SNS COLLEGE OF ENGINEERING

Kurumbapalayam (Po), Coimbatore – 641 107

AN AUTONOMOUS INSTITUTION

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B.E / B.Tech DEGREE END SEMESTER EXAMINATIONS, APR. / MAY. 2024

Sixth Semester

B.E. – Electrical and Electronics Engineering

19EE605 – Protection and Switchgear

(Regulations -2019)

Duration: 3 Hours   Max. Marks 100

PART – A (10*2 = 20 Marks)		
1	**Write the effects of power system faults if the fault remains un-cleared.** Serious results of the uncleared fault, is fire which may not only destroy the equipment of its origin but also may spread in the system and cause total failure.	**2**
2	**Justify the need for protection schemes for power system.** The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible in operation. The devices that are used to protect the power systems from faults are called protection devices.	**2**
3	**What do you infer from R-X diagram of distance relays?** The R-X diagram of distance relays illustrates the relationship between the impedance seen by the relay and its operation characteristics, aiding in understanding relay behavior and coordination in power systems.	**2**
4	**Outline the principle of operation of differential relays.** Differential relays operate by comparing the currents entering and leaving a protected zone. If there's a mismatch, indicating a fault, the relay trips, providing fast and selective protection for the zone.	**2**
5	**Mention the role of CT and PT in a protection system.** Current Transformers (CTs) step down high currents to levels measurable by protective relays, ensuring accurate fault detection. Potential Transformers (PTs) step down high voltages to levels suitable for relays, providing accurate measurements for protection and control purposes in power systems.	**2**
6	**List the various faults that would affect an alternator.** • Stator winding faults (short circuits, open circuits) • Rotor winding faults (broken rotor bars, shorted rotor windings) • Bearing faults (wear, misalignment) • External faults (overloading, voltage fluctuations) • Cooling system failures • Insulation degradation	**2**
7	**Point out the general characteristics of numerical protection.** Numerical protection offers high-speed fault detection, accurate measurement, and extensive flexibility in settings and operation. It integrates advanced algorithms for fault analysis, communication capabilities for remote monitoring, and self-diagnostic features, enhancing reliability and adaptability in power system protection.	**2**

8	**In what way, the static relays are meritorious than electromagnetic relays?** Static relays offer faster operation, higher reliability, and improved accuracy compared to electromagnetic relays. They have no moving parts, reducing wear and maintenance needs, while also enabling more precise control and advanced features like programmability and communication capabilities.	2
9	**Define rate of rise of restriking voltage in circuit breakers.** The rate of rise of restriking voltage (RRRV) in circuit breakers refers to the speed at which the voltage across the breaker contacts increases after interruption and during the re-ignition of the arc. It's a critical factor in breaker design to prevent restriking and ensure effective interruption of current.	2
10	**Differentiate between the operation of RCCB and MCB.**	2

Aspect	RCCB (Residual Current Circuit Breaker)	MCB (Miniature Circuit Breaker)
Purpose	Protects against earth leakage and residual currents	Protects against overcurrents and short circuits
Operation	Detects imbalances in current between live and neutral	Trips when current exceeds its rated threshold
Sensing Mechanism	Uses a differential current transformer	Relies on thermal or magnetic mechanisms for detection
Trip Characteristics	Triggers when a residual current threshold is exceeded	Trips when current exceeds its set limit
Applications	Used in circuits where electrical leakage poses a risk	Commonly employed in circuits for overload protection

PART – B (5*13 = 65 Marks)

11. (a) **(i) Summarize the importance of protective schemes employed in power system.** **06**

An electrical power system consists of generators, transformers, transmission and distribution lines, etc. Short circuits and other abnormal conditions often occur on a power system. The heavy current associated with short circuits is likely to cause damage to equipment if suitable protective relays and circuit breakers are not provided for the protection of each section of the power system. Short circuits are usually called faults by power engineers. Strictly speaking, the term ‘fault’ simply means a ‘defect’. Some defects, other than short circuits, are also termed as faults. For example, the failure of conducting path due to a break in a conductor is a type of fault.

If a fault occurs in an element of a power system, an automatic protective device is needed to isolate the faulty element as quickly as possible to keep the healthy section of the system in normal operation. The fault must be cleared within a fraction of a second. If a short circuit persists on a system for a longer, it may cause damage to some important sections of the system. A heavy short circuit current may cause a fire. It may spread in the system and damage a part of it. The system voltage may reduce to a low level and individual generators in a power station or groups of generators in different power stations may lose synchronism. Thus, an uncleared heavy short circuit may cause the total failure of the system.

A protective system includes circuit breakers, transducers (CTs and VTs), and protective relays to isolate the faulty section of the power system from the healthy sections. A circuit breaker can disconnect the faulty element of the system when it is called upon to do so by the protective relay. Transducers (CTs and VTs) are used to reduce currents and voltages to lower values and to isolate protective relays from the high voltages of the power system. The function of a protective relay is to detect and locate a fault and issue a command to the circuit breaker to disconnect the faulty element. It is a device which senses abnormal conditions on a power system by constantly monitoring electrical quantities of the systems, which differ under normal and abnormal conditions. The basic electrical quantities which are likely to change during abnormal conditions are current, voltage, phase-angle (direction) and frequency. Protective relays utilise one or more of these quantities to detect abnormal conditions on a power system.

