PART - B

unit - 5 - protective relaying

Introduction

The protective relays are used in power system to give an alarm or to cause prompt removal of any element from service when the element behaves abnormally.

→ However the abnormal behaviour of an element might cause damage or interference within effective operation of rest of the system.

→ The protective relay helps to minimise the damage to the equipment and interruptions to the service when electrical failure occurs.

→ Along with some other equipments the relays helps to minimise damage and improve the service.

→ The protective relaying scheme includes protective current transformers, voltage transformers, relays, time delay relays, auxiliary relays, secondary circuits, trip circuits etc.

* Functions of protective Relaying?

⇒ The different functions of protective relaying are as follows.

1) The removal of equipment component which is behaving abnormally by closing the trip circuit of circuit breaker or to sound an alarm

2) in order to disconnect the abnormally operating

operating part to avoid damage or interference with effective operation of rest of the system.

3) To prevent the subsequent faults by disconnecting the abnormally operating part

4) relays are helpful to disconnect the faulty part as quickly as possible to minimise the damage to the faulty part of s/m itself.

5) to improve s/m performance, s/m reliability, s/m stability & service continuity the relays are helpful.

However the faults in the power s/m can't be avoided completely but they can be minimised.

* protective zones

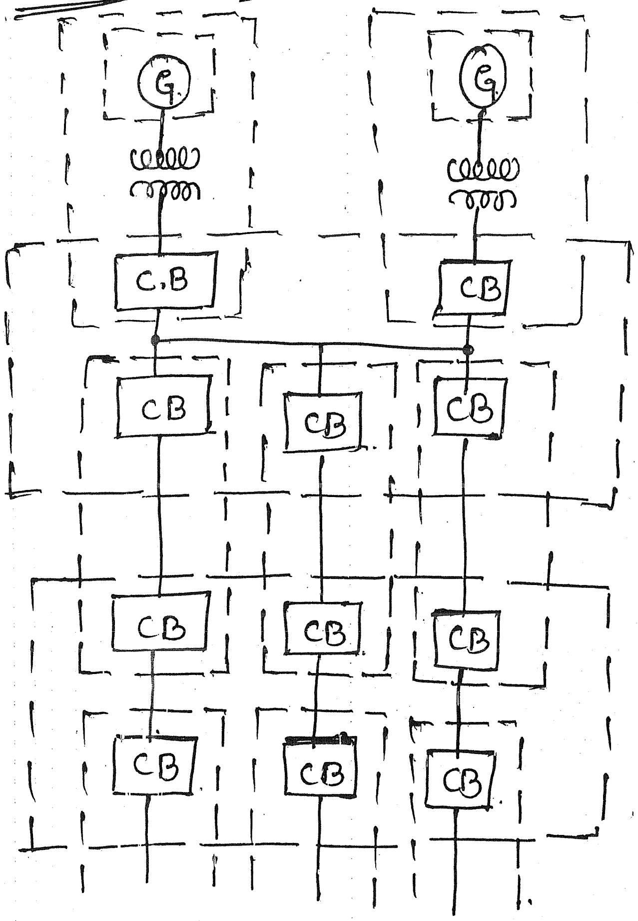


fig - a) protective zones

as shown in the above fig a, the CB's are placed at the appropriate points such that any element of the entire s/m can be disconnected for repair work.

A protective zone is a separate zone which is established around each s/m element.

* The significance of such a protective zone is that any fault occurring within a given zone will cause the tripping of relays which causes opening of all the circuit breakers located within that zone.

→ The various components which are provided with protective zones are transformers, generators, tr-lines, bus bars, cables, capacitors etc. No part of the system is to be unprotected.

The above fig shows the various protective zones, used in the system. The boundaries of protective zones are decided by the locations of current X^{T}ers.

* In practice various protective zones are overlapped. The overlapping of protective zones is done to ensure complete safety of each and every element of the sim. The zone which is unprotected is called <u>dead spot</u>.

* If the failures are within the region where two adjacent protective zones are overlapped, more circuit breakers get tripped than minimum necessary to disconnect the faulty element.

* If there are no overlaps, then the dead spot may exist, means circuit breakers lying within the protective zone may not trip eventhough the fault occurs.

→ Which may leads the damage to the system

* However the probability of the failure in the overlapped regions is very low, consequently the tripping of too many CBS will be also infrequent. The below fig shows overlapping of protective zones

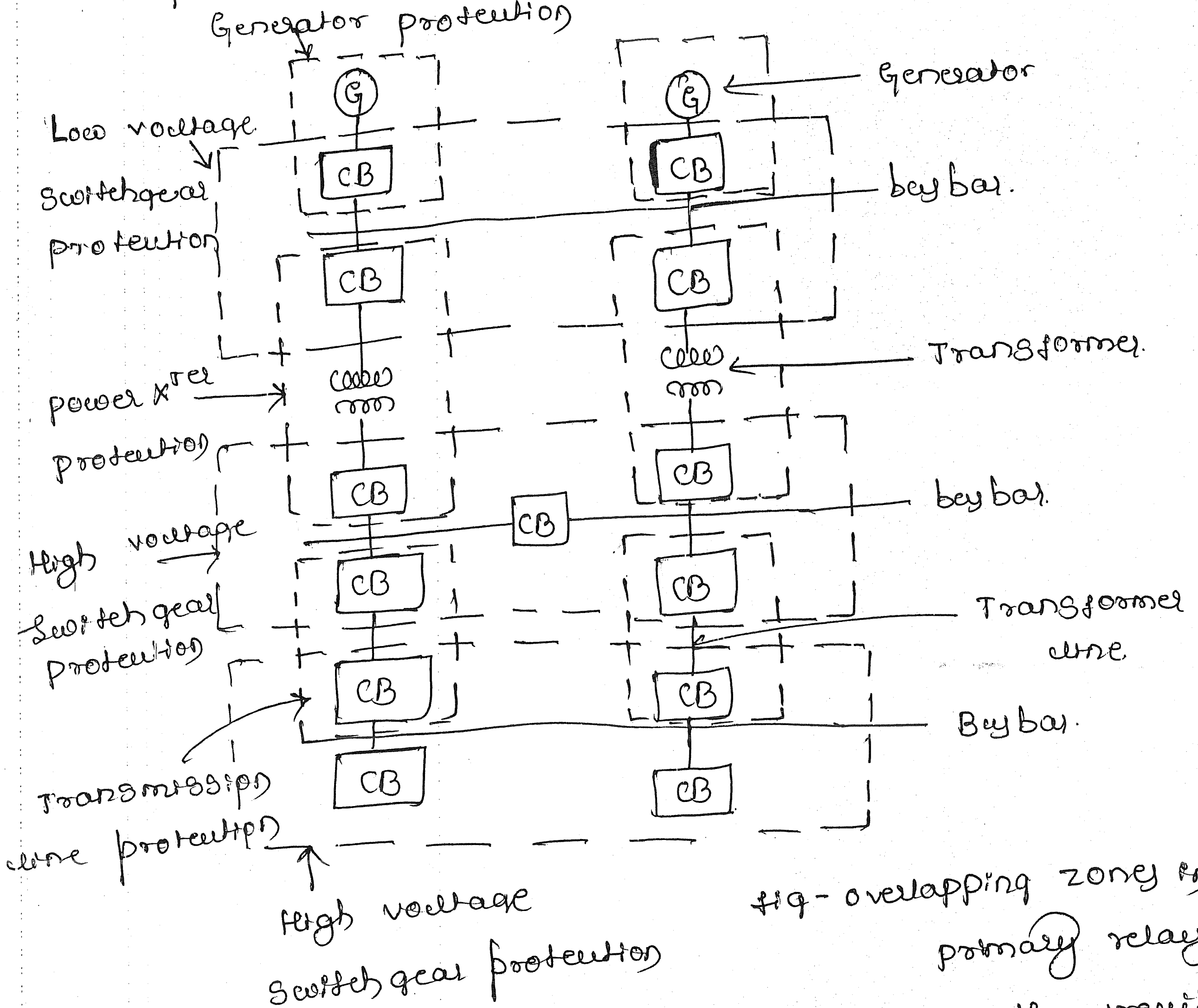


fig - overlapping zones in primary relaying.

from the above fig it is clear that the circuit breakers are located in the connections to each power sim element. This provision makes it possible to disconnect only the fault element from the system

* primary & Backup protection

Basically the protection provided by the protective relaying equipment can be categorised into two types 1) primary protection
2) Backup protection

* primary protection :- primary protection is the 1st step and it is responsible to protect all the power s/m elements from all the types of faults.

The Backup protection comes into picture when primary protection fails. However the backup protection is provided /considered as main protection which can fail due to certain reasons like.

1) Failure in circuit Breaker
2) Failure in protective relay.
3) Failure in tripping circuit
4) Failure in dc tripping voltage.
5) Loss of voltage or current supply to the relay.

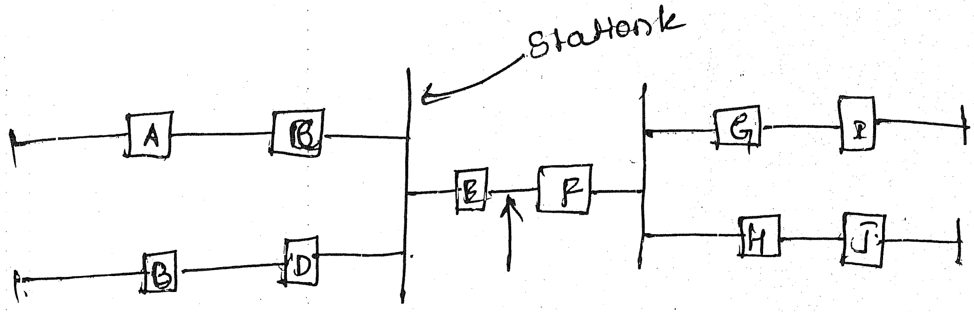
∴ if the backup protection fails & main protection fails then there is possibility to the severe damage to the s/m.

→ When the primary protection is made as inoperative for the maintenance purpose, the backup protection itself acts like main protection

→ The arrangement for the backup protection should be made such the failure in the main protection should not cause the corresponding failure in backup protection.

→ This is made satisfied only when the backup relaying & primary relaying do not have anything common.

* <u>Concept of Backup relaying.</u>



~~fig~~ Backup relaying.

Let us consider the backup relaying employed ~~considered~~ for tr-line EF as shown above.

The relays C, D, G & H are primary relays while A, B, I & J are backup relays.

→ Normally the backup relays are tripped if the primary relays fails.

→ i.e. if the primary relay E fails to trip the backup relays A & B are tripped.

→ Now the backup relays and associated backup relaying equipments are physically apart from the faulty equipment.

→ The backup relays A & B will provide protection to station k. & even the backup relays at A & F will provide backup protection for the faults in line DB.

→ The backup relays will provide primary protection when the primary relays are out of service. & while operation of backup relay larger part of the s/m is disconnected.

→ However the important requirement of backup relaying is that it must be operated with sufficient time delay so that the primary relay is given to chance to operate.

→ When the fault occurs both the type of relays stars operating but however the primary relay is excepted to ~~operate~~ trip 1st & backup relay will reset without having had time to complete its relay operation.

* Methods of Backup protection

* Relay backup protection :- In this type of protection a single breaker is used by both primary as well as backup protection but the two protective systems are different.

* Breaker backup protection :- In this method separate breakers are provided for primary & backup protection But both the types of breakers are used at the same station.

* Remote backup protection :- In this method, separate breakers are provided for primary & backup protection. The two types of breakers are at the different

stations and they are completely isolated & they are independent of each other.

* **Centrally co-ordinated backup protection:-** In this method, primary protection is at various stations. There is a central control room and backup protection for all the stations is performed at the central control room. If any element of any part of the sm fails load flow gets affected which is sensed by the control room. The control source consists of a digital computer which helps to decide proper switching action. The method is also called as centrally controlled backup protection.

* Classification of protective relays.

All the relays consists one or more elements which gets energised and actuated by the electrical quantities of the circuit. Most of the relays used nowadays are electro-mechanical type which works on the principle of electromagnetic attraction and electro-magnetic induction.

* Electromagnetic attraction type relays

The electromagnetic attraction type relays operate on the principle of attraction of an armature by the magnetic force produced by undesirable current or movement of plunger in a solenoid

The various types of these relays

1) Solenoid type :- In this relay, the plunger or iron core moves into a solenoid and the operation of the relay depends on the movement of plunger.

2) attracted armature type:- this relay operates on the c/n setting. When c/n in the circuit exceeds beyond the limit, the armature gets attracted by the magnetic force produced by the undesirable c/n. The c/n rating of the relay plays important role.

3) Balanced beam type:- the armature is fastened to balance beam. For normal c/n the beam remains horizontal but when c/n exceeds, the armature gets attracted and beam gets tilted causing the operation.

* Induction type relays.

These relays works on the principle of an electromagnetic induction. However the use of these relays is limited to ac quantities.

1) Induction disc type :- In this relay a metal disc is allowed to rotate b/n the two electromagnets. Basically there are two types of constructions are used for this type of relays

① shaded pole type ② watthour meter type.

2) Induction cup type :- In this relay, electromagnets act as stator & they are energized by relay coils. & the rotor is metallic cylindrical cup type.

* Directional type relays.

These relays works on direction of c/n or power flow in the circuit. the various types of these relays are →

1) Reverse c/n type :- The relay is actuated when the direction of c/n is reversed or phase of c/n becomes more than the predetermined value.

2) Reverse power type :- This type of relay is actuated when the phase displacement b/n applied vtg and current attains a specified value.

* Relays Based on Timing.

As the name indicates these type of relays can be controlled by the time instant b/n instant of relay operation & the time instant at which the contacts will trip.

The time relays are classified as follows.

1) Instantaneous type
2) definite time lag type
3) Inverse time lag type

* Instantaneous type :- In this type of relay no time is lost b/n the operation of relay & tripping of contacts. & However no intentional time delay is provided.

* Definite time lag type :- in this type of relay a definite time lag is provided b/n the operation of relay & tripping of contacts.

* Inverse time lag type :- In this type of relay, the operating time is approximately inversely proportional to the actuating quantity.

* distance type relays :-

These relays works on principle of measurement of voltage to current ratio. & these type of relay consists two coils. one coil is energized by current while other is by voltage. The torque produced is proportional to the ratio of the two quantities & relay operates when the ratio reduces below a set value.

⇒ The different type of distance type of relays are as follows. ⇒

1) Impedance type :- in this type of relay the ratio of voltage to current which is nothing but the impedance is considered which is propotional to the distance of relay from fault.

2) Reactance relays :- in this type of relay the operating time is propotional to the reactance, which is again propotinal to the distance of relay from fault point.

3). Admittance relays → This is also called as mho type of relay & Here operating time is propotional to the admittance.

* Differential type of relays.

A differential type of relay operates when the vector difference of two or more electrical quantities in the ckt in which relay is connected exceeds a set value

1) current differential type :- In this type of relay, the relay compares the c/n entering a section of the s/n & c/n leaving the section. While during fault condition these currents are different.

2) voltage differential type :- Here two xTers are used. the secondaries of both transformers are connected in series with the relay in such a way that the induced emfs are in opposition under normal conditions.

* other types of relays.

1) under voltage, current, power relay. → these type of relay operates when V, I or power in a ~~circuit~~ circuit falls below a set value.

2) over voltage, c/n, power relay :- This type of relay actuates when voltage, c/n, or power in a circuit rises above a set value.

3) Thermal relay :- this type of relay actuates due to the production of heat by the current in the relay coil.

4) Rectifier relay :- In this type of relay the quantities to be sensed are rectified and then given to the moving coil unit of the relay

5) permanent magnet moving coil relay :- In this relay, the coil carrying current is free to rotate in the magnetic field of a permanent magnet. This used for dc circuits

6) static relay :- this type of relay uses some electronic method for sensing the actuating quantity.

7) Gas operated relay :- The gas pressure is adjusted according to the variations in the actuating quantity. example - Buchholz relay.

* Essential qualities and characteristics of protective relaying.

1) Reliability
2) Selectivity & discrimination
3) speed and time
4) Sensitivity
5) stability
6) adequateness
7) Simplicity & economy.

* **Reliability**

→ A protective relay should be reliable which is a basic quantity of protective relay.

→ Reliability will indicate the ability of the relay s/m to operate under predetermined conditions.

→ However the reliability of protection s/m depends on the reliability of various components such as CB'S, relays, CT, PT, cables, trip circuits etc.

→ The reliability of the s/m can't be expressed in the mathematical expressions but can be judged from the statical data. The statical survey and records give good idea about the reliability of the protection s/m.

→ The reliability for the s/m can be achieved by considering the following factors

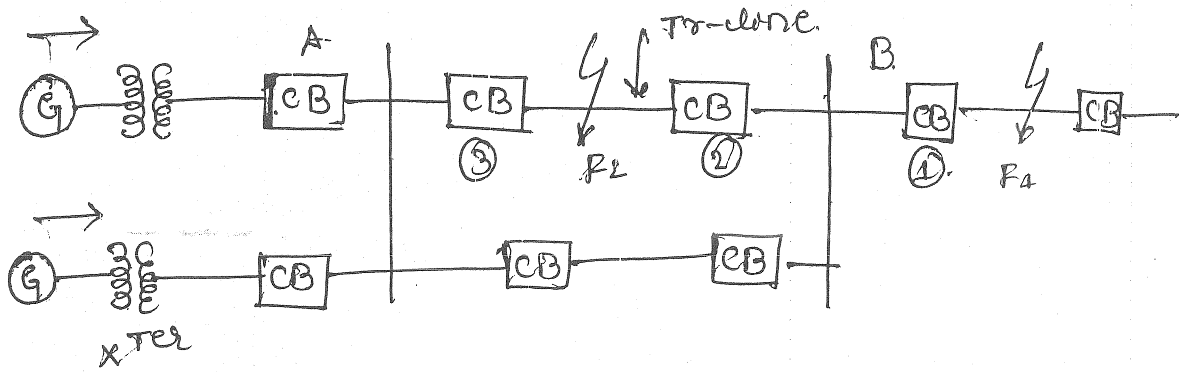
i) High contact pressure
ii) Good contact material
iii) Simplicity
iv) Dust free enclosure
v) careful maintenance

* **Selectivity & discrimination**

The selectivity is defined as it is the ability of the protective s/m to identify the faulty part correctly and separate only that faulty part of the power s/m without affecting the rest of the healthy part of the s/m.

→ The discrimination to distinguish b/n. i.e. it is the quality of the protective s/m to differenciate b/n normal and abnormal condition and also b/n abnormal condition and protective zone.

→ The protective s/m should not operate for the faults beyond its' protective zone. for example consider a portion of a typical power s/m as shown below.



-fig-

from the above fig it is clear that if fault F2 occurs on tr-line then the CBS ② & ③ should operate and disconnect the line from the remaining s/m

However the protective s/m should be selective while selecting faulty tr-line for fault F2 & it isolate it without tripping the adjacent tr-line breakers or XTer.

If the protective s/m is not selective then it operates for the faults beyond its protective zones & large part of the s/m gets isolated.

* **Speed and time**

A protective s/m must disconnect the faulty system as early as possible. If the faulty s/m ~~is not~~ disconnected for long time. then →

① the devices carrying fault c/n may get damaged.

② The failure leads to the reduction of s/m voltage. ∴ the reduction of voltage will affect the operation of motors and generators.

③ If the fault remains for longer time, the other faults may be gets generated.

The high speed of protective s/m avoids the possibility of such undesirable effects. However the fault clearing time should be as small as possible inorder to have high speed operation of protective s/m.

even though small fault clearing time is preferred, in practice certain time lag is provided because → ① To have clear discrimination b/n primary & backup protection.

② To prevent unnecessary operation of relays under different conditions such as transients starting inrush of current.

* **Sensitivity** :- The protective system should be sensitive so that it can operate reliably when required. Now the sensitivity of the s/m is the ability of the

relay s/m to operate with low value of actuating quantity.

The relay sensitivity is the function of volt-amperes input to the relay coil necessary to cause its operation. if smaller is the value of volt-ampere input more sensitive is relay. ∴ 1VA input relay is more sensitive than the 5 VA input relay.

Mathematically the sensitivity is expressed by the factor ks. which is defined as the ratio of minimum short circuit current in the protected zone to the minimum operating current required for the protection to start.

ie $k_s = I_s / I_o$

Where k_s = sensitivity factor

I_s = Minimum short circuit c/n in the zone

I_o = Minimum operating c/n for protection.

* **Stability** → The stability is the quality of the protective system due to which the s/m remains inoperative and stable certain specified conditions such as transients, disturbance, through faults Inorder to provide s/m stability, certain modifications are required in the s/m design.

* **Adequateness** :- There are no of faults and disturbancy those may practically appear in the power system However it is impossible to provide a protection

against each and every abnormal condition which may exist in practice, due to economical reasons, The adequateness of the slm can be assessed by considering following factors

1. Ratings of various equipments
2. cost of the equipments.
3. Locations of the equipments
4. probability of abnormal condition due to internal and external causes
5. discontinuity of supply due to the failure of the equipment.

* **Simplicity and economy**

In addition to all the important qualities it is necessary that the cost of the slm should be well within limits. In practice sometimes it is not necessary to use ideal protection scheme which is economically unjustified. In such cases compromise is done.

The protective slm should be as simple as possible so that it can be easily maintained. The complex slm are difficult from the maintenance point of view. The simplicity and reliability are closely related to each other. The simpler systems are always more reliable.

* Terminologies used in protective relaying.

The various terminologies used in the protective relaying are →

1) protective relay :- It is electrical relay, which closes its contacts when an actuating quantity reaches a certain preset value. Due to closing of contacts.

2) Relay time :- It is the time b/n the instant of fault occurrence and the instant of closure of relay contacts.

3) Breaker time :- It is the time b/n the instant at circuit breaker operates and opens the contacts, to the instant of extinguishing the arc completely.

4) Fault clearing time :- The total time required b/n the instant of fault and the instant of final arc interruption in the CB is fault clearing time. It is sum of the relay time and CB time.

5) pickup :- A relay is said to be picked up when it moves from 'OFF' position to 'ON' position. Thus when relay operates it is said that the relay has picked up.

6) pickup value :- It is the minimum value of actuating quantity at which relays starts operating.

7) Dropout or reset :- A relay is said to be dropout or reset when it comes back to original position.

* **Time delay** :- The time taken by relay to operate after it has sensed the fault is called time delay of relay. Some relays are instantaneous, while in some relays intentionally a time delay is added.

* **Sealing relays** or **holding relays** :- in this type of relay the relay contacts are designed for light weight & hence they are very delicate. When the protective relay closes its contacts, it is relieved from other duties such as time lag, tripping etc.

* **Current setting** :- The pickup value of the current can be adjusted to the required level in the relay which is known as current setting of relay. The c/n setting of relay can be achieved by the use of tapping on relay coil, as show below.

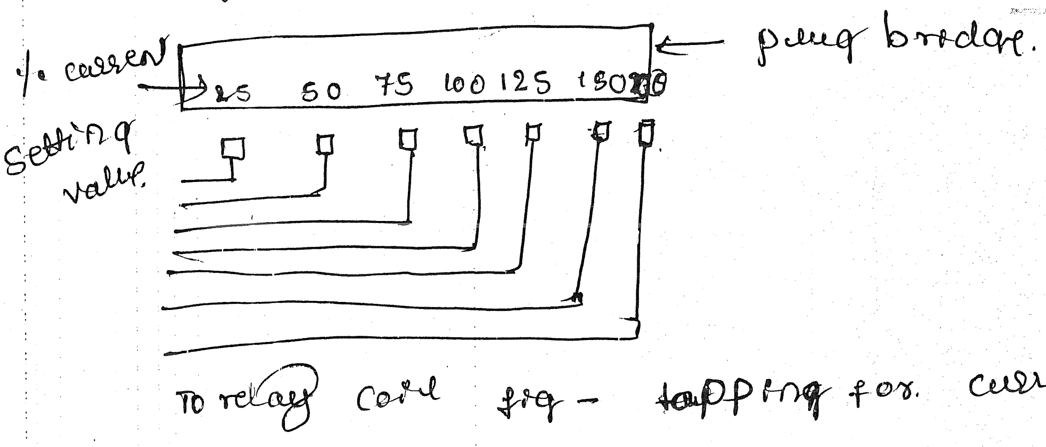


fig - tapping for current setting

as shown above the tap values are expressed in terms of % full load rating of CT with which relay is associated.

pickup current = % current setting × Rated secondary c/n of CT.

* **plug setting multiplier** :- (PSM) it is defined as the ratio of actual fault c/n in the relay coil to the pick-up c/n is called plug setting multiplier it is expressed Mathematically as follows.

PSM = Fault c/n in relay coil / pickup value

$$= \frac{\text{Fault c/n in relay coil}}{\text{\% current setting} \times \text{Rated secondary c/n of CT}}$$

* **operating force** :- The torque or force which tends to close the relay contacts is called operating force.

* **Restraining force** :- The force or a torque which opposes the operating force is called Restraining force. It prevents the closing of the relay contacts.

Unit-6. - Induction type relay

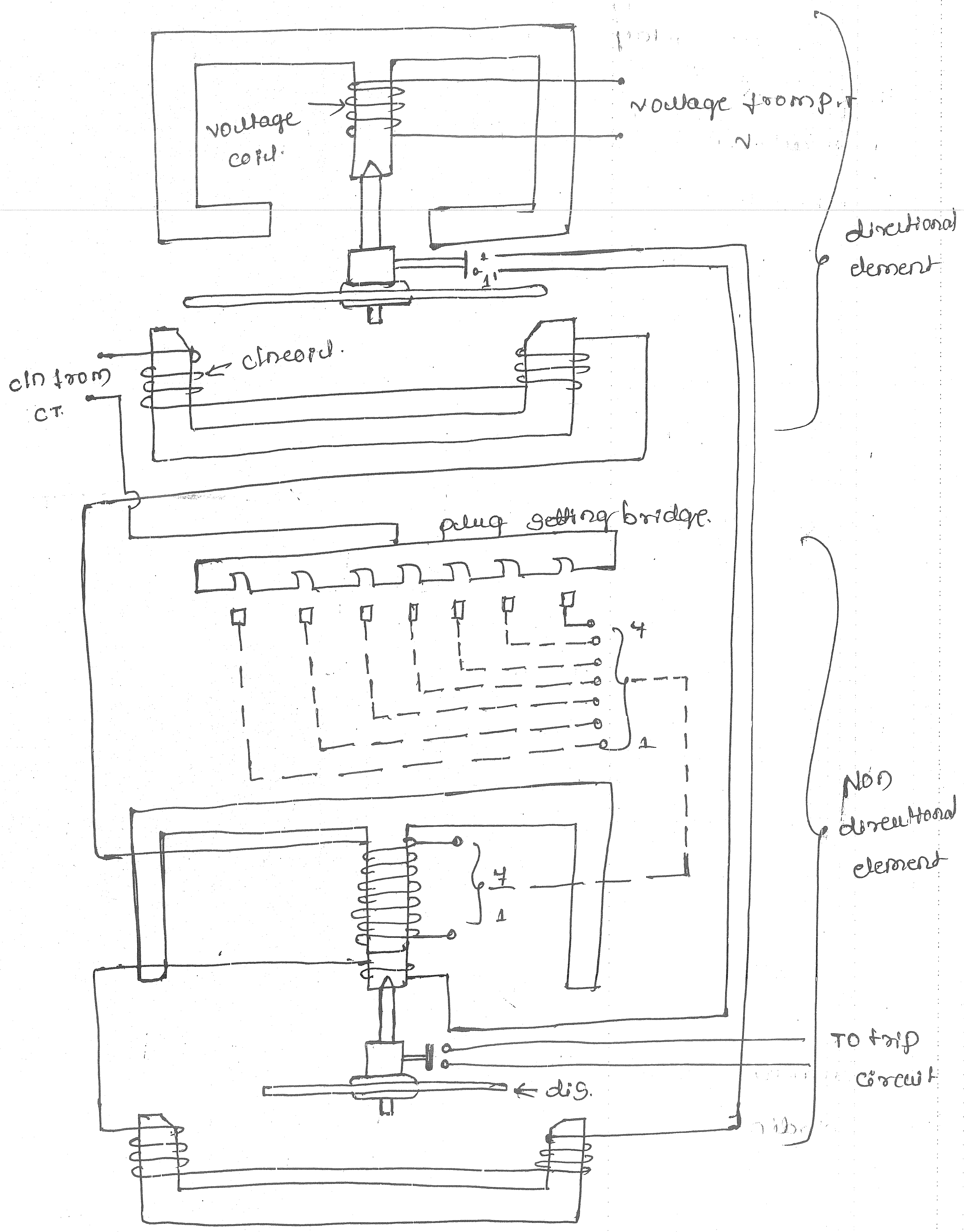


fig - Directional overcurrent relay.

The directional induction type overcurrent relay uses two different relay elements mounted on a common case. they are →

1) directional element which is directional power relay.
2) Non directional element which is nondirectional over current relay.

The schematic diagram of directional overcurrent relay is as shown in the above fig.

* **Directional element** :- The directional element is nothing but directional power relay which operates when power in the circuit flows in a particular direction.

→ The voltage coil of this element is energized by a s/m voltage through a potential transformer. where c/n coil is energized by the s/m current through a current transformer.

→ The trip contacts of this relay (1-1') are connected in series with the secondary wdg of nondirectional element.

* **Nondirectional element** :- The current coil of the directional element is connected in series with the primary winding of nondirectional element.

→ as shown in the above fig the plug setting bridge is provided to adjust current setting as per requirement.

→ The trip contacts (1-1') are in series with winding on lower magnet of nondirectional element i.e unless and until the trip contacts (1-1') are closed by the movement of disc of directional element, the nondirectional element can't operate.

→ i.e the movement of nondirectional element is controlled by the directional element.

*operation :-

under normal operating condition the power flows in proper direction. & hence the directional element of the relay is inoperative Thus the secondary winding on the lower magnet of nondirectional element is open & hence nondirectional element is also inoperative.

→ When the fault takes place, the c/n or power in the circuit has a tendency to flow in the reverse direction. The c/n flows through the cc of directional element which produces the flux.

→ The c/n in the voltage coil produces another flux. the two fluxes to interact with each other & they produce torque due to which the disc starts rotating.

→ As the disc rotates the trip contacts (1-1') gets closed.

→ The design of directional element is made such that it is much more sensitive and if voltage fally under short circuit, the cc is responsible to produce sufficient torque to have disc rotation.

→ However they are so much of sensitive even they operate at 2% of power flow in reverse direction.

→ Now the c/n also flows through the primary coil on the upper magnet of non directional element. Then it energizes the winding to produce the flux.

→ This amount of flux induces an emf in the secondary coil of nondirectional element.

→ Now as the contacts (1-1') are closed. the secondary winding ~~of~~ has a closed path. Hence induces emf drives the current through & produces another flux.

→ Now both the fluxes will interact to produce another driving torque due to which the disc starts rotating.

→ ∴ finally the contacts of trip circuit gets closed & it opens the circuit breaker to isolate faulty session.

→ However the directional relay has to operate 1st inorder to have operation of Non directional element.

→ The certain conditions are to be considered to operation of this relay they are as follows

① The direction of c/n in the ckt must reverse to operate directional element.

2) The c/n value in the reverse direction must be greater than the c/n setting.

3) The high value of c/n must persist for a certain time period which is more than the time setting of relay.

* **Directional characteristics**

Let us study the phasor diagram to understand the directional characteristics of the relay.

Let V = Relay voltage through PT

I = Relay coil c/n through CT

θ = Angle b/n V & I.

The s/m ~~voltage~~ current is generally lagging the voltage but with suitable connection the relay c/n is made to lead the voltage by an angle θ. due to this, the correct operation of relay at all the types of faults under all the s/m condition is ensured.

∴ the c/n I leads voltage V by an angle θ.

Let ϕ_V = Flux produced by voltage V

& ϕ_V lags voltage V by an angle ϕ

ϕ_I = flux produced by current I.

