CBCS SCHEME

USN

18EE72

Seventh Semester B.E. Degree Examination, Dec.2023/Jan.2024
Power System Protection

Time: 3 hrs. Max. Marks: 100

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

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

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Module-1

1 a. Discuss briefly the role of protective relay in a modern power system. **(06 Marks)**

b. Explain the nature and causes of faults. Discuss the consequences of faults on a power system. **(08 Marks)**

c. Draw a neat sketch of an induction disc relay and explain its operating principle. **(06 Marks)**

OR

2 a. Explain the working principle, types and application of thermal relays. **(06 Marks)**

b. What is numerical relay? What are its advantages over conventional type relays? **(06 Marks)**

c. Explain various types of overcurrent relays with its characteristic curve. **(08 Marks)**

Module-2

3 a. What are the various overcurrent protective scheme? Explain their merits, demerits and field of application. **(07 Marks)**

b. Describe the operating principle, constructional features and area of application of reverse power or directional relay. **(07 Marks)**

c. Distinguish between an earth fault relay and an overcurrent relay. Explain various methods to energize an earth fault relay. **(06 Marks)**

OR

4 a. Explain the impedance relay with its operating principle. **(06 Marks)**

b. Explain stepped time-distance characteristics of three distance relaying units used for I, II and III zone of protection. **(08 Marks)**

c. Discuss the effect of arc resistance on the performance of different types of distance relays. **(06 Marks)**

Module-3

5 a. What are the important operating principles used in wire pilot schemes? Explain Transley scheme of wire pilot protection. **(07 Marks)**

b. Describe the behaviour of simple differential protection scheme during normal, external and internal fault. **(08 Marks)**

c. Explain balanced voltage differential relaying scheme. **(05 Marks)**

OR

6 a. Describe with neat sketch, the percentage differential protection of a modern alternator. **(08 Marks)**

b. Explain with neat diagram the working of Buchholz relay. **(07 Marks)**

c. Discuss buszone protection with neat diagram. **(05 Marks)**

Module-4

7 a. With a neat sketch, explain the recovery rate theory and energy balance theory of arc interruption in a circuit breaker. **(08 Marks)**

b. Explain the interruption of capacitive current with neat sketch and waveform. **(06 Marks)**

c. Discuss the working of air blast circuit breaker. **(06 Marks)**

OR

8 a. Explain with neat diagram the direct testing of circuit breaker. **(06 Marks)**

b. With a neat sketch, explain the construction and working of non-puffer type SF6 circuit breaker. **(08 Marks)**

c. Write short notes on HVDC circuit breaker. **(06 Marks)**

Module-5

9 a. Explain the construction and operation of the HRC cartridge fuse. What are its advantages and disadvantages? **(10 Marks)**

b. Explain with neat figure:
(i) Rod gap arrestor
(ii) Expulsion type arrestor **(10 Marks)**

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OR

10 a. Explain the term insulation coordination. Describe the construction of volt time curve and terminology associated with impulse testing. **(10 Marks)**

b. What are the various components of GIS? Briefly describe their functions. **(10 Marks)**

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Q.1.a

Protective relays play a critical role in safeguarding electrical systems from potential failures and catastrophic events. These devices monitor the health of the system and initiate actions to mitigate risks. However, like any other electrical equipment, protective relays require regular maintenance and testing to ensure they operate effectively. Protective relays act as guardians, constantly monitoring electrical equipment and circuit performance for abnormalities. These relays help minimize the risk of equipment damage, prevent electrical fires, and ensure operator safety. Moreover, they are crucial in maintaining power quality and stability in a range of applications, including power transmission and distribution systems, industrial plants, and even in residential homes.

Q.1.b

NATURE AND CAUSES OF FAULTS :

1. Insulation Aging & Equipment failure :

Various electrical equipments like generators, motors, transformers, reactors, switching devices etc cause short circuit faults due to malfunctioning, ageing, insulation failure of cables and windings. These failures result in high current to flow through the devices or equipment which further damages it.

2. Weather Conditions :

→ It includes lightning strikes, heavy rains, heavy winds, sault deposition on over head lines and conductors, snow & ice accumulation on transmission lines etc. These environmental conditions interrupt the power supply and damage to installations.

→ Over Voltage due to lightning can puncture or break insulation.

→ Deposition of fine cement, dust, soot in industrial areas or sault in coastal areas or dust etc on surface of insulators, reduces the insulation strength and result in flashover.

3. External Causes :

→ External objects like birds, Kite string, squirrels, Snakes, tree contact etc may cause faults on overhead lines. It happens when their body touch one of the phase and the earth wire or even any metallic structure which is at earth potential.

→ If the conductors are broken, there is a failure of conducting path and the conductor becomes open-circuited. If the broken conductor falls to the ground, it results in Short circuit.

4. Human Errors :

→ Electrical faults are also caused due to human errors like selecting improper rating of devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under maintenance or repair.

→ Sometimes CB may trip due to errors in switching operations, wrong connections, defects in protective devices etc.

Effects of Faults :

* The most dangerous fault is a short circuit. It have the following effects on a power system, if it remains uncleared.

(i) Heavy short circuit current: may cause damage to equipment or any other element of the system due to over heating. This happens because when fault occur, it creates a low impedance path for the current to flow. So very high currents flow resulting in damage of equipments, insulation and other components.

(ii) Electrical fires: Short circuit cause flashover & sparks. The arcs associated with these short circuits may even cause fire hazards. This fire not only destroys the faulty element, it may spread to other parts of the s/m.

5. Quality of System Components:

→ Certain faults occur due to poor quality of system components or because of poor faulty design. This can be reduced by improving the system design by using good quality components and better operation & maintenance.

(iii) Reduction in Supply Voltage: When fault occur in the system because of low impedance path, current increases to a high value, at the same time voltage drops. So the power produced by the source is affected. and eventually this results in loss of industrial loads.

(iv) Unbalanced Voltage & currents: Short circuit being an unsymmetrical fault, results in the flow of unbalanced current & voltages. Thereby heating rotating machine.

(v) Loss of System Stability & Reliability: Short circuit results in loss of system stability. Individual generators may lose synchronism, resulting in complete shutdown of system. Also the interconnected control areas, may also loose the stability. Hence the Power System will not be reliable.

(vi) Interruption of Supply: The above faults may cause an interruption of supply to consumers, thereby resulting in loss of revenue.

(vii) Danger to operating Personnel: Faults can cause electric shock to individuals. Severity of shock depends on the current & voltage at fault location. It might even lead to death.

(viii) Disturb interconnected active circuits: Fault not only affect the location at which they occur, but also disturbs all the interconnected circuits to the faulted line. It might even result in shutdown of entire system, if the fault is severe.

Q.1.c

Induction Disc Relay:

There are two types of construction of induction disc relays, namely the shaded pole type, as shown in fig(c) below and watt hour meter type as shown in fig(d)

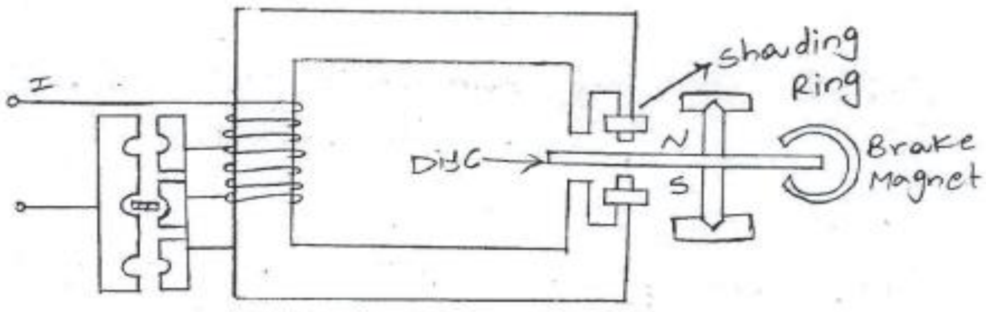
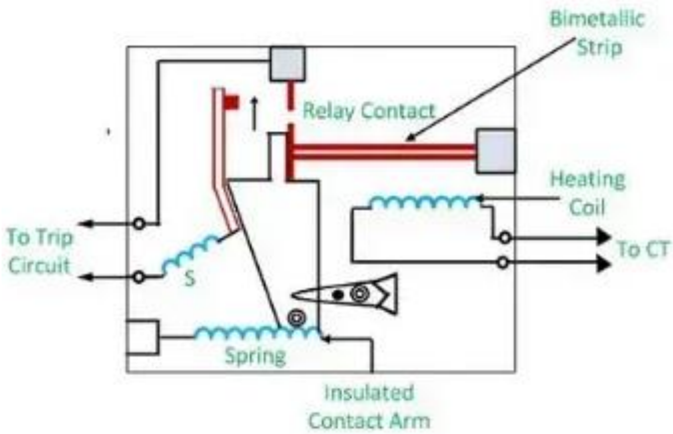


fig c Simple construction

The fig above shows a simple theoritical figure (c), where as fig(d) shows the construction which is actually used in practice. The rotating disc is made of aluminium. In the shaded pole type construction, a c- shaped electromagnet is used. one half of each pole of the electromagnet is surrounded by a copper band known as the shading ring. The shaded portion of the pole produces a flux which is displaced in spaced and time with respect to the flux produced by the unshaded portion of the pole. Thus two alternating fluxes displaced in space and time cut the disc and produce eddy currents. Torques are produced by interaction of each flux with eddy current produced by other flux. The resultant torque causes disc to rotate.

