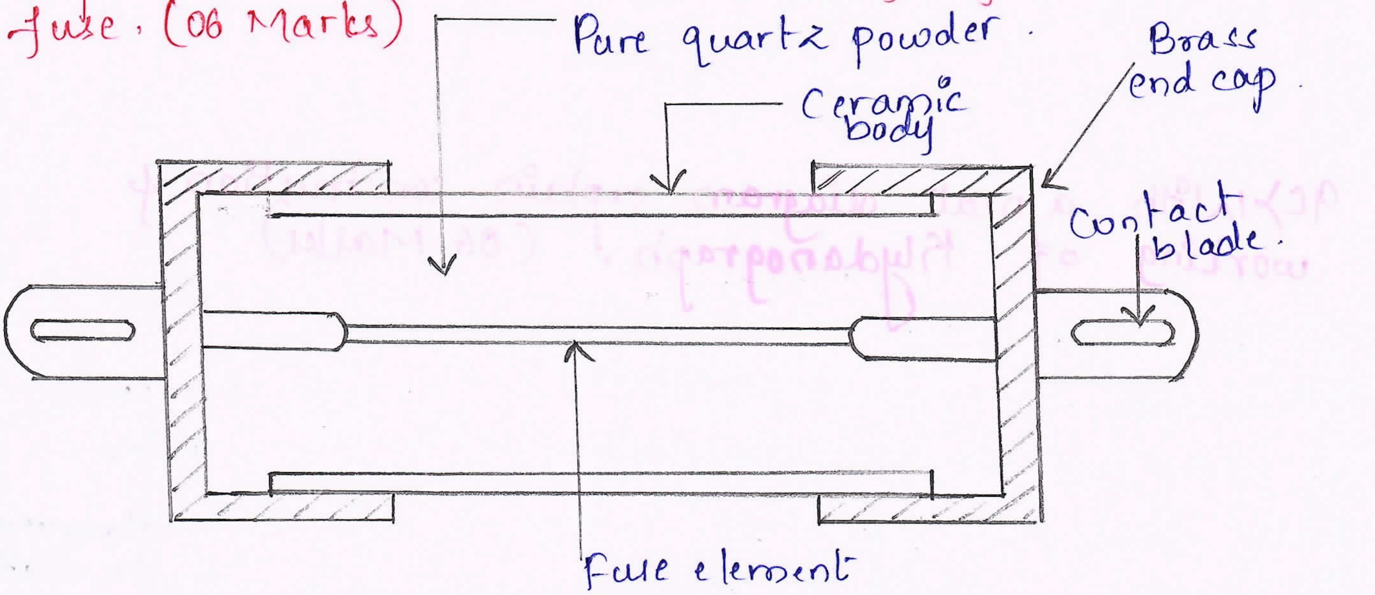
* **Current transformer:**

The CT used in GIS are essentially in-line CTs. Gas insulated CTs have classical co-axial geometry & consist of following parts, the tubular primary conductor, an electrostatic shield ribbon-wound toroidal core & gas tight metal enclosure filled with SF_6 gas.

* Earthing Switch:

Two-types of earthing switches are used in GIS. Maintenance & fast earthing switch.
The maintenance earthing switch is a slow device used to ground the high voltage conductors during maintenance schedule in order to ensure safety of maintenance staff.
The fast earthing switch is used to protect the circuit connected instrument VT from core saturation caused by direct current flowing through its primary as a result of remnant charge.

9 b) Explain the construction & working of HRC cartridge fuse. (06 Marks)



* Construction:

HRC fuse consist of cylindrical body of ceramic material usually silver, pure quartz powder, brass end cap & copper contact blades. The fuse element is fitted inside the ceramic body & the space within the body surrounding the element is completely filled with powdered quartz. The ends of the fuse element are connected to the metal end caps which are screwed to

the ceramic body. End contacts are welded to the metal end caps. The contact blades are bolted on the stationary contacts on the panel.
The fuse element has two or more sections joined together by means of tin joint because tin joint prevents formation of long arc. As melting point of tin is much lower than that of silver, tin will melt first under fault condition which prevent silver from attaining high temperature.