& ϕ_I is in phase with current I

The phasor diagram is as shown below

& voltage V is considered as reference

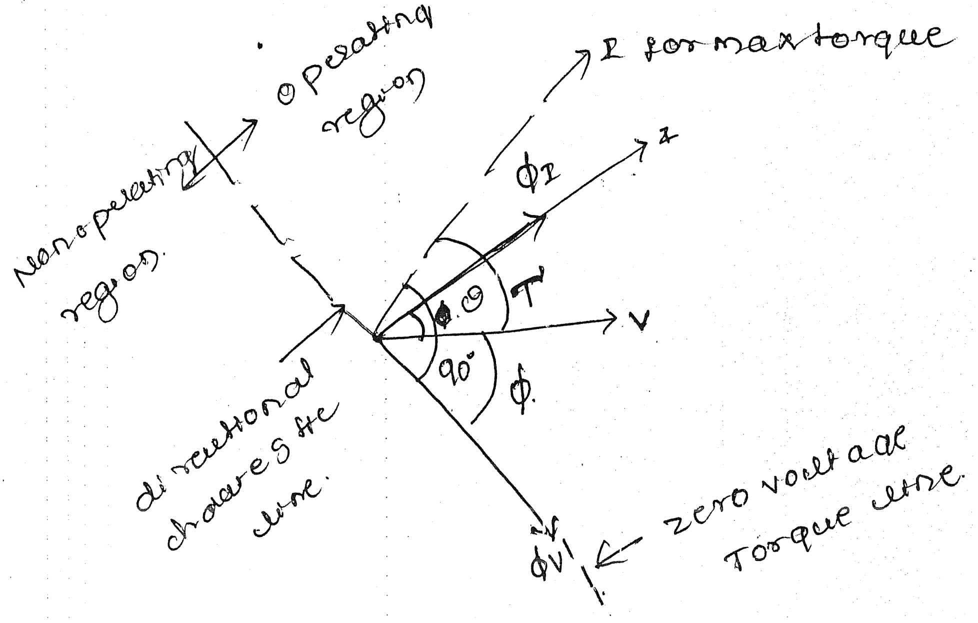


fig - phasor diagram of ~~directional chaaristiy~~ directional characteristic.

The torque is proportional to the fluxes ϕ_V, ϕ_I and sine of angle b/n both the fluxes.

$$\therefore T \propto \phi_V \phi_I \sin(\phi_V \wedge \phi_I)$$

$$\propto \phi_V \phi_I \sin(\theta + \phi)$$

Now $\phi_V \propto V$ $\phi_I \propto I$.

$$\therefore T = KVI \sin(\theta + \phi)$$ where k is constant

Max torque occurs when $\sin(\theta + \phi)$ is 1 ie $\theta + \phi = 90°$.

& torque is zero when $\sin(\theta + \phi) = 0$

ie $\theta + \phi = 0°$ or $180°$.

However the above condition is satisfied when the relay c/n I in in phase with ϕ_V. The corresponding line is called zero torque line shown in above fig.

Maximum torque angle :- it is denoted by τ

We have $T = KVI \sin(\theta + \phi)$ & Max torque angle occurs at $\phi = 90 - \tau$

$\therefore T = KVI \sin(\theta + 90° - \tau)$

$$\therefore T = KVI \cos(\theta - \tau)$$

* Nondirectional Induction type of overcurrent relay.

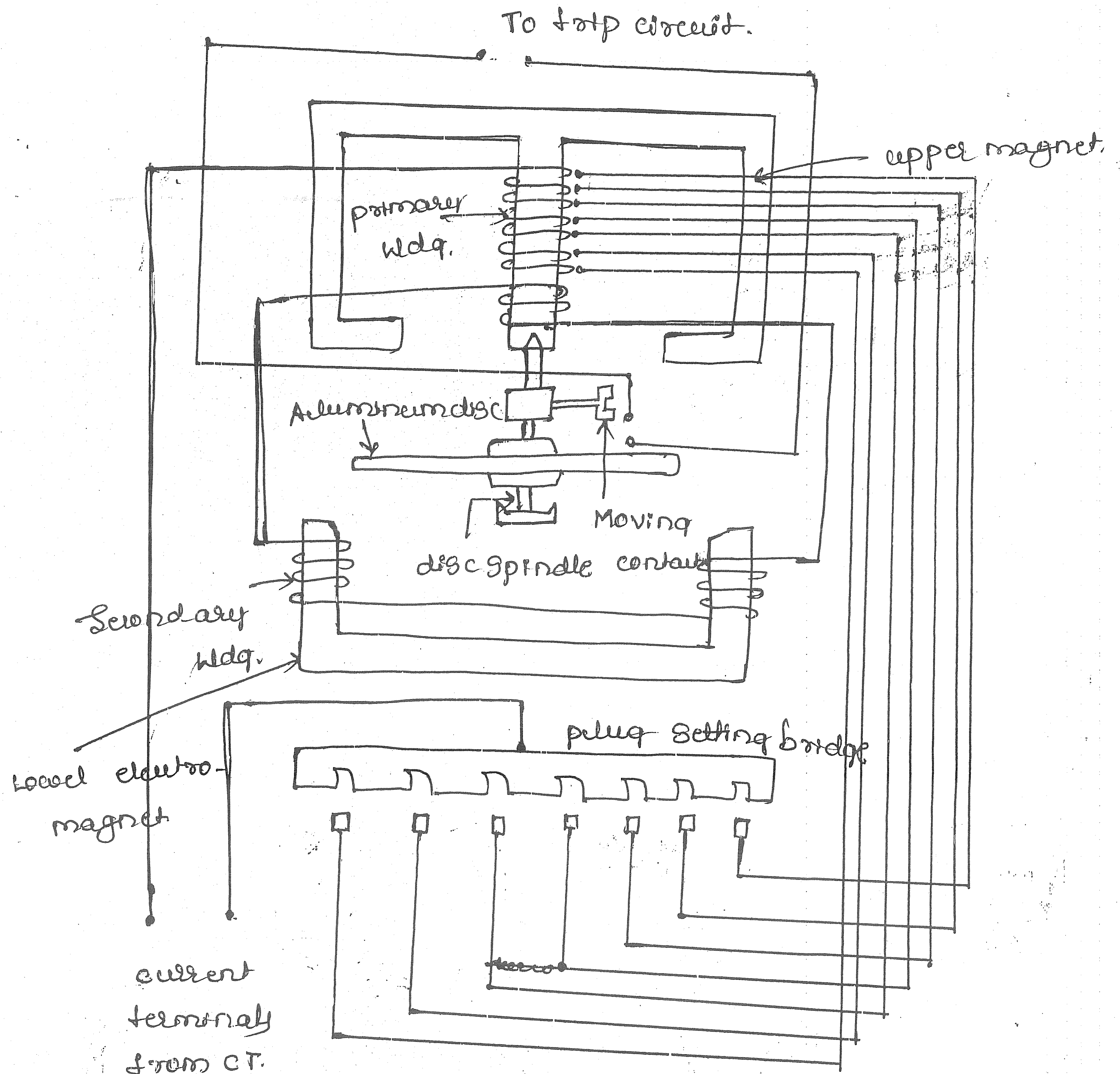


fig - Nondirectional Induction overcurrent relay.

Non directional Induction type of overcurrent relay is also known as earth leakage induction typ relay.

* The overcurrent relay operates when the c/n in the circuit exceeds a certain present value.

* above fig shows constructional details of Nondirectional Induction typeof overcurrent relay. The construction of relay is having similar construction to a watt-hour meter, with slight modification.

* as shown in the fig it consists of two electromagnets. The upper magnet is E shaped while lower magnet is U shaped. The light aluminium disc is free to rotate b/n two magnets.

* The spindle of light aluminium disc consist of moving contacts, when disc rotates the moving contacts comes in to the contact with fixed contacts which are the terminals of trip circuit.

* The upper have two windings, primary and secondary the primary is connected to the secondary of CT on the line to be protected.

* It consists of plug setting bridge, with the help of this bridge the no of turns of primary winding can be adjusted, to obtain the desired current setting for relay.

* There are 7 sections of tappings to have overcurrent range from 50% to 200% in steps of 25%.

* The current rating of relay may be 10A, but for 50% setting the relay will start operating at 5A. ∴ adjustment can be done by inserting a pin b/n spring loaded jaw of plug setting bridge
* The secondary winding on the central limb of upper magnet is connected in series with the winding on the lower magnet.
* When c/n exceeds its preset value, disc rotates and moving contacts on spindle makes connection with trip circuit terminals.
* angle through which disc rotates is in b/n 0° to 360°
* The travel of moving contacts can be adjusted by adjusting angle of rotation of disc.

* operation

under normal operating condition the restraining force is more than the driving force hence disc remains stationary.

under fault condition when c/n becomes high, the disc rotates through the preset angle and makes contact with fixed contacts of trip circuit. The trip circuit opens the circuit breaker, isolating faulty part from rest of healthy system.

* Time-current characteristics (Nondirectional Induction type of over current relay)

The time required to rotate the aluminium disc depends on Torque. The torque varies as c/n in the primary circuit.

* If the torque is more then lesser is the time required hence the relay has inverse time characteristics as shown below.

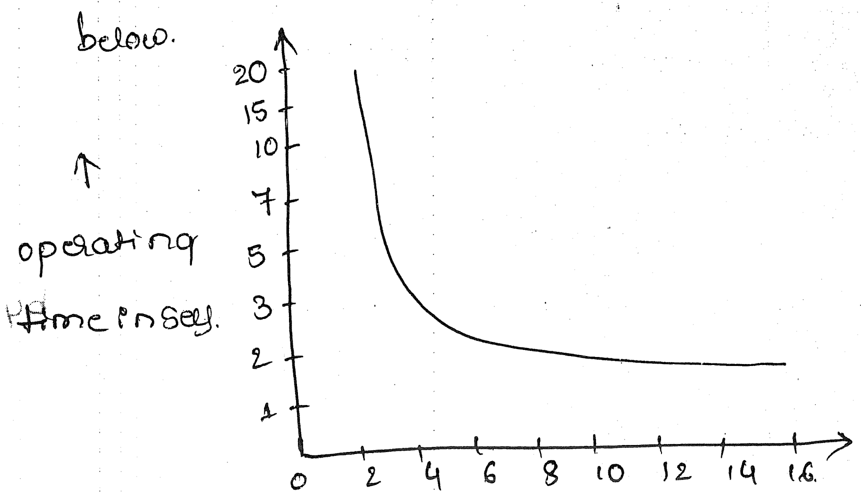


fig - time-current characteristics.

The above fig shows characteristics of overcurrent relay such characteristics are known as Inverse Definite Minimum type (I.D.M.T) characteristics.

→ this is due to the characteristic will shows inverse relation b/n time and c/n for small values of currents, But as c/n increases relay must require certain definitive time ∴ the characteristics becomes straight line for higher values of currents.

* Such IDMT characteristic can be obtained by saturating the iron in the upper magnet so that there can't be increase in the flux once c/n achieves certain high value.

PSM = $\frac{\text{fault c/n in relay coil}}{\text{rated secondary CT current} \times \text{c/n setting}}$

plug setting Multiplier.

∴ fault c/n in relay coil = line fault c/n × CT ratio.

* **Differential protection** :- In overcurrent relays, a c/n sensed but such relays are very sensitive as they can't differentiate b/n heavy loads and minor fault conditions. in such cases the differential relay are used.

Defn :- A differential relay is defined the relay that operates when the phasor difference of two or more similar electrical quantity exceeds a predetermined value.

* **Types of differential relay.**

1) c/n differential relay.
2) Biased beam relay or % differential relay.
3) voltage balance differential relay.

* **current differential relay.** :- Most of the relays are of current differential relay type.

Let us consider an over current relay connected in the circuit as shown below.

in order to operate as the current differential relay.

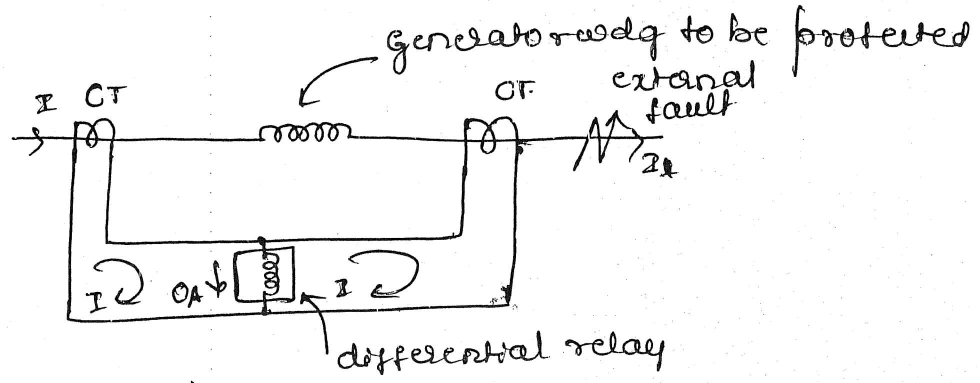


fig a) c/n differential relay

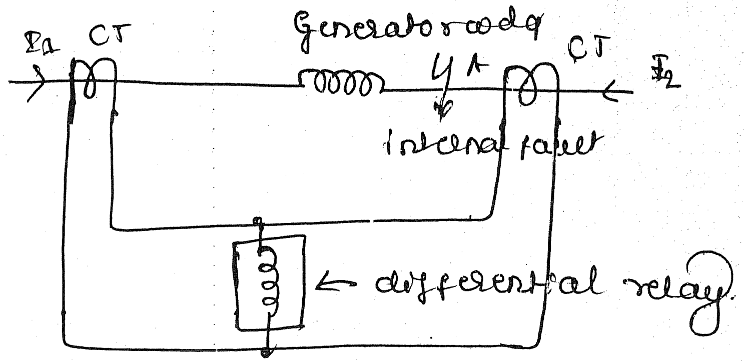


fig b- action of differential relay.

AS shown in above fig two current transformers having same ratio are connected on either side of the circuit to be protected. AS shown above the secondaries of current transformers are connected in series so that they carry induced currents in the same direction.

* as shown in fig@ Let c/n I is flowing through the primary of current transformer towards the external fault & as the CT'S are identical, the secondaries of CT'S will carry equal currents.
* under normal operating condition relay will be in-operative, even though external fault occurs no change in relay operation.
* If there is a occurance of internal fault, the c/n flows through the fault from both sides Now the c/n

flowing through the relay is $I_1 + I_2$ due to this high current the relay will operate.

However it is not needed to flow the fault c/n always from both sides., the amount of current flowing through the relay depends upon the fault being fed

* This relay have certain disadvantages

1) as shown above the CT'S are connected through cables known as pilot cables, The impedance of such pilot cables generally cause a slight difference b/n the c/ns at at the ends of the section to be protected. ∴ even though for a very small difference in two c/n'S the relay will even though their is a no fault in the s/m.

2). under heavy c/n ~~flows~~, the capacitance of pilot cable may cause inaccurate operation of the relay.

3) under severe fault conditions the CT may saturate and cause unequal secondary currents., which may cause inaccurate operation of relay.

* Voltage Balance differential relay

This type of relay is also known as opposed voltage method. in this method the overcurrent relay is connected in series with the secondary of CT'S.

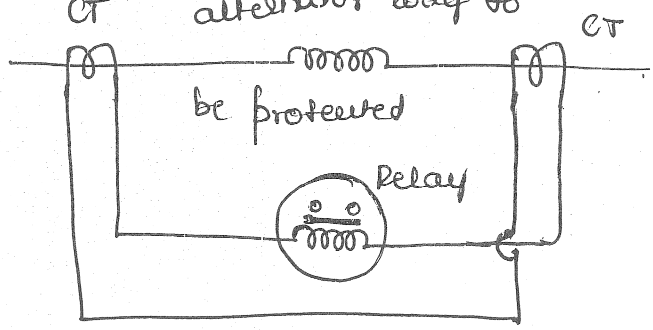


fig - voltage balance differential relay under normal operating condition. the c/n at the two ends of the section to be protected is same. Therefore their is no voltage drop across the relay to cause the current to flow.

under fault conditions, the currents in the two secondaries of current transformers are different. which will causes a large voltage drop across the relay. Thus the voltage balance of the circuit gets disturbed. Hence large c/n flows through the relay due to which relay operates to open circuit breakers.

* Biased beam relay or percentage differential relay.

As the name suggests this relay is designed to operate for the differential current in terms of its fractional relation with the actual c/n flowing through the protected circuit.

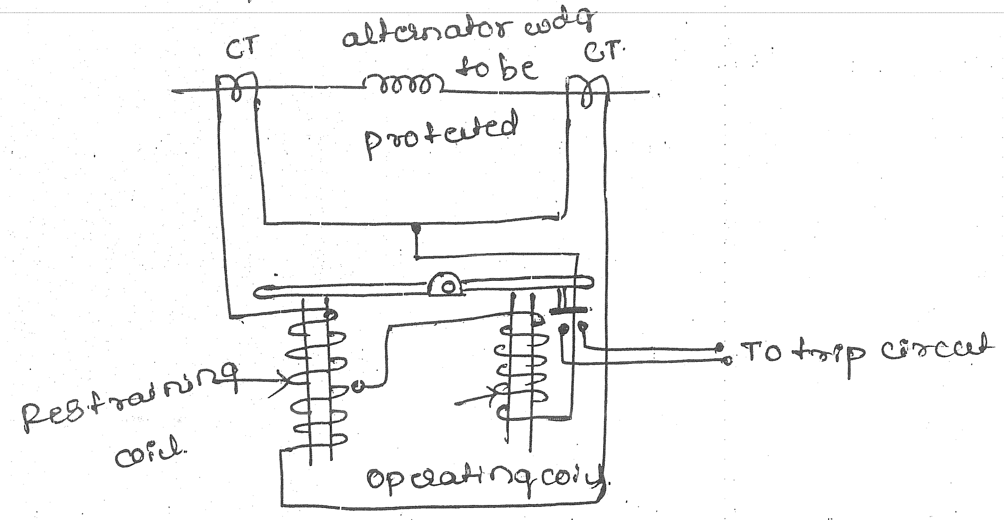


fig - biased beam relay.

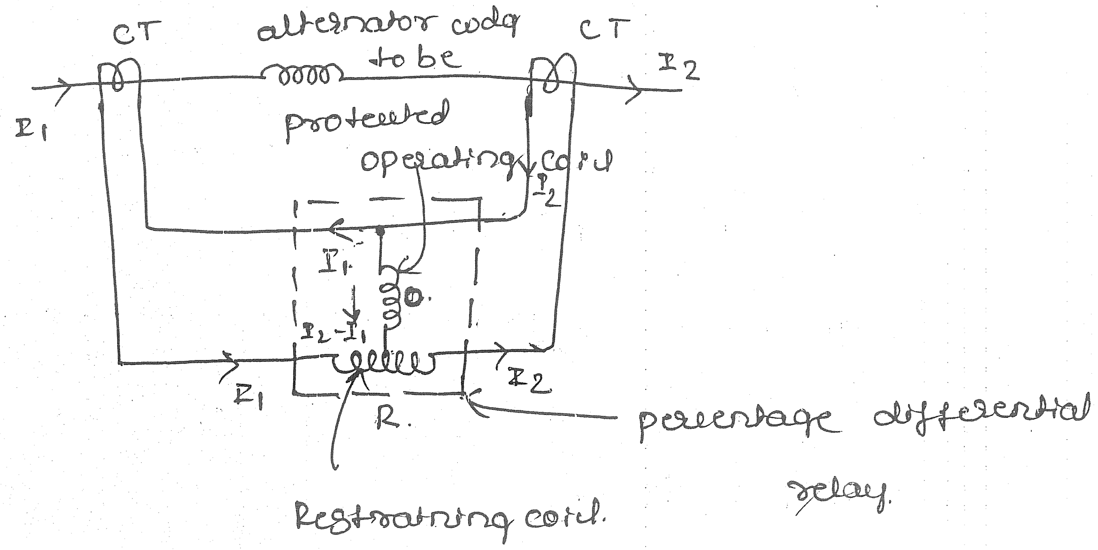


fig-b) Simple circuit of biased beam relay.

As shown in fig(b) the operating coil O, will carry a differential c/n $I_2 - I_1$, while the restraining coil

R carries the c/n proportional to $\frac{I_1+I_2}{2}$ as the operating coil is connected at the mid point of restraining coil.

Let N be the number of turns of restraining coil.

∴ c/n I_1 flows through N/2 turns & I_2 also flows through N/2 turns

∴ effective ampere turns $= \frac{I_1 N}{2} + \frac{I_2 N}{2} = N\left(\frac{I_1+I_2}{2}\right)$

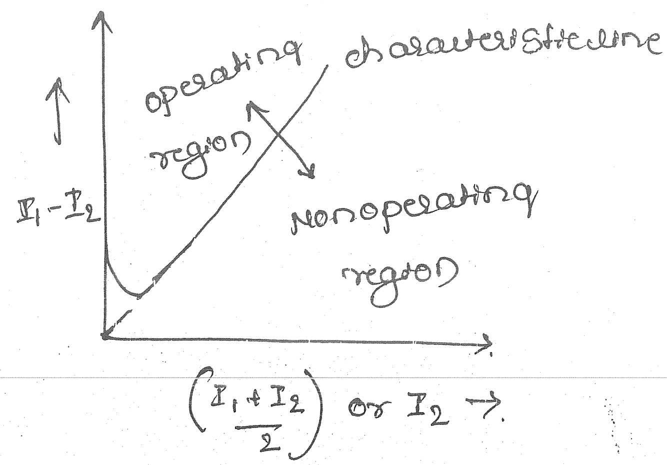
Thus it can be assumed that the c/n $\frac{I_1+I_2}{2}$ flows through the entire N turns of the restraining coil R.

* under normal operating coil the force produced by the restraining coil is much more greater the the operating force produced by the operating coil

∴ relay is inoperative.

* But when internal fault occurs the operating force is more than the bias force, due to this, the beam moves & trip contacts are closed to open CB

* The operating characteristics of this relay is as shown below.



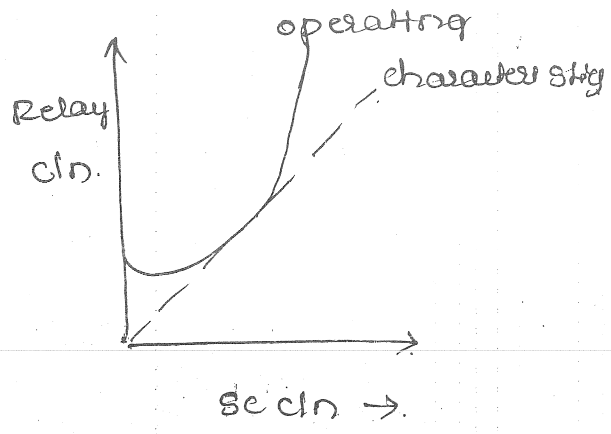


fig -c) operating characteristics   fig -d) increase in slope characteristic

from the fig it is clear except at low c/n the characteristics is a straight line.

→ ∴ the ratio of the differential operating c/n to the avg restraining c/n is a fixed percentage hence the relay is named as percentage differential relay

→ The relays with constant slope characteristic is called as constant slope % differential relay

→ In some relays the slope of characteristic will increase as se c/n increases.

→ constant slope relay require good accuracy in the performance of CT.

* distance relays

The relay which operates when the ratio V/I i.e impedance is less than the predetermined value as the ratio of V/I affects the operation of relay i.e these relays are also known as ratio relays.

* types of distance relays

1) Impedance relay which is based on meast of impedance Z.

2) Reactance relay which is based on meast of reactance X.

3) admittance or Mho relay which is based on meast of admittance Y.

* Impedance Relay.

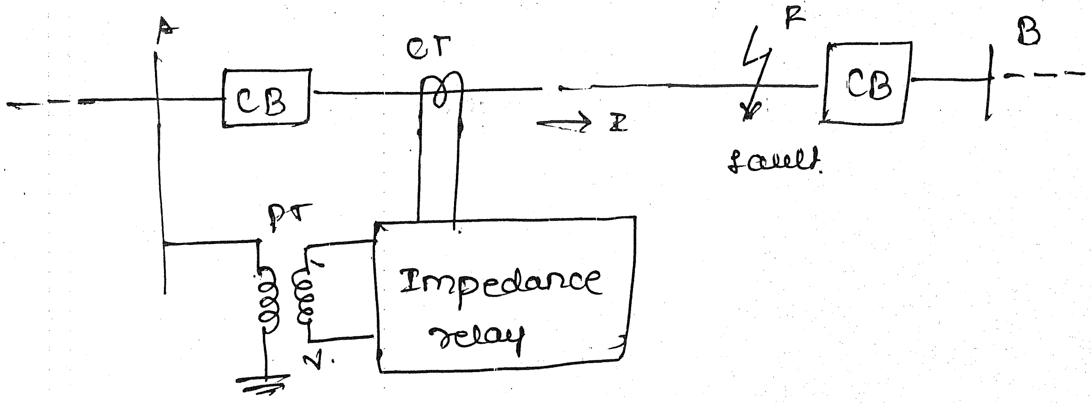


fig - Basic operation of impedance relay.

The above fig shows basic operation of impedance relay. The relay works corresponding to the ratio of voltage V and current I of the circuit to be protected.

→ There are two elements in this relay one produces a torque propotional to current while other produces a torque propotional to voltage

→ However the torque produced by the current element ~~produces~~ is balanced against torque produced by the voltage element.

→ The current element produces pickup torque, ie operating torque, ie +ve torque

→ The voltage element produces restraining torque, which is said to be a -ve torque ∴ the relay is voltage restrained overcurrent relay.

→ as shown in the above fig the c/n ~~element~~ is energised by the current through CT, while voltage element is energized by the voltage through PT, the section ~~of~~ AB of the line is to be protected.

→ under normal operating condition the ratio of voltage V & c/n I is denoted as Z_L, ie impedance of the line, the relay is inoperative during normal operating condition.

→ When fault occurs at point F the voltage decreases & current increases. ∴ the V/I reduces drastically.

∴ when impedance value Z_L, reduces than it predetermined value Z_L, it trips & makes the circuit breaker to open.

* **Torque equation :-**

The +ve torque produced by the c/n element is propotional I^2 while the negative torque produced by the voltage is propotional to V^2.

Let control spring effect produces a constant torque of $-k_3$. ∴ the torque equation becomes

$$T = k_1 I^2 - k_2 V^2 - k_3 \quad \text{—— (1)}$$

where k_1, k_2 are the constants, where V, & I are rms value.

At the balance point, when the relay is on the verge of operating, the net torque is zero, hence we can write.

$$k_1 I^2 - k_2 V^2 - k_3 = 0. \quad \text{—— (2)}$$

$$\therefore k_2 V^2 = k_1 I^2 - k_3$$

Divide equation on both sides by $k_2 I^2$.

$$\therefore \frac{V^2}{I^2} = k_1/k_2 - \frac{k_3}{k_2 I^2}$$

$$Z^2 = k_1/k_2 - k_3/k_2 I^2 \quad \text{—— (3)}$$

$$Z = \sqrt{k_1/k_2 - k_3/k_2 I^2}$$

Generally the spring effect is neglected as its effect is dominant at low currents which which are generally do not occur. ∴ $k_3 = 0$.

$$\therefore Z = \sqrt{k_1/k_2} = V/I = \text{constant} \quad \text{—— (4)}$$

* operating characteristics

$Z = \sqrt{K_1/K_2} = V/I =$ constant from this equation it is stated that the impedance relay is depends on a given constant value of the ratio V/I which can be expressed as impedance.

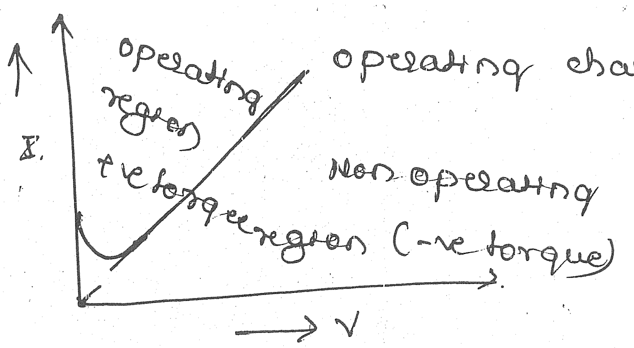


fig - operating characteristics.

for a particular fault position the ratio of V/I is constant. It changes if the impedance value is constant. fault position changes

* If fault is near to relay then the ratio of V/I is low & if fault position is away from the relay the the ratio V/I is higher and higher.
* ∴ the relay is installed to operate for the section which is to be protected & once it is installed & placed particular section it is inoperative beyond that section
* By adjustments, the slope of the characteristic can be changed so that the relay will respond to all the values of impedance less than any upper desired limits.

* operating characteristics on R-X diagram.

The operating characteristics of an impedance relay can be more easily represented by a diagram known as R-X diagram which is shown as below. This plane is called as R-X plane. The impedance z can be expressed as

$$z = R + jX$$

$$|z| = \sqrt{R^2 + X^2}$$

$$z^2 = R^2 + X^2 \quad \text{——— (1)}$$

Mathematically $x^2 + y^2 = r^2$ represents an equation of circle

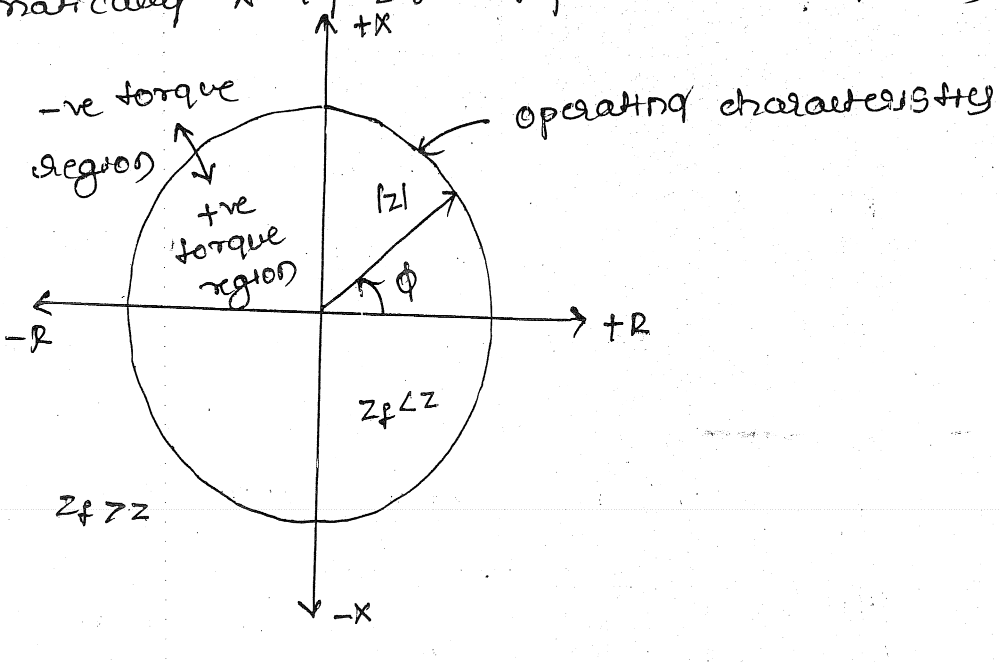


fig - characteristic on R-X diagram.

Where x & y are vertical & horizontal co-ordinates & r is radius. from equation (1) we can write

$\tan\phi = X/R \implies \phi = \tan^{-1} X/R$

However the values of ratio of V & I determine the length of the radius vector z while the ϕ b/n V & I determines the exact position of the vector z.

at any value of Z less than the radius of the circle the relay operates. ∴ the entire portion inside the circle is +ve torque region ie operating region of the relay. While outside the circle is negative torque region ie inoperative region.

If Z_f = Impedance b/n relay & fault point
Z = Set value for impedance = Radius of circle

for $Z_f < Z$ —— Relay operates
$Z_f > Z$ ⟶ Relay inoperative

* Reactance relay

In reactance relay the operating torque is obtained by the current while the restraining torque is due to current-voltage directional relay. The overcurrent element produces +ve torque and directional unit produces negative torque.