Q.2.a



Working Principle of Thermal Relay:
A thermal relay works depending upon the above mentioned property of metals. The basic working principle of thermal relay is that, when a bimetallic strip is heated up by a heating coil carrying over current of the system, it bends and makes normally open contacts.
Construction of Thermal Relay:
The construction of thermal relay is quite simple. As shown in the figure above the bimetallic strip has two metals – metal A and metal B. Metal A has lower coefficient of expansion and metal B has higher coefficient of expansion.
When over current flows through the heating coil, it heats up the bimetallic strip. Due to the heat generated by the coil, both of the metals are expanded. But expansion of metal B is more than expansion of metal A. Due to this dissimilar expansion the bimetallic strip will bend towards metal A as shown in the figure below.
The strip bends, the NO contact is closed which ultimately energizes the trip coil of a circuit breaker.
The heating effect is not instantaneous. As per Joule's law of heating, the amount of heat generated is

$$H \propto I^2 Rt$$

Where, I is the over current flowing through the heating coil of thermal relay. R is the electrical resistance of the heating coil, t is the time for which the current I flows through the heating coil. Hence from the above equation it is clear that, heat generator by the coil is directly proportional to the time during which the over current flows through the coil. Hence there is a prolonged time delay in the operation of thermal relay.
That is why this type of relay is generally used where over load is allowed to flow for a predetermined amount of time before it trips. If overload or over current falls down to normal value before this predetermined time, the relay will not be operated to trip the protected equipment.
A typical application of thermal relay is overload protection of electric motor.

Q.2.b

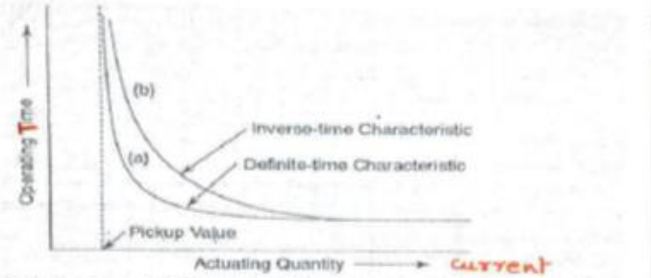
- Microprocessor-based relay, works on numbers representing instantaneous values of the signals. Hence, they are named **numerical relay.** Other popular nomenclatures for such relays are **digital relay,computer-based relay** or **microprocessor-based relay.**
- In numerical relays, the software, runs in the background and which actually runs the relay.
- What distinguishes one numerical relay from the other generally is the software.
- Conventional relay performs comparison only .
- The numerical relay does not have any such limitation because of its ability to perform real-time computation.
- Existlng relaying concept can be implemented using the numerical technique.
- The possibilities of developing a new numerical relay are almost endless and there is very little standardization.

Q.2.c

→ Variety of time - current characteristics is available.

→ The name assigned to the relay indicates the characteristics as described below

1. Definite - time overcurrent relay :
   - * operates after a predetermined time, when current exceeds pick - up value.
   - * Fig(a) shows the time - current characteristics
   - * The operating time is constant.
   - * This definite time is fixed usually with the help of intentional time delay mechanism, provided in the relay unit.



Definite-time and inverse-time characteristics of overcurrent relays

- * This relay also operates in definite time when the current exceeds the pick - up value.
- * Here also the operating time is constant, irrespective of the current.
- * Curve is shown in previous Fig.(a)
- * Here the only difference is that it is not having any intentional time delay. It operates in 0.1 sec or less.
- * Relays having operating time < than 0.1 sec are termed as " high set " or " high speed " relays.

3. Inverse time Over current Relay:

* operates when current exceeds its pick-up value.
* Here operating time is not constant.
* The operating time decreases as the current increases.
* Curve (b) in fig shows inverse time characteristics.

4. Inverse definite Minimum Time Overcurrent Relay (IDMT)

* It gives **inverse-time** characteristics at lower values of fault current.
* Also gives definite-time characteristics at higher values of fault current.
* Usually inverse-time characteristics is obtained when Plug setting multiplier is below 10.
* For PSM between 10 & 20 characteristics tend to become a straight line.
* Characteristics is shown in Fig (next page).

5. Very Inverse-time Overcurrent Relay:

* It gives more inverse-time characteristicls than IDMT relay.
* Its time-characteristics lies between IDMT & extremely inverse-time characteristics.
* This has better Selectivity than IDMT relay.
* When IDMT faills this can be used.
* Standard time-current characteristics is given by

* Electromagnetic relay have the steepest inverse-time characteristics.
* time current characteristics of extremely Over-current relay
  $I^2 \cdot t = K$.
* Most suited for protecting machines against overheat.
* Also used for protection of alternators, power transformers, earthing transformers, cables etc. Because heating characteristics of these are governed by $I^2 \cdot t = K$.

7. Special characteristics:

* time current characteristics greater than extremely inverse relay.
* Used in industrial applications.
* time current chara is $I^n = K$. where $n = 2$.
* To protect rectifier transformers $I^8 = K$ is needed.
* It is suitable to be graded with fuse

DEFINING SHAPE OF TIME CURRENT CHARACTERISTICS

general expression, $t = \frac{k}{I^n - 1}$

IDMT relay $t = \frac{0.14}{I^{0.02} - 1}$

very - inverse $t = \frac{13.5}{I - 1}$

Extremely inverse $t = \frac{80}{I^2 - 1}$

Q.3.a

→ Thus the relay must be selective with each other. For proper selectivity of relays, we have following schemes:

(i) Time - graded system

(ii) Current - graded system

(iii) Combination of time & current graded system

→ In this scheme definite - time overcurrent relays are used.

→ When definite time relay operates for a particular fault current, first it starts a timing unit, this timing unit trips the circuit breaker only after a preset time.

→ This preset time is independent of the value of fault current.

→ The operating time of the relay is adjusted in increasing order from the far end of the feeder.

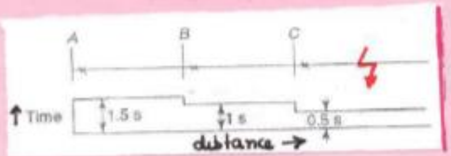


Fig 2.1 Time - graded Overcurrent Protection of a feeder

→ This is shown in Fig 2.1.

→ The difference in time setting is kept as 0.5 sec.

→ This difference is to cover the operating time of the CB and errors in the relay & C .

→ Now we can reduce this time to 0.4 sec or 0.3 sec, with the help of fast circuit breakers & modern accurate relay.

→ When the fault is beyond C, then all relays come into action as the fault current flows through all of them.

→ Relay at C will have the least time setting. So it operates at 0.5 sec. & fault is cleared. Then Relay at A & B will be reset.

→ In case if CB at C fails, then the fault remains uncleared, then relay at B operates & will trip CB at B, after 1 sec.

Drawback :

→ For the fault near the power source, operating time is more.

→ Usually the faults near power source will have larger currents and hence it needs to be cleared quickly. But this scheme takes the longest time in clearing heaviest fault.

→ This is undesirable because the heaviest fault is the most destructive.

* This scheme is suitable where impedance b/w substations are low. (ie, distance between substations low). So to some extend fault current will be same.

(ii) CURRENT- GRADED SYSTEM

* In this scheme relays will pick-up the higher values of current.

* Usually that will be towards power source.

* Here we use <u>High- Speed instantaneous over-current relays</u>

* As seen in the figure 2.2, the operating-time is kept the same for all the relays.

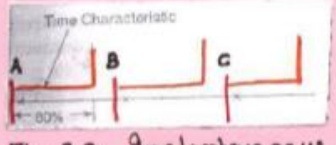


Fig 2.2. Instantaneous overcurrent Protection

* Current - setting of the relay corresponds to fault current level in the feeder Section.

* For an ideal relay, The relay A should trip for faults between A & B. B should trip for faults between B & C. And C should trip for faults beyond C. But this ideal operation is not achieved due to following reasons :

(i) Relay A cannot differentiate fault very close to B. It is unable to find whether the fault is on which side of B. If the fault is in section BC near B, relay understands its in AB.

This is because there is very small difference in fault current

(ii) Magnitude of Fault current cannot be determined accurately, as all the circuit parameters will not be known.

(iii) During faults, there might be transient conditions, so performance of relay will not be accurate.

* Hence relays will be properly protecting only about 80% part of the feeder. This scheme cannot protect the entire part of the feeder. (Fig 2.2).

* Since they cannot protect entire feeder, this system is not used alone, it is used in conjunction with IDMT relays.

* Current graded scheme is used where impedance or distance between substations are more, so that margin of difference in fault current will also be more.

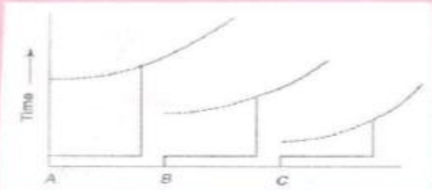


Fig 2.3 Combined instantaneous & IDMT relays.

* Advantage of this system is operating time is less near power source.

(iii) COMBINATION OF CURRENT & TIME GRADING :

→ Widely used for protection of distribution lines.

→ Here also IDMT relays are used. They have combined features of current and time grading.

→ IDMT relays have arrangements for current as well as time.

→ Current setting is made according to fault current level. Higher current levels are towards the source.

→ Time - setting is also done increasing towards the source. Here also the difference in operating time is kept 0.5 sec.

→ Impedance Z_s will be small (source imp) compared with farther points Z_1. So when fault occur near the substation,

Fault current = $\frac{E}{Z_s}$,

If fault occur at far end, then

fault current = $\frac{E}{(Z_s + Z_1)}$.

→ If Z_1 is high, compared with Z_s , there will be more difference in the fault current for fault at near end and fault at far end.

→ So here we need inverse time relay, so that it will trip faster for fault near the source end.

→ At low values of fault current, its characteristics is inverse - time characteristics. At high values of fault current, it gives definite - time characteristics.

Q.3.b

REVERSE POWER OR DIRECTIONAL RELAY

* Fig 2.4 shows an electromagnetic directional relay.
* Direction relay is energized by 2 quantities, namely Voltage & current.