* Working :

When fault occurs the fuse element melts before fault current reaches its first peak. As the element melts, it vapourises & disperses. During arcing period, the chemical reaction between the metal vapour & quartz powder forms a high resistance which helps in quenching the arc. Thus current is interrupted.

9c) With a neat diagram explain construction & working of Klydanograph. (06 Marks)

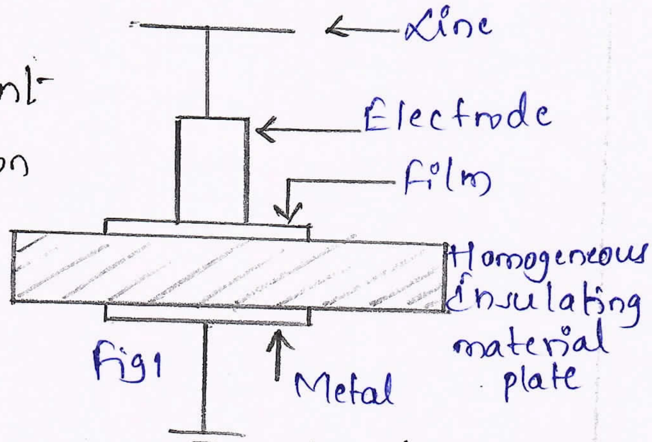
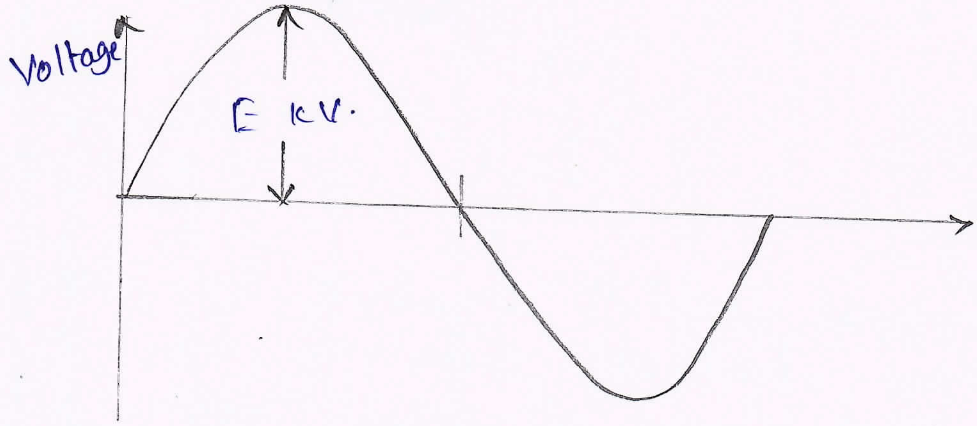
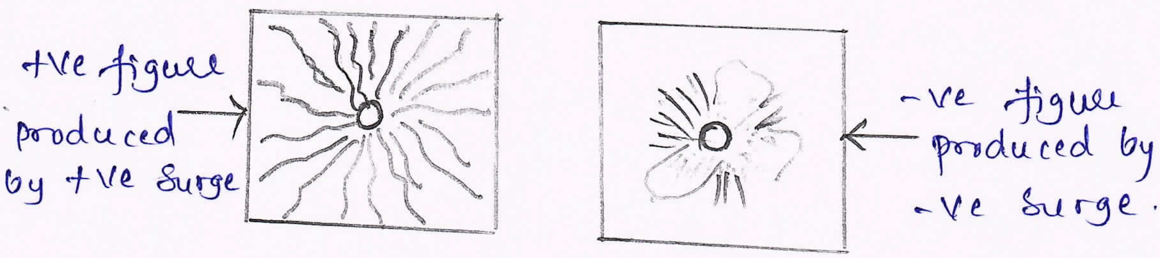


Fig1

The Klydanograph is an instrument for the measurement of surge voltage on transmission lines caused by lightning.
It measures voltage by means of Litchenberg figures, when suitably couple to the line whose surge voltage is to be measured. The electrode rests on a emulsion side of a photographic film or plate, which inturn rests on smooth surface of an insulating plate made of homogeneo-us insulating material backed by a metal plate electrode as shown in fig. 1

The photographic film is turned by clockworks mechanism for bringing in the element of time. These assemblies are generally placed in the same box for simultaneously measuring the voltages on the three phases of transmission line. With this arrangement +ve Litchenberg fig. is produced by +ve surge & -ve Litchenberg fig. is produced by -ve surge as shown in fig. 2





10 a) Explain the lightning phenomenon with the help of relevant diagram. (08 Marks)

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 w.r.t. ground that the air breaks down & insulating property of the surrounding air is destroyed.