* Construction

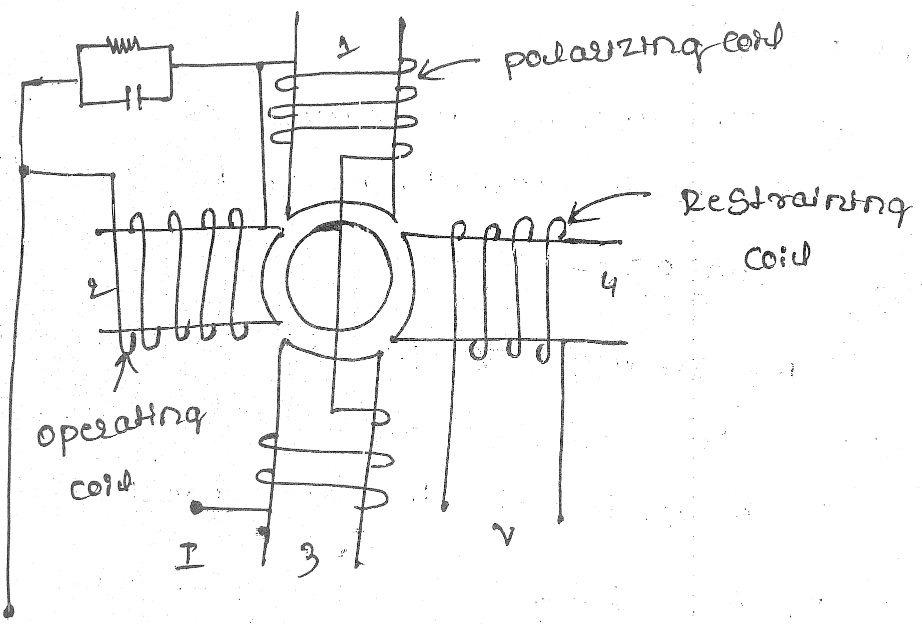


fig - Schematic arrangement of reactance relay.

The above fig shows schematic representation of reactance relay which is a induction cup type. It is a four pole structure.

* as shown above it has operating coil, polarizing coil and restraining coil.
* Initially current I flows from pole 1, through iron core stalling to lower pole 3. The winding on pole 4 is fed from supply voltage V.
* The operating torque is produced by the interaction of fluxes due to the windings carrying current coils ie the interaction of fluxes produced by the poles 1, 2 and 3.

* The restraining torque is produced due to the interaction of fluxes due to the poles 1, 3 & 4.

∴ The operating torque is propotional to the square of current (I^2) while restraining torque is propotional to the product of voltage and current I (VI).

* However the desired maximum torque angle is achieved with the help of RC circuit.

* Torque equation :-

The driving torque is propotional to the square of current while the restraining torque is propotional to the product of V & I.

∴ The net torque equation of the relay neglecting the spring effects given by.

$$T = k_1 I^2 - k_2 VI \cos(\theta - \tau)$$

at the balance net torque is zero,

$$\therefore k_1 I^2 - k_2 VI \cos(\theta-\tau) = 0$$

$$\therefore k_1 I^2 = k_2 VI \cos(\theta-\tau)$$

$$k_1 = k_2 \frac{V}{I} \cos(\theta-\tau)$$

$$k_1 = k_2 Z \cos(\theta-\tau)$$

Adding capacitor, the torque angle is adjusted to 90°

$$\therefore k_1 = k_2 Z \cos(\theta - 90°)$$

$$k_1 = k_2 Z \sin\theta$$

$$\boxed{\therefore Z \sin\theta = k_1/k_2}$$

Let us consider the impedance ∆le as shown below.

$Z\sin\theta = X =$ Reactance

$Z\cos\theta = R =$ Resistance

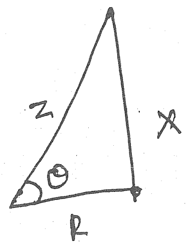


fig - impedance ∆le

$X = k_1/k_2 =$ constant

$\therefore$ The relay operates on the reactance

The constant X means a straight line ||el to X-axis.

* operating characteristics.

The operating characteristics of admittance relay is a straight line ||el to x-axis on R-X diagram

⇒ as shown in the below fig all the impedance vectors having their tips lying on straight line representing constant reactance.

* It is clear the resistance component of the impedance has no effect on the operation of the relay.

* The relay responds only to the reactance component of the impedance. The relay will operate for all the impedance whose heads lie below the operating characteristics as shown below.

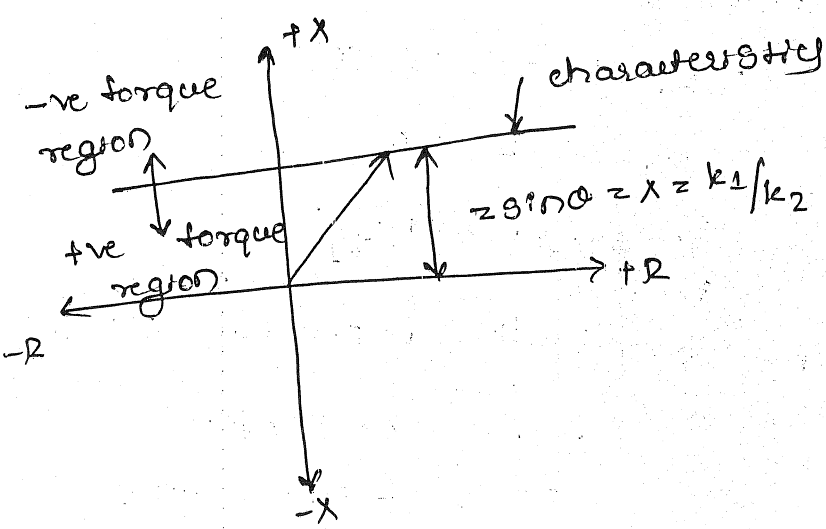


fig - operating characteristics of reactance relay

* Disadvantages

1) This type of relay is not be able to discriminate when used on tr-line.

2) It is not possible to use a directional relay of the type used with base relay of the type used with base impedance relay because in that case the relay will operate even under normal load conditions if the sim is operating at or near upf conditions

* Mho relay or admittance Relay

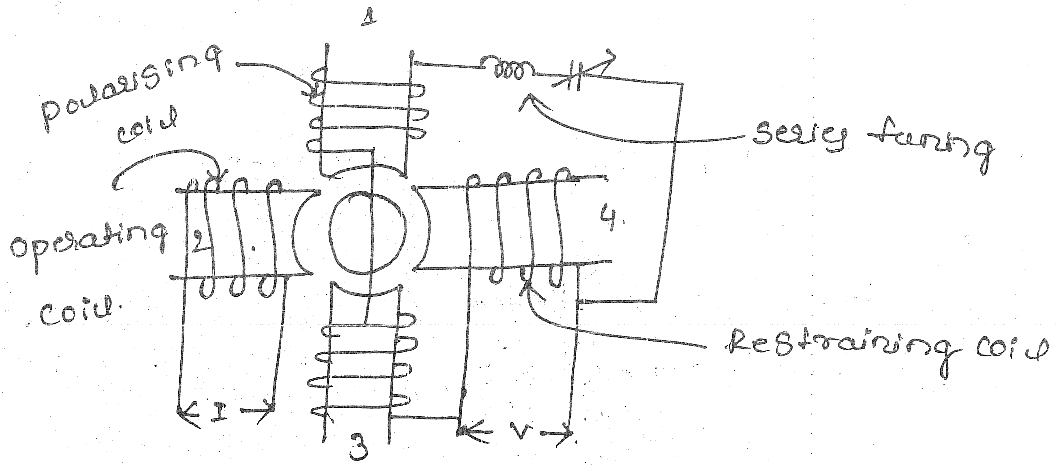


fig - schmatic arrangement of admittance relay.

In the impedance relay a separate unit is required to make it directional. The mho really is made inherently directional by adding a voltage winding called polarizing winding.

* Construction

The structure of mho relay is induction cup type, it consists of operating coil, polarizing coil & restraining coil.

→ The schematic arrangement of mho really is as shown in the above fig.

→ In this relay the operating torque is obtained by V and I element while restraining torque is obtained by voltage element.

→ The operating torque is produced by the interaction of fluxes due to the windings carried by poles

1, 2 and 3. while the restraining torque is produced by the interaction of the fluxes due to the windings carried by the poles 1, 3 & 4.

→ ∴ The restraining torque is ~~produced~~ proportional to the square of voltage (V^2). while the operating torque is proportional to the product of voltage and current (VI).

→ However the torque angle is adjusted using series tuning circuit.

* **Torque equation**

The operating torque is proportional to VI while the restraining torque is proportional to V^2

∴ The torque equation is given by

$$T = k_1 VI \cos(\theta - \tau) - k_2 V^2 - k_3.$$

Where k_3 = control spring effect.

Generally k_3 is neglected & at the balanced condition net torque is zero.

$$\therefore k_1 VI \cos(\theta - \tau) - k_2 V^2 = 0.$$

$$k_1 VI \cos(\theta - \tau) = k_2 V^2.$$

$$k_1 \cos(\theta - \tau) = k_2 \frac{V^2}{VI}$$

$$k_1 \cos(\theta - \tau) = k_2 \frac{V}{I}.$$

$$\therefore Z = k_1/k_2 \cos(\theta - \tau)$$

∴ The above equation represents the equation of circle with diameter k_1/k_2 passing through origion.

* operating characteristics.

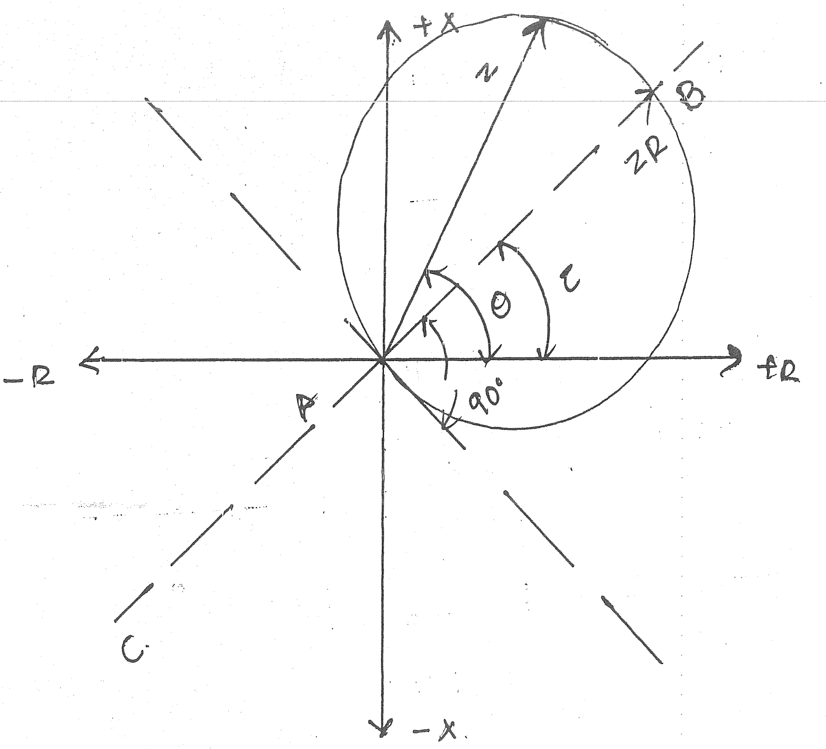


fig - operating characteristics of mho relay.

from the torque equation it is clear that the characteristic of this relay is a circle passing through the origion with diameter k_1/k_2

Let $k_1/k_2 = Z_R$ = ohmic setting of relay
= diameter.

→ This type of relay operates when the impedance seen by the relay within this circle.

→ consider two lines AB and AC with mho relay located at the point A, the relay is going to be operated for the faults occuring within the section AB only and not for the faults occuring in the section AC.

* Three stepped distance protection of tr-line

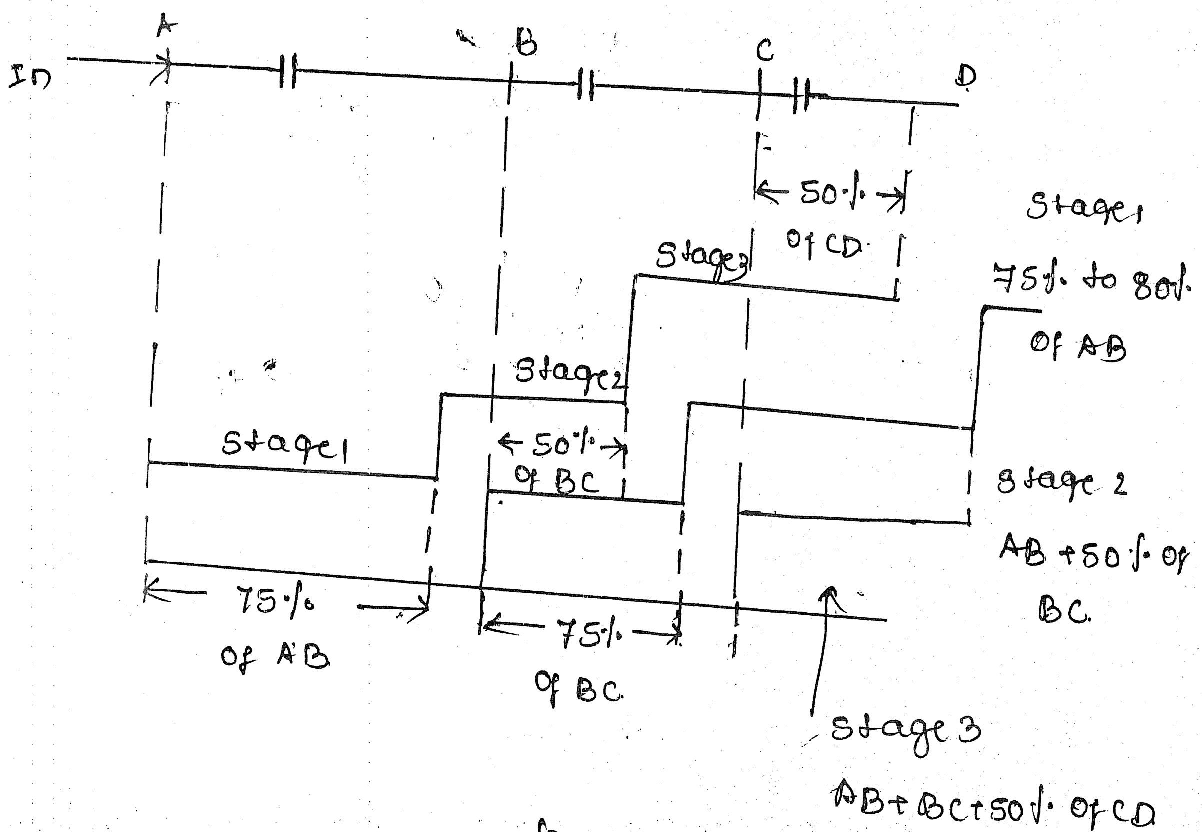


fig - High speed for line protection.

practically in some cases it is much more necessary to operate the relay very fast, within 20ms, their is need to rapidly disconnect the fault. Such a relays are known as high speed distance relays.

* The high speed protection of tr-line uses the combination of.

1) definite impedance relay elements are used to operate instantaneously when fault

occur within the nearest 75% or more of the tr-line section to be controlled.

2) A short definite time lag is introduced to cover the faults in the remaining sections of line & for backup protection to the remaining section.

→ However the protection practically uses three steps using 3 definite impedance elements on each phase.

step-1) → it is set to operate within 1st 75% to 80% of the tr-line section.

step-2) it is set to operate remaining 25% of the next line section. and 50% of the faults beyond

step-3) it is set to operate the next line section. the 50% of the time delay of 0.4 seconds for step 2 the time delay 0.8 second is used & for step 3 the

However with the help of this very fast & rapid fault clearing can be achieved

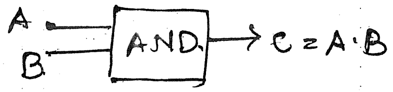
* **Microprocessor based relay.**

Now let us consider the relay logic which is important to understand the microprocessor based relay.

The three basic logic functions are.

1) AND 2) OR 3) NOT

1) AND function.

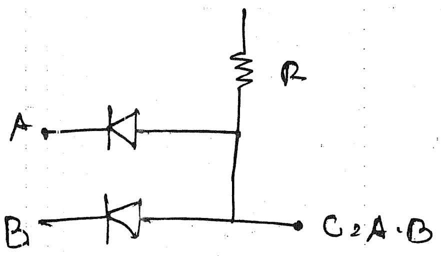


a) Block diagram

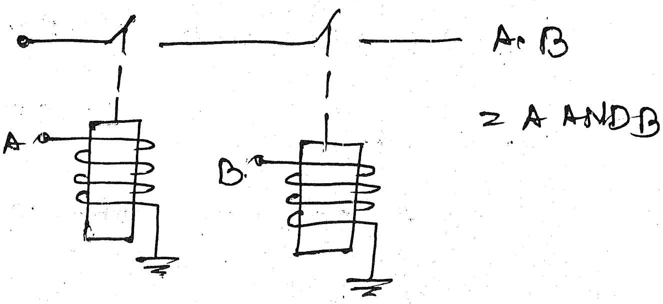
A	B	C = A·B
0	0	0
0	1	0
1	0	0
1	1	1

b) truth table.

The above fig shows the Block diagram & truth table of AND gate.



c) diode AND



d) AND with relays.

fig c & d represents the AND gate with diode and AND with relays.

* OR function

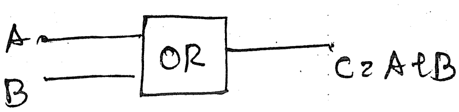
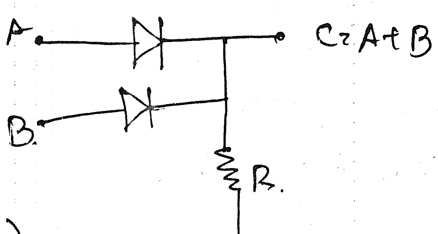


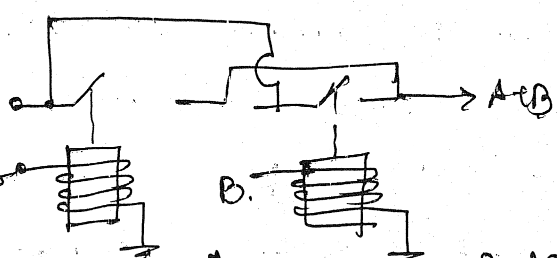
fig- Block diagram

b) truth table

A	B	C = A+B
0	0	0
0	1	1
1	0	1
1	1	1

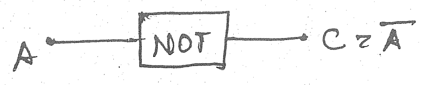


c) diode OR



d) OR with relays

* NOT function.



a) Block Schematic

A	C = $\bar{A}$
0	1
1	0.

b) Truth table

The NOT function is inverting of the input.

By using NOT with basic AND and OR the two logical functions can be obtained ie NAND & NOR.

* Microprocessor based overcurrent relay.

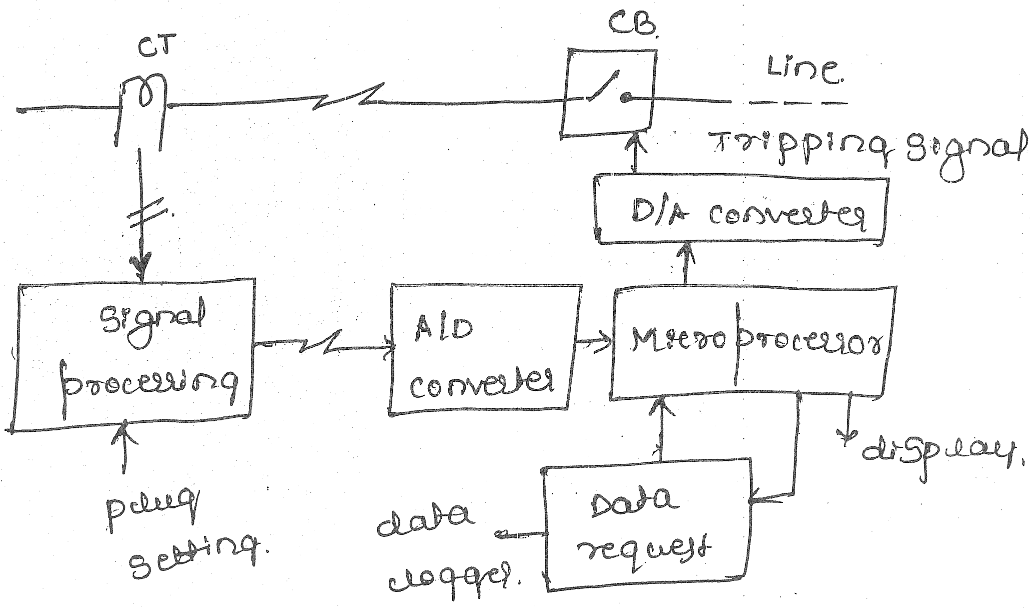


fig - Microprocessor based overcurrent relay.

above fig shows block diagram representation of Microprocessor based over current relay.

→ as shown above the output of line CT is given to the signal processing unit, where i/p signal is processed.

→ The signal. processing unit consisting of surge protector, rectifier, smoothening filter, auxiliary CT etc.

→ The out signal of signal processing unit is analog in nature, with the help of A/D converter the signal converts into digital which is accepted by the microprocessor.

→ The digital signal received is compared with reference to generate the proper tripping signal

→ which is a digital again it is converted into analog to operate tripping coil, this is achieved by D/A converter.

→ The data logger captures the data and feed into the microprocessor when there is a request from the microprocessor.

→ finally the information can be displayed with proper display device by taking signal from the micro processor.

→ The main advantage of such relay is it is programmable.

→ one more advantage is microprocessor unit can perform the relay operation of several systems

* The various advantages of micro processor based relay are.

1) very efficient and reliable.

2) very fast for operation
3) Highly accurate
4) programmable in nature
5) Economical for large slms.
6) one unit can perform relaying of several systems
7) They are useful centrally co-ordinated backup protection.

Only care must be taken the microprocessor unit must be properly shielded as the relay is gets affected due to interferences and environment & proper care of earthing must be taken.

* **Buchholz Relay**

The Buchholz relay is gas operated relay, which is used to protect oil immersed x^{Tey} against all the types of internal faults. This relay is named after its inventor Buchholz.

→ Some time the slow ~~operating~~ developing faults called incipient faults in x^{Ter} tank below oil level, operate Buchholz relay which gives an alarm & if the faults are severe then it disconnects x^{Ter} from the supply.

It uses the principle that, whenever their is a occurance of fault, oil in the x^{Ter} tank decomposes & generates gases. The 70% component of such gases is hydrogen which is light and hence moves upwardly toward converter through pipe.

→ due to the collection of gas in the upper portion of the relay, the relay operates & gives an alarm

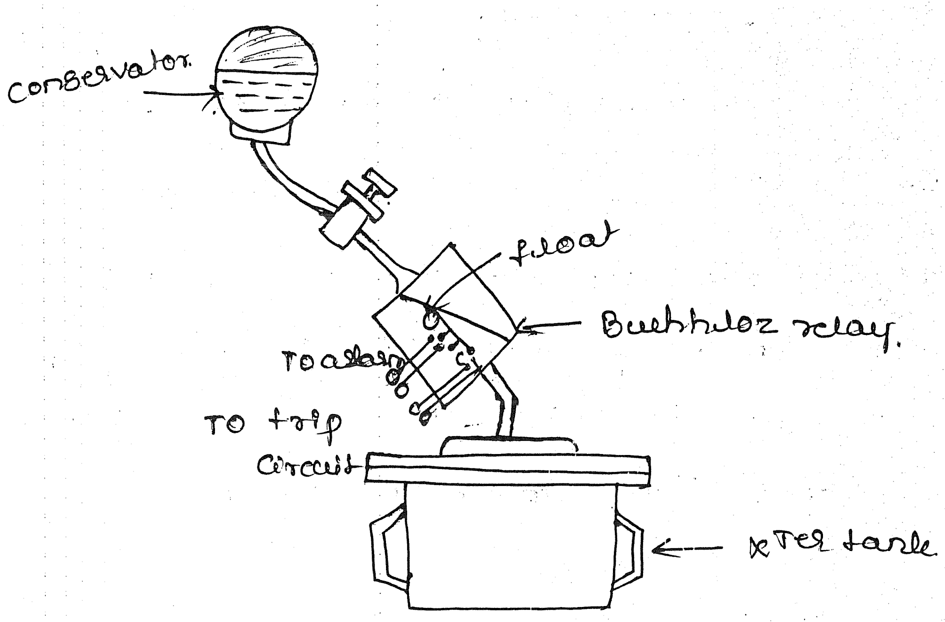


fig a- Basic arrangement of Buchholz relay

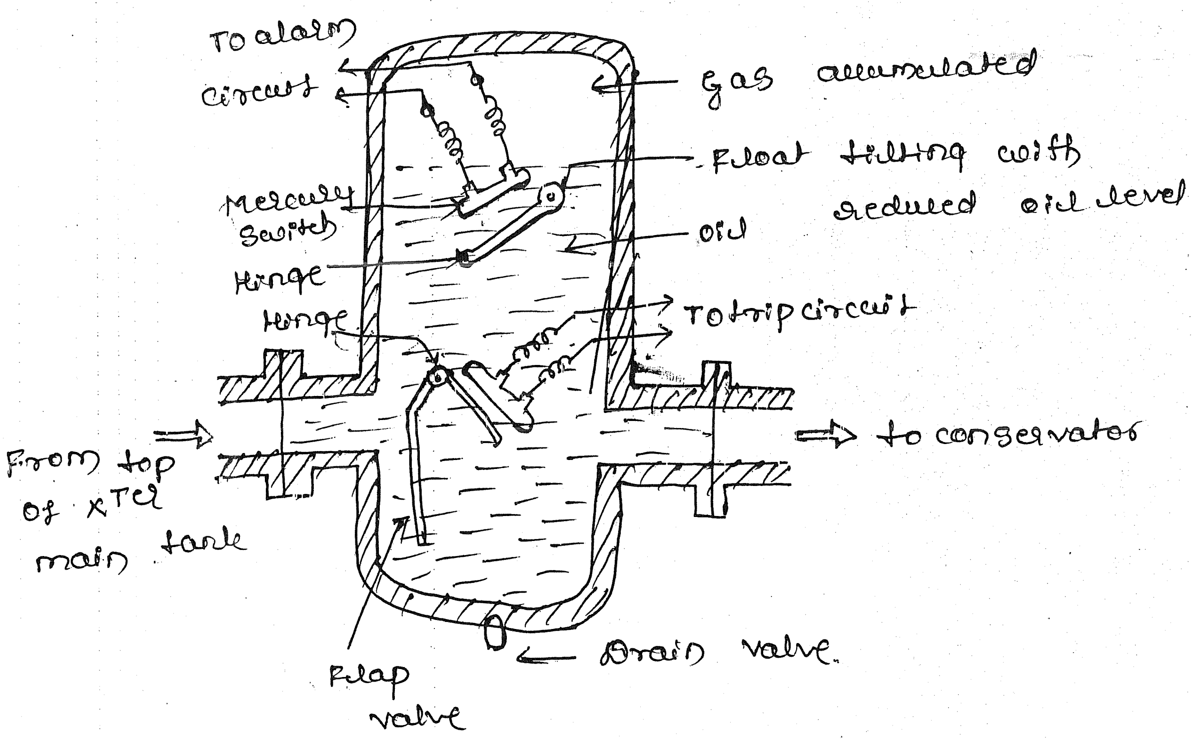


fig-b) construction of Buchholz relay.

under normal conditions the Buchholz relay is full of oil. It consisting of a cast housing containing a hollow float, A mercury switch is attached to a float. another flap valve is attached in the lower part which is the path of oil b/n tank & the conservator.

* **operation**

There are many types of internal faults such as insulation fault, core heating, bad switch contacts, faulty joints etc.

→ When fault occurs the decomposition of oil in the main tank starts due to which the gases are generated, & the major component of such gas is Hydrogen.

→ Hydrogen gas tries to rise upward towards conservator & it is gets accumulated in the upper part of the Buchholz relay.

→ When gas gets accumulated in the upper part of housing, the oil level inside the housing falls due to which the hollow float tilts and close contacts of the mercury switch attached to it. which causes the alarm circuit to sound an alarm.

→ due to alarm the operator comes know that there is some fault has been occured.

→ Then the X^{TER} is disconnected and the gas sample is tested.

→ However if some serious fault such as internal SC b/n phases, earth fault inside the tank etc, i.e. then considerable amount of gas is generated. They due to fast reduction in oil level the pressure inside tank increases.

→ Now the flap valve gets deflected the trip circuit which opens the CB. they X^{mer} is totally disconnected from supply.

→ The connecting pipe b/n the tank and the conservator should be straight as possible & it should slope ~~tow~~ upwards conservator at a small angle. the angle should be 10° to 11°.

→ for the economic considerations, Buchholz relays are not provided for the x^{mers} having rating below 500kVA.

* <u>Advantages</u>

1) It is the simplest protection in case of x^{mer}
2) Normally protective relay will not indicate the appearance of fault, it operates when fault occurs. But Buchholz relay gives an indication of fault at very 1st stage of fault occurrence.

* <u>Limitations</u>.

1) Buchholz relay is used only for oil immersed x^{mer} having conservator tanks.
2) The faults below oil level are detected.
3) The relay is slow to operate having minimum operating time of 0.1 seconds and avg time is 0.2 seconds.

* Applications

1) Local overheating
2) entrance of air bubbles in oil
3) core bolt insulation failure
4) Short circuited laminations.
5) loss of oil & reduction of oil level due to leakage.
6) Bad and loose electrical contacts.
7) Short circuit b/n phases.
8) Winding short circuit.
9) Bushing puncture
10) Winding earth faults.

* Negative sequence relays.

The negative sequence relays are also called as phase unbalance relay, because these relays will provide protection against -ve sequence component of unbalanced currents, which are existing due to unbalanced loads or phase-phase faults.

=> However the unbalanced currents are dangerous to motors and generators which cause overheating. Negative sequence relays are generally used to provide protection to generators and motors against unbalanced currents.

=> negative sequence relay provide protection against phase to phase fault which are responsible to produce -ve sequence components.

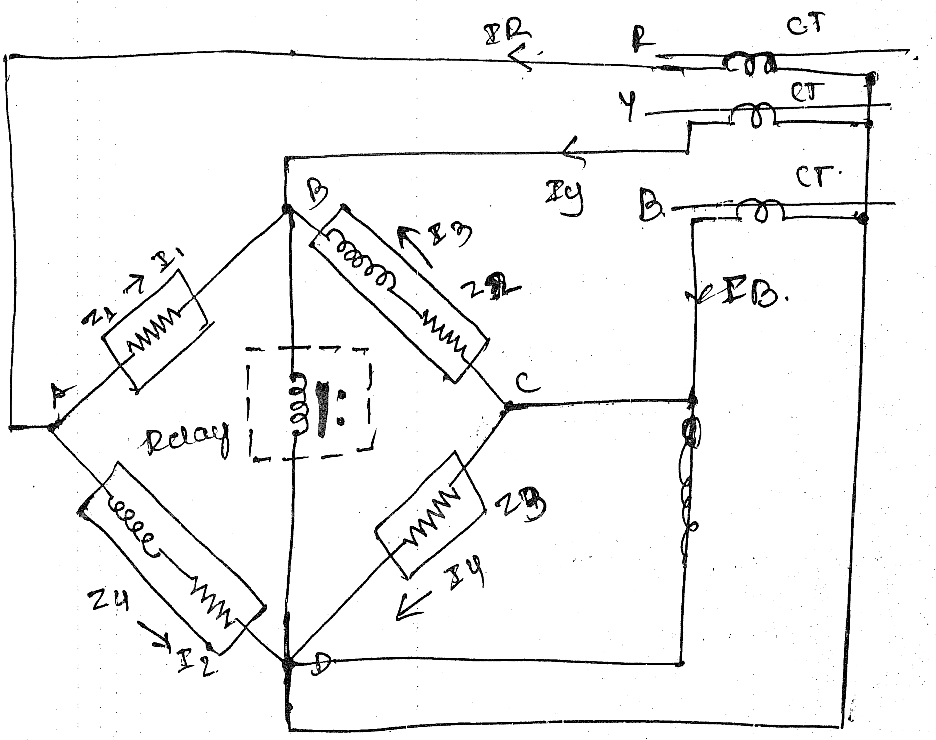


fig - Negative phase sequence relay

→ The above fig shows schematic arrangement of negative phase sequence relay.