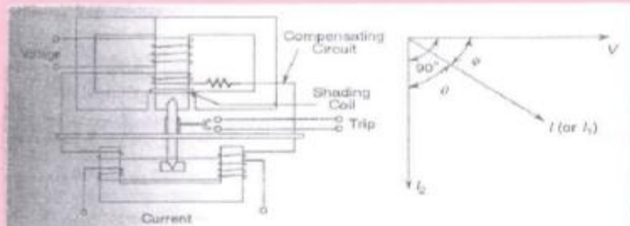
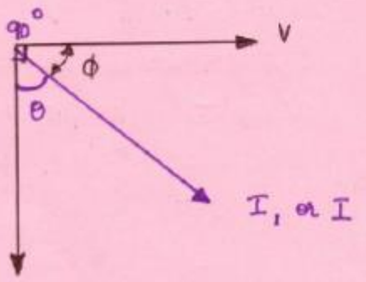


Fig 2.4 Induction Disc type directional relay

* Fluxes ϕ_1 & ϕ_2 are set up by voltage & current respectively.
* Flux ϕ_1 induces Eddy currents, these interact with ϕ_2 and thus produces Torque.
* Similarly flux ϕ_2 induces Eddy currents in the disc, which interact with ϕ_1 and produce a Torque.
* This resultant torque rotates the disc.
* Torque is proportional to $VI \cos\phi$.
  where ϕ → Ph angle b/w V & I.

* So from equation we can say Torque is maximum when $\phi = 0$, ∴ $\cos 0 = 1$ ie when there is no Phase difference between V & I. (ie inphase).
* To produce maximum Torque during fault conditions, when Pf is very poor, a compensating winding & Shading is provided.
* We have already discussed in previous chapter that Torque produced by induction relay is given by $T = \phi_1 \phi_2 \sin\theta \propto I_1 I_2 \sin\theta$ where ϕ_1 & ϕ_2 are flux produced by I_1 & I_2. 6
* The angle b/w ϕ_1 & ϕ_2 or I_1 & I_2 is θ as shown in phasor.

∠ b/w ϕ_1 & ϕ_2 → θ



→ Load current I or I_1 lags behind V by angle ϕ
→ I in voltage coil (I_2) lags behind V by 90°

$$T = I_1 I_2 \sin(90 - \phi) \propto I_1 I_2 \cos\phi \propto VI\cos\phi$$

Q.3.c

* Relays which are used for protection of a section of Power system against earth fault are called Earth fault relay.
* Similarly relays which are used for protection against Phase fault are called as Phase Fault relays or overcurrent relays.
* Operating principle and constructional features are same for both.
* They differ only in current levels.
* Plug Setting for earth fault relay varies from 20% to 80% of CT, (in steps of 10%) Where as Plug setting of the Phase fault relay will be 50% to 200% of CT 2°, in steps of 25%.

* Usually for Phase Fault relay, this name is not common, it is generally termed as overcurrent relay.

* But this differs from general overcurrent relays, they operate when current exceeds pick-up value, but here they operate only for protection against Phase faults.

→ Earth fault relay may be energized by a residual current. Fig 2.11 (a).

→ i_a, i_b & i_c → currents in 2° of CT of different Phases.

→ Sum of currents is known as residual current ($i_a + i_b + i_c$).

→ Under normal condition residual current = 0.

→ When Fault occur, residual current = non zero.

→ When residual current exceeds pick-up value, earth fault relay operates.

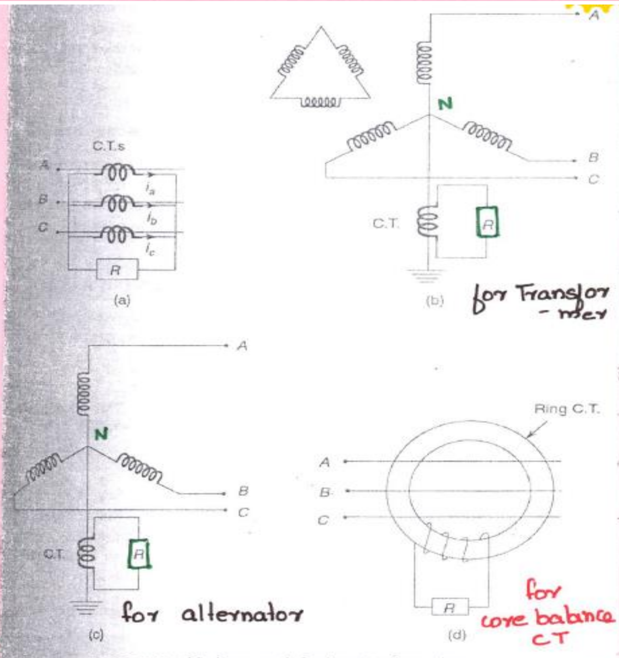


FIGURE 2.11 Various earth fault protective schemes

→ Manufacturer provides the range of Plug Setting Multiplier from 20% to 80% of CT 2° in steps of 10%.

→ Magnitude of the earth fault I depends on fault impedance value.

→ fault impedance further depends on type of neutral earthing

→ Usually Neutral may be solidly grounded, or grounded through resistance or reactance.

→ fault impedence for Earth fault > fault impedance for Ph fault
⇒ Earth fault current is low than Ph fault current.
Its setting is below normal load current. Since impedance is High Burden is High.

→ Fig 2.11 (b) & (c) shows earth fault protection for Transformer & alternator. When Fault occur here, Zero sequence components flow to ground through N. It actuates Earth fault relay.

Figure 2 (d) shows connection of earth fault relay using special type of CT, known as core-balance CT. This encircles the 3-Phase conductors.

Q.4.a

Principle of Operation of Impedance Relay

In the normal operating condition, the value of the line voltage is more than the current. But when the fault occurs on the line the magnitude of the current rises and the voltage becomes less. The line current is inversely proportional to the impedance of the transmission line. Thus, the impedance decreases because of which the impedance relay starts operating.

The figure below explains the impedance relay in much easier way. The potential transformer supplies the voltage to the transmission line and the current flows because of the current transformer. The current transformer is connected in series with the circuit.

Consider the impedance relay is placed on the transmission line for the protection of the line AB. The Z is the impedance of the line in normal operating condition. If the impedances of the line fall below the impedance Z then the relay starts working.

Let, the fault F1 occur in the line AB. This fault decreases the impedance of the line below the relay setting impedance. The relay starts operating, and its send the tripping command to the circuit breaker. If the fault reached beyond the protective zone, the contacts of the relay remain unclosed.

Operating Characteristic of an Impedance Relay

The voltage and the current operating elements are the two important component of the impedance relay. The current operating element generates the deflecting torque while the voltage storage element generates the restoring torque. The torque equation of the relay is shown in the figure below

$$\boldsymbol{T} = k_1 I^2 - k_2 V^2 - k_3$$

The $-K_3$ is the spring effect of the relay. The V and I are the value of the voltage and current. When the relay is in normal operating condition, then the net torque of the relay becomes zero.

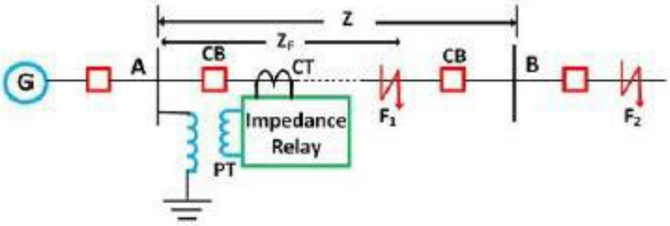
$$k_2 V^2 = k_1 I^2 - k_3$$

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

If the spring control effect becomes neglected, the equation becomes

$$Z = \sqrt{\frac{k_1}{k_2}} = Constant$$

The operating characteristic concerning the voltage and current is shown in the figure below. The dashed line in the image represents the operating condition at the constant line impedance.

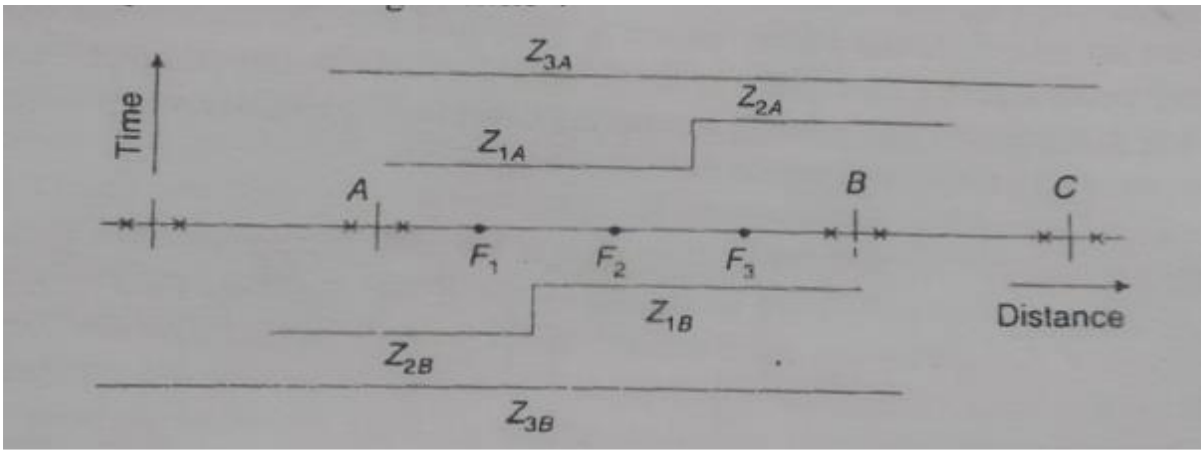


Principle of operation of an Impedance Relay

Circuit Globe

The operating characteristic of the impedance relay is shown in the figure below. The positive torque region of the impedance relay is above the operating characteristic line. In positive torque region, the impedance of the line is more than the impedance of the faulty section. Similarly, in negative region, the impedance of the faulty section is more than the line impedance

Q.4.b



Q.4.c

* Arc resistance is the number of seconds that a material resists the formation of a surface conducting path.
* So when a flashover from Ph to Ph or Ph-ground occur, an arc resistance is added to the impedance of the line.
* So the resultant impedance as seen by the distance relay is increased.
* In case of ground fault, the resistance of the ground is also introduced in the path.
* Earth Resistance + arc resistance = fault resistance
Combination of these is known as fault resistance.