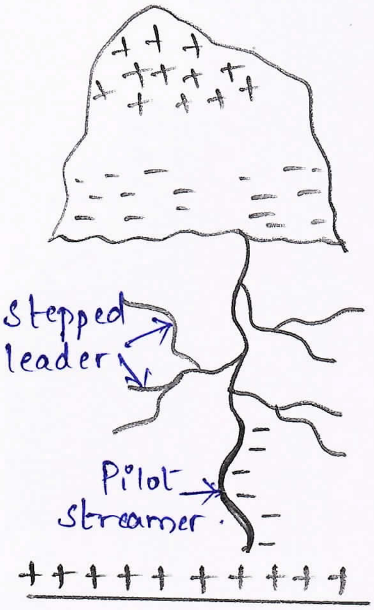


Fig a

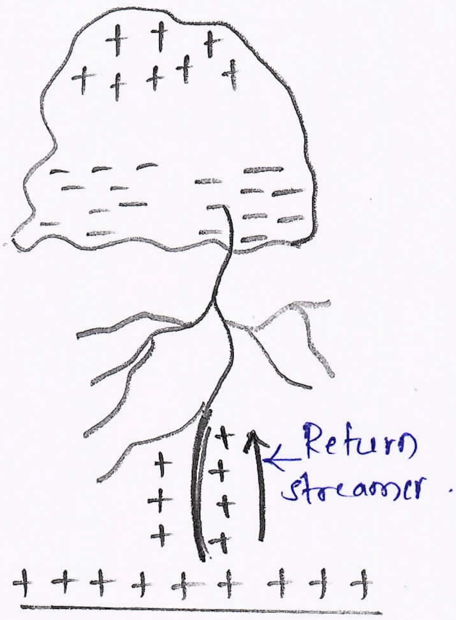


fig b

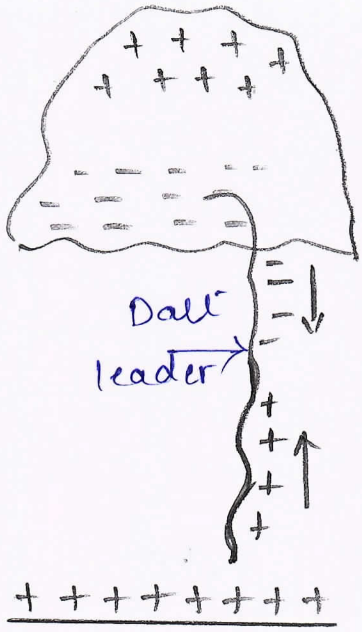


fig c.

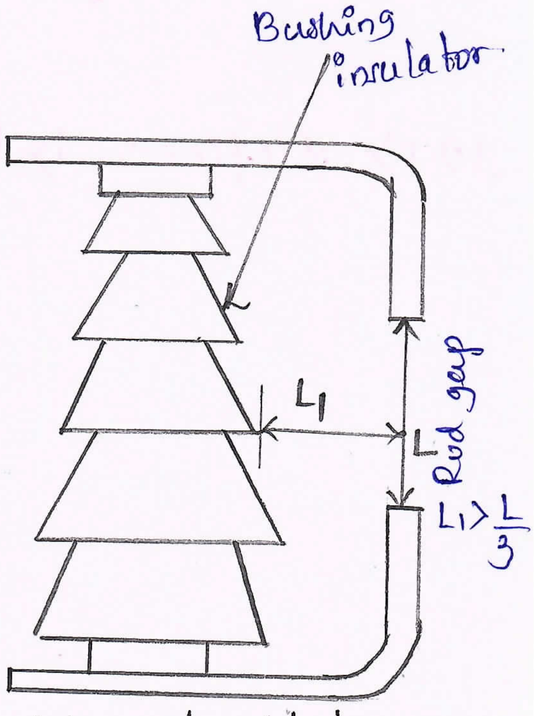
When potential gradient of about 10kV/cm is setup in the cloud, air surrounding cloud gets ionised & first process of actual lightning discharge starts. At this instant a streamer called pilot streamer start from the cloud towards ground which is not visible. Depending upon the state of ionisation of air surrounding pilot streamer it is branched into several paths, a stepped leader is formed as shown in fig a. A portion of charge in the center from which strike originated is lowered & distributed over this entire system of temporary conductors. This process continues until one of the leaders strikes the ground.