→ as shown above basically it consists of a resistance bridge n/w. The magnitudes of the impedances of all the branches of n/w are same

→ as shown above the impedances Z_1 & Z_3 are purely resistive while Z_2 & Z_4 are combination of resistances and reactance.

→ The flow of c/n in the branches Z_2 and Z_4 lag by 60° angle from the currents in the branches Z_1 & Z_3

⇒ The current I_R is divided into two equal parts I_1 & I_2 while I_2 lags I_1 by 60°. The phasor diagram is as shown below.

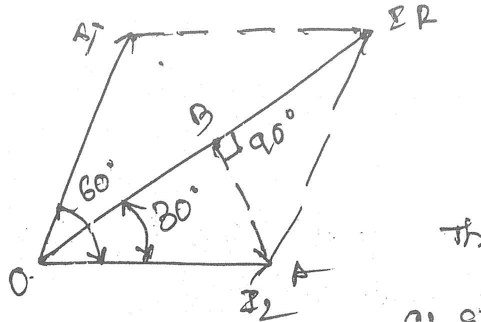


fig-b

$\overline{I_1} + \overline{I_2} = \overline{I_R}$

Let $I_1 = I_2 = I$

The perpendicular line is drawn as shown above from B to A, which ~~equally~~ bisects the diagonal.

$\therefore OB = I_R/2$ Now from $\triangle$le OAB

$\cos 30° = OB/OA$

$\sqrt{3}/2 = \frac{(I_R/2)}{(I_R)} \Rightarrow I = I_R/\sqrt{3} = I_1 = I_2$ ——— ①

Now I_1 leads I_R by 30°, while I_2 lags I_R by 30°.

* Similarly the currents I_B gets divided into two equal parts I_3 & I_4 & I_3 lags I_4 by 60°.

Now $I_B/\sqrt{3} = I_3 = I_4$ ——— ②

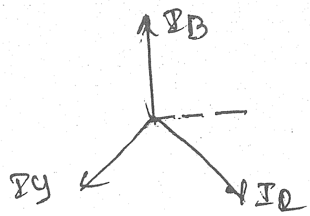
$\therefore$ The c/n I_4 leads I_B 30° & I_3 lags I_B by 30°.

Now c/n entering the relay at the junction point B as shown in fig the vector sum of I_4, I_3 & I_y.

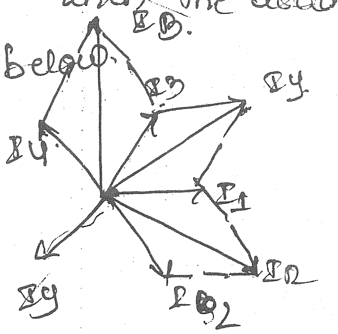
$\therefore I_{relay} = \overline{I_1} + \overline{I_3} + \overline{I_y}$

$= I_y + I_R/\sqrt{3}$ (I_R leads by 30°) $+ \frac{I_B}{\sqrt{3}}$ (I_B lags by 30°)

The vector sum of all currents when the load is balanced is as shown below.



c) fig-CT secondary current



d) vector sum

It is seen that

$\bar{I_1} + \bar{I_3} = -\bar{I_Y}$

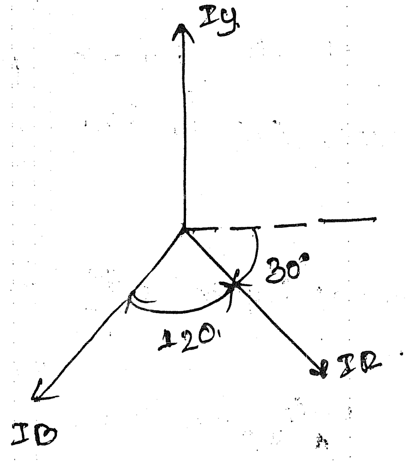
$\therefore I_1 + I_3 + I_Y = 0$ ∴ the c/n entering the relay at point B is zero. & at junction · O/P is also zero.

∴ The relay is inoperative for balanced c/n.

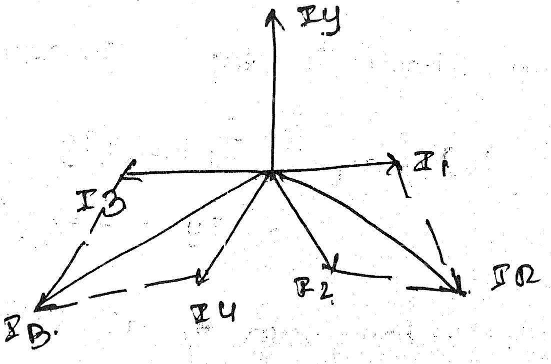
⇒ Now let us consider there is a unbalanced load on generator or motor due to which -ve sequence c/n exist.

⇒ as shown in fig a the currents I_1 & I_3 are equal & opposite at the junction point B ∴ I_1 & I_3 cancel each other.

⇒ Now relay coil carry the c/n I_Y & when its c/n is more than the predetermined value the relay trips closing the contacts of trip ckt. & opens CB.



e) CT secondary currents



f) - vector sum

fig - Negative sequence currents

* Negative sequence protection

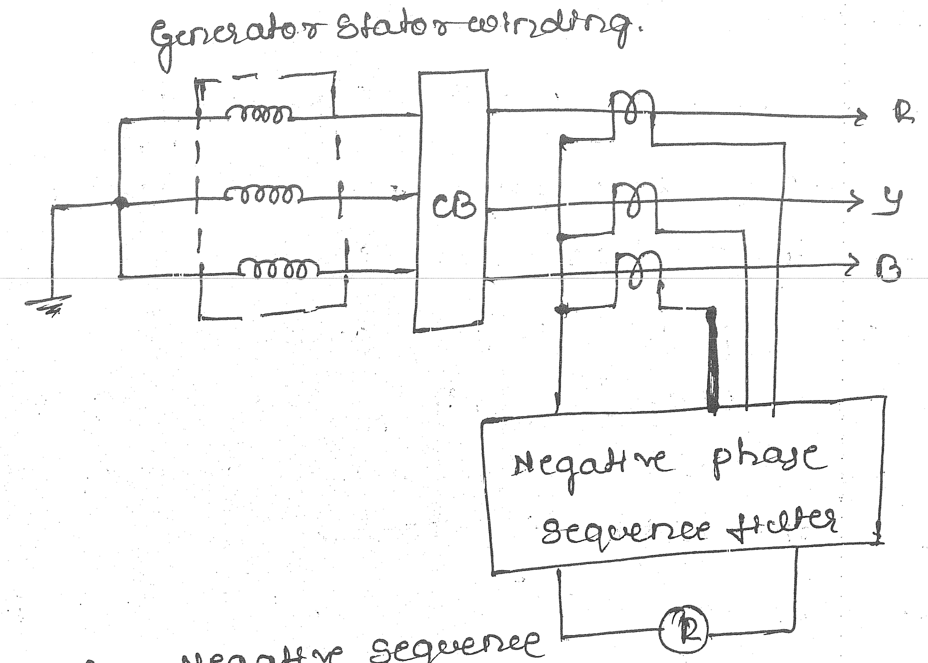


fig - Negative sequence protection.

When the load on generator is unbalanced, -ve phase sequence current flow.

→ The -ve sequence components produce a rotating magnetic field which rotates at a synchronous speed with opposite direction of rotor field.

→ ∴ the relative speed b/n the two is double the Ns.

∴ double frequency currents are induced in the rotor.

→ These currents will cause severe heating of stator.

∴ it is much more necessary to provide -ve phase sequence protection to the generators against the unbalanced load currents

→ The relative asymmetry of a 3-ϕ generator is given by the ratio of -ve sequence c/n to the rated current. Mathematically it is expressed as

$$\% S = I_n / I \times 100.$$

% S → percentage asymmetry

I_n → negative sequence c/s.

I → Rated current

The arrangement for negative sequence protection is as shown above, A negative phase sequence filter is connected to the secondary of CTS.

→ A -ve phase sequence filter consisting of resistors and inductors, they are arranged in such a way that under normal operating condition the relay is inoperative

→ When unbalanced load occurs, a negative phase sequence filter produces an o/p proportional to the negative phase sequence components & relay operates to open CB.

Unit - II principles of circuit Breaker

defination → A circuit breaker will make or break a circuit manually or automatically under no load, full load or short circuit conditions.

each of CB mainly consisting of a fixed contact & moving contact.

* Formation of Arc

Under abnormal conditions heavy amount of current flows through the contacts of CB before they are gets opened.

→ as soon as the contacts of circuit breaker are starts opening the area of contact decreases & which will increase c/n density and increase in temperature.

→ The medium b/n the contacts of CB may be air or oil

→ The heat which is generated in the medium is sufficient enough to ionise the air or oil, ~~which~~ which will acts as conductor.

→ ∴ the arc is gets streaked b/n the contacts, However the potential difference b/n the contacts of CB is sufficient to maintain the arc.

→ The amount of c/n flowing b/n the contacts depends on the arc resistance. with increase in arc resistance the c/n flowing will be smaller. Here arc resistance will depend on following factors.

a) Degree of ionisation → If there are less number of ionised particles b/n the contacts then the arc resistance is more.

b) Length of arc ⇒ The arc resistance is a function of length of arc ie is more the length, more is arc resistance.

c) cross section of arc ⇒ If the area of cross section of arc is less then arc resistance is high.

* Initiation of Arc

For the initation of arc there must be some electrons. when fault occurs CB contacts starts separating from each other and electrons are emitted & which are produced by the following method.

1) By high voltage gradient at the cathode, resulting in field emission.

2) By increase of temp, results to thermionic emission.

* By high voltage gradient.

When moving contacts are gets separated from each other, the contact area b/n the contacts of CB decrease and pressure is also decreased. A high amount of fault c/n causes the potential drop b/n the contacts which will remove electrons from cathode surface, this process is called field emission

* By increase of Temperature

When the contacts are gets separated contact area decreases which will increase the c/n density & at the same time the temp also increase which will cause emission of electrons known as thermal electron emission.

* Maintenance of an arc

We know that the initiation of arc is due to field emission & thermionic emission. The electrons which are travelling toward anode will collide with another electrons to deactivate them & thus arc is maintained

The ionization is facilitated by.

1) High temperature of the medium around the contacts due to high c/n density, Therefore kinetic energy gained by the electrons will increase.
2) The increase in the kinetic energy of moving electrons due to the ~~high c/n density~~ voltage gradient will deactivate more electrons from neutral molecules.
3) The separation of contacts of CB will increase the arc length, causes increase of neutral molecules. which will decrease the density of gas & increase of free path for the movement of electrons.

* Arc Extinction

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It is much more essential to extinguish the arc as early as possible there are two methods to extinguish the arc in circuit breaker.

a) High resistance method

b) Low resistance or current zero method.

* **High resistance method :-** In high resistance method the arc resistance is increased with time, it will reduce the current to such a value which is not sufficient to maintain the arc. ∴ such c/n is to interrupted & arc gets extinguished.

This method is applicable for dc circuit breakers.

→ The resistance of arc is increased by lengthening the arc, cooling the arc, reducing the cross section of arc & splitting the arc.

* Low Resistance method.

The low resistance or c/n zero method is applied for ac circuit breakers.

→ In this the resistance is kept low until current is zero, where ~~resistance~~ extinction of arc takes place naturally and it is prevented from restriking.

Imp.

* Requirements of circuit breaker.

The necessary requirements of circuit breaker are as follows

1) It will not operate with flow of overcurrent,

during healthy conditions.

* The faulty circuit only is isolated without affecting healthy CB.
* The normal working current & short circuit c/n must be safely isolated with the help of circuit Breaker.
* The faulty section of the s/m is isolated with the help of CB, as quickly as possible keeping min time delay.

Basic principle of operation of CB

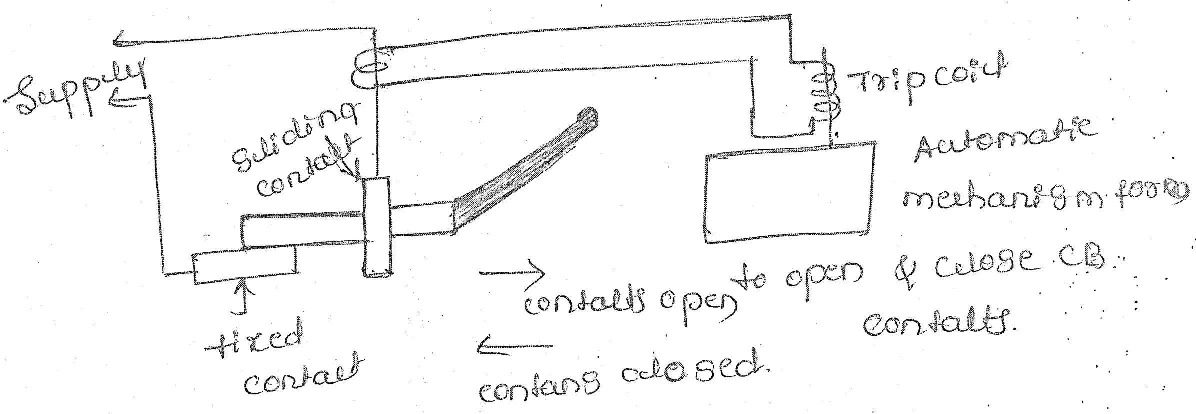

fig - Basic principle operation CB.

The above fig shows diagram of circuit breaker it consisting of fixed contact and moving contact. A handle is attached at the end of the moving contact. it can be operated manually or automatically.

→ However the automatic operation needs a separate mechanism which consisting of trip coil.

→ The trip coil is energized by secondary of CT. & the terminals of CB are brought to power supply.

→ under normal operating condition the emf produced in the secondary winding of the transformer is not sufficient to energize the trip coil completely for its operation. ∴ the contacts are remain in closed position carrying normal working current.

→ Under abnormal or faulty condition high c/n in the primary winding of the CT includes sufficient emf in the secondary winding so that the trip coil is energized which causes the opening of CB contacts.

→ as the contacts of CB are open the arc is struck b/n the contacts. The production of large amount of arc delay the c/n interruption & in addition to that it produces large amount of heat which causes the damage to the s/m. i.e it makes the arc extinction as early as possible with minimum time delay.

→ The time interval which is passed b/n the energization of trip coil up to the instant of contact separation is called opening time.

→ The time period ~~b/n~~ from contact separation to the extinction of arc is called arcing time.
It depends on fault c/n & availability of voltage.

DC circuit breaking.

The breaking in dc circuits can be explained as follows: Let us consider a circuit which ~~will~~ consisting of a generator with voltage E, resistance R, inductor L as shown below.

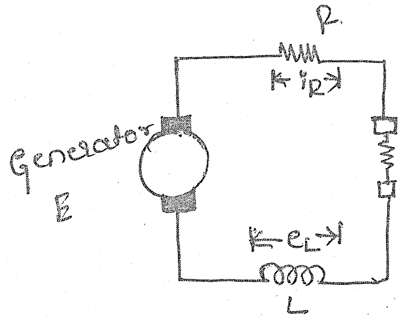

fig-a

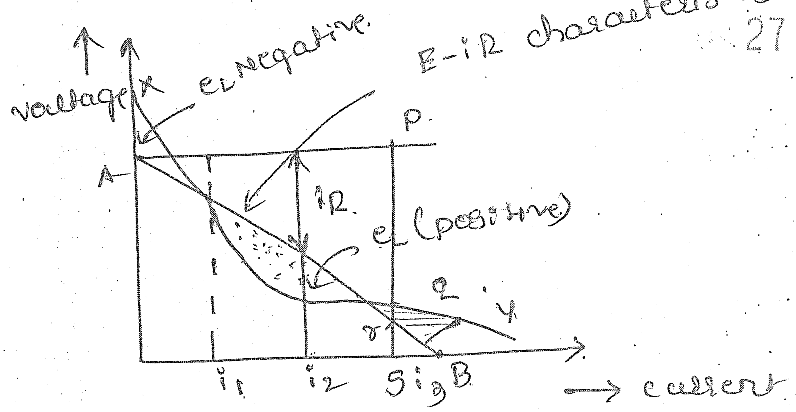

fig-b) voltage-current relationship.

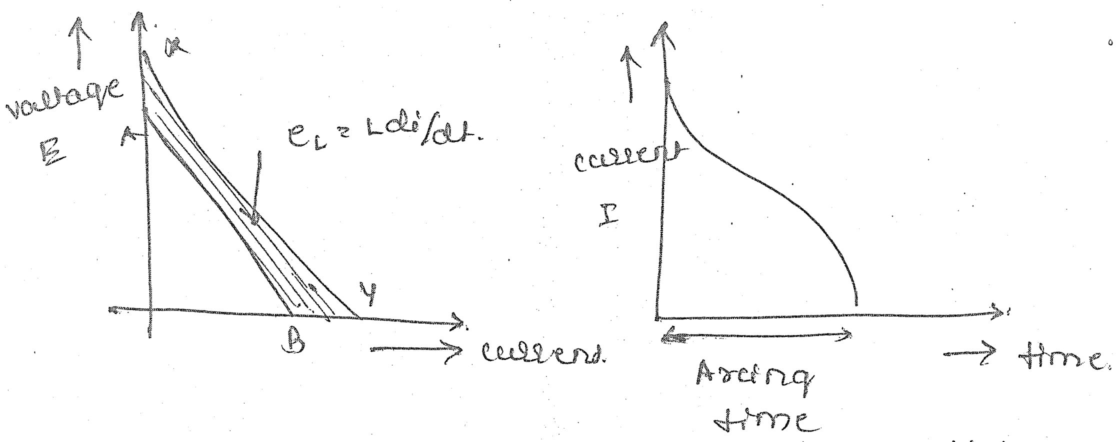

fig-c) Arc voltage characteristics

The voltage current relationship is as shown in fig b. from the fig it is clear that the curve AB represents voltage E-iR, where i is the c/n at any instant.

→ The curve X-Y represents the voltage - current characteristics of the arc for decreasing c/ns.

→ When the circuit breaker starts opening it carries load current $I = E/R$

→ section pr represents the voltage drop $i_3 R$ where QS represents arc voltage. which is more than the available voltage.

→ The arc becomes unstable & the difference in voltage is supplied by inductance L ie $e_L = L\,di/dt$.

→ The voltage across inductance L is +ve in the region of currents i_1 & i_2 since arc lies below the curve AB.

→ The arc current in this region tries to increase interruption of c/n which is not possible. Afterwards the arc is lengthened with separation of contact which increase the arc voltage above the curve AB.

→ The operation in dc CB is said to be ideal ~~of the characteristic is said to be ideal~~ if arc vtg is above the curve AB even in the region i_1 & i_2. which is shown in fig c.

→ The arc voltage is greater than E-iR and the balance b/n voltages is supplied by the voltage across the inductance e_L, which is proportional to rate of change of c/n di/dt.

→ Thus the function of the circuit breaker is to raise the arc characteristics without affecting its stability

* AC Circuit Breaking

There is a difference b/n the breaking in dc and ac circuits. In ac circuits the current passes through zero, twice in one complete cycle.

→ When the currents are reduced to zero, the breakers will be operated in cut off current which will avoid the striking of arc.

Now before going to study the actual current interruption in ac circuit we will see some theory which will help us to understand this concept. 29

* Short circuit in R-L series circuit *

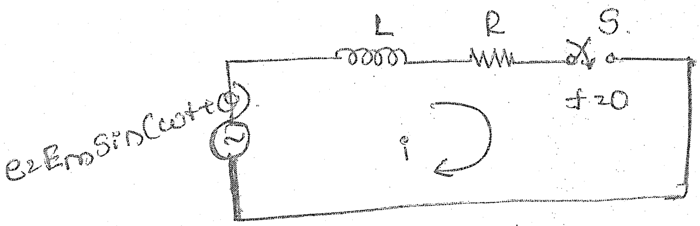

fig - R-L series circuit.

Let us consider a series R-L circuit as shown in above fig, in which switch S is closed at a time instant t=0.

Apply KVL to the above circuit.

$L\,di/dt + Ri = e \Rightarrow L\,di/dt + Ri = E_m \sin(\omega t + \Phi)$ — (1)

Now this equation can be solved to get the expression for current i, which is a non homogeneous differential equation whose solution consists of two parts namely complementary solution & particular solution

ie $i = i_c + i_p$ —— (2)

* Complementary Solution → In order to obtain complementary solution let us consider eqn (1), whose & equate the equation equal to zero.

$L\,di/dt + Ri = 0$ —— (3)

$\Rightarrow L\,di/dt = -Ri$

$di/dt = -\frac{Ri}{L}$

$\Rightarrow di/i = -\frac{R}{L} dt$ integrate the equation.

$\log i = -R/L\, t + k$ where k is constant.

consider $k = \log_e A$

$\therefore \log_e i = \log_e e^{(-R/L)t} + \log_e A$

$\log_e i = \log_e A e^{(-R/L)t}$

taking antilog on both side we get

$i = A e^{(-R/L)t}$

this is a complementary solution, this component of eln is exponentially decaying component, known as DC component.

* particular Solution

~~for particular~~ solution we will take a trial solution as $i = C\cos(\omega t + \theta) + D\sin(\omega t + \theta)$ —— (a)

differentiating the above equation for di/dt & d^2i/dt^2

$di/dt = -C\omega\sin(\omega t + \theta) + D\omega\cos(\omega t + \theta)$

$d^2i/dt^2 = -C\omega^2\cos(\omega t + \theta) - D\omega^2\sin(\omega t + \theta)$

considering the di/dt value in equation (1)

$L\, di/dt + Ri = E_m \sin(\omega t + \theta)$

we get $C = -E_m\, \omega L / R^2 + \omega^2 L^2$

$D = E_m\, R / R^2 + \omega^2 L^2$

put the values of C & D in eqn (a).

$$i = \frac{-E_m \omega L}{R^2+\omega^2L^2} \cos(\omega t+\theta) + \frac{E_m R}{R^2+\omega^2L^2} \sin(\omega t+\theta) \quad \text{---} (5)$$

now if ϕ is the impedance angle then

$\tan\phi = \omega L/R$, $\quad \sin\phi = \frac{\omega L}{\sqrt{R^2+\omega^2L^2}}$ $\quad \cos\phi = \frac{-E_m}{\sqrt{R^2+\omega^2L^2}}$

$$\therefore i = \frac{-E_m}{\sqrt{R^2+\omega^2L^2}} \sin\phi \cos(\omega t+\theta) + \frac{E_m}{\sqrt{R^2+\omega^2L^2}} \cos\phi \sin(\omega t+\theta)$$

$$= \frac{E_m}{\sqrt{R^2+\omega^2L^2}} [\sin(\omega t+\theta) \cdot \cos\phi - \cos(\omega t+\theta) \sin\phi]$$

$$= E_m/\sqrt{R^2+\omega^2L^2} \quad \sin(\omega t+\theta-\phi)$$

$$i_p = E_m/\sqrt{R^2+\omega^2L^2} \quad \sin(\omega t+\theta-\phi)$$

above equation is sinusoidal in nature & it is called as ac component.

$\therefore$ complete solution $\quad i = i_c + i_p$

$$= Ae^{-(R/L)t} + \frac{E_m}{\sqrt{R^2+\omega^2L^2}} \sin(\omega t+\theta-\phi)$$

inorder to find the value of A put initial conditions At $t=0$, $i=0$. & $R << \omega^2L^2$.

$$\therefore \sqrt{R^2+\omega^2L^2} \simeq \omega L.$$

& $\phi = \tan^{-1} \omega L/R \simeq 90°$

case-i) If switch is closed at e = 0.
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$t = 0; \; e = 0 \quad \therefore \theta = 0 \quad \& \; i = 0$ at $t = 0$.

$$0 = A + \frac{E_m}{\sqrt{R^2 + \omega^2 L^2}} \sin(-90^\circ)$$

$$\therefore A = E_m / \sqrt{R^2 + \omega^2 L^2} = E_m / \omega L.$$

this is the max value of A. ∴ dc component is max when switch is closed at zero voltage.

case-ii) If switch is closed at e = Emax.

$t = 0 \quad e = E_{max} \quad \therefore \theta = 90^\circ = \pi/2$

$$0 = A + E_m / \sqrt{R^2 + \omega^2 L^2} \sin(90^\circ - 90^\circ)$$

$$\boxed{A = 0}$$

if switch is closed at $e = E_{max}$ then A = 0 i.e dc component is zero.

* Current interruption in AC circuit Breakers.

Now let us consider the c/n interruption in ac circuit Breakers, which employ zero point interruption technique.

Let us consider an alternator on no load to which a circuit Breaker is connected which is shown below.

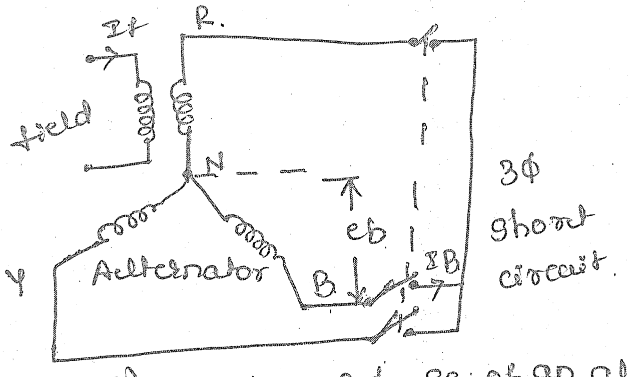


fig a) - sudden 3φ sc of an alternator.

As shown in the above fig, the circuit Breaker is open with its other side is short circuited.

→ When phase B voltage is zero wrt to neutral, the CB is closed. under this condition the B phase current will be maximum dc component and its current waveform will be unsymmetrical about normal zero axis. as shown in below fig ②

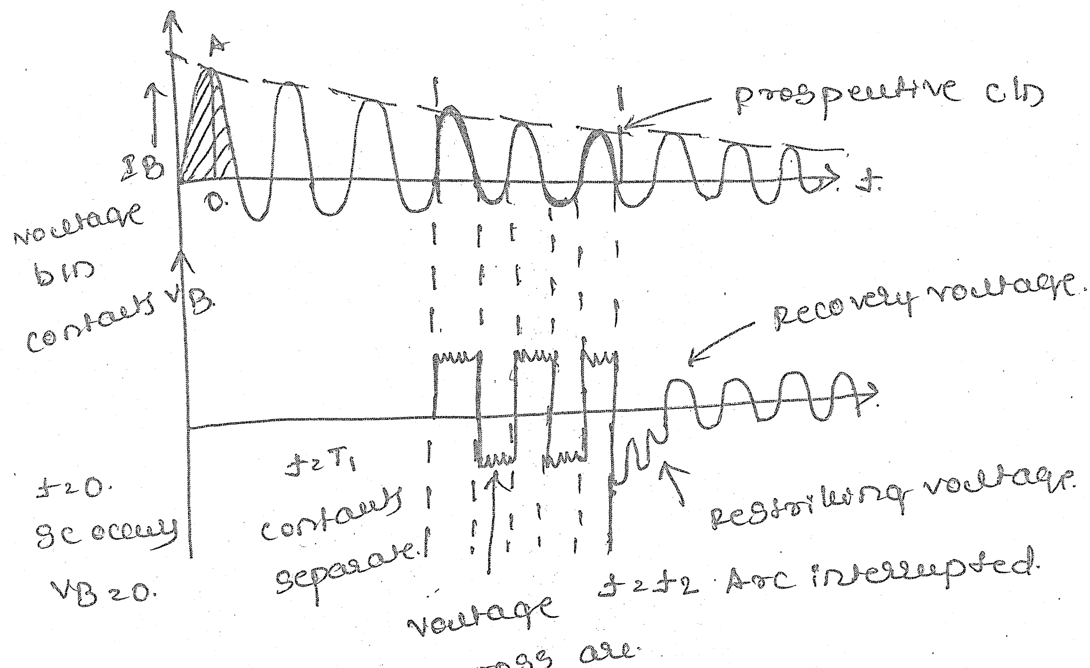


fig - current & voltage during fault clearing

The c/n is zero before t=0. as the alternator is on no load condition. Now the SC is applied at t=0

& c/n increases to a high value during 1st quarter of cycle.

→ The peak of 1st c/n loop is shown by OA which is maximum instantaneous value of c/n during SC.

→ This instantaneous peak value of 1st c/n loop is known as making c/n which is expressed as kA peak.

→ Now the circuit breaker contacts will separate after few cycles which are taken by relay and other operating mechanism.

→ Now at the time instant $t = T_1$ the contacts of CB separate, Now rms value of SC c/n at that instant of contact separation is called breaking current.

→ The arc is struck b/n the contact when they start separating the arc current varies sinusoidally for few cycles & at time instant $t = T_2$ the arc is interrupted as the dielectric strength of arc space builds sufficiently, which will avoid arc continuation and arc is extinguished.

→ From the waveform it is clear that Before the time instant $t = 0$, the contacts are closed so the voltage b/n them is zero. at the time instant $t = T_1$ the contacts begin to separate and voltage across them start increasing. Due to the increased arc resistance the voltage across the contacts increases in the next cycles & finally at $t = T_2$ the arc is completely extinguished.

Arc interruption theories.

There are two main theories explaining current zero interruption of arc.

1) Recovery rate theory or Slepan's theory.
2) Energy balance theory or cassie's theory.

* Slepian's theory :-

Slepian described the process, as a race b/n the dielectric strength and restriking voltage. After every current zero, there is a column of residual ionized gas, which may leads to cause the to strike the arc by developing necessary restriking voltage & this voltage is much more sufficient to drag the electrons out of their atomic orbit which produces large amount of heat.

⇒ ∴ in this theory the rate at which +ve ions and electrons combine to form neutral molecule, is compared with rate of rise of restriking voltage.

⇒ If the restriking voltage rises more rapidly than the dielectric strength, the space gap breaks down and arc strikes again.

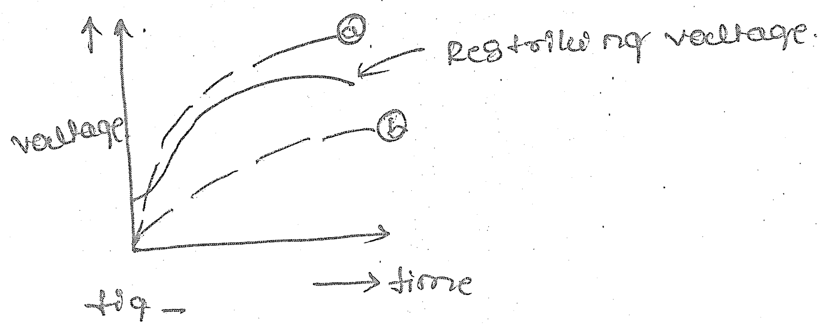


fig -

from the fig it is clear that

a) Rate of dielectric strength is more than restriking voltage

b) Rate of dielectric strength is less than the rate of rise of restriking voltage.

* The assumption made while developing this theory is that the restriking voltage and rise of dielectric strength are comparable quantities, which is not quite correct

* The theory does not consider the energy relations in the arc extinction.

* <u>Cassie's theory</u>.

→ Cassie suggested that, the reestablishment of arc <u>or</u> interruption of an arc both are energy balance process.

→ If the energy input to an arc ~~or interruption of an arc~~ continues to increase, the arc restrikes and if not, arc gets interrupted.

→ The theory makes the following assumptions.

a) Arc consists of a cylindrical column having uniform temperature at its cross section. The energy distributed in the column is uniform.

b) The temperature remains constant.

c) The cross-section of the arc adjusts itself to accomodate the arc current.

d) power dissipation is prapotional to cross sectional area of arc column.