* In case of Ph-Ph fault only arc resistance is present and there is no earth resistance.

* Arc resistance

$$R_{arc} = \frac{29 \times 10^3 \cdot l}{I^{1.4}} \ \Omega$$

where $l \rightarrow$ length of arc in meters

$I \rightarrow$ Fault current in Ampere

* Arc length is usually increased by wind accompanying a lightning storm.

* Arc resistance taking into account the wind velocity and time is given by

$$R_{arc} = \frac{16300\,(1.75\,S + Vt)}{I^{1.4}} \ \Omega$$

where $S \rightarrow$ conductor spacing in meter

$V \rightarrow$ wind velocity in km/hr.

$t \rightarrow$ timing or time in sec

$I \rightarrow$ fault current in amperes

* arc resistance is treated as resistance in series with the line impedance. → MHO RELAY > impedance relay > reactance relay
(more effect) (less effect)

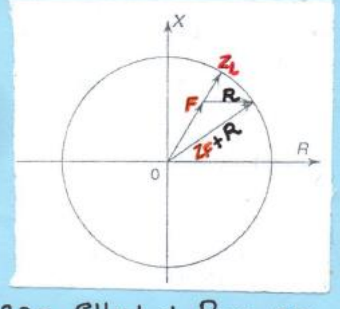
* 

Fig 2.30 Effect of Rarc on impedance relay

→ Fig 2.30 shows the effect of arc resistance on an impedance relay.

→ Relay is set to protect a line of impedance Z_L.

→ If a fault occur at point F, an arc resistance of R is introduced, the relay will measure $Z_F + R$

→ Z_F is impedance of line upto point F.

→ If arc resistance is greater than R, then the impedance measured by the relay will be greater than the radius of circle. & thus the relay fail to operate. So OF is the maximum distance which can be protected.

Fig 2.31 shows the effect of arc resistance on MHO relay.

Here Z_ℓ is not the radius of circle as in previous.

Here impedance measured by the relay is $(Z_F + R)$ and that is less than Z_ℓ. arc resistance causes under reach.

In this mho circle angle α is same as characteristic angle of line φ.

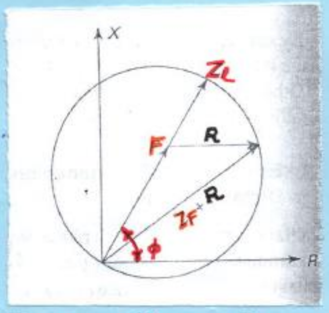


Fig 2.31 Effect of R_{ac} on MHO Relay

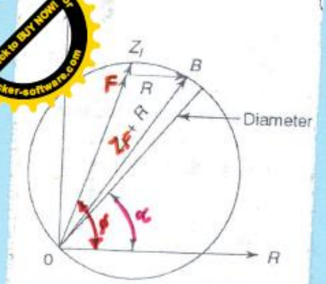


Fig 2.32 MHO circle shifted towards R axis

→ Mho circle is shifted towards R axis, that angle of Mho circle α is less than characteristic angle of the line φ.

→ In this case, the value of $(Z_F + R)$ may be even > than Z_ℓ. But it is less than the diameter of the circle.

→ So here relay operates as long as $(Z_F + R)$ remains within the circle.

* So such characteristics have greater tolerance for arc resistance.

Q.5.a

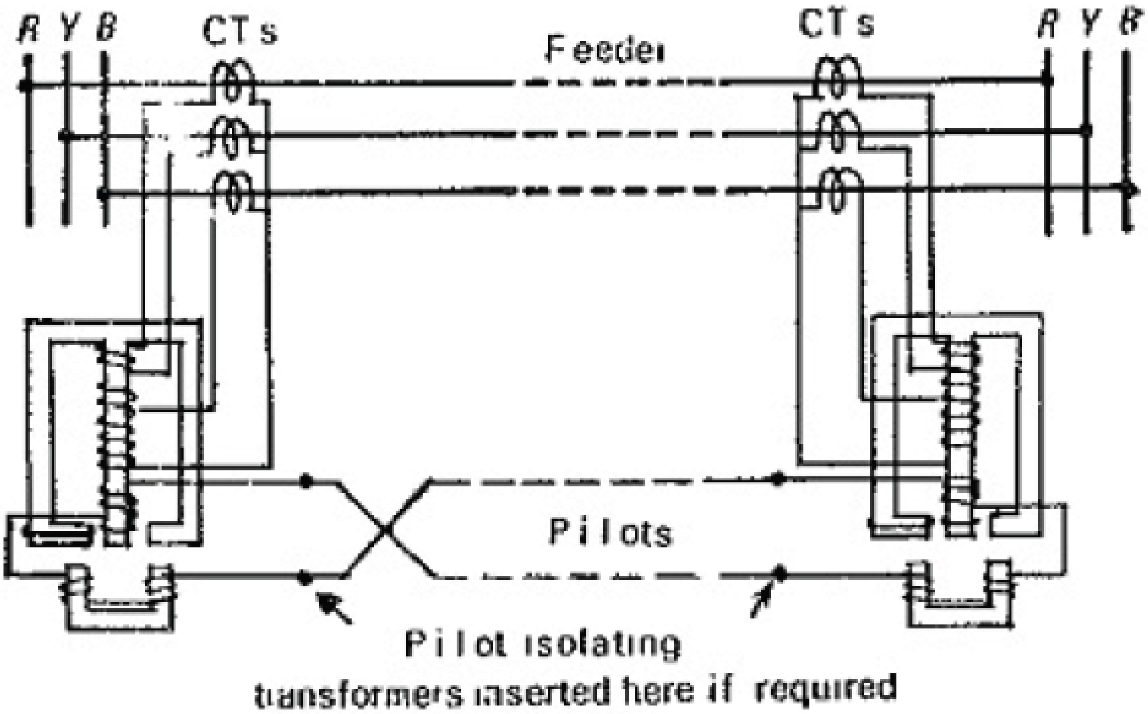
Operating schemes which are used in wire pilot protection

1. Circulating Current Scheme
2. Balanced Voltage (or Opposed Voltage) Scheme
3. TransleyScheme
4. Half-Wave Comparison Scheme

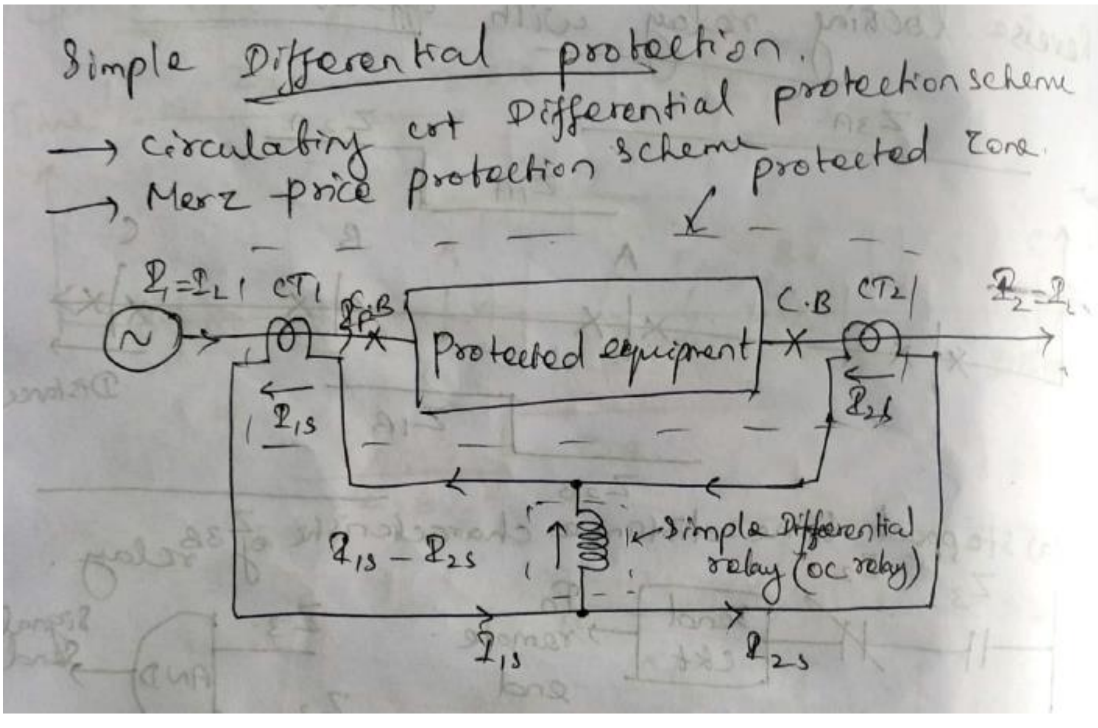
Transley Scheme

- It is of the balanced voltage type and is suitable for pilot circuits up to a loop resistance of 1000 ohms.
- Associated with the CTs at each end is an induction disc type relay whose secondary circuits are connected in opposition by Pilot Wire Protection Relay.
- Summation of the secondary line current is carried out in the tapped winding of the upper electromagnet of the relay.
- The upper electromagnet system acts as a quadrature transformer and produces at the pilot terminals a voltage which varies with the primary current.

- No current will flow in the circuit under normal conditions; whereas in the case of a fault there is a discrepancy between the currents flowing at the two ends which will cause a resultant difference between the secondary voltages and thus a current in this circuit.
- Under such conditions when the current flow occurs in both the upper and the lower magnet the relay operates.