When one of the leader strikes the ground, an extremely bright return streamer as shown in fig b. propogates upwards from ground to the cloud following the same path as the main channel of the downward leader. The charge distributed along the leader is thus discharged progressively to ground giving rise to the very large currents (1kA to 200kA) associated with lightning discharges. It is this instant which gives rise to the lightning flash which is visible with our nacked eyes.

After the neutralisation of the most of the -ve charge on the cloud, any further dichaage from another charge center will make use of the already ionised path & it will have single branch associated with high current. This streamer of dischaage is called Dart leader as in fig. C. The dart leader can cause more severe damage than the return stroke.

10 b) With the help of neat diagram explain the working of Rod gap & arcing horn to protect against travelling waves. (08 marks)

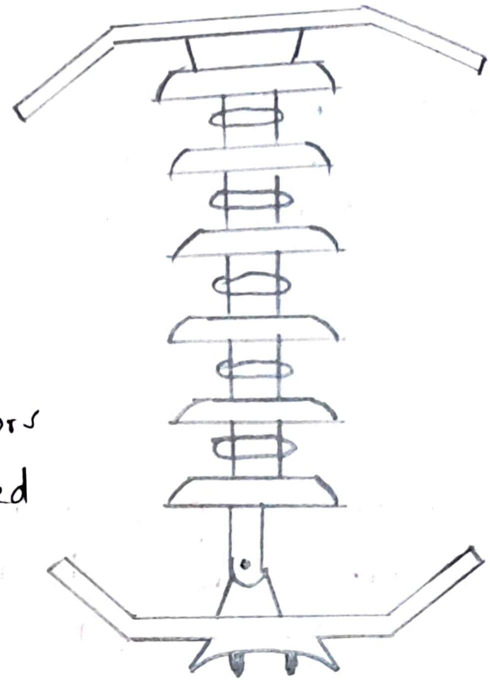
* Rod gap :



Rod gap provides simples & cheapest protection to line insulators, equipment insulators & bushing of transformers.
Rod gap consists of two rods of approximately 1.2cm diameter or square which are bent at right angles as shown. One rod is connected to line while the other is connected to ground.
The distance between gap & the insulator should be more than 1/3rd of gap length. (ie $L_1 > L/3$) in order to prevent the arc from being blown to the insulator.
The major drawback of rod gap is that, every operation of rod gap creates an LG fault which can only be cleared by the operation of CB.

* Arcing Horn :
It is a protective device developed to keep an insulator string free from arc. It consist of small horns attached to the clamp of the line insulator string. Horns with large spread, both at the top of the insulator & at the clamp are required to be effective.

In order to avoid cascading because of lightning impulse, gap between horns should be considerably less than the length of the string. Protection of line insulators by arcing horns thus results in reduced flashover voltage.
The protection of line insulators by arcing horns is specially used in hilly areas.



10 c) Define: i) Fuse ii) Fusing factor. (04 Marks)

i) Fuse: It is a protective device used for protecting cables & electrical equipment against overloads and/or short circuits. It breaks the circuit by fusing the fuse element when current flowing in the circuit exceeds certain predetermined value.

ii) Fusing Factor: It is the ratio of minimum fusing current to the rated current of fuse.

ie Fusing factor = $\frac{\text{Minimum fusing Current}}{\text{Rated Current}}$

This factor is always more than unity (1).

(Rajeshwari Nanannavar).

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