The energy equation expressed by cassie is given by $\frac{dQ}{dt} = EI - N$

where Q = Energy content / length of arc in cm

E = volts/cm

I = Total current

N = Total power loss/cm.

However the breakdown occurs if power fed to the arc is more than power loss.

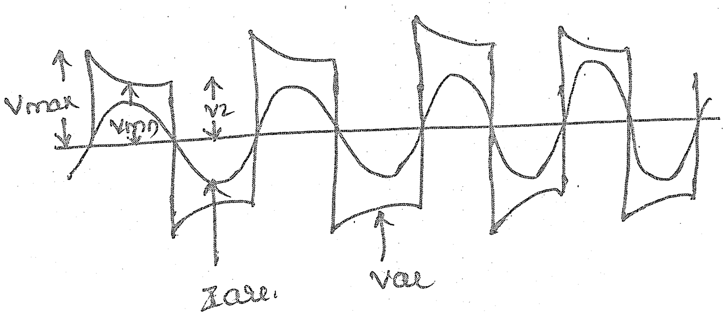


fig - waveform of ac arc.

after current zero, contact space contains ionized gas and they have zero resistance. Now there is rising restriking voltage, this rising restriking voltage cause the e/n to flow b/n the contacts.

→ Intially when the restriking v/g is zero, automatically current & power is zero.

→ In b/n these two extreme limits, power dissipated rises to maximum.

→ due to heat generated exceeds the rate at which heat can be removed from contact space, ionization will persist & breakdown will occur, giving an arc for another half cycle.

* interruption of capacitive currents. [capacitance switching]

* In a power s/m capacitor banks are used, which are helpful to supply reactive power, at leading power factor.
* There are various conditions such as opening a long tr-line on no load or disconnecting a capacitor bank etc. in which it is necessary to interrupt the capacitive currents which is a difficult task for CB.
* to understand the concept of let us consider a simple circuit as shown below

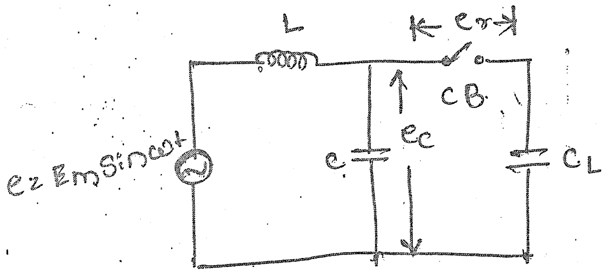


fig - interruption of capacitive currents.

* The value of C_L is more than C, the voltage across a capacitor can't change instantaneously. The ckts. supplied to the capacitor are normally small & interruption of such ckt will takes place at 1st ckt zero.
* Whenever such a ckt is gets opened then the charge is trapped in the capacitance C_L.
* Now the voltage e_c across the load capacitance C_L will hold the same value when ckt is opened, this vtg is nothing but the peak of supply voltage as pf angle is nearly 90° leading.

* After opening the ckt the voltage vc across the capacitance C oscillates & approaches nearly steady value. But due to small value of capacitance C, the value attained is close to the supply voltage.
* The recovery voltage er is nothing but the difference b/n ec & eL, its initial value is zero as the CB will be closed & increases slowly in the beginning.
* When Vc reverses after half cycle, the recovery voltage is twice the normal peak value. ∴ during this condition arc may restrike.
* The circuit will be enclosed and eL oscillates at a high frequency. the supply voltage at this instant will be at its -ve peak ∴ high frequency oscillation takes place.
* at the instant of restriking of arc the Vr is zero. the voltage across CL is -3 times peak value of the normal supply voltage. The recovery vtg starts increasing. If again arc restrike then high frequency oscillation of eL takes place.

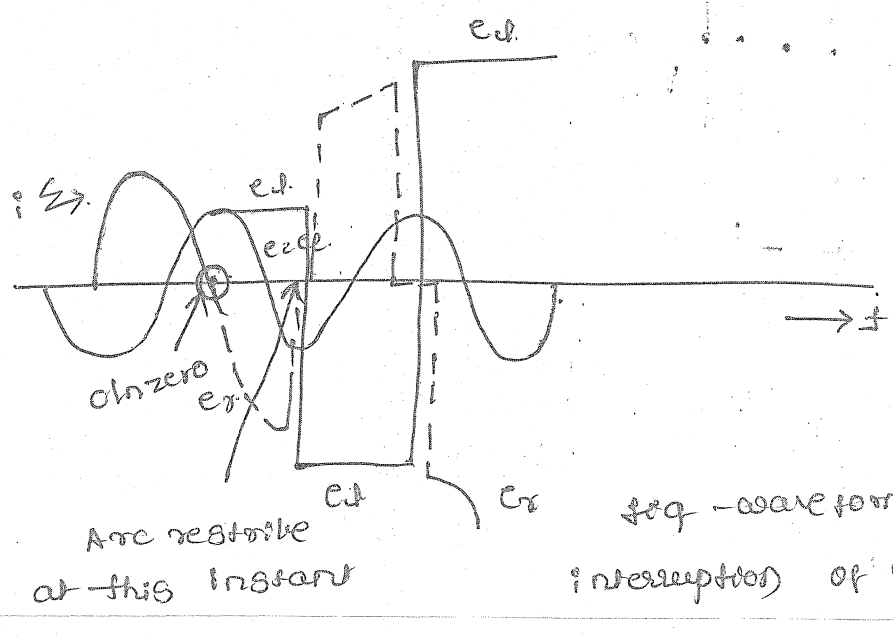


fig - waveform showing interruption of capacitive ckt.

* current chopping [Interruption of low magnetizing current]

→ There are certain conditions such as disconnecting transformer on no load, in which it is necessary to interrupt small inductive currents

→ The no load current of the transformer is normally smaller than normal current rating of the breaker.

→ Interrupting such current will causes severe duty on the circuit breaker, this phenomenon is called current chopping.

Let us consider the circuit as shown below.

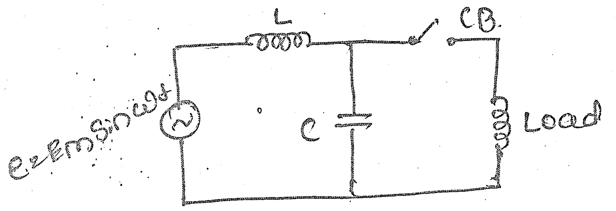


fig - circuit diagram showing interruption of Inductive currents.

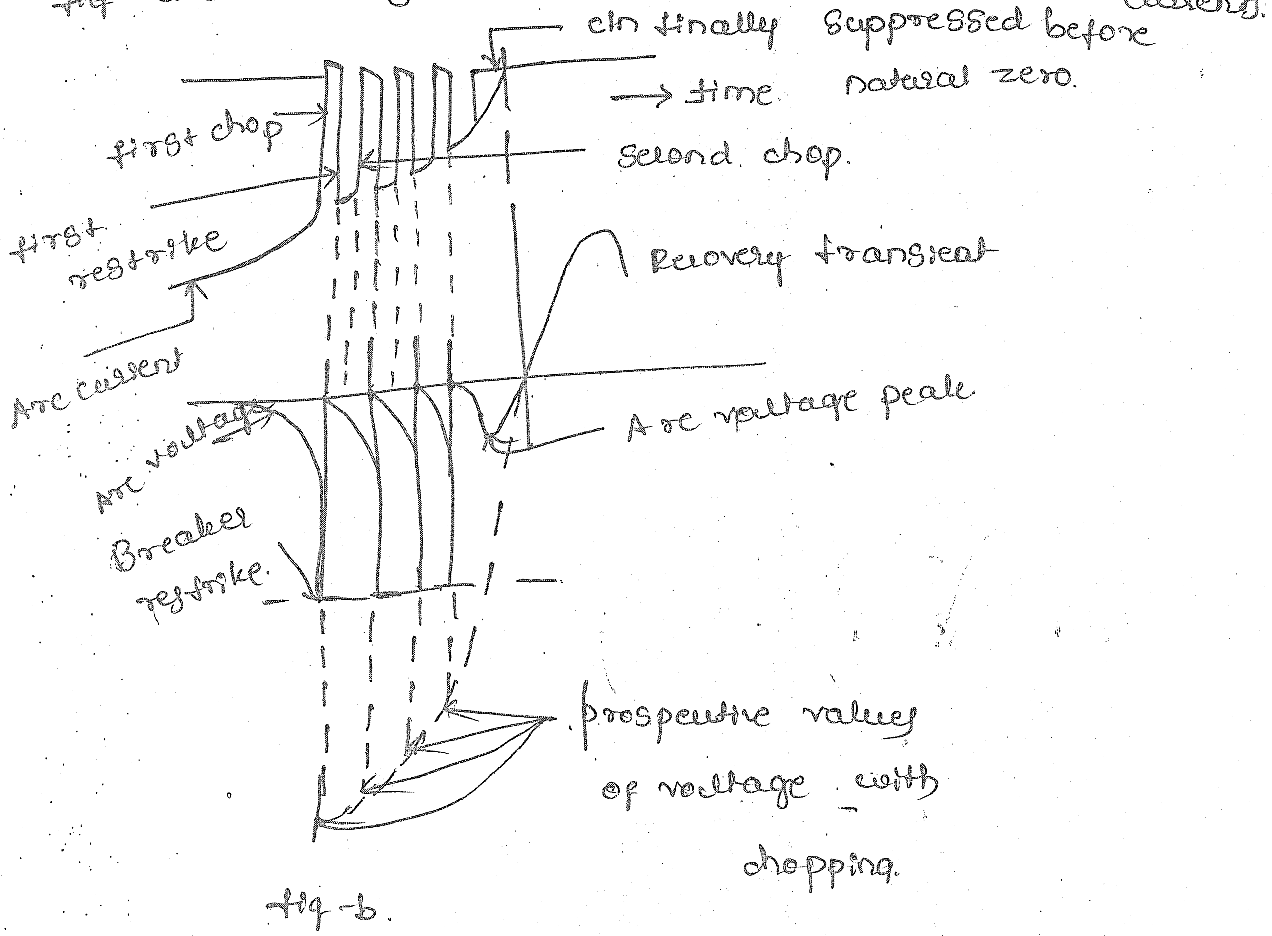


fig - b.

While interrupting low inductive current the rapid deionization of the contact space and blast effect may cause the c/n to reduce to zero value before the natural c/n becomes zero.

→ This current chopping cause large voltage oscillation

→ Let the arc c/n is i, when it is chopped down to zero value, the stored energy in the inductor $\frac{1}{2}LI^2$ will be discharged into the capacitance so that the capacitor is charged to a prospective voltage v such that

$$\frac{1}{2}LI^2 = \frac{1}{2}CV^2$$

$$V = i\sqrt{L/C} \text{ volts}$$

This prospective voltage is extremely high as compared to the normal s/m voltage, the frequency of natural oscillation is given by

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

to understand this let us consider a small example of 220kV circuit breaker interrupting magnetizing c/n of 10 A rms, c/n chopped at 7A,

L = 35H & 0.0020µF capacitance.

$$V = 7\sqrt{35/0.0020 \times 10^{-6}}$$

$= \underline{926 \text{ kV}}$ voltage appears across CB contacts //

* Resistance switching :- We know that the interruption of low inductive currents as well as interruption of capacitive currents will gives rise to severe voltage oscillations. These excessive voltage oscillations during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts, this process is known as Resistance switching.

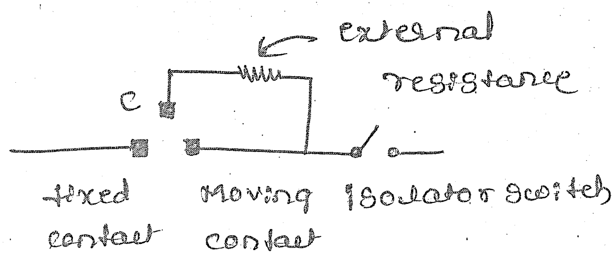


fig a) - typical resistor connection.

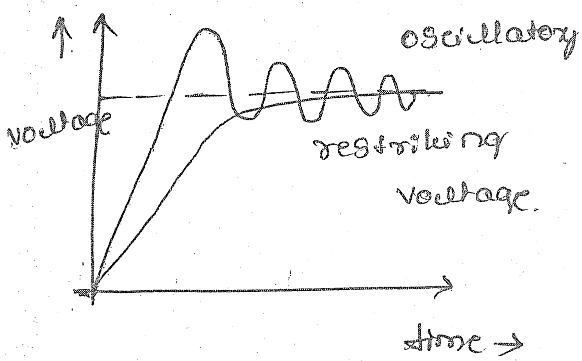


fig-b

→ When the resistance is connected across the arc, arc current flows through the resistance.

→ which will lead to decrease in arc current and increase in rate of deionization of arc path & increase in resistance of arc, which will leads to the increase in current through the shunt resistance.

→ However this process continues until the current through the arc is diverted through the resistance either completely or in major part.

→ If even small value of C/B remains in the arc then the path becomes unstable & it is easily extinguished.

* Resistance Switching

As shown in the fig a the arc first appear across points A & B which is then transferred across A & C.

Now we will derive a relation which will show how damping is achieved. Let us consider a circuit and Laplace transform equivalent circuit as shown below.

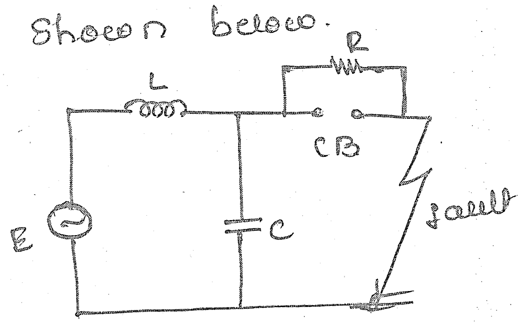


fig-c circuit

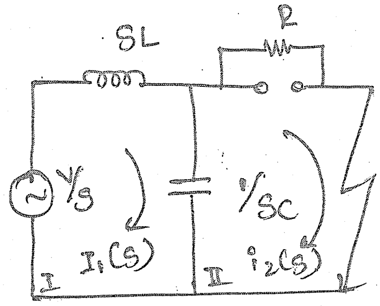


fig-d equivalent circuit

Apply KVL to the 1st loop.

$$V/S = \left(SL + 1/SC\right) I_1(S) - 1/SC\,(I_2(S)) \quad \text{——— (1)}$$

apply KVL to the 2nd loop

$$0 = -1/SC\, I_1(S) + \left(R + 1/SC\right) I_2(S) \quad \text{——— (2)}$$

$$\Rightarrow \frac{1}{SC} I_1(S) = \left(R + 1/SC\right) I_2(S)$$

$$\Rightarrow I_1(S) = (RSC + 1)\, I_2(S)$$

$$I_1(S) = (1 + RSC)\, I_2(S)$$ — put this value in eqn (1)

$$\therefore V/S = \left(SL + 1/SC\right)(1 + RSC) I_2(S) - 1/SC\, I_2(S)$$

$$\therefore V/S = \left[SL + S^2RLC + 1/SC + R - 1/SC\right] I_2(S)$$

$$V/S = (RLCS^2 + LS + R)\, I_2(S)$$

$$\therefore I_2(S) = \frac{V}{S(RLCS^2 + LS + R)} = \frac{V/RLC}{S(S^2 + 1/RC + 1/LC)}$$ divide Nr & Dr by RLC

using partial fractions

$$I_2(S) = \frac{V}{R}\left\{ 1/S - \frac{(S + 1/2RC)}{(S + 1/2RC)^2 + 1/LC - (1/2RC)^2} - \frac{\frac{1}{2RC}}{(S + 1/2RC)^2 + 1/LC - (1/2RC)^2} \right\}$$

put $x = 1/2RC$ $y = 1/LC - (1/2RC)^2$

$$I_2(S) = V/R \left\{ 1/S - \frac{S + x}{(S+x)^2 + (\sqrt{y})^2} - \frac{x}{(S+x)^2 + (\sqrt{y})^2} \right\}$$

taking inverse Laplace transform

$$i_2(t) = V/R \left(1 - e^{-xt}\left(\cos\sqrt{y}\,t + x/y \sin\sqrt{y}\,t\right)\right]$$

Now natural frequency of oscillation

$$f_0 = 1/2\pi \sqrt{1/LC - 1/4C^2R^2}$$

the value of R is equal to or less than $1/2\sqrt{L/C}$

for critical damping $R = 1/2\sqrt{L/C}$

for different values of R, the oscillations observed as follows

* Circuit Breaker Ratings.

A circuit Breaker is a mechanical switching device which is capable of making, carrying and breaking current under normal circuit conditions & breaking the current under specified abnormal conditions.

* Some of the important characteristics or ratings of high voltage ac circuit breaker are as follows

1) Rated voltage

It is a voltage of a circuit breaker which refers to a higher s/m voltage for which it is designed.

→ It is expressed in kV & the value is rms value

→ In case of 3-ϕ circuit it is nothing but phase to phase voltage.

→ however a circuit breaker is assigned to two voltage ratings one corresponding to maximum nominal s/m voltage & other maximum design voltage.

2) Rated Insulation level.

The different circuit breakers connected in power system they are subjected to power frequency over voltages due to various effects such as regulation, Ferranti effect etc.

Defi - Ferranti effect ⇒

→ The circuit breakers must be capable to withstand such a overvoltages, which can be tested by carrying different tests on circuit breaker.

→ during single phase to ground fault, voltage of healthy line to earth increases ∴ higher values insulators are suggested.

→ However the insulation is provided for each pole external and internal b/n live parts and earth.

* **Rated current**

It is defined as rms value of the current that can be carried by the circuit breaker continuously with increase in temperature within the specified limits.

→ some of preferred values of rated currents are 400, 630, 800, 1250, 1600, 2000 A rms etc.

→ The temperature rise is dependent on conductivity of the material ∴ while designing high conductivity material must be used, If material is having also conductivity then the cross-section of the conductor is increased.

* **Rated frequency :-**

The performance of CB is greatly influenced by frequency, the different characteristics like breaking capacity are based on rated frequency.

→ With increase in frequency, eddy currents in the metallic part will increase which will cause more heating and rise of temperature of current carrying parts.

→ Hence if a ckt breaker is designed for one particular frequency & it is used at some another frequency then the temperature will not be at specified limits. ∴ the rating of CB is changed accordingly.

→ The breaking time is also affected by the frequency the breaking time will decrease with increase in frequency.

* Rated duration and short circuit

→ The short time current of the circuit breaker is rms current that can be carried in the closed position during specified time under given conditions.

→ It is expressed in kA for a period of one second.

→ The rated duration of short circuit is also one second. However the insulation should not be damaged

→ The design for normal current rating is sufficient to carry short circuit current for 1sec.

* Rated short circuit breaking current

It is the rms value of highest short circuit current which the circuit breaker is capable of breaking under specified conditions of T.R.V. & power frequency voltage.

The voltage appearing across CB after arc interruption is nothing but transient Recovery voltage (TRV).

→ The limit on breaking current is governed by specified conditions of TRV & power frequency recovery voltage. this limit can be obtained by conducting short circuit test.

→ The c/n waveform is as shown below.

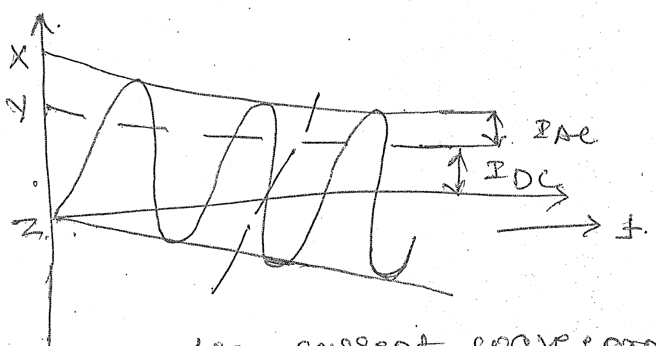


fig - current waveform

The breaking current is expressed in two values.

i) the rms value of ac component at the instant of contact separation given by $I_{AC}/\sqrt{2}$

ii) The percentage dc component at the instant of contact separation is given by $\frac{I_{DC} \times 100}{I_{AC}}$

* Rated Short Circuit Making Current.

→ it is defined as the peak value of 1st current loop. of short circuit current which the CB is capable of Making at its rated voltage.

→ The CB should be able to close without difficulty & withstand mechanical force which developed during closure, this is checked by by carrying out 'current' test.

Rated making c/s = $1.8 \times \sqrt{2} \times$ Rated sc breaking current

= $2.5 \times$ Rated sc breaking c/s

$\sqrt{2}$ is rms value to peak value

& 1.8 is considered to double the effect of sc c/s.

* **Rated peak withstand current.**

It is defined as instantaneous value of short circuit current which circuit breaker can withstand safely in closed position.

→ It is expressed in terms of kA.

→ The value suggested for this current is equal to rated short circuit making current.

* **Rated operating sequence**

It represents the sequence of opening and closing operations which CB can perform under specified conditions.

→ As per specifications the CB should be able to perform the operating sequence as per following ways

i) O-t-CO-T-CO ii) CO-t'-CO.

O - operation of opening

t - 3mins for CB not to be used for rapid auto reclosure

CO - closing followed by opening

T - 3minutes t' - 15sec for CB not to be used for rapid auto reclosure

* Transient Recovery voltage.

The transient Recovery voltage has effect on the behaviour of CB. This voltage appears b/n the contacts immediately after final arc interruption.

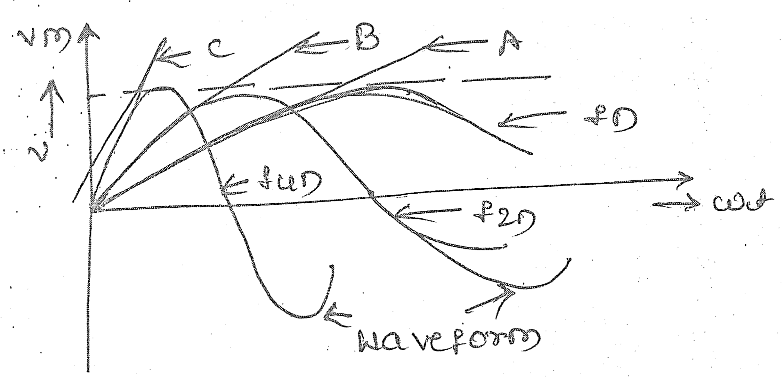
→ This causes high dielectric stress b/n the contacts, If this dielectric strength of the medium b/n the contacts does not build up faster than the rate of rise of transient recovery voltage then breakdown occurs which causes the restriking of arc.

⇒ ∴ It is very important that the dielectric strength of the contact space must increase rapidly than the rate of rise of transient recovery voltage ∴ the interruption of ckt by the CB takes place successfully.

⇒ If contact space breaks down within the period of 1/4th of a cycle from intial arc extinction then the phenomenon is called Reignition.

⇒ If the breakdown occurs after 1/4 of a cycle, the phenomenon is called Restrike.

* Effect of Natural frequency on TRV.



Waveform showing TRV.

A, B, C → Tangents indicate slope of TRV. at t=0.

fig - effect of frequency on TRV.

With increase in the Natural frequency the rate of rise of TRV at c/n zero increases as shown below.

→ Rate of rise of TRV causes voltage stress on the contact gap, which will continue the ~~gap~~ arc, If the frequency is increased then relatively very small time is available to build dielectric strength of the contact gap.

→ However the rate of rise of TRV is related with the breaking capacity of the CB. ∴ rate of rise of TRV is dependent on natural frequency

* **Effect of power factor on TRV.**

At the instant of final c/n zero the voltage appearing across the CB contacts is affected by the pf of the current.

→ at c/n zero the arc is extinguished, after this power frequency voltage appears across the CB.

→ The instantaneous value of the voltage at c/n zero depends on phase angle b/n c/n & voltage.

→ for upf load both voltage & c/n are in phase & they are zero at the same instant as shown below.

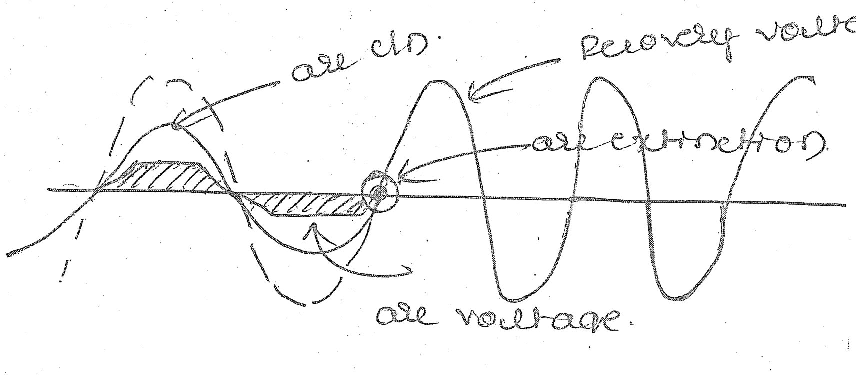
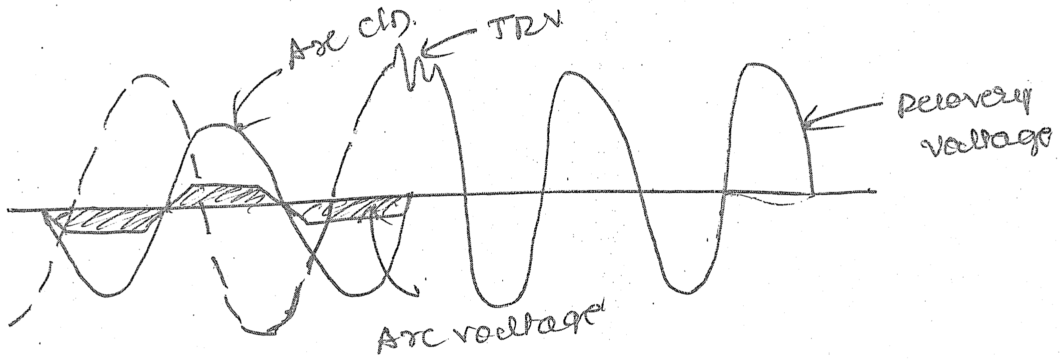


fig. unity power factor



If we consider zpf c/ns the peak voltage E_{max} is impressed on the CB contacts at the c/n zero instant.

→ The instantaneous voltage gives more transient & provides high rate of rise of TRV.

∴ at low pf interrupting op c/n difficult.

* Recovery voltage

It is defined as voltage having normal power frequency which appears after the transient voltage.

* effect of reactance drop on Recovery voltage.

Let us consider the voltage appearing across the circuit breaker is V_1 before the fault occurance, as the fault c/n increases, the voltage drop in reactance also increases.

⇒ After fault clearing the voltage appearing is V_2 which is slightly less than V_1. ∴ the s/m takes some time to regain the origional value.

* effect of Armature reactance on Recovery voltage.

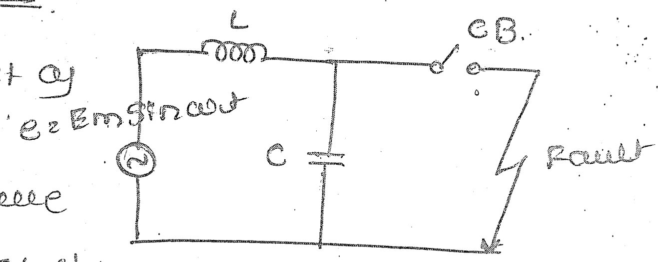
The short circuit currents are at lagging power factor.

⇒ These lagging p.f currents have a demagnetising armature reaction in alternators

⇒ ∴ due to demagnetising armature reaction causes reduction of induced emf of alternator.

⇒ ∴ to regain the original value of emf it takes sometime. ∴ The power frequency component of recovery voltage is less than the normal value of s/m voltage.

* **Single frequency transient**



Let us consider the circuit as shown above.

This circuit will produce the single frequency restriking voltage transient.

fig -

The natural frequency of oscillation is given by

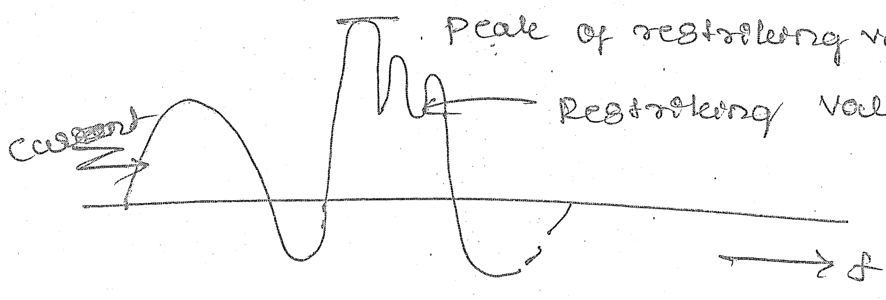
$$f_n = 1/2\pi\sqrt{LC}$$

where L = Inductance in henry C = capacitance in farady

Depending upon the values of L & C, the frequency ranges from 10 Hz to 10 kHz.

⇒ The circuit configuration in actual power system is complicated & it has distributed capacitance & inductance

⇒ for such circuits the TRV has several components of frequencies as shown below.



* Double frequency transient

In the previous section we have considered inductance L & capacitance C only one side of the CB, But it may be on both sides of circuit Breaker. This is as shown below.

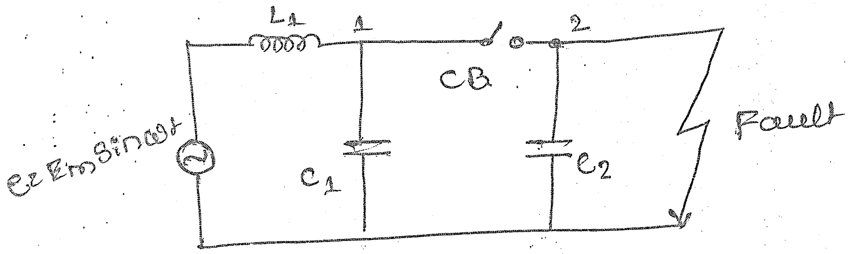


fig - a).

as shown above the points 1 and (2) are equipotential points before clearing the fault.

⇒ after arc extinction there will be two circuits which may oscillate at their own natural frequencies and they a composite double frequency transient appears across the circuit breaker which is shown below.

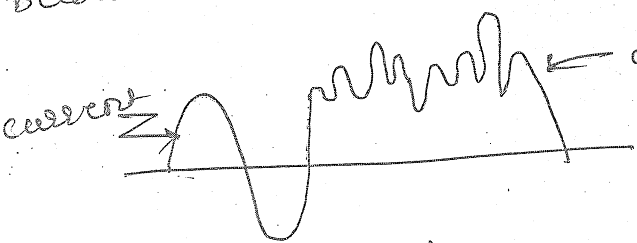


fig - b.

The circuit configration, the type of fault, & the type of natural earthing are the important factors which will decide the frequency, rate of rise and peak value of the TRV.

* Derivation of Rate of rise of TRV

We know that the transient voltage appears across the circuit breaker contacts at the instant of arc extinction is called as Restriking voltage.

→ The rate of rise of TRV is dependent on sim parameters

→ Let e be the restriking voltage in volts then

RRRV = de/dt volts/μsec.

→ The maximum instantaneous value attained by the restriking voltage is called as peak restriking voltage.

→ The peak value of TRV, time to reach the peak frequency of TRV and initial rate of rise are some of the important properties of TRV which are significant.

→ Let us consider a simplest form of equivalent circuit as shown in the above fig.

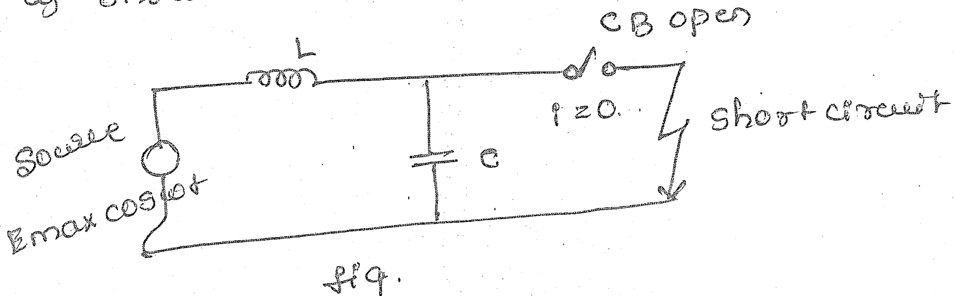


fig.