Q.5.b



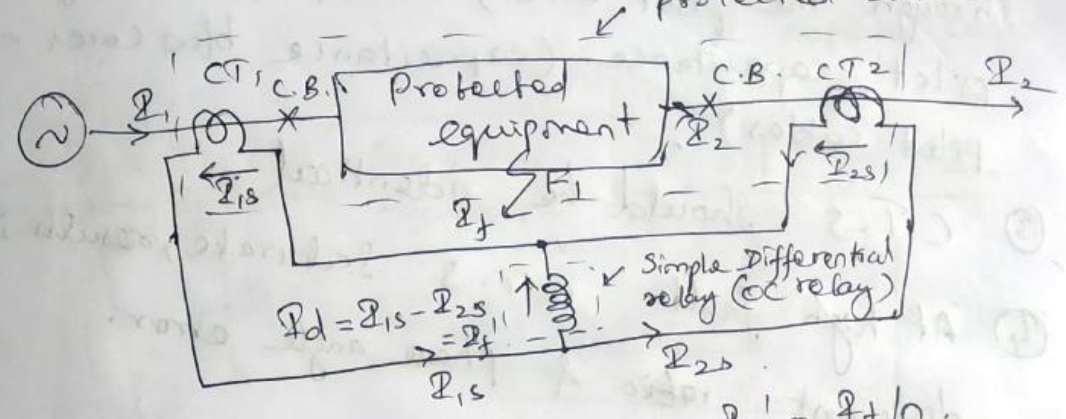
Case (i) During External Fault :-

$I_1 = I_2 = I_F$

$I_{1s} = I_{2s} = I_F' = I_F/n.$

$I_{1s} - I_{2s} = 0 .$

Case (ii) During Internal Fault :



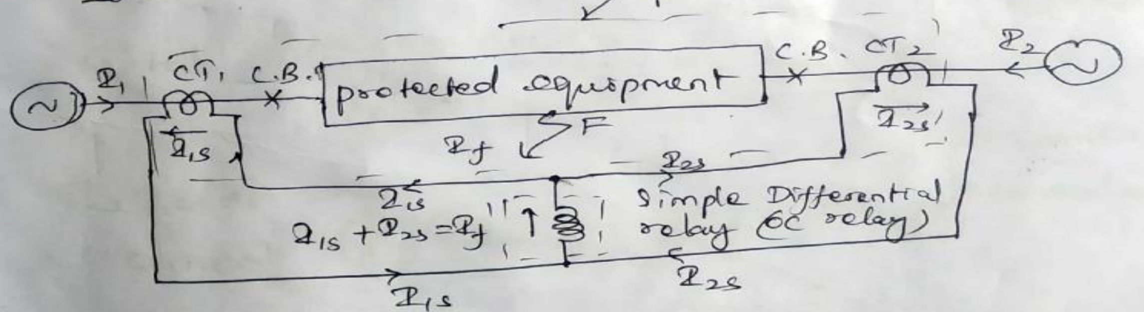
$I_{1s} = I_1/n \quad ; I_{2s} = I_2/n \quad ; \quad I_f' = I_f/n.$

$I_1 = I_2 + I_f . \quad , \; I_d = I_{1s} - I_{2s} = I_f'.$

↳ called spill crt.

when I_d > preset value then relay will trip.

Case (iii) Internal fault for Double-end-fed system



Q.5.c

BALANCED VOLTAGE DIFFERENTIAL PROTECTION

* Fig 3.18 shows the principle of differential Protection based on balanced voltage principle.
* In this scheme CT 2° are connected such that for normal condition & through fault conditions, 2° currents of CT's on both sides oppose each other and their voltage are balanced.
*

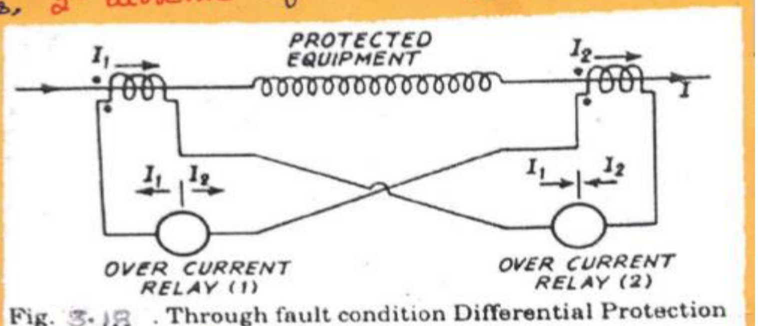


Fig. 3.18 . Through fault condition Differential Protection based on balanced voltage principle.

* During internal fault, the condition changes as shown in Fig 3.19.
* Current flowing through the relays will be $(I_1 + I_2)/2$ at each end & the direction of flow is as shown.

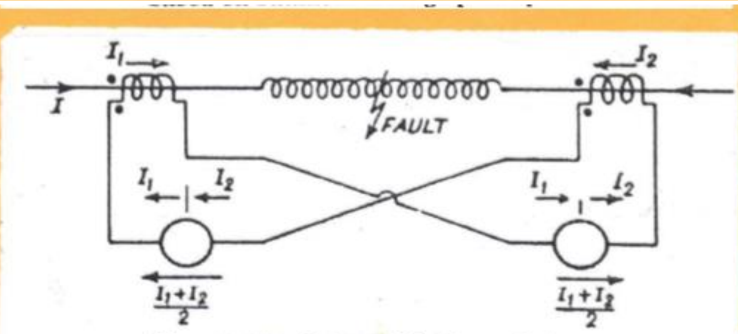


Fig. 3.19 . Internal fault condition.

* CTs used in such protection are with air gap core so that core do not get saturated and overvoltages are not produced during zero 2° current under normal working conditions.

Q.6.a

* It is commonly used for protection above 1MW in generator.
* It protects against winding faults i.e, Ph to Ph & Ph to Gr.
* The scheme is also called as biased differential protection or longitudinal differential protection.
* Currents at both ends are sensed using CTs.
* Wires connecting relay coils to the CT 2° are called Pilot wires.
* Normal conditions, current in pilot 2° fed from CT 2° are =.
* So differential current $I_1 - I_2$ through the operating coil of the relay will be zero.

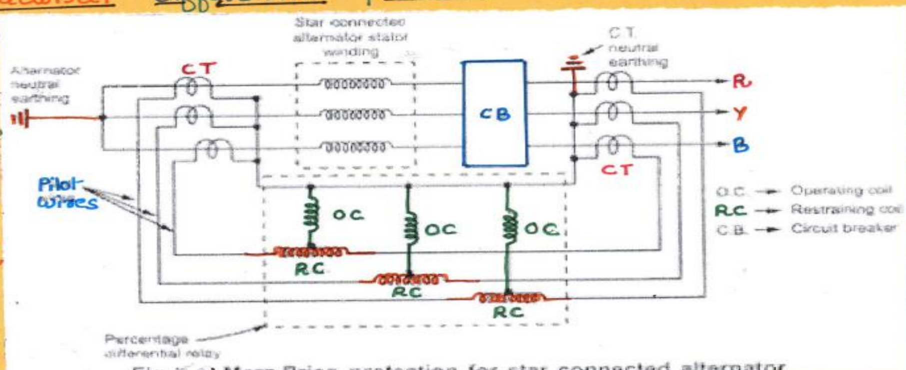


Fig.3.2] Merz-Price protection for star connected alternator

* So differential current $I_1 - I_2$ through the operating coil of the relay will be zero.
* Hence Relay is inoperative and s/m is said to be BALANCED.

→ When fault occur inside the protected zone (internal fault) of the stator windings, differential current $I_1 - I_2$ flows through the operating coil of the relay.

→ Due to this current the relay operates

→ This trips the generator circuit breaker to isolate the faulty section.

→ At the same time field is also disconnected.

→ Differential relay gives protection against short circuit fault in stator windings of generator.

→ CTs are connected in star and are provided on both sides as shown in Fig 3.21.

→ Restraining coils are energized from the 2^0 connections of CT in each Phase, through pilot wires.

→ Operating coil of the relay is energized by the tappings from restraining coils & from CT neutral earthing connection.

→ CTs at both ends should have equal ratio and equal accuracy. If not it results in wrong operation of relay.

→ Cause of unequal currents on both sides of CT without any faut are due to ratio errors, unequal length of leads, unequal 2^0 burdens etc.

→ Scheme provides fast protection of stator against Ph to Ph & Ph to Gr faults.

→ If Neutral point is not grounded, then additional sensitive earth fault relay should be provided in the circuit.

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- Scheme provides fast protection of stator against Ph to Ph & Ph to G faults.
- If Neutral point is not grounded, then additional sensitive earth fault relay should be provided in the circuit.

Q.6.b

It causes an alarm to sound and alert the operator. For reliable operation, a mercury switch is attached with the float. Some manufacturers use open-topped bucket in place of a bob. When the oil level falls because of gas accumulation, the bucket is filled up with oil. Thus, the force available to operate the contacts is greater than with hollow floats. The accumulated gas can be drawn off through the petcock via a pipe for analysis to know the type of fault. If there is a severe fault, large volumes of gases are produced which cause the lower float to operate. It finally trips the circuit breakers of the transformer.

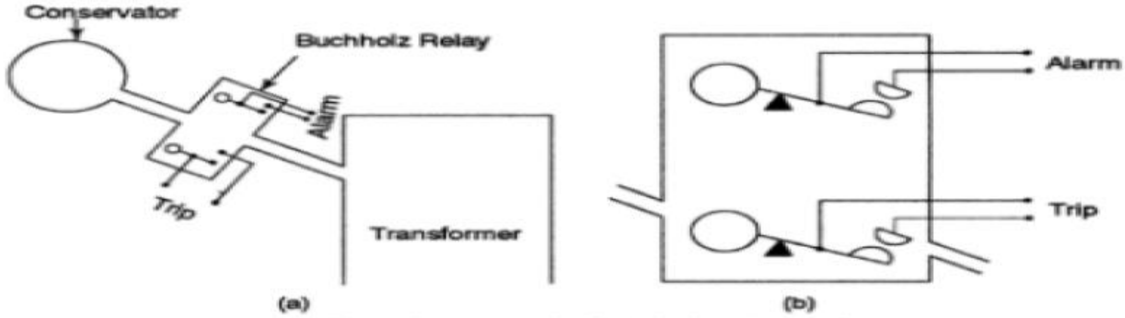


FIGURE 6.12 (a) Transformer tank, Buchholz relay and conservator
(b) Buchholz relay

The buchholz relay is a slow acting device, the minimum operating time is 0.1 s, the average time 0.2 s. Too sensitive settings of the mercury contacts are not desirable because they are subjected to false operation on shock and vibration caused by conditions like earthquakes, mechanical shock to the pipe, tap changer operation and heavy external faults. This can be reduced by improved design of the mercury contact tubes.

Q.6.c

BUS ZONE PROTECTION

1. Differential current Protection:

* Fig 3.31 shows a scheme of differential current protection of a bus zone.

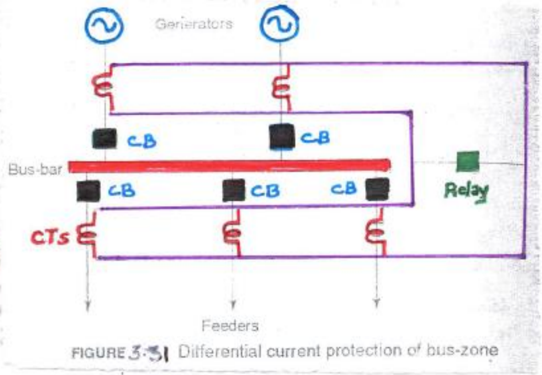


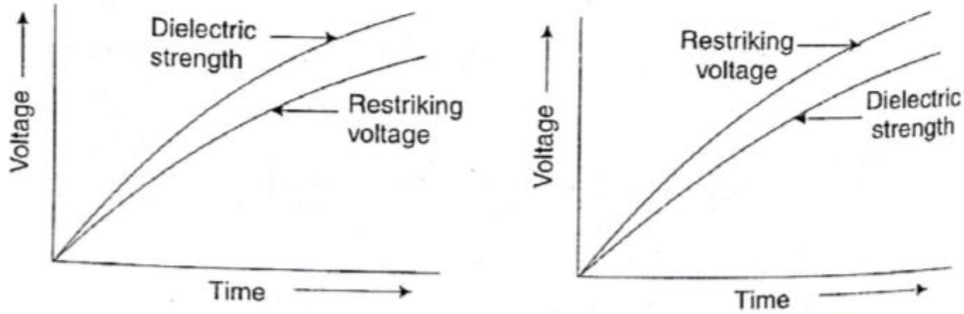
FIGURE 3.31 Differential current protection of bus-zone

* The operating principle is based on Kirchoffs Law.
The algebraic sum of all the currents entering & currents leaving the bus-zone must be zero, unless there is a fault.
* Relay is connected to trip all the circuit breakers.
* In case of a bus fault, the algebraic sum of currents will not be zero and relay will operate.
* Drawback of this scheme is that there may be a False operation in case of external fault. If one of the CT saturates, then its output is reduced and sum of all CT 2° currents will not be zero.
* To overcome this difficulty, high impedance relay or biased differential scheme can be used.

Q.7.a

Recovery Rate Theory

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



(a) Arc extinguishes (b) Arc does not extinguish

Energy Balance Theory

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

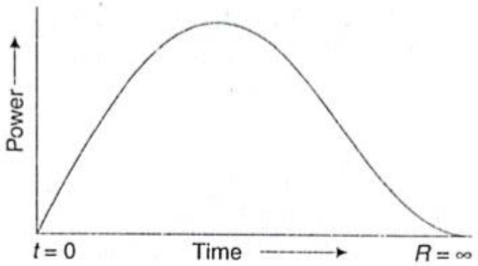
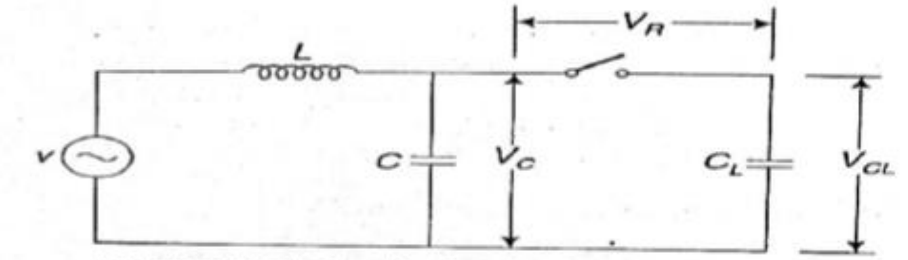
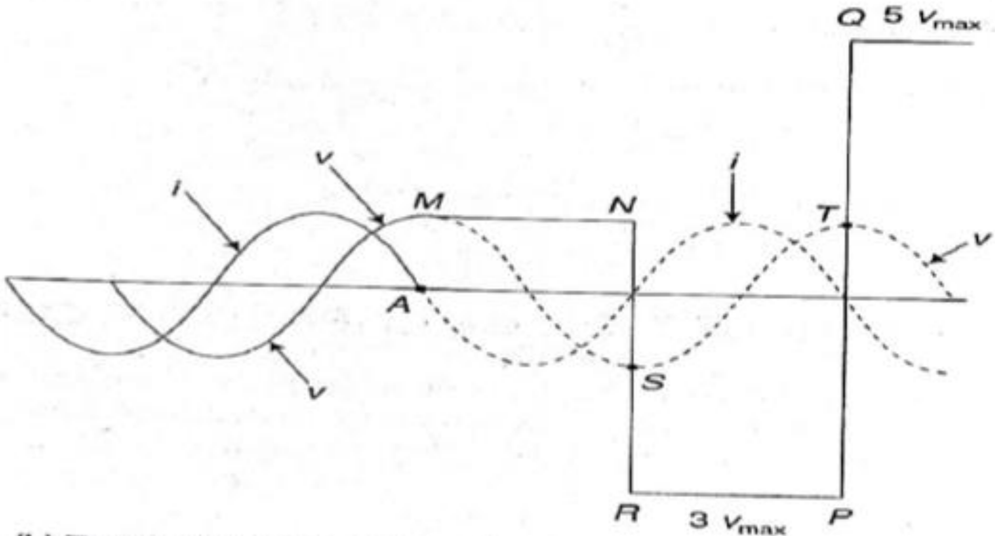


Fig. 14.6 *Energy balance theory*

Q.7.b



(a) Electrical circuit of a simple power system



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

Fig. 14.13 *Interruption of capacitive current*

Q.7.c

9.9 Air Blast Circuit Breaker

In air blast circuit breakers, compressed air at a pressure of 20-30 kg/cm^2 is employed as an arc quenching medium. Air blast circuit breakers are suitable for operating voltages of 132 kV and above. They have also been used in 11 kV-33 kV range for certain applications. At present, SF_6 circuit breakers

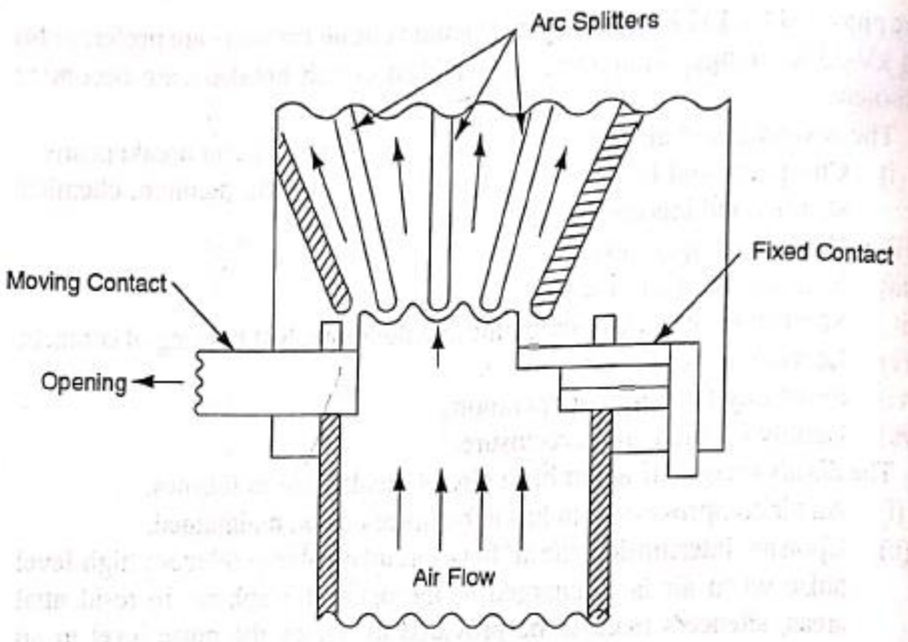
An air-blast circuit breaker may be either of the following two types.

(i) Cross-blast Circuit Breakers.

(ii) Axial-blast Circuit Breakers.