Where L = Total inductance b/n circuit breaker & source

C = capacitance to earth of the circuit.

Let us consider initially the CB is closed and at that time current flowing through it is 'i'

$$i = \frac{E_m}{\omega L} \cos(\omega t - 90^\circ)$$

$$\therefore i = \frac{E_m}{\omega L} \sin\omega t$$

If the applied source voltage is $E_m \cos\omega t$, since the effect of 'c' can be neglected as it is short circuited by the breaker switch

→ When the CB is opened, then if current is interrupted it can be simulated by assuming a cancelling current equal and opposite to origional current which is injected at circuit breaker.

→ The voltage which is necessary to carry this current is the voltage which appears across the circuit breaker contacts immediately after interruption.

→ Looking at circuit from the breaker terminals L & C appear in ||el and the equation of cancelling c/n is,

$$i = \frac{1}{L}\int e\,dt + C\,de/dt \quad \text{—— (1)}$$

Where e = voltage across breaker terminals nothing but restriking voltage differentiate eqn (1)

$$di/dt = e/L + C\,d^2e/dt^2 \quad \text{—— (2)}$$

now the solution of 'e' will thus depend on the c/n and if interruption takes place at current zero i.e when t = 0 then,

$$i = \frac{Em}{\omega L} \sin\omega t \quad \text{And after opening of CB}$$

$$di/dt = \frac{Em}{\omega L} \cdot \omega\cos\omega t$$

$$= Em/L \cos\omega t \quad \text{at } t=0 \quad \text{—— (3)}$$

put eqn (3) in equation (2) $\therefore Em/L \cos\omega t = e/L + C\,d^2e/dt^2$.

now the solution for this equation is given by

$$e = Em\left[1 - \cos\left(t/\sqrt{LC}\right)\right]$$ this is the expression for restriking voltage. where Em = peak value of recovery voltage phase to neutral in volts.

t = Time in sec

L = Inductance in henries.

C = capacitance in farads

e = Restriking voltage

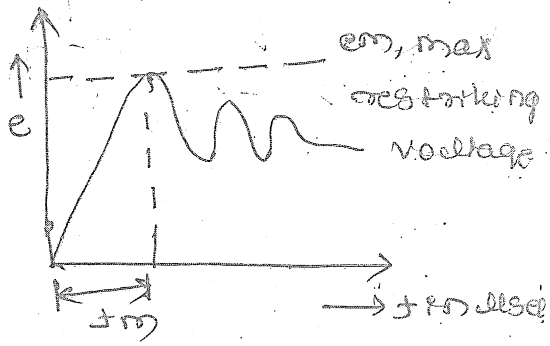


fig -

* Expression for Maximum value of Restriking voltage Em and corresponding time tm.

Now

$e = E_m\left[1-\cos\left(t/\sqrt{LC}\right)\right]$ If e is to be maximum.

then $\cos\left(t/\sqrt{LC}\right) = -1$ where $t = t_m$

$\cos\left(t_m/\sqrt{LC}\right) = -1$ $\therefore \dfrac{t_m}{\sqrt{LC}} = \pi$.

$\therefore$ time at which maximum restriking voltage occurs is

$$\boxed{t_m = \pi\sqrt{LC}}$$

and peak value of restriking voltage is $e_m = 2E_m$.

where E_m is equal to recovery voltage.

* Expression for RRRV and Max RRRV.

$$RRRV = \frac{de}{dt} = \frac{d}{dt}\left[E_m\left(\cos\left(t/\sqrt{LC}\right)\right)\right]$$

$$RRRV = \frac{E_m}{\sqrt{LC}}\sin t/\sqrt{LC}.$$

$\text{Max RRRV} = E_m/\sqrt{LC}$ When $\sin t/\sqrt{LC} = 1$

$\Rightarrow t/\sqrt{LC} = \pi/2$

$$\boxed{t = \frac{\pi\sqrt{LC}}{2}}$$ for Max RRRV

* frequency of oscillation of Restriking voltage.

$$f_n = 1/2\pi\sqrt{LC}$$

$$\sqrt{LC} = 1/2\pi f_n$$

$$\text{Max RRV} = \frac{E_m}{\sqrt{LC}} = 2\pi f_n E_m$$

Max RRRV = $2\pi E_m f_n$

* Restriking voltage under various conditions

1) $e = V_{ar}\left[1-\cos(t/\sqrt{LC})\right]$

where V_{ar} = active recovery voltage ie the instantaneous value of recovery voltage at zero & V_{ar} can be written as $V_{ar} = k_1 k_2 k_3 E_m$.

Here E_m is peak value of s/m voltage

k_1 is factor which takes into account effect of circuit pf and $k_1 = \sin\phi$ if $\phi = 90°$ $k_1 = 1$

k_2 is factor which accounts effect of armature reaction on recovery voltage.

k_3 is phase factor or 1st pole to clear factor.

* In short circuit test on 3 pole 132kV CB, the following observations are made pf of fault 0.4, recovery voltage 0.9 times full line value, the breaking of cb symmetrical, frequency of oscillations of restriking voltage 16kHz, Assume neutral is grounded and fault is not grounded. Determine average RRRV.

$\Rightarrow \quad e = V_{ar}\left[1 - \cos\left(t/\sqrt{LC}\right)\right]$ where $V_{ar} = k_1 k_2 k_3 E_m$

k_1 = takes into account p.f effect $= \sin\phi$

k_2 = Takes into account armature reaction effect $\simeq 0.9$

k_3 = phase factor or 1st pole to clear

= 1 for both neutral factor and fault grounded

= 1.5 for any one of the two not grounded.

In the problem $k_1 = \sin\phi = \sin[\cos^{-1} 0.4] = 0.9165$

$k_2 = 0.9 \quad k_3 = 1.5$.

peak value of voltage ie line to ground is

$E = \frac{132}{\sqrt{3}} \times \sqrt{2} = 107.77\,kV$.

$f_n = 1/2\pi\sqrt{LC}$ ie $1/\sqrt{LC} = 2\pi f_n = 2\pi \times 16 \times 10^3$

$1/\sqrt{LC} = 1 \times 10^5$.

Time to reach maximum restriking voltage is

Maximum $t_m = \pi\sqrt{LC} = \pi/1 \times 10^5$

Maximum restriking voltage $= 2V_{ar}$

$= 2k_1 k_2 k_3 E_m$

$= 2 \times 0.9165 \times 0.9 \times 1.5 \times 107.77 \times 10^3$

$= \underline{\underline{2.66 \times 10^5\,V}}$

Average RRRV

$$\frac{\text{Max restriking voltage}}{\text{Time to reach Max restriking voltage}} = \frac{2.66692 \times 10^5}{\pi / 1 \times 10^5}$$

$= 8.48 \times 10^9\ V/sec$

$= 8.48 \times 10^6\ kV/sec$

$= 8.48\ kV/\mu sec$.

* In a short circuit test on a 130kV, 3phase s/m, the breaker gave the following results; pf of fault 0.45, recovery voltage 0.95 times full line voltage, breaker current symmetrical, and restriking transient had a natural frequency 16kHz, Determine avg RRRV, Assume fault is grounded.

⟹ $E_m = \frac{\sqrt{2} \times 130}{\sqrt{3}} = 106.144 kV.$

$Var = k_1 k_2 k_3 E_m$

$= 0.8930 \times 0.95 \times 1 \times 106.144$

$= 90.047262 kV.$

$k_1 = \sin\phi = 0.8930$

$k_2 = 0.95$

$k_3 = 1$

∴ Maximum $e = 2 Var = 180.09452 kV$

Maximum time $= \pi\sqrt{LC}$ & $f_n = 1/2\pi\sqrt{LC}$.

Maximum $t = 1/2f_n$

$= 1/2 \times 16 \times 10^3$

∴ Average RRRV $= \frac{Max\, e}{Max\, t} = \frac{180.09452}{1/2 \times 16 \times 10^3} = 5.7630$ kV/μsec

* Calculate the RRRV of 132kV circuit breaker with neutral earthed. S.C. data as follows :- Broken ckt is symmetrical, restriking voltage has frequency 20KHz pf 0.15 Assume fault is also earthed

$\Rightarrow$ $k_1 = \sin\phi = \sin(\cos^{-1} 0.5) = 0.9886$

$k_2 = 1$ and $k_3 = 1$ both grounded

$E_m = \frac{\sqrt{2} \times 132}{\sqrt{3}} = 107.77\,kv$

$V_{ar} = k_1 k_2 k_3 E_m = 106.54\,kv$

$\therefore$ Maximum $e = 2V_{ar} = 213.09778\,kv$

$t_m = \pi\sqrt{LC}$ $\quad \therefore \pi\sqrt{LC} = t_m = 1/2f_n$ sec

$f_n = 1/2\pi\sqrt{LC}$

$\therefore$ Maximum $t_m = 1/2 \times 20 \times 10^3$ sec

$\therefore RRRV = \frac{e_{max}}{t_{max}} = \frac{213.09778}{[1/(20\times10^3\times2)]} = 8.52\,kv/\mu sec$

* A 50Hz generator has emf to neutral 7.5kv (rms) The reactance of generator and the connected sm is 4 Ω and distributed capacitance to neutral is 0.01μF with resistance negligible find.

i) Maximum voltage across the circuit breaker contacts

ii) Frequency of oscillations.

iii) RRRV average upto 1st peak of oscillations.

$\Rightarrow$ $X = 2\pi f L = 4\Omega$

$\Rightarrow L = \frac{4}{2\pi \times 50} = 0.0127H$

and $E_m = \sqrt{2} \times 7.5 = 10.606\,kv$

i) Maximum voltage $= 2 \times E_m$

$= 2 \times 10.606$

$= 21.212\ kV$

ii) $f_n = 1/2\pi\sqrt{LC}$

$= 1/2\pi\sqrt{0.0127 \times 0.01 \times 10^{-6}}$

$= \underline{\underline{14.1227}}\ kHz$

iii) Maximum time to reach maximum voltage

is $t_m = \pi\sqrt{LC}$

$= 1/2f_n$

$= 1/2 \times 14.2227 \times 10^3$ sec

∴ Average RRRV = $\dfrac{\text{Maximum voltage}}{t_m}$

$= \dfrac{21.212}{[1/(2 \times 14.1227 \times 10^3)]}$

$= \underline{\underline{0.599\ kV/\mu sec}}$ //

2/12/17 – 2, 8, 10, 26, 32, 36, 41, 61, 65,

Unit - I Switches & fuses.

The collection of various equipments used for the switching and protecting purpose in a power system is called switchgear.

⇒ **Fuse** → it is a protecting device, which consists a small piece of metal, when excessive current flows through it, the metal element melts and the ckt is interrupted & circuit gets disconnected from the supply. hence it helps to protect the circuit due to excessive current.

⇒ **Switch** → a switch is a device which is used to open or close an electrical circuit in an conventional way. switch can be used on full load or no load conditions but it can't be used to interrupt the fault currents which is the basic difference b/n fuse & switch

* Energy management of power system.

An energy management system is a system which consists of computer Aided tools, which are operated by electric utility grid operators to monitor, control & optimize the performance of generation and/or transmission system.

→ The function of monitoring & controlling is referred as SCADA (Supervisory control & data Acquisation)

→ With EMS it is possible to control centerally various devices, & also it is possible to have metering, Submetering, & monitoring. functions through EMS which helps in data collection & decision making across the sites.

→ Energy management software contains various energy related software applications, which include utility bill tracking, real time metering, building simulation & modeling, energy audits etc.

→ EMS helps to reduce the energy cost & consumptions.

→ EMS collects the data & utilise this data to report, monitor & engagement.

→ Data collection includes gathering of historic or real time interval data with variable interval periods.

→ Reporting includes verification of energy data with benchmarking and setting high level energy reduction targets

→ Monitoring involves analysis of data & tracking of energy consumption to identify cost saving.

→ Engagement involves manual or automated responses to the collected & analysed data of energy.//

k. oxidation ⇒.

* Block diagram of EMS.

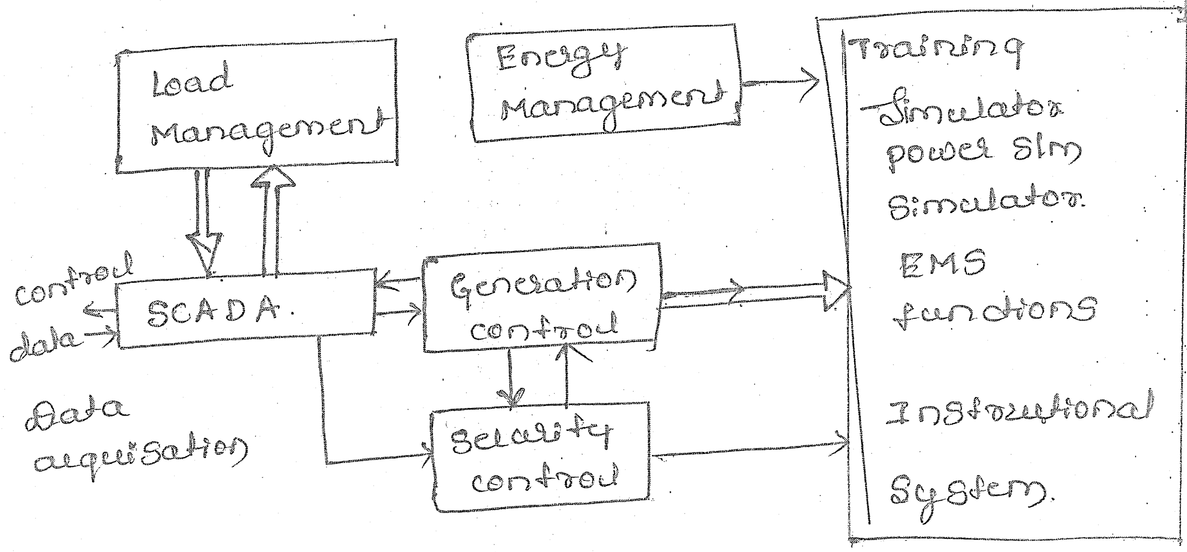


fig - Block diagram of EMS

The block diagram of a typical EMS is as shown above. The main element of EMS is SCADA, which does the function of generation control & load management.

* It has training Simulator which performs the simulations of power system under various operating conditions

* SCADA slm performs the functions of data collection, supervisory control and economic dispatch or/power identifying a device that should not be operated, analysis of alarm signals, load shedding, logging etc.

* The major functions of automatic generation control load frequency control and economic dispatch of power

* Economic dispatch is nothing but minimum cost dispatch of electrical power.

* The load frequency control and economic dispatch operate in real time.

Energy management performs different functions such as system load forecast, transaction evaluation, tr-loss minimization, & production cost calculation.

→ Security control begins with current state & the program is sequentially executed.

* A list of contingency are processed of applicable to present state
* It performs load flow analysis, contingency analysis and short circuit analysis for 1-φ and 3-φ faults for different fault condt locations within the power slm n/w.

* <u>define Switchgear</u>

* The combination of electrical disconnect switches, fuses, relays and circuit breakers used for switching and interrupting the currents in the power system during normal and abnormal conditions is called switchgear.

* <u>Functions of switchgear</u>

1) To provide protection to the equipments by interrupting SC and overload conditions.
2) other functions are interruption of small inductive currents, capacitor switching, interruption of short line faults.
3) To provide safe and easy access for the

general routine inspection and preventive maintenance

* <u>Switchgear includes following equipments</u> 21

i) various types of switches
ii) isolators
iii) Fuses
iv) circuit breakers
v) Lightning arrestors
vi) PT, CT
vii) Metering panels
viii) controlling panels

* Introduction to <u>Fuse</u>

fuse was invented by scientist Edison in the year 1880. it is a simple protective device which works on the principle of current interruption. if c/n become much more excessive.

→ It is used for overload and short circuit protection in medium voltage range upto 66kv.

→ fuse is always connected in series with the circuit or appliance to be protected.

* aluminium	240°F	658.7°C	2.86 μΩ-cm Specific resistance
copper	2000°F	1084°C	1.72
Lead	624°F	327°C	21.0
zinc	787	419	6.1
Tin	463	231.85	11.3
Silver	1830	960.5	1.64

* Types of Fuses.

1) Expulsion fuse
2) Rewirable fuse or Semienclosed fuse.
3) cartridge fuse
4) drop - out fuse
5) Liquid fuse
6) open fuse
7) Striker fuse
8) Switch fuse
9) HRC fuse.

* Expulsion fuse → it consists of modern cut-outs, in such fuse are occuring during the c/n interruption is extinguished by the expulsion produced by the arc.

* Rewirable fuse — this type of fuse is placed in semienclosed carrier, fuse carrier can be pulled out & the fuse element can be replaced after the fuse operation, such a fuses are commonly used in our houses.

disadvantages

1) The protective capacity is not certain, means in some cases fuse may gets melt at some lower ~~this current value~~ the rated or higher than c/n value.

2). The fuse wire is subjected to the deterioration due to oxidation through the continous heating of fuse element.

due to which the c/n rating of the fuse is decreased & it starts operating at lower c/n.

3) Accurate calibration of the fuse wire is impossible, because the fusing c/n depends on the length of fuse element.

4) It has low breaking capacity & hence it can't be used for high fault level circuits.

5) The speed is slow.

6) sometime their may be occurance of external flame & fire.

* cartridge fuse :- This fuse is totally enclosed fuse, & fuse element is placed in a totally enclosed carrier. However entire cartridge is required to be replaced once fuse operates.

* Drop-out fuse :- in such a fuse, the fuse carrier drops out once the fuse operates, & the dropping out of fuse carrier provides the necessary isolation b/n the terminals.

* Liquid fuse :- The fuse in which arc is gets extinguished using a liquid medium is called liquid fuse. The liquid medium is generally oil. The various types of liquid fuse are→

i) oil - break circuit breaker.

ii) oil - expulsion fuse.

iii) oil - blast fuse.

* open fuse :- This type of fuse consists a plain fuse wire & the fuse operates without any provision for extinguishing the arc.

* Striker fuse :- In this fuse, there exists a combination of fuse and mechanical device. When fuse operates, striker gets released under pressure which gives the tripping indication.

* Switch fuse :- This fuse is a combination of a switch and a fuse, The combined unit is called ~~a~~ switch fuse.

* HRC fuse :- It is high rupturing capacity fuse, It is also called breaking capacity cartridge fuse. In such a fuse, the arc is gets extinguished with the help of quartz sand powder.

Such a powder ~~helps~~ provides high resistance which helps to extinguish the arc.

* Definations :-

* fuse - fuse is a protective device, which consists of a small piece of metal, which is connected in series with the circuit. it protects the circuit due to excessive current.

* fuse element :- fuse element is a part of fuse, which melts when excessive c/n flows through it.

* current rating of fuse.

It is maximum current, which fusing element can normally carry. It depends on.

1) Temperature rise of fuse contacts of fuse holder

2) fusing element material.

3) deterioration of fuse due to oxidation

* deterioration ⇒
* oxidation ⇒ .

* Fusing current

→ it is the minimum value of current at which the fuse element melts to interrupt circuit current known as fusing current. Its value is always more than the current rating of the fuse.

* fusing c/n depends on different factors.

1) fuse element material.
2) shorter the fuse, lesser the fuse length, greater is the c/n.
3) diameter of the element, If more the diameter more is the current.
4). Location of the terminals.
5). The surroundings in which the fuse is to be used.
6) The type of encloser used whether semienclosed or totally enclosed.

* fusing factor

fusing factor is defined as it is the ratio of minimum fusing current to the current rating of fuse as minimum fusing current is more than the c/n rating the fusing factor is always greater than one

$$\text{Fusing factor} = \frac{\text{Minimum fusing current}}{\text{current rating of fuse}}$$

for household fuse, fusing factor is generally 2

* prospective current and cut-off characteristics of fuse

The rms value of the 1st loop of fault current is known as prospective current.

When fault occurs, the c/n starts increasing, & this fault c/n is asymmetrical in nature & large for 1st loop. But before achieving its maximum value, fuse element is gets melted.

The rms value of the 1st loop of the fault c/n is called as prospective c/n.

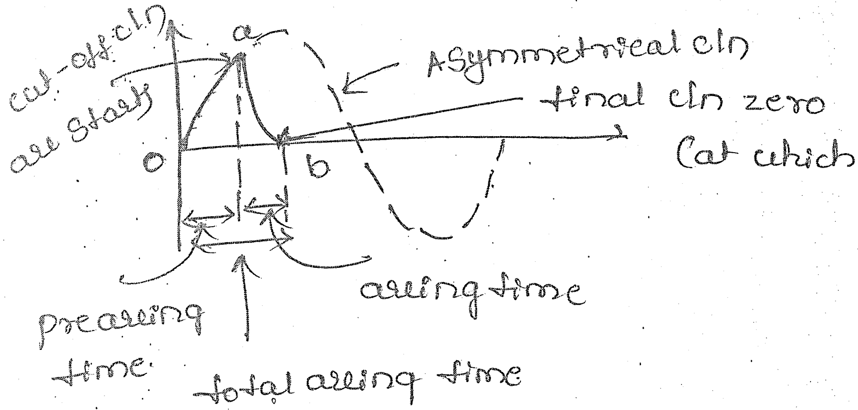


fig - cut-off characteristics.

* cut-off characteristics.

The c/n value at which the fuse melts, before fault c/n reaches its peak value is called cut-off current. or it is also defined as the maximum value attained by the fault current just when the fuse melts. It is the c/n corresponding to the point 'a' as shown in the above fig.

* cut-off value depends on.
1) current rating of fuse
2) value of prospective c/n.
3) Asymmetry of the fault c/n waveform.

* pre-arcing time.

it is the time between the commencement of the fault c/n. & the instant at which fuse melts & arc starts.

prearcing time is b/n the point o and a.

* Arcing time.

It is the time b/n the end of prearcing time and the instant when the arc gets completed. b/n a & b

* Total operating time :- It is the sum of prearcing time and arcing time.. time period b/n e and b. However the operating time of a fuse generally very small as compared to circuit breakers.

* Breaking capacity :- The breaking capacity is the fuse rating corresponding to the rms value of the ac component of maximum prospective c/n at its service voltage.

* voltage rating of fuse.

Normally voltage rating of the fuse is specified by the manufacturers. The rated voltage of the fuse must be equal to or greater than

1) voltage of a single phase circuit.
2) Line voltage.
3) voltage b/n two outer wires in 3 wire dc circuits

* Time - current characteristics.

The fuse has inverse time-c/n characteristics, this means; ~~this means~~ as the magnitude of fault c/n is higher, smaller is the time taken by the fuse to melt. in the similar manner when fault c/n is low, the time taken by the fuse is more.

* fuse element material

The desirable characteristics of any fuse element are

1) Low melting point
2) High conductivity
3) Low cost
4) free from deterioration due to oxidation.

it is observed that no metal can possess all these characteristics. lead, zinc, tin, copper, aluminium and silver are earlier used metals which are used as fuse elements

→ for small c/n values lead - tin alloy is used to make a fuse element.

→ The combination of lead - tin alloy consists of 37% of lead and 63% of tin.

→ this alloy is preferred because
  1) It has less tendency to spread over
  2) It is quite homogeneous.

→ for large values of current copper or silver is used for making fuse element.

* The present trend is to use silver ~~through~~ but it is costlier because of following reasons.

1) The silver has low coefficient of expansion such that their no critical failures are occurred.

2) The conductivity of silver is very high & it will not affected due to the continous operation and due to surge currents

3) Due to high conductivity, the mass of silver required for a given rating of fuse is less than other materials.

4). Because of its low specific heat, silver elements can be raised from normal operating temp to vapourization much & quicker than other elements.

* Fuse law.

When fuse achieves steady state condition then we can write

Heat generated = Heat lost due to conduction, convection & radiation. —— ①

Heat generated = I^2R watts. —— ②

I = c/n through the fuse element = fusing c/n.

R = Resistance of fuse element.

Let us consider circular shape of fuse element —— ③

$$R = \rho l/a = \frac{\rho l}{(\pi/4)\, d^2}$$

ρ = specific resistance, l = length of fuse element.

d = diameter of fuse element.

Now for a fuse wire of diameter d, the heat lost can be obtained as.

Heat lost = Effective surface area × constant
= dl × constant —— ④

Now put eqn ②, ③, ④ in eqn ①.

ie $I^2 \propto \frac{\rho l}{(\pi/4\, d^2)}$ = dl × constant

so

$I^2 \rho l = \pi/4\, d^3 l \times \text{constant}$

$I^2 = k' d^3$

$k' = \frac{\text{costant}}{\rho}$ = Another constant

$$I = k'\sqrt{d^3} = k' d^{3/2} \quad \text{——} (5)$$

equation (5) is called fuse law & k is fuse constant.

* Advantages of fuse.

1) It is a simplest & cheapest form of protective device.
2) It requires no maintenance.
3) The minimum operating time of fuse can be made much smaller than that of the CB
4) Inverse time-c/n characteristics of fuse enable it to use for overload protection

* disadvantages.

1) the fuse is required to be replaced or rewired after its operation
2) The replacement or rewiring takes a lot of time.
3) it is not possible to provide secondary protection to fuse.
4) The current - time characteristics can't be obtained unless their is much difference in relative sizes of fuses

*. <u>HRC fuse</u>

This is High Rupturing capacity cartridge type of fuse which is a simplest form of fuse, which is used for distribution purposes. The <u>low</u> and <u>uncertain</u> breaking capacity of semienclosed fuse is overcome in HRC fuse.

* <u>construction</u>

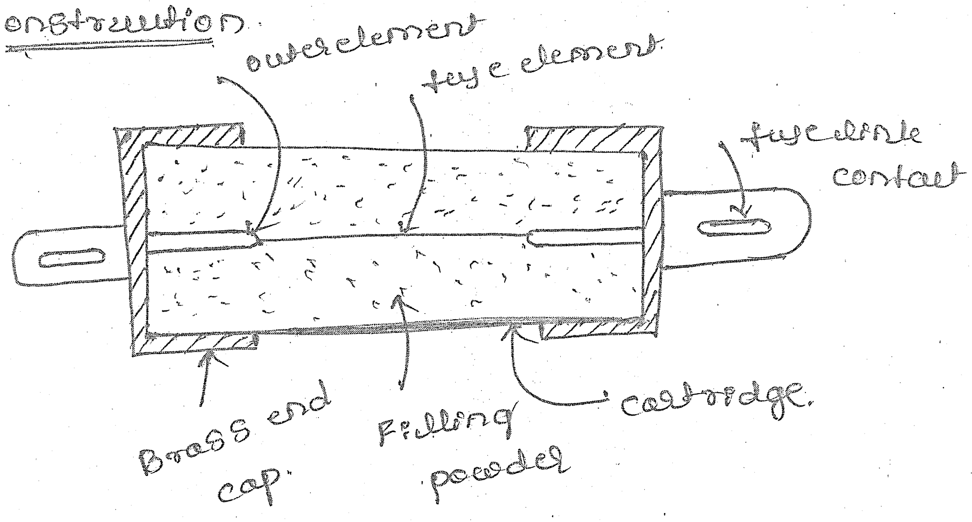


fig - construction of HRC fuse

The construction of HRC fuse is as shown above fig. the body of this fuse is of heat resisting ceramic with metal end caps.

→ The metal used for the end caps is generally <u>brass</u>. Between the end caps, the fixed elements are mounted, which are properly welded to the end caps.

→ the fuse element is silver which is attached by the fixed elements.

→. The body of the fuse is cylindrical in shape, the space of body is completely filled with a filling powder. & the filling powder is generally quartz, sand, plaster of paris <u>or</u> marble dust.

→ The filling powder material is selected such that its chemical reaction with silver ~~metal should~~ ~~form a~~ vapour should for very high resistance substance.

→ this type of high resistance substance will helps in arc quenching & acts as cooling medium

* **Operation** :- under normal operating condition the c/n flowing through the fuse element is rated ~~valu~~ or below the rated value. Hence the temp is also below the melting point. & during this condition the fuse element safely carry current without overheating.

But when due sc fault current occurs the c/n increases to a very high value, which increases the temperature of the element upto melting point temp. ∴ the fuse element gets melted before fault c/n reaches its peak value.

→ The chemical reaction b/n silver vapour & filling powder will for high resistance substance which helps to quench the arc quickly

* The various steps for the operation of HRC fuse.

1) occurance of fault
2) Increases the c/n through the fuse element to a high value.
3) Melting of silver element
4) vapourization of the silver element

5) formation of high resistance substance.
6) Extinction of arc.

* The electrical phenomena associated with the operation of HRC fuse are.

1) Formation of high resistance substance due to the chemical reaction b/n silver vapour & filling powder.
2) as c/n is cut-off the high resistance gets converted to an insulator.
3) creation of transient voltage at the instant of breaking fault c/n.

→ The physical phenomena include rise of temp & generation of high internal pressure.

* characteristics of HRC fuse.

1) cut-off characteristics
2) time-c/n characteristics
3) I^2t characteristics.

* cut-off characteristics.

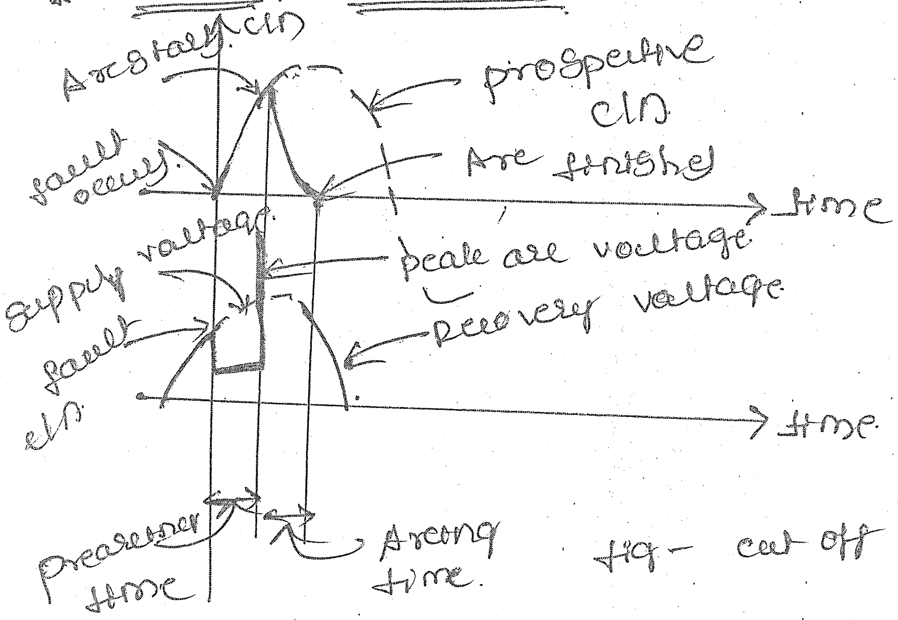


fig - cut off characteristics of HRC fuse

→ during occurance of fault excessive amount of current flows through the fuse, & fuse element starts melting.

→ The fault current has a large positive peak value but before it reaches its peak value the fuse blows.

→ The rms value of 1st loop of fault c/n is known as prospective c/n.

→ The current at which fuse melts & arc starts is called cut-off current.

→ When fault occurs voltage decreases & fuse melts. with arc formation, the arc voltage reaches to a value which is several times more than the supply voltage. However this voltage depends on fuse length and cross-section.

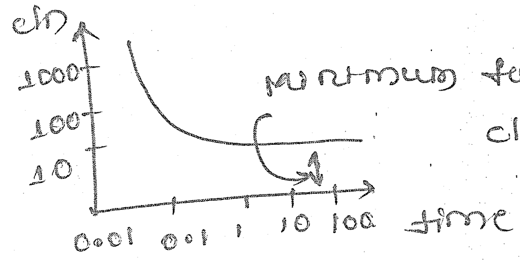
→ The above fig shows cut-off characteristics of HRC fuse

→ As mentioned earlier, cut off value depends on the normal c/n rating of fuse. & the prospective c/n is asymmetric in nature.