9.9.1 *Cross-blast Circuit Breakers*

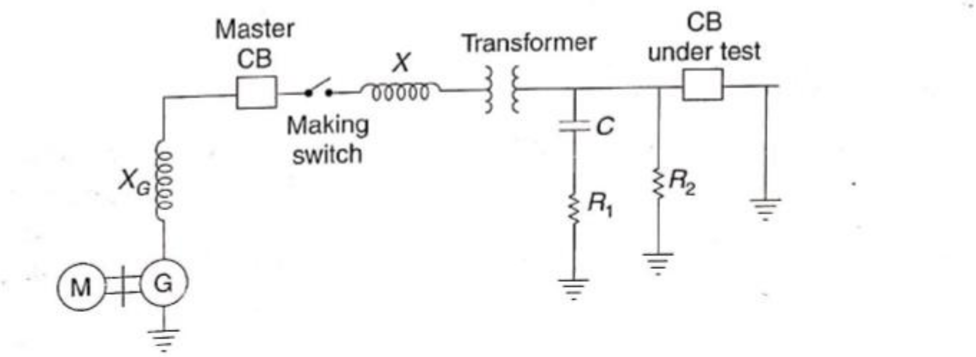
In a cross-blast type circuit breaker, a high-pressure blast of air is directed perpendicularly to the arc for its interruption. Figure 9.18 (a) shows a schematic diagram of a cross-blast type circuit breaker. The arc is forced into a suitable chute. Sufficient lengthening of the arc is obtained, resulting in the introduction of appreciable resistance in the arc itself. Therefore, resistance switching is not common in this type of circuit breakers. Cross-blast circuit breakers are suitable for interrupting high current (up to 100 kA) at comparatively lower voltages.



Q.8.a

14.19.3 Direct Testing

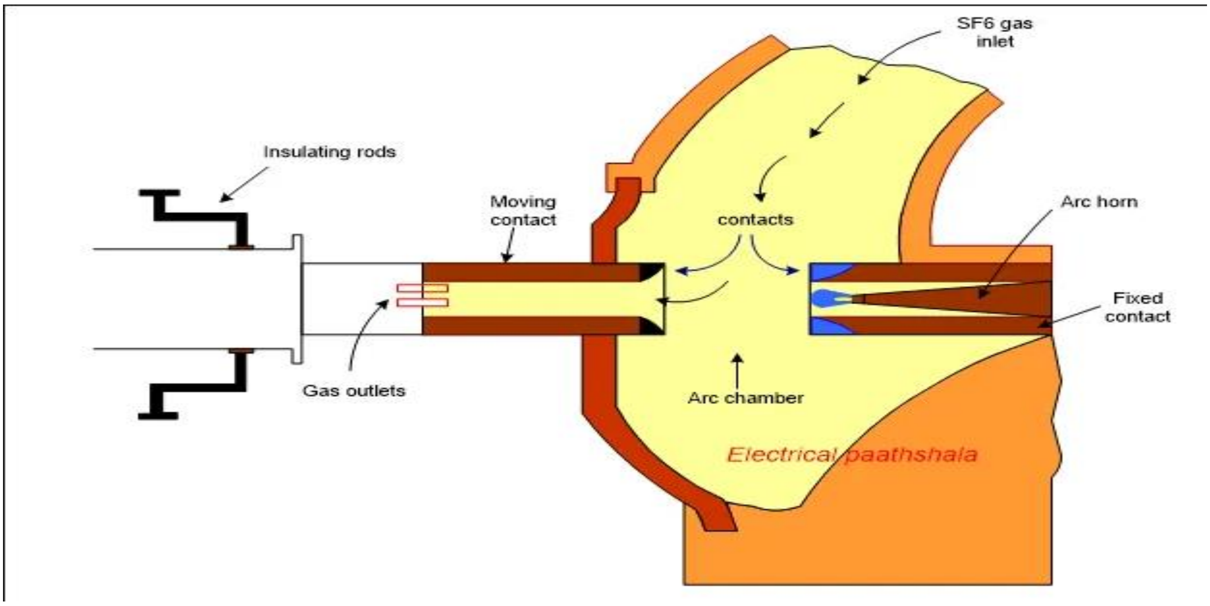
In direct testing, the circuit breaker is tested under the conditions which actually exist on power systems. It is subjected to restriking voltage which is expected in practical situations. Figure 14.30 shows an arrangement for direct testing. The reactor X is to control short-circuit current. C, R_1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



Q.8.b

Non puffer type SF6 circuit breaker

This type of SF6 circuit breaker is widely used, hence we will discuss the construction and working in detail.



Construction

The non-puffer type sf6 circuit breaker has an Interrupter part, the arc quenching process is performed in this part.

It consists of two contacts, the fixed contact and the moving contact. Both these contacts are hollow cylinders.

The fixed contact has arc horns connected with it as shown in fig. below. These arc horns prevent the switching components during flashover.

The moving contact has rectangular gas outlets as shown in the fig. below. The gas after the process of arc extinction moves out from these rectangular holes.

The tips of arc horn and both contacts are coated with the copper-tungsten arc resistant material.

The main arcing process is done in arc chamber as shown in fig. A SF6 gas reservoir is connected with the arc chamber with a valve connected.

The valve is synchronized with the moving contact of the circuit breaker. It means, as soon as the moving contact separates from the fixed contact during any fault, then the valve of SF6 gas tank will automatically open and flow of gas will inlet to the arc chamber.

Working

Initially the contacts are in closed position surrounded by the Sulphur

hexafluoride gas (SF6) at a pressure of around 2.8 kg/

When there is a fault in the system then the moving contact begin to separate from the fixed contact.

According to the arc interruption theory, the surrounding medium will ionise and arc will be struck between the contacts.

The valve connected with the SF6 gas tank will open and now the pressurised gas will come in the arcing chamber, now the pressure in the chamber is

around 14 kg/ .

Now, SF6 gas will flow through the arc and it will quench the arc in very short time as explained earlier.

After the extinction of arc and interruption of current, the gas moves out from the gas outlets and with the suitable methods, the gas gets recombined and reconditioned for further use.

Q.8.c

Q.3.b

Time →

Fig. 14.27 *Artificial current zeros in dc*

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

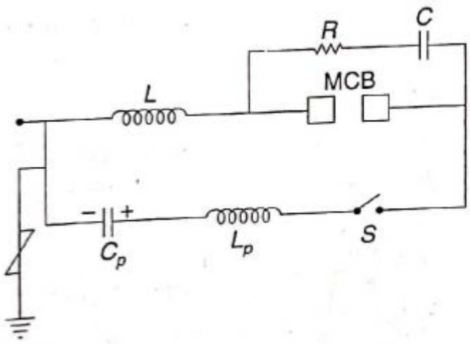


Fig. 14.28 *HVDC circuit breaker*

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

Q.9.a

15.4.4 High Rupturing Capacity (HRC) Cartridge Fuse

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

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

panel.

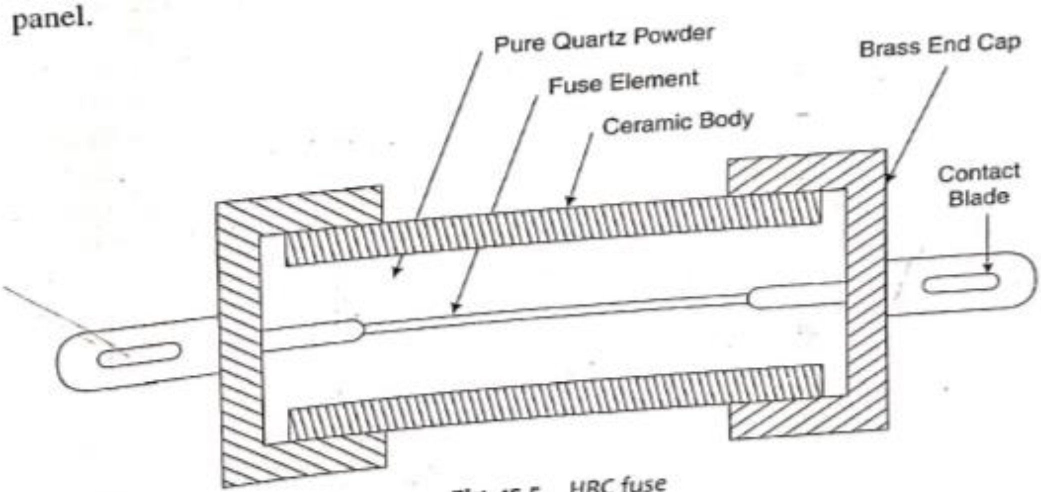


Fig. 15.5 *HRC fuse*

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

Q.9.b

(i) Expulsion type lightning arrester

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

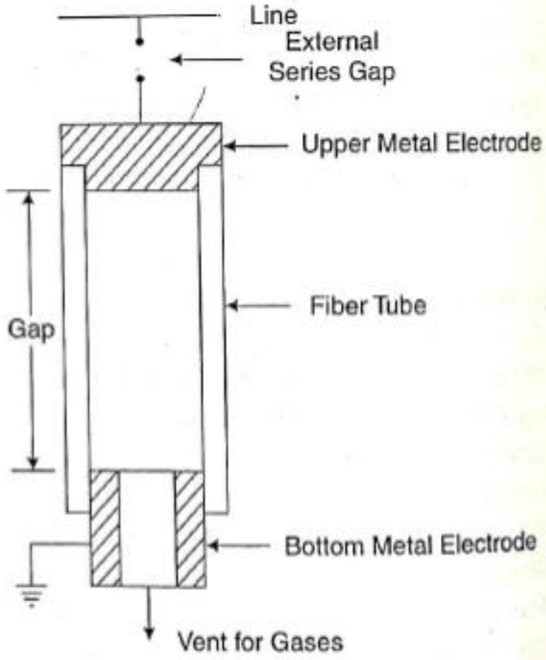


Fig. 16.16 *Expulsion type lightning arrester*

11.8.1 Rod Gap

A rod gap provides the simplest and cheapest protection to line insulators, equipment insulators and bushings of transformers. It is clear that in case of serious overvoltages, the over-insulation of any one part of the power system may cause the breakdown of the insulation of some vital and perhaps inaccessible part. Thus, it is preferred that it is the line insulators that flashover rather than the bushings of a transformer breaking down. Again, it is preferred that a bushing breakdown before the insulation of the transformer of which it forms a part. In the case of transformers, rod gaps which are also called co-ordinating gaps are installed to protect the apparatus. Rod gaps provide back-up protection to the bushings of transformers in case of the primary protective devices, i.e. lightning arresters fail.