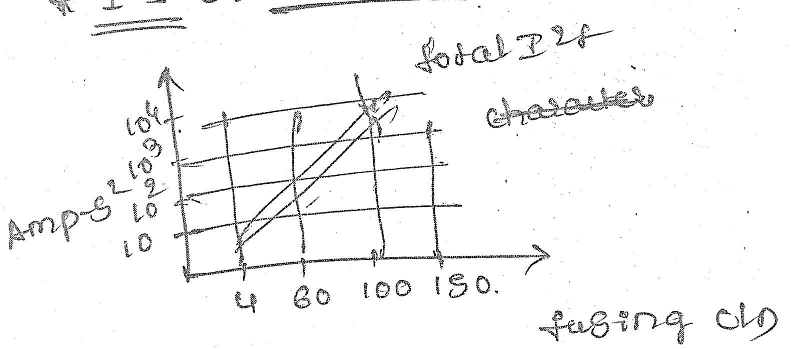
→ The breaking capacity of the HRC fuse is represented by its normal service voltage & rms value of the prospective current //

* **Time-current characteristics**

The HRC fuse shows inverse time-c/n characteristics. as fault c/n is high the operating time becomes less.



* **I^2t characteristics**



The information about heating effect due to the pre-arcing c/n & at the time of quenching can be obtained with the help of I^2t chart it indicates amount of energy released which is passed through the equipment which is to be protected.

* ~~[illegible]~~ — [illegible]

* 14 Advantages of HRC fuse.

Various advantages of HRC fuse are

1) HRC fuse is capable to clear high values of SC current.
2) The operation of HRC fuse is fast.
3) it has inverse time-current characteristics.
4) The performance is very much consistent.
5) It provides reliable discrimanation.
6) The cost of HRC fuse is less as compared to other protecting device.
7) No maintenance is required
8) The operation is much more reliable.

* Disadvantages of a HRC fuse.

1) HRC fuse is to be replaced after each operation.
2) However the replacement of fuse takes time.
3) Inter locking is not possible.
4) When HRC fuse is subjected to high temperature the production of Heat will affect the adjacent contacts associated with switches etc.

* Selection of HRC fuse

The following points must be considered while selecting the HRC fuse

1) The level of over current protection required.
2) The normal current of the circuit.
3) The voltage appearing across the fuse after its operation which should not be greater than its rating.
4) The rupturing capacity of HRC fuse, may not be less than the ckt to be interrupted.
5) The discrimination is needed when HRC fuse is used with other +

* Applications of HRC fuse

The main applications of HRC fuse are as follows →

i) HRC fuse is used for low voltage distribution system against the overload and short circuit condn

ii) this type of fuse can also be used for backup protection to the circuit breakers.

iii) protection for meshed feeders with steady load condition.

* HRC fuse with tripping device

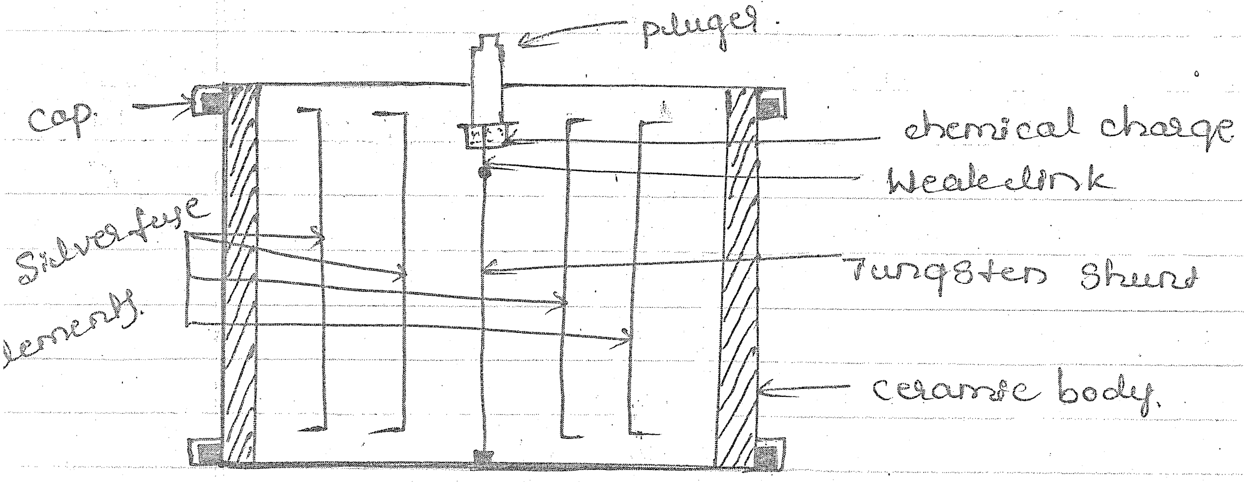


fig - HRC fuse with tripping device

Above fig shows HRC fuse with tripping device. The body of fuse is made up of ceramic with a cap which is fixed at both ends. with the help of cap at one end, the plunger is inserted which will acts as a tripping device for the associated circuit breakers. Between the end caps number of silver fuse elements are connected. The plunger is electrically connected with tungsten shunt with weak link, connected to the cap at other end.

operation :- When fault occurs the silver fuse elements gets melted due to which the current gets transferred to the tungsten shunt wire due to which the weak link fused. The chemical charge forces the plunger to move upward, However the upward movement of plunger is controlled so that it should not eject ~~out~~ completely outside from the body of fuse which operates the trip circuit of the breaker to open it.

* Advantages.

The HRC fuse with tripping device has the following advantages over the normal HRC fuse

1) The plunger gives the visual indication when the fuse blows
2) Low voltage HRC fuses may be built with a breaking capacity of 16500 to 33000 A at 440V.
3) In a three phase system if one phase fuse blows off then the supply to the motor continues but single phasing occurs which causes overheating of motor ~~oof~~ winding due to overloads. During that condition HRC fuse with tripping device operates the CB & disconnects all 3 phases, it will show that one fuse is blows off, the entire 3-ϕ supply gets disconnected due to the operation of CB.

* Liquid fuse.

A fuse which uses a liquid instead of powder for arc extinction is known as liquid fuse. However oil is used as liquid for arc extinction. The liquid fuse is very popularly used in high voltage systems.

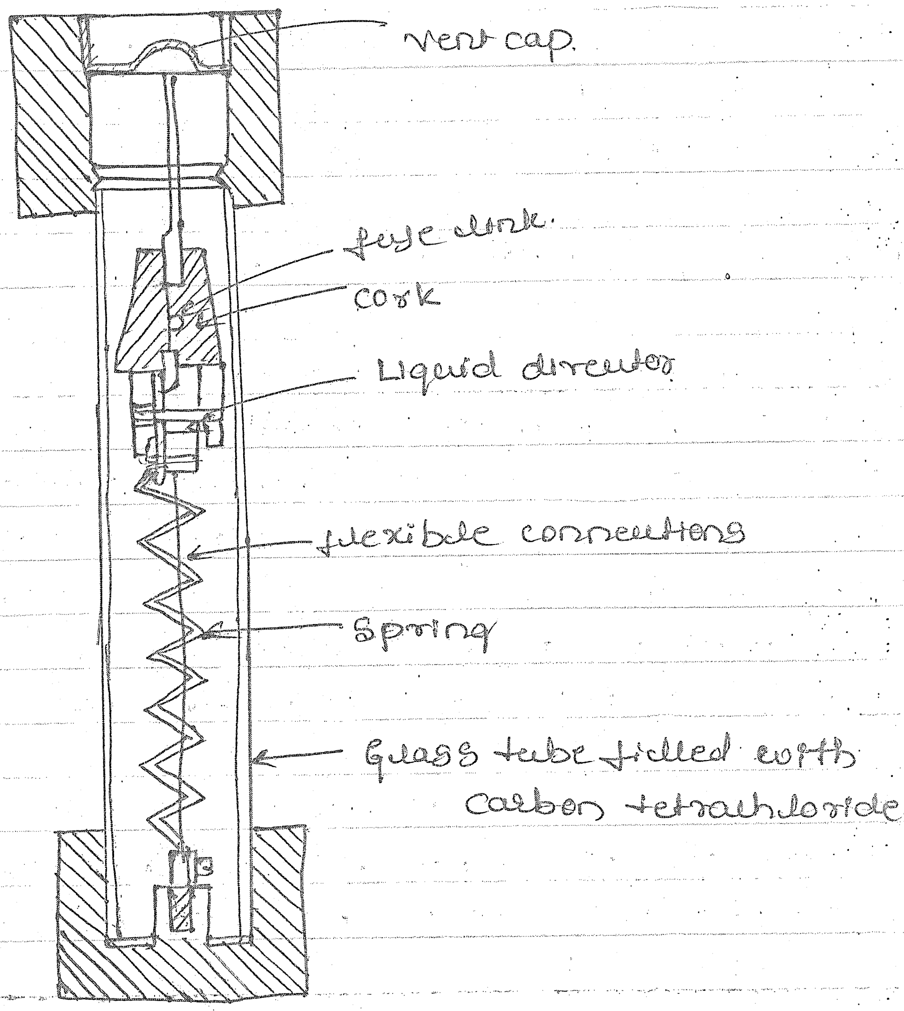
→ The liquid fuse is having breaking capacity of the order 6000A is used for the systems upto 132 kV.

→ The above fig shows constructional details of liquid fuse

→ The liquid fuse is basically consists of a glass tube the glass tube is filled with carbon tetrachloride solution. However the glass tube is sealed with the caps at both the ends. The caps are made up of brass.

→ The fuse element is fixed at the one end of the tube which it is again connected to spiral spring & the spring is fixed at other end of the glass tube.

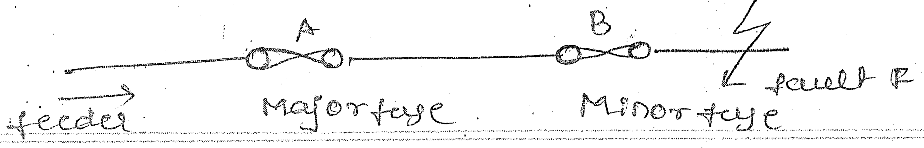
When fault occurs fuse element melts, as fuse element melts the part of Spiral spring enters into a liquid through the liquid director also called as baffle. The gas generated at the time of melting of fuse element is responsible to push some part of liquid into the passage through the liquid director. due to which the liquid entered into the passage, the arc gets extinguished completely and effectively.



* Discrimination

When there are two or more than two protective devices are used for the protection of same circuit then there must be proper co-ordination b/n both the protective devices. With this proper co-ordination the correct operation of correct device takes place, without affecting the other is called discrimination.

Let us consider a simple case of two fuses A & B connected in series as shown below.



as shown in the above fig fuse A is major fuse while fuse B is minor fuse. When the fault occurs beyond the fuse B then only fuse B has to operate without affecting the operation of fuse A.

In order to achieve this, while selecting the fuses it is checked that prearcing time of fuse A is more than the total operating time of fuse B, which is called as proper discrimination b/w fuse A & fuse B.

* **Isolating & earthing switch.**

In order to disconnect the part of power system for maintenance and repair purpose isolating switches are used. The main feature of such a isolator switch is, they are operated for no load condition.

→ Isolators are operated after switching off the load by means of circuit breaker. & these isolators are connected on both sides of circuit breaker. hence in order to open isolators, the CBs must be opened first.

→ The isolators do not have any current breaking or current making capacity, but they will provide additional safety by earthing isolated circuit.

* **General construction of an isolator.**

→ The isolators which are used in power system they are three pole isolators. all the poles of isolators are exactly identical.

→ The live part of isolator is having conducting copper or aluminium rod with fixed and moving contacts

f attendance cc - ⊗, 4, 12, ⊗, ⊗, 34, 35, 37, 41, ⊗, ⊗, ⊗, — 18/2/16.

when the moving part is opened, the conducting rod move apart to achieve isolation.

→ during open position they provide visible isolation distance. The simultaneous operation of ~~all three poles is performed single operating~~ mechanism & mechanical interlocking of three poles

→ All the isolators are eqed with manual or motor operated mechanism.

* In order to avoid wrong functioning of isolators, two types of interlockings are provided.

1) Interlocking b/n all three poles which gives simultaneous operation.
2) Interlocking with circuit breakes.
While opening CBs are opened 1st & then isolators. while closing the isolators are closed 1st & then the CBs.

* Types of isolators

1) Horizontal central rotating double break isolator
2) vertical break isolator
3) pantograph isolator.

* operating instructions for isolating switches

→ The important operating instructions for isolating switches are.

1) while closing the isolator must be closed 1st then the circuit breakers.
2) It can be operated with less pressure
3) while operating manually the isolator hand gloves must be put.
4) It is a no load device hence it can not be operated when it carries load current.

* Applications of isolating switches

The various applications of isolating switches are

→ They helps to isolate the equipments from the buses for maintenance purpose.
→ Sectionalizing the buses.
→ Bypassing the buses.
→ Transfering the loads.

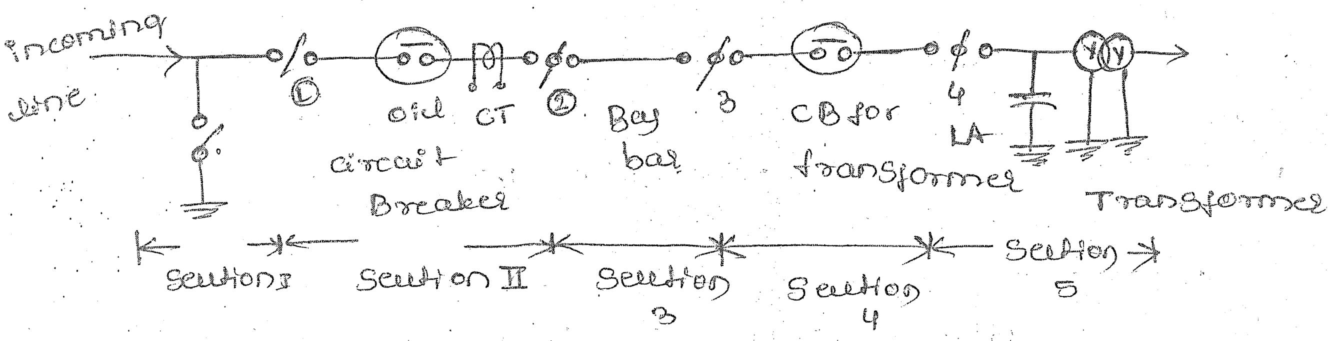


fig - Line diagram of substation with isolating switches

As shown in the above fig there are 5 sections with the help of isolator each section can be dis-connected for repair & maintenance. for example the maintanance of section 4 is to be done then the circuit breaker in that section is to be opened 1st then isolators 3 & 4 are to be opened. after the maintance isolators 3 & 4 are to be closed 1st the CB is to be enclosed.

* Load breaking switches.

A load breaking switch is a disconnecting device with a particular set of capabilities.

→ load breaking switch combines the functions of isolator and switch.
→ it is capable to make and break the circuits at normal load ~~conditions~~ currents.

load breaking switches are also known as load interrupting switch or load disconnecting switch.

→ The various types of load breaking switch are

1) Single operation
2) Ring main unit
3) switch - fuse combination.

* Features of load breaking switch are

1) High breaking capacity which is given by breaking currents.
2) High electrical & mechanical sustainability to withstand the stresses.
3) Rolling contact system for smooth operation
4) Double breaking on each phase
5) very compact design.
6) Quick making & breaking operation independent of normal operation.

* Functions of EMS.

1) Network configration / Topology processor.
to estimate and analyse the state of entire electrical network, a new topology is available
* new topology processor continously retains & updates electrical s/m topology. Such as branch impedances, loading & status of CB, connectivity.

2) State estimation :- it performs the determination of best estimate from the real time measurements.

3) contigency analysis :- contingency is unseen event in which important component of the s/m is to be removed from service, it may involve generator, tr-line or transformer.

* Roll NO - 13/2/17 - 1, 0, 1, 7, 10, 22, 30, 31, 35, 43, 46, 47, 48, 50, 52, 53, 54, 55, 56, 57, 58, 59, 60, 61 to 67
* 14/2/17 → 1, 0, 10, 16, 22, 30, 31, 35, 37, 43, 52, 53, 54, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67
* 17/2/17 → 3, 8, 10, 16, 17, 20, 27, 33, 36, 37, 44, 49, 60, 61
* 18/2/17 → 3, 5, 10, 16, 20, 37, 44, 49, 55, 58, 61, 62, 64,
* 20/2/17 → 8, 26, 30, 36, 41, 48, 54, 60, 61, 65.

4) Three phase balanced operator power flow :- It involves the study of balanced power flow on tr-line & load flow analysis with voltages & phase angles at various points

5) optimal power flow :- It deals with optimization of a specified objective function with associated constraints.

6) Dispatcher training simulator :-
It is the computer based training sim for operators of electrical power grid

* **Selection of fuses.**

The selection of proper fuse plays very important role, An improper blowing out of fuse results in an unnecessary interruption of flow of power & failure of some circuits.

The following factors to be considered while selecting a fuse.

1. Nature of load → It includes the consideration of load whether it is steady or fluctuating load

→ Steady load → For steady load it is necessary to decide whether the fuse is required to give both overload and short circuit protection. For providing both, the steady current rating of the fuse is higher than the normal rated current.

If only the short circuit protection is required then the fuse current rating can be much higher than the normal rated current.

b) Fluctuating load :- In fluctuating loads like motors, switching capacitors, fluorescent lights etc. lot of variations in current.

∴ the fuse must be selected such that it will not blow under transient overloads Hence ~~fuse must be selected~~ the current-time characteristics of fuse must be always above transient current characteristics of the load by sufficient margin.

2) It should be able to withstand momentary over-current due to starting a motor & transient current surges due to switching on transformers, capacitors and fluorescent lighting etc.

3) Its operation must be ensured when sustained overload or short circuit occurs.

4) It should provide proper discrimination with the other protective devices.

5) The fault currents are generally very high & hence proper peak current value, fusing factor, rupturing capacity & category of duty must be considered while selecting the fuse.

* protection against overvoltages *

* Causes of overvoltages.

Overvoltages or Surges on power system are due to various causes. Overvoltages arising on power system are classified into two main categories.

1. External overvoltages
2. Internal overvoltages.

* External overvoltages :- The external overvoltages are caused due to atmospheric disturbances, mainly due to lighting.

* These overvoltages take the form of a unidirectional impulse whose maximum possible amplitude has no direct relationship with the operating voltage of the system.

* The overvoltages are mainly due to the following reasons →

1. due to direct lighting strokes.
2. Electromagnetically induced overvoltages due to lightning discharge taking place near the line known as side stroke.
3. the voltages induced ~~overvoltage~~ due to the change in the atmospheric conditions along the line length.
4. Electrostatically induced overvoltages due to the presence of charge clouds nearby.
5. Electrostatically induced overvoltages due to the frictional effects of small particles such as dust or dry snow in the atmosphere.

* Internal overvoltages → internal overvoltages are caused by change in the operating conditions of the network.

Internal overvoltages are further divided into two groups.

① Switching overvoltages (or transient overvoltages of high frequency).

→ These overvoltages are caused by the transient phenomena which appear when the state of network is changed by a switching operation or fault condition

→ The frequency of these overvoltages vary from few hundred Hz to few kHz. & it is governed by the inherent capacitances & inductances of the circuit.

for example if the fault occurs in any phase the voltage w.r.t to the ground of the other two healthy phases can exceed the normal value until the fault is cleared

② Temporary overvoltages (or steady state overvoltages of power frequency)

These overvoltages are the steady-state voltages of power-system frequency which may result from the disconnection of the load, particularly in the case of long transmission lines.

Transient overvoltages arising on the power system are assessed by the over voltage factor,

→ over voltage factor is defined as, it is the ratio of the peak overvoltage to the rated peak-frequency phase voltage. it is also known as amplitude factor.

* Lightning phenomena

The discharge of the charged cloud to the ground is known as lightning phenomena.

→ A lightning discharge through air occurs when cloud is raised to a such high potential with respect to the ground, the air breaks down & the insulating property of the surrounding air is destroyed.

→ The cloud and ground form two plates of a 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 the cloud & rain in the lower part.

* If the lower part of cloud is negatively charged, the earth is positively charged by the induction.

* to happen lightning discharge, it requires the break-down of air b/n the cloud & the earth. With increase in charge the potential b/n cloud and the earth increase as a result the potential gradient increases

* The potential gradient or electricfield required for the breakdown of air is 30kV/cm peak. But there is large moisture content in the air ~~and breakdown~~ at high altitude, thats why the breakdown of air takes place at 10kV/cm.

The process of lightning mechanism is well explained with the help of fig as shown below.

fig-a

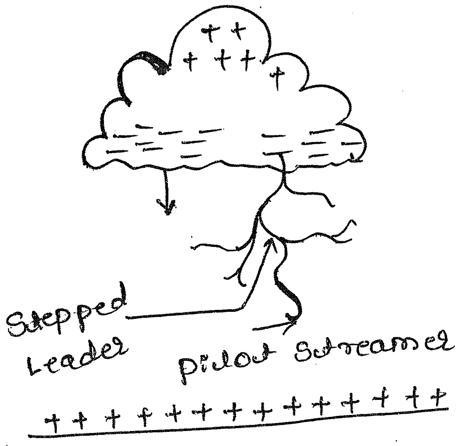


fig-b

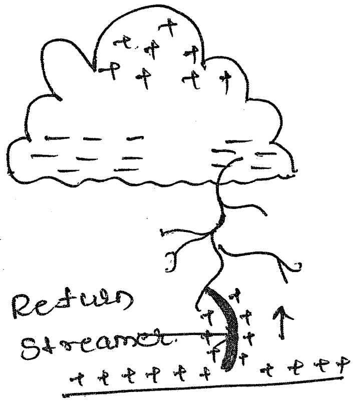


fig-c

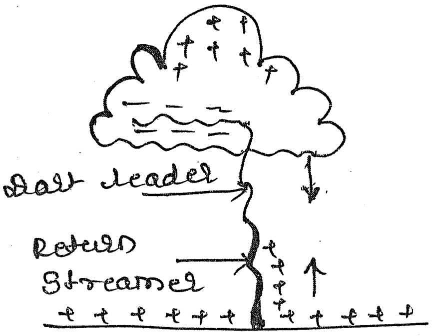


fig - lightning mechanism.

* When the potential gradient of about 10kV/cm is set up in the cloud, the air surrounding the cloud gets ionised and first process of the actual lightning discharge starts.

→ At this instant, a streamer called a 'pilot streamer' starts from the cloud towards the ground which is not visible.

→ The current associated with this streamer is of the order of 100 amperes, and the most frequent velocity of propagation of the streamer is about 0.15 m/μs

→ depending upon the state of ionisation the air surrounding the pilot streamer, is branched into several paths, a stepped leader is formed. as shown in fig-a because of its zig-zag shape it is known as stepped leader. it consists a series steps about 50m in length

→ The velocity of propogation of these steps should be more than 16.6 percent that of the light.

→ The process of distribution of strike continues until one of the leader strikes the ground. & extremely bright return streamer will be formed as shown in fig-b) & propagates upward from the ground to the cloud following the same path as the main channel of the downward leader.

→ After the neutralization of most of the negative charge on the cloud any further discharge from the cloud may have to originate from another charge centre within the cloud near the already neutralised charge centre.

→ Such discharge from another charge centre will follow the already ionised path, this streamer is known as dart leader as shown in fig-c.

→ The velocity of propogation of the dart leader is about 3% that of the light.

The dart leader can cause more severe damage than the return stroke.

* Even though the discharge current in the return streamer is relatively large but it continues only for a few microseconds. it contains less energy hence it is known as cold lightning stroke

The dart leader is known as hot lightning stroke because even though the c/n in this leader is smaller but it contains relatively more energy & it continues for some milliseconds.

It ~~may~~ has been observed that every thunder-cloud may consist as many as 40 separate charged centres due to which a heavy lightning stroke may occur. This lightning stroke is known as multiple stroke or repetitive stroke.

* Wave shape of voltage due to lightning.

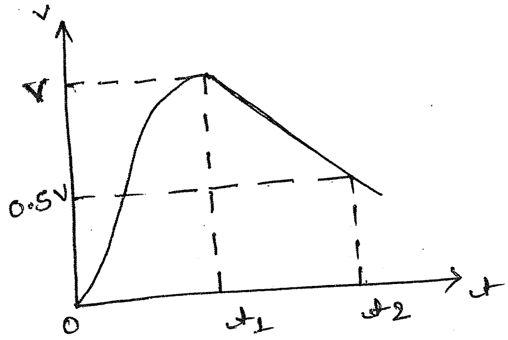


fig - wave shape of voltage due to lightning.

lightning phenomena will set up steep-fronted, unidirectional voltage waves which are represented as the difference of two exponentials.

Thus
$$v = V(e^{-at} - e^{-bt}) \quad \text{--- (1)}$$

Where a & b are the constants which determine the shape and v is the magnitude of steep voltage & V is equal to the peak value of the impulse voltage wave.

* The steep is dependent on whether the surge is induced or it is the result of direct stroke.
* The wave shape is generally defined in terms of the times t_1 & t_2 in microseconds.
* Where t_1 is the time taken by the voltage wavefront to reach its peak value & t_2 is the time taken for the tail to fall 50% of peak value.

* over voltages due to Lightning

Lightning causes two types of overvoltages namely direct stroke & indirect stroke.

direct stroke occur on line conductor ~~on~~ the top of tower & on the ground wire.

Indirect stroke appear on overhead line conductors.

* **direct stroke on overhead conductors.**

These strokes are more dangerous & the effects of such strokes are severe and harmful. In case of direct stroke the discharge is directely from cloud to overhead line.

* From the overhead line the c/n may flows through insulators, pole to the ground.
* ~~If this current I flows in direct stroke to be phase conductor, forward & backward.~~

If a overhead line conductor is struck by lightning then the rise in voltage at the point is given by.

$$V_x = I_{stroke} \times \frac{Z_L}{2} \quad \text{——} ①$$

where I_{stroke} = current in the lightning stroke

Z_L = surge impedance of the line.

the term $\frac{Z_L}{2}$ indicates the charge on the conductor flows to the both sides of the conductor in the form of travelling waves.

If we consider $Z_L = 1000\,\Omega$, $I_{stroke} = 40kA$

then the voltage developed will be

$$V_x = (40\times10^3) \times (1000/2) = 20\times10^6 = 2\times10^7 \text{ volts}$$

this much of voltage is produced during stroke.

* If this lightning stroke appears at a point away from a substation or generating station this over-voltage and the current flows along the line in both the directions causes damages to the insulators.

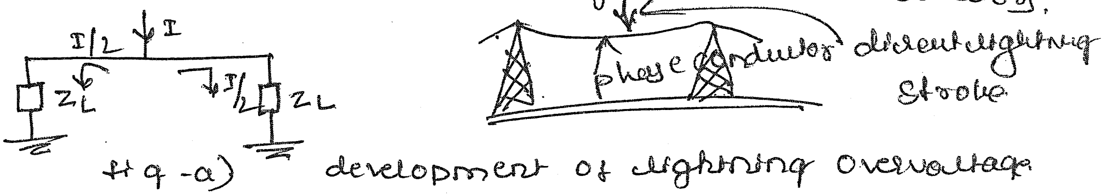


fig-a) development of lightning overvoltage

Direct Stroke on Tower

If there is a direct lightning stroke on the tower then its voltage is increased. Its value is given by

$$V_{stroke} = L_T \, di/dt + R_T i$$

Where V_{stroke} = voltage surge b/n the top of tower & earth.

L_T = inductance of tower

R_T = Resistance of tower

i = c/n flowing through the tower due to stroke.

For example if we consider $R = 10\,\Omega$, $i = 30kA$,

$di/dt = 10kA/\mu s$ & $L = 10\mu H$

$\therefore V_{stroke} = (10 \times 10) + 10 \times 30 = 400kV$

this much of voltage will appear b/n the top of tower & earth. If this voltage is more than impulse flash over level then flash over may occur b/n the tower & line conductor.

Due to this travelling waves may also be formed in both the directions of the conductor & it may cause the damage of substation equipments.

Indirect Strokes

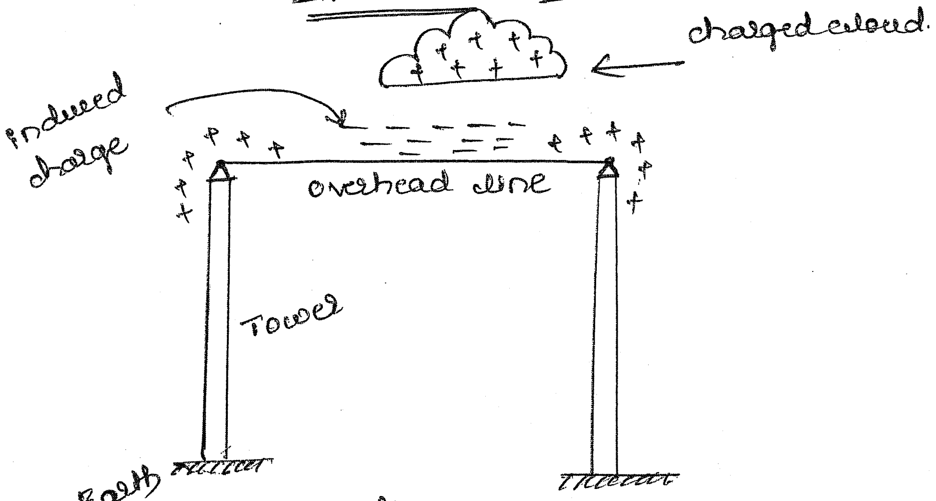


fig -

* The effect of indirect strokes is similar to that of the direct strokes. Their effect is more severe in case of distribution line than in case of high voltage lines.
* The indirect strokes are due to electrostatically induced charges on the conductors due to the presence of charged clouds.
* Sometimes the currents may be induced electromagnetically due to lightning discharge near to the line which results in indirect stroke. as shown in below fig.

As shown in the above fig let us consider a positively charged cloud above the line. It induces negative charge on the line by electromagnetic induction & other portion of the line is positively charged.
* The induced positive charges slowly leak to the earth through the insulators.

Whenever there is discharge from the cloud to the earth the negative charge on the wire is isolated & it can't move quickly to the earth over the insulators due to this the negative charge goes along the line in both directions in the form of travelling waves. Maximum surges in a transmission line are caused by indirect lightning stroke.

Klydonograph & Magnetic link

* Klydonograph.

Klydonograph is an instrument used for the measurement of surge voltage on transmission lines caused due to lightning.

→ It measures the voltage by means of Litchenberg figures when suitably coupled to the line whose surge voltage is to be measured.

* 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 up of homogeneous insulating material as shown in below fig.

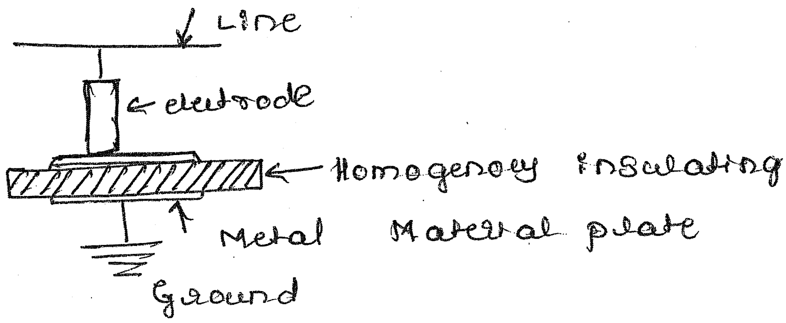


fig-a) klydonograph.