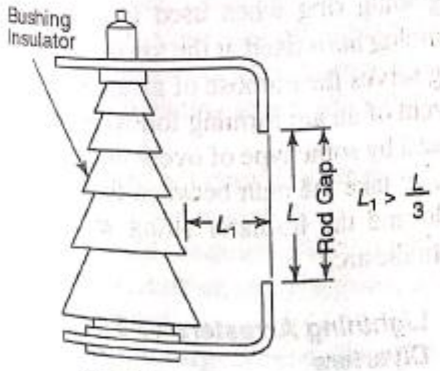


FIGURE 11.13 Rod gap

A rod gap consists of two rods of approximately 1.2 cm diameter or square, which are bent at right angles as shown in Fig. 11.13. One rod is connected to the line while the other rod is connected to ground. In case of a transformer, they are fixed between bushing insulators. In order to avoid cascading across the insulator surface under very steep-fronted waves, the rod gap should be adjusted to breakdown at about 20 per cent below the impulse flashover voltage of the insulation of the equipment to be protected (i.e. bushing insulator of a transformer in Fig. 11.13). Further, the distance between the gap and the insulator should be more than one-third of the gap length (i.e. $L_1 > \frac{L}{3}$) in order to prevent the arc from being blown to the insulator. The accurate breakdown value of the rod gap cannot easily be predicted because the breakdown of air depends upon the atmospheric conditions (i.e., humidity, temperature and pressure), as also upon polarity, steepness and the waveshape of the wave.

The major disadvantage of the rod gap is that it does not interrupt the power frequency follow current after the surge has disappeared. This means that every operation of the rod gap creates an L-G fault which can only be cleared by the operation of the circuit breaker. Thus, the operation of the rod gap results in circuit outage and interruption of power supply.

Q.10.a

11.10 Insulation Coordination

Insulation coordination is the correlation of the insulation of electrical equipment and lines with the characteristics of protective devices such that the insulation of the 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 the different components in any power system and their arrangement in a reasonable manner so that the whole power system is protected from overvoltages of excessive magnitude. Thus, the insulation strength of various equipment, like transformers, circuit breakers, etc. should be higher than that of the lightning arresters and other surge protective devices. The insulation coordination is thus the matching of the volt-time flashover and breakdown characteristics of equipment and protective devices, in order to obtain maximum protective margin at a reasonable cost. The volt-time curves of equipment to be protected and the protective device are shown in Fig. 11.24. Curve A is the volt-time curve of the protective device and curve B is the volt-time curve of the equipment to be protected. From volt-time curves A and B of Fig. 11.24, it is clear that any insulation having a voltage withstanding strength in excess of the insulation strength of curve B will be protected by the protective device of curve A.

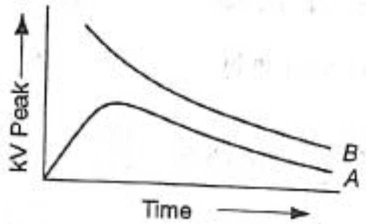


FIGURE 11.24 Volt-time curves of protective device and the equipment to be protected

11.10.1 Volt-time Curve

The breakdown voltage of any insulation or the flashover voltage of a gap depends upon both the magnitude of the voltage and the time of application of the voltage. The volt-time curve is a graph of the crest flashover voltages plotted against time to flashover for a series of impulse applications of a given wave shape. The construction of the volt-time curve and the terminology associated with impulse testing are shown in Fig. 11.25. The construction of the volt-time curve is based on the application of impulse voltages of the same wave shape but of different peak values to the insulation whose volt-time curve is required. If an impulse voltage of a given wave shape and polarity is adjusted so that the test specimen (i.e. a particular insulation) flashes over on the front of the wave, the value of voltage corresponding to the point on front of the wave at which flashover occurs is called front flashover. If an impulse voltage of the same wave shape is adjusted so that the test specimen flashes over on the tail of the wave at 50 per cent of the applications and fails to flashover on the other 50 per cent of the applications, the crest value of this voltage is called the critical flashover voltage. If an impulse voltage causes flashover of the test specimen exactly at the crest value, then it is called crest flashover. If flashover does not take place, the wave is called a full wave and if flashover does take place, the wave is called a chopped wave. The applied impulse voltage reduced to just below the flashover voltage of the test specimen is called the 'critical withstand voltage. The rated withstand voltage is the crest value of the impulse wave that the test specimen will withstand without disruptive discharge.

Figure 11.25 illustrates for an assumed impulse, its wave front flashover,

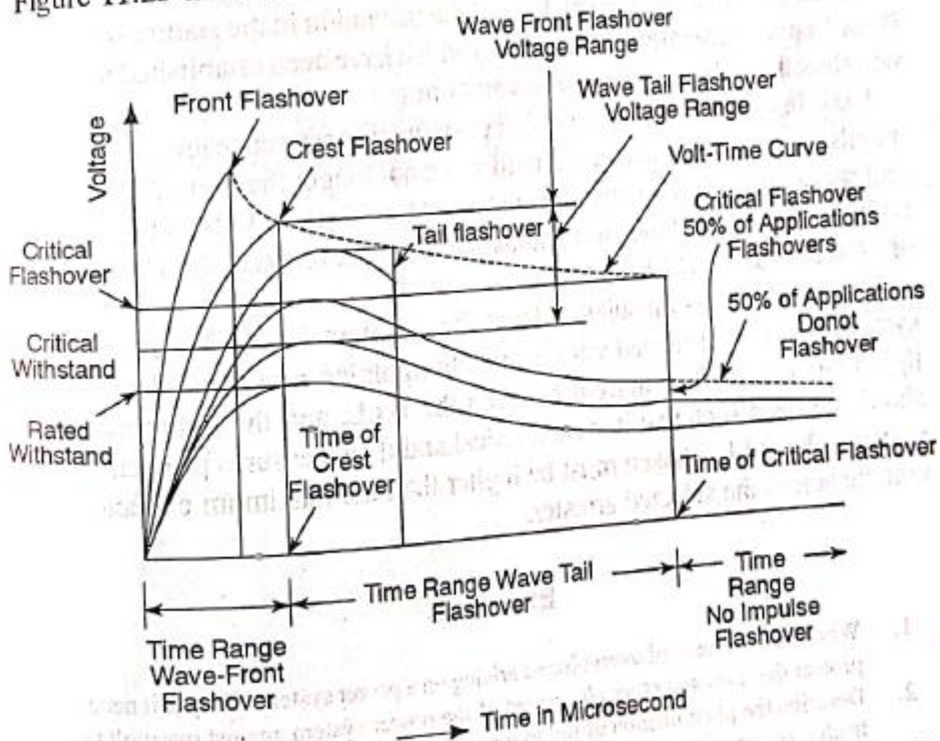


FIGURE 11.25 Construction of volt-time curve and the terminology associated with impulse testing

Q.10.b

17.2.2 Modules/Components of GIS

The following are the principal modules insulated by SF_6 gas in a GIS:

(i) Busbar
(ii) Isolator or disconnector
(iii) Circuit breaker
(iv) Current transformer
(v) Earthing switch

The auxiliary gas insulated modules/accessories (excluding control panel) required to complete a GIS are

(i) Instrument voltage transformer
(ii) Surge and lightning arrester
(iii) Terminations

Busbar

The busbar which is one of the most elementary components of the GIS system, is of different lengths to cater to the requirement of circuit or bay formation. Co-axial busbars are commonly used in isolated-phase GIS as this configuration results in an optimal stress distribution. The main high voltage conductor made of aluminium or copper is centrally placed in a tubular metal enclosure, and supported by the disc/post insulator, at a uniform distance to maintain concentricity. Two sections of bus are joined by using plug-in connecting elements.

Isolator or Disconnector

Isolators are placed in series with the circuit breaker to provide additional protection and physical isolation. In a circuit, two isolators are generally used, one on the line side and the other on the feeder side. A pair of fixed contacts and a moving contact form the active part of the isolator. The fixed contacts are separated by an isolating gas gap. Isolators are either on-load type load-break switch or no-current break type. They can be motorised for remote control or driven manually. In GIS system, motorized isolators are preferred. Necessary interlocks are provided between the circuit-breaker isolator and earthing switch.

Circuit Breaker

The circuit breaker is the most critical module of a GIS system. It is metal-clad and utilises SF_6 gas, both for insulation and fault interruption. Puffer type SF_6 circuit breakers are commonly used to accomplish fault current interruption in GIS.

Current Transformer

The current transformers used in GIS are essentially in-line current transformers. Gas insulated current transformers have classical coaxial geometry and consist of the following parts: the tubular primary conductor, an electrostatic shield ribbon–would toroidal core and the gas-tight metal enclosure filled with SF_6 gas. The primary of a current transformer is a tubular metal conductor linking two gas-insulated modules, placed on either side of the current transformer. A ribbon–wound silicon steel core formed in toroidal shape is used for the magnetic circuit of the current transformer. A coaxial electrostatic shield, at ground potential, is placed between the high-voltage primary and the toroidal magnetic core of the current transformer for ensuring zero potential at the secondary of the current transformer.

Earthing Switch

Earthing switches used for GIS system are of two types, namely, maintenance earthing switch and fast earthing switch. The maintenance earthing switch is a slow device used to ground the high voltage conductors during maintenance schedule, in order to ensure the safety of the maintenance staff. On the other hand, the fast earthing switch is used to protect the circuit-connected instrument voltage transformer from core saturation caused by direct current flowing through its primary as a result of remnant charge (stored online during isolation/switching off the line). In such a situation, the use of a fast earthing switch provides a parallel low resistance path to drain the residual static charge quickly, thereby protecting the instrument voltage transformer from the damages which may be caused otherwise.

The earthing switch is the smallest module of a GIS. It is made up of two parts: a fixed contact located at the live bus conductor and a moving contact system mounted on the enclosure of the main module.