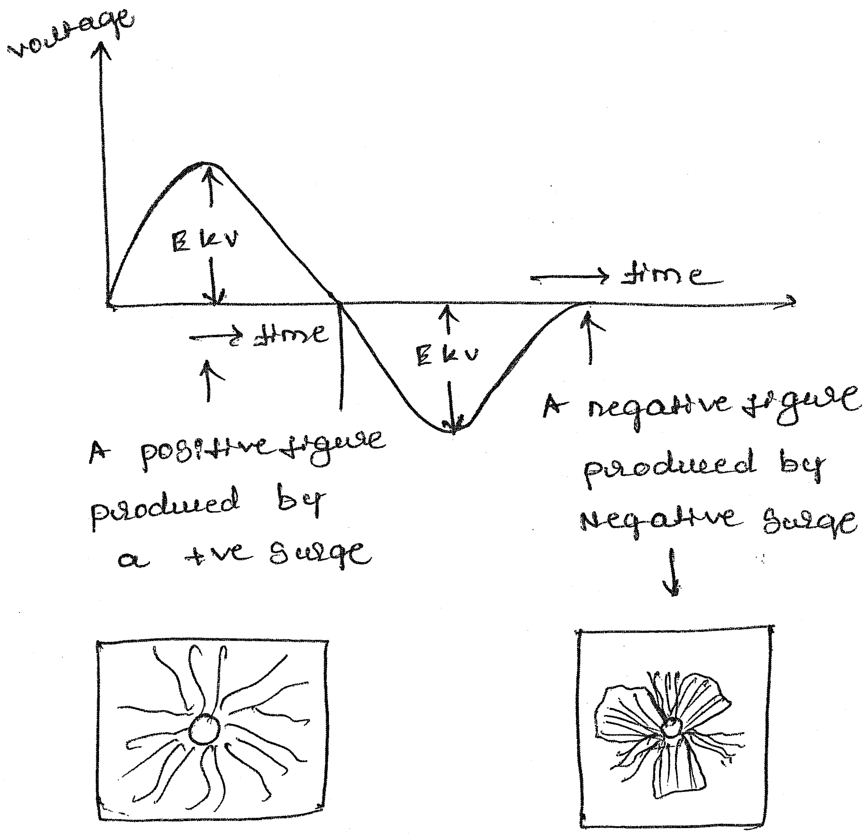


fig-b) +ve & -ve lichtenberg figures produced by +ve & -ve surge voltages of same magnitude & wave shape.

The photographic plate is moved by clockwork mechanism, three assemblies are generally placed in the same box, for simultaneously measuring the voltages on the three phases of a tr-line.

With this arrangement, a +ve Litchenberg figure is produced by a positive surge & a -ve Litchenberg figure is produced by a negative surge as shown in fig-b.

positive Litchenberg figures are found to be superior than the negative ones for voltage meast purpose. Since they are much larger than negative figures.

Diameter of positive Litchenberg figure is the function of the maximum value of the impressed voltage. The shape & configuration of figure depend on the wave shape of the impressed voltage.

* protection of Generating Stations and Substations from direct Stroke

→ generally the generating stations are housed in big buildings while the Substations are housed in outdoor.

* To protect these structures from direct stroke three important points are to be taken into the consideration namely interception, conduction & dissipation must be fulfilled.

* It requires an object with good electrical connection with the earth having low impedance to attract the leader stroke.

* It also require a low resistance connection with the body of the earth.

* In order to have good electrical connection, the upper portion of metal structure may be used. instead of this even a separate metallic system called shield mounted on the structure or near to it may be used.

* The total outdoor substation is provided with earthed overhead shielding screen.

* The earthing screen consists of a network of copper conductors mounted all over the electrical equipment in the plant or substation. This shield is appropriately connected to the earth atleast at two points with the help of low impedance path. occurance of any direct stroke is directly diverted to the earth as the shield provides low resistance path.

* It is designed in such way that out of 1000 strokes, 999 strokes will be diverted to earth through this shielding while only 1 stroke may strike on the protected equipment which is called 0.1% exposure.

* The clearance b/n line conductor and overhead shielding should be more than minimum clearance b/n phase & earth

* For a small station, it is sufficient to use one or two ground wires across the station from adjacent line towers as shown below. fig a.

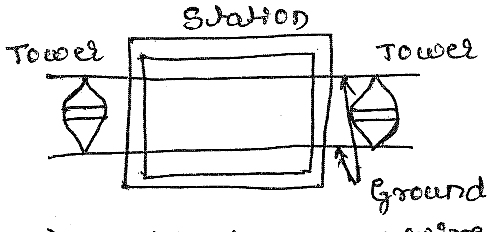


fig-a) overhead ground wire carried over a small station b/n adjacent towers.

* For more extensive station extra ground wire may be used fanning out from the towers to the station structure, as also over the station if mechanically feasible, as shown in fig b

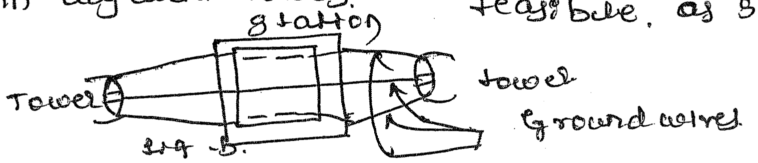


fig-b.

* Protection against Travelling waves

Shielding the lines and stations by overhead ground wires, masts or rods undoubtedly provides adequate protection against direct lightning strokes and also reduces electrostatically or electromagnetically induced overvoltages, but such shielding will not provide protection against travelling waves which may occur in over the lines & reach the terminal equipment.

* The travelling waves may cause the following damages to the electrical equipment

① Internal flashover caused by the high peak voltage of the surge may damage the insulation of the winding.

② Internal flashover b/n interturns of the transformer may be caused by the steep-fronted

③ External flashover b/n the terminals of the electrical equipment caused by high peak voltage of the surge may result in damage to the insulators

④ Resonance & high voltages resulting from the steep-fronted wave ~~by~~ may cause internal or external flashover of an unpredictable nature causing building up of oscillations in the electrical equipment

Hence it is ~~absoutely~~ absolutely necessary to provide some protective devices at the station or sub-stations for the protection of equipment against the travelling waves caused by lightning.

The protective devices used for this purpose are ~~as~~:
① Rod gap
② Arcing Horn
③ Surge diverter etc.

* <u>Rod gap</u>

$L_1 > L/3$

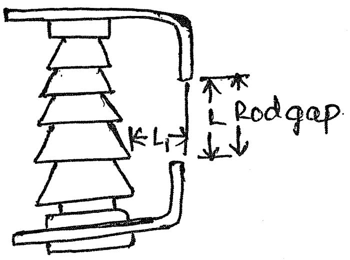


fig- rodgap.

* Rod gap provides the simplest & cheapest protection to the line insulators, equipments ~~insulators~~ and bushings of transformers.
* In case of transformers, rod gaps known as co-ordinating gaps are installed to provide protection for apparatus.
* Rod gaps provide back-up protection to the bushings of transformers in case of primary protective device failure ie failure of lightning arrester.
* As shown in the above figure A rod gap consisting of two rods of approximately 1.2cm diameter or square which are bent at right angles, one rod is connected to the line while the other rod is connected to the ground.
* In case of transformers they are fixed b/n bushing insulators.
* In order to avoid cascading across the insulator surface under very steep-fronted waves, the rod gap should be adjusted, ~~is adjusted~~ in such way that the breakdown should occur at 20% below the flash over voltage of insulator.
* The distance between the gap & the insulator should be more than one third of the gap length ie $L_1 > L/3$ to prevent the arc from being blown on the insulator.
* Under the normal operating conditions the gap is nonconducting. When the high voltage surge occurs

on the line, there is spark in the gap. and current in surge is diverted to the earth, ∴ excessive charge on the line is passed to the earth through this arrester

* The breakdown value of the rod gap can't be predicated easily because the breakdown of air depends upon the atmospheric conditions (i.e. humidity, temp, & pressure) & also upon polarity, steepness & the waveshape of wave

* The major disadvantage of the rod gap is that it does not interrupt the power frequency of current after the surge has disappeared.

* it means that every operation of the rod gap creates the L-G fault which is cleared only by the operation of circuit breaker.

* ∴ the operation of the rod gap results in circuit outage and interruption of power supply.

* Arcing Horn *

The damage to line insulators due to heavy arc which is formed due to the overvoltage is a serious maintenance problem.

* Several protective devices have been developed to keep an insulator string free from arc.

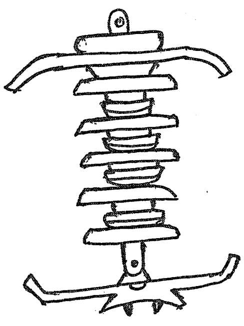


fig - Suspension string with arcing Horns

* Arcing Horn is one of the such protective device. it consists of small horns attached to the clamp of the line insulator string.

* Horns with a large spread, both at the top of the insulator and at the clamp are required to be effective. as shown in above fig.

* In case of lightning impulse, the arc formed tends to cascade the string.
* In order to avoide the cascading, the gap b/n horns should be less than the length of string.
* protection of line insulators by arcing horns results in reduced flashover voltage.
* The protection of line insulators by arcing horns is especially used in hilly areas.
* The grading ring when used in conjunction with an arcing horn, fixed at the top of the insulator string serves the purpose of an arcing shield.
* Arc formation followed by flashover caused by some type of over voltage, the arc will usually take the path b/n the horn and the shield & the insulator string will remain clear from the arc.

* Surge arrester

Lightning arresters are also known as surge arrester or surge diverters, They are connected b/n the line & ground at the substation. & they always act in parallel with the equipment to be protected.

* The main ~~function~~ purpose of lightning arrester is to discharge the surge to ground.

The action of the surge diverter can be studied with the help of fig as shown below.

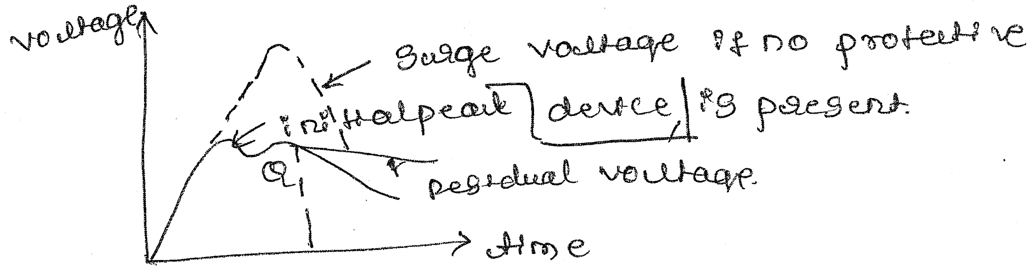


fig - voltage characteristic of surge diverter

As shown in the above fig, when the travelling surge reaches the diverter, it sparks over at a certain prefixed voltage as shown by the point P. & it provides a low - impedance path to ground for the surge current.

* The c/n flowing to ground through the surge impedance of the line limits the amplitude of the over voltage across the line to ground known as residual voltage as shown by the point Q.

* An ideal lighting arrester posses the following characteristics

① It should not draw any c/n at normal power frequency voltage ie during normal operation.

② It will breakdown quickly when abnormal transient voltage above the breakdown value appears ∴ low impedance path from line to ground can be provided.

③ The discharge c/n after breakdown should not be excessive so that the diverter itself may damage.

④ It must be capable of interrupting the power frequency follow - up current after the surge is discharged.

* Impulse ratio of lightning arrester

It is defined as the ratio of the breakdown impulse voltage of a wave of specified duration to the breakdown voltage of power frequency wave. The impulse ratio of any lightning arrester is a function of time duration of the transient wave.

* Types of lightning arrester

① Expulsion type LA
② Non linear surge diverter
③ Metaloxide surge arrester (MOA)

* Expulsion type lightning arrester.

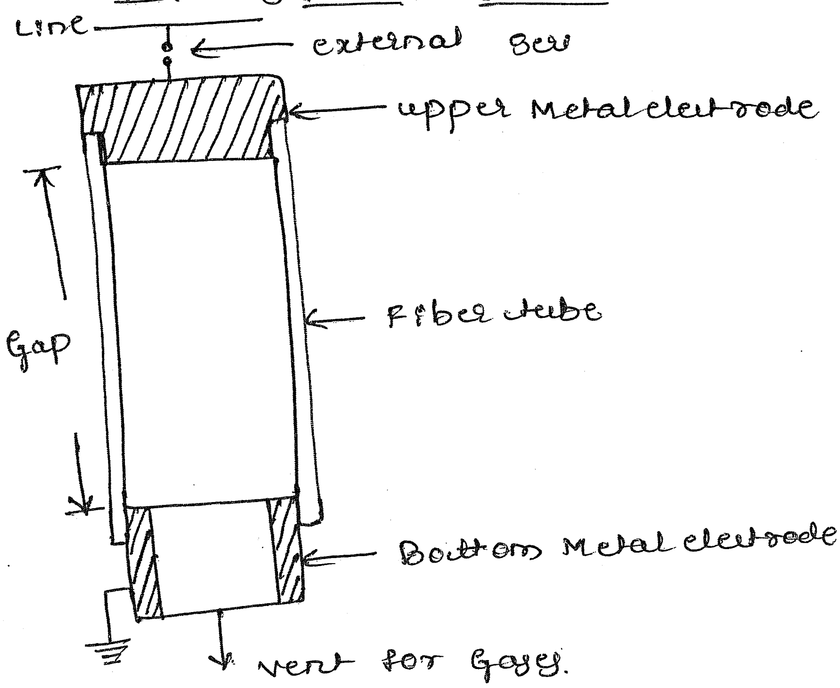


fig - Expulsion type lightning arrester.

The above fig shows Expulsion type LA, which is also known as Expulsion gap or protector tube.

* As shown above it consisting 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.

* When surge appears on the conductor, the series gap breaks down, results in the formation of arc in the fibre tube between the two electrodes.

* The heat of arc vaporises some of the fibre of the tube walls resulting in the generation of an inert gas.

* The 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.

* The arrester is known as Expulsion type lightning arrester because the gases formed during its operation are expelled from the tube through a vent.

* Metal oxide surge arrester

The metal oxide surge arrester abbreviated as MOA is a recently developed ideal surge arrester.

* It is constructed by a series connection of zinc oxide (ZnO) elements having non-linear resistance.
* The metal oxide surge arrester has the following advantages →

1. Series spark gap is not required.
2. It has very simple construction & it is fully solid-state protective device.
3. The size of arrester is significantly reduced.
4. Quick response for steep discharge current.
5. They have very small time delay to respond for overvoltages.
6. Superior protective performance.
7. They have outstanding durability for operating duty cycle.
8. Negligible power follow-up current after a surge operation.

MOA is suitable for gas insulated substations (GIS), since it can be directly installed in SF6.

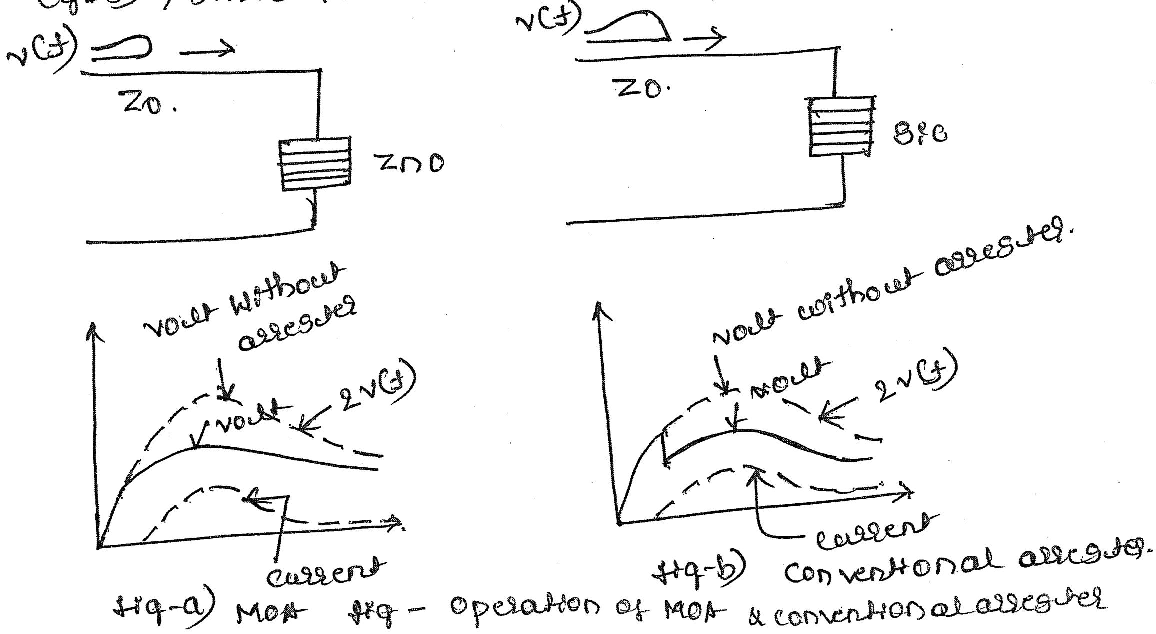


fig-a) MOA fig-b) conventional arrester.
fig - operation of MOA & conventional arrester

responding to an on-coming surge

The above fig illustrates the operations of MOA & conventional arrester responding to an on-coming surge v(t). The voltage wave shape of MOA is smooth & can be expressed as follows

$$V = 2v(t) - Z_0 i \quad \text{——— (1)}$$

where Z_0 is the surge impedance of the line & i is the instantaneous current of the arrester.

→ The voltage wave shape of conventional arrester has a peak value at the time of sparkover of the series gap. The voltage after the sparkover or the discharge voltage is expressed with the help of above equation

* the protection performance of conventional arrester is controlled by the sparkover voltage & the discharge voltage & the protection performance of MOA is related to the discharge voltage

* The protection level of MOA is decided by the maximum discharge voltage encountered under normal operating conditions.

* However their is a difficulty to get clear-cut expression like V-t curve in a conventional arrester. the individual voltage waveform should be considered is considered in precise discussion of insulation co-ordination.

For rough estimation of the voltage waveform it is convenient to consider the following expression

i.e $V = V(i)$ ——— (2).

→ The voltage waveform or the time dependance of V can be calculated by either eqn (1) & (2).

A graphical method of solving equation is as shown below.

* The voltage and current values corresponding to v(t) are represented by Po which is the intersection point of two curves corresponding to the equation ① & ②

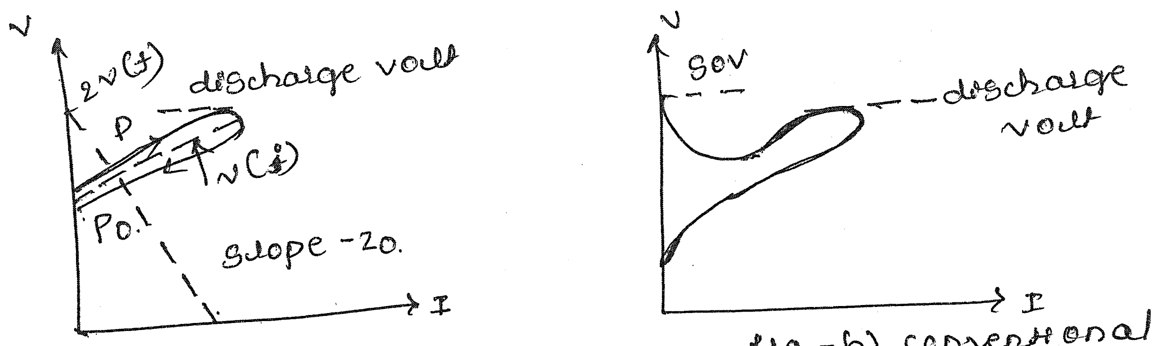


fig-a) MOA

fig-b) conventional

fig - Transient V-I characteristics of MOA & conventional arresters.

The point Po moves on the v(i) curve shown by dotted line as shown in fig-a

~~fig b indicates corresponding~~

from fig b it is clear that the change from Sparkover voltage to a lower discharge voltage is abrupt.

* The main disadvantage of MOA is, the absence of spark-gap results in a continuous flow of current through the device so their is possibility of thermal runaway.

* The absence of spark-gap makes the voltage grading slm necessary

* The MOA is self regulating, in that the o/n flow of 0.5 to 1mA at normal supply voltage leads to reliable operation even in polluted condition

* **Testing of lightning arrester**

Various tests are to be performed on lightning arrester to evaluate its performance they are as follows

1. 1/50 impulse sparkover test
2. Wave front impulse spark over test
3. peak discharge residual voltage at rated diverter current
4. impulse current withstand test.
5. switching impulse voltage test.
6. peak discharge residual voltage at low current
7. discharge capacity of durability.
8. Transmission line discharge test
9. low current long duration test
10. power duty cycle test
11. pressure relief test.

* **Insulation co-ordination**

Insulation coordination is the correlation of the insulation of electrical equipments & lines with the characteristics of protective devices, such that the insulation of whole power system is protected from excessive overvoltages.

* The main aim of insulation coordination is the selection of suitable values for the insulation level of different components of power system & their arrangement should be done in proper way so that whole power system is to be gets protected from overvoltages.
* Therefore the insulation strength of various equipments like transformers, circuit breakers etc should be higher than that of LAs & other protective devices.

* The insulation coordination should match the volt-time flashover and breakdown characteristics of the equipment & protective devices in order to obtain maximum protective margin at reasonable cost.

* The volt-time curves of the equipment to be protected & the protective device are as shown below.

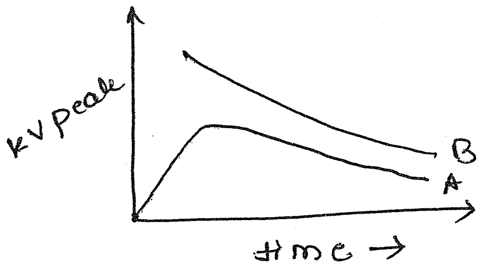


fig - volt-time curves of protective device and the equipment to be protected.

→ curve A is the volt-time curve of the protective device & curve B is the volt-time curve of the equipment to be protected.

* from the above fig it is clear that any insulation having a voltage withstanding strength in excess of insulation strength of curve B will be protected by the protective device of curve A.

* Basic Impulse insulation level (BIL)

The insulation strength of the equipments like transformers, CBs etc should be higher than the LA & other surge protective devices. In order to protect the equipment of the power system from over voltages of excessive magnitude, it is necessary to fix the insulation level ~~of~~ for the system to see that, any insulation in the system does not breakdown or flashover below this level & to apply the protective devices which provides the effective protection of apparatus

* The common insulation level for all the insulation in the station is known as Basic Impulse Insulation level (BIL) which have been established in terms of withstanding voltages of apparatus and lines.
* Basic Impulse insulation level can be defined as the reference level expressed in impulse crest voltage with a standard wave not longer than a 1.2/50 microsecond wave, according to the Indian standards.
* The basic impulse insulation level for system is selected such that the s/m could be protected with a suitable lightning protective device, for example lightning arrester.
* The margin b/n the BIL and the lightning arrester should be fixed such that it is economical & it also ensures protection to the system.
* The BIL chosen must be higher than the maximum excepted surge voltage across the selected arrester.//

* <u>protection of transmission lines against direct strokes</u>

The transmission lines are effectively protected against direct lightning strokes with the use of ground wire.

* Increasing the length of insulator string allows a higher voltage before flashover occurs.
* Therefore protective methods must be adopted to avoid flashover or breakdown of line insulators due to overvoltage caused by direct lightning strokes.
* The most generally accepted & effective method of protective lines against direct strokes is by the use of overhead ground wires.
* This method of protection is known as shielding method.

this method does not allow the arc path to form b/n the line conductor & ground.

* Ground wires are conductors running parallel to the main conductors of the tr-line supported on the same towers and adequately ground at every tower.

* They are made up of galvanised steel wires or ACSR conductors, they are provided to shield the lines against direct strokes by attracting the lightning strokes to themselves rather than allowing them to strike the lines.

* overhead ground wires protect the lines by direct stroke

* In order to provide efficient protection to the lines against direct stroke, the ground wires must satisfy the following requirements

① There should be an adequate clearance b/n the ~~ground~~ line conductors and ~~line~~ ground ~~conductors~~, or the tower structure.

② There should be an adequate clearance b/n the ground wires and line conductors, especially at the midspan in order to prevent flashover to the line conductors up to the protective voltage level used for the line design.

③ The tower footing resistance should be as low as possible.

* A few terms relating to protection of tr-line are explained below.

* protective ratio :- it is defined as the ratio of induced voltage on a conductor with ground wire protection to, the induced voltage which exist on the conductor without ground wire protection.

* **protective angle**

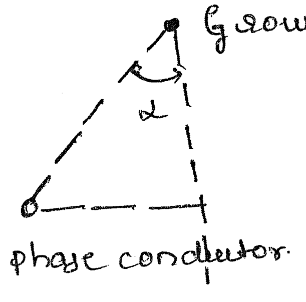


fig - protective angle α of an overhead groundwire.

The protective angle α afforded by a ground wire is defined as, The angle b/n the vertical line through the groundwire and a slanting line connecting the ground wire & phase conductor to be protected.

* The protective angle (α) is excepted b/n 20° to 45°.
* When protective angle does not exceed 30°, good shielding of the line conductors is obtained & probability of direct stroke to the conductor is reduced
* protective angle of 45° is satisfactory when the tower is on a hill-side.

* **protective zone**

It is defined as the volume b/n the base plane cbc and slanting planes ac, extending from the ground wire to the plane of the conductors.

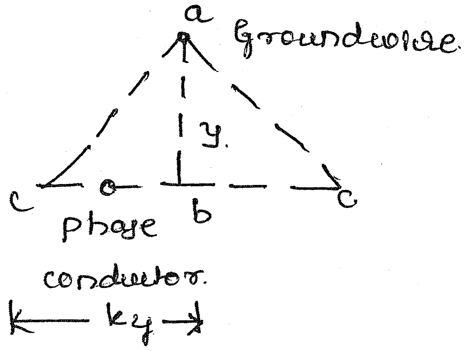


fig - a)

zone of protection of an overhead ground wire

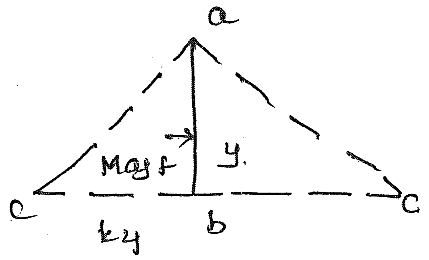


fig - b.

Zone of protection of a rod or mast.

fig-a shows the cross section of the volume. The plane ac cuts the base plane at c, at a distance ky from the point b. vertically under the apex a.

* The ground wire is at a height y = ab above the base plane, The ratio ky/y = k is known as ~~prospect~~ protective ratio.

* In fig b line ab represents a rod or mast with a height y, then it is said to be protective zone around the mast. The radius on the base line is equal to ky & protective ratio is ky/y = k.

Height of ground wire

For protection against direct stroke, the ground wire should be located at a height y, at least 10% greater than y, calculated, calculated from the following equation.

$$\frac{X}{H} = \sqrt{2(y/H) - (y/H)^2} - \sqrt{2\left(\frac{h}{H}\right) - (h/H)^2} \quad (1)$$

Where X is horizontal spacing b/n the conductor and the ground wire.

H = Height of cloud   y = height of ground wire,

h = height of conductor.

* However the protective angle & protective ratio vary, experience has shown that double - circuit lines will be completely shielded if two ground wires are used, placed one above, height above the top conductor equal to the vertical spacing b/n conductors.

For horizontally arranged single circuits, two overhead ground wire will give complete shielding if placed above the plane of the conductors at a height about two-thirds the spacing b/n conductors.

The distance b/n the ground wire should be equal to the spacing of conductors.

* Coupling factor *

When the voltage of same polarity as that of the ground wire voltage has induced on the conductors, the entire ground wire or tower top voltage does not appear across the line insulation.

* The ratio of induced voltage on the conductor to the ground wire voltage is known as coupling factor.

The coupling factor with the effect of corona considered is calculated by the following equation

$$\text{coupling factor } (C) = \sqrt{\text{electrostatic coupling} \times \text{electro-magnetic coupling}}$$

* The electromagnetic & electrostatic coupling factors are equal unless the effective radius of the ground wire is increased by a corona, in such case, the electrostatic coupling increases & the electromagnetic coupling remains unaffected.

coupling factor is calculated by the equation

$$C = \frac{\log b/a}{\log 2h/r} \quad \text{—— (1)}$$

Where C = coupling factor, a = distance from conductor to ground wire, b = distance from conductor to image of ground wire, h = height of ground wire above ground

r = radius of ground wire

* The electromagnetic coupling factor is calculated using the actual radius of the ground wire & the electrostatic coupling factor is calculated by the same equation using the effective radius of the ground wire due to corona.

~~Module~~ - 4 - ~~Substation~~

* Introduction to Gas insulated substation.

Gas insulated substations have been used in power system over the last three decades because of their high reliability, easy maintenance, small ground space requirement etc. In India also few GIS units are under various stages of installation.

The basic insulation level (BIL) required for gas insulated substation is different than the conventional substation. Gas insulated bay has a surge impedance 70 Ω more than that of the conventional oil filled cables, but much less than the overhead line (300 Ω to 400 Ω).

* However the life of GIS is affected by the several factors such as, conductive particles, particle discharges & contamination.
* The GIS require less number of lightning arresters than the conventional one.

Some problems associated with GIS are as follows →.

a) Switching operations generate very fast transient over voltages (VFTOS).

b) VFTOS may cause secondary breakdown inside a GIS and Transient Enclosure voltages (TEV) outside the GIS.

c) prolonged arcing may produce corrosive/toxic by products.

d) support spacers can be weak points when are by products & metallic particles are present.

For the above mentioned reasons VFTOs generated in a GIS should be considered as an important factor in the insulation design. In a GIS, very fast transient overvoltages (VFTOS) are caused by two ways.

a) due to switching operation &

b) Line to enclosure faults.

The gas insulated substation consisting of following components.

1) circuit breaker.
2) disconnector switch
3) Earthing switch
4) current transformer
5) voltage transformer.
6) Bus bar & connectors.
7) power transformer.
8) surge arrester
9) cable termination.
10) SF6/air or SF6/oil bushing.

* **Advantages of GIS substation.**

1) It occupies very less space (1/10th) compared to ordinary substations. Hence Gas insulated substations (GIS) are most preferred where area for substation is small.

2) Most reliable compared to Air Insulated substations, number of outages due to the fault is less.

3) Maintenance free

4) can be assembled at the shop and modules

can be commissioned in the plant easily.

* Reduction in radio interference with the use of earthed metal enclosures.

* It is not necessary that high voltage or extra high voltage switchgear has to be installed outdoors.

* More optimal life cycle costs because of lesser maintenance, down time and repair costs.

Disadvantages of GIS Substation.

1) cost is higher compared to ordinary conventional substations.
2) care should be taken no dust particles enter into the live compartments which results in flash overs
3) When fault occurs internally, diagnosis of the fault and rectifying this takes very long time
4) SF_6 gas pressure must be monitored in each compartment, reduction in the pressure of the SF_6 gas in any module results in flash over and faults.
5) switching operation generate very fast transients over voltages.
6) Field non uniformities reduce withstanding levels of GIS

* Economics of GIS *

The equipment cost of GIS is naturally higher than that of AIS due to the grounded metal enclosure, The installation cost of GIS is less expensive than AIS, & site development cost for a GIS will be much lower than compare to AIS, because much smaller area is required for the GIS.

The GIS development increases as the system voltage increases because high voltage AIS take very large areas because of the long insulating distances in atmospheric air.

Cost comparison in the early days of GIS projected that, on a total installed cost basis, GIS costs are equal to AIS costs at 345kV. For higher voltages, GIS was excepted to cost less than AIS.

* **Grounded systems.**

Grounded systems are equiped with a grounded conductor, the grounded conductor can be used as a current carrying conductor to accommodate all neutral related loads.

A network of equipment grounding conductors is routed from the service equipment enclosure to all metal enclosures throughout the electrical system.

* The grounding conductor carries the fault c/n back to the source and returns over the faulted phase & trips to open the overcurrent protection device.
* The neutral of any grounded s/m serves for two main purposes - ① it permits the utilization of line-to-neutral voltage & they will serve as a c/n - carrying conductor to carry any unbalanced c/n, & ② it plays important role in providing a low - impedance path for the flow of fault c/ns to facilitate the operation of the overc/n devices in the circuit.