Protection is needed not only against short circuits but also against any other abnormal conditions which may arise on a power system. A few examples of other abnormal conditions are over speed of generators and motors, overvoltage, under frequency, loss of excitation, overheating of stator and rotor of an alternator etc. Protective relays are also provided to detect such abnormal conditions and issue alarm signals to alert operators or trip circuit breaker.

A protective relay does not anticipate or prevent the occurrence of a fault, rather it takes action only after a fault has occurred. However, one exception to this is the Buchholz relay, a gas actuated relay, which is used for the protection of power transformers. Sometimes, a slow breakdown of insulation due to a minor arc may take place in a transformer, resulting in the generation of heat and decomposition of the transformer's oil and solid insulation. Such a condition produces a gas which is collected in a gas chamber of the Buchholz relay. When a specified amount of gas is accumulated, the Buchholz relay operates an alarm. This gives an early warning of incipient faults. The transformer is taken out of service for repair before the incipient fault grows into a serious one. Thus, the occurrence of a major fault is prevented. If the gas evolves rapidly, the Buchholz relay trips the circuit breaker instantly.

The cost of the protective equipment generally works out to be about 5% of the total cost of the system.

(ii) Briefly discuss the essential qualities of protection systems. **07**

The basic requirements of a protective system are as follows:

(a) Selectivity or discrimination

(b) Reliability

(c) Sensitivity

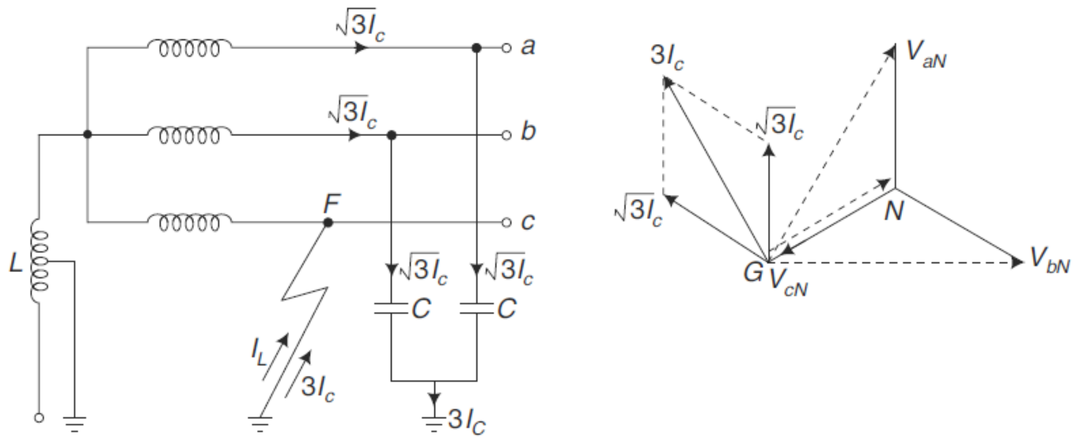
(d) Stability

(e) Fast operation

(a) Selectivity or Discrimination

Selectivity, is the quality of protective relay by which it is able to discriminate between a fault in the protected section and the normal condition. Also, it should be able to distinguish whether a fault lies within its zone of protection or outside the zone. Sometimes, this quality of the relay is also called discrimination. When a fault occurs on a power system, only the faulty part of the system should be isolated. No healthy part of the system should be deprived of electric supply and hence should be left intact. The relay should also be able to discriminate between a fault and transient conditions like power surges or inrush of a transformer's magnetising current. The magnetising current of a large transformer is comparable to a fault current, which may be 5 to 7 times the full load current. When generators of two interconnected power plants lose synchronism because of disturbances, heavy currents flow through the equipment and lines. This condition is like a short circuit. The flow of heavy currents is known as a power surge. The protective relay should be able to distinguish between a fault or power surge either by its inherent characteristic or with the help of an auxiliary relay. Thus, we see that a protective relay must be able to discriminate between those conditions for

	which instantaneous tripping is required and those for which no operation or a time-delay operation is required. **(b) Reliability** A protective system must operate reliably when a fault occurs in its zone of protection. The failure of a protective system may be due to the failure of any one or more elements of the protective system. Its important elements are the protective relay, circuit breaker, VT, CT, wiring, battery, etc. To achieve a high degree of reliability, greater attention should be given to the design, installation, maintenance and testing of the various elements of the protective system. Robustness and simplicity of the relaying equipment also contribute to reliability. The contact pressure, the contact material of the relay, and the prevention of contact contamination are also very important from the reliability point of view. A typical value of reliability of a protective scheme is 95%. **(c) Sensitivity** A protective relay should operate when the magnitude of the current exceeds the preset value. This value is called the pick-up current. The relay should not operate when the current is below its pick-up value. A relay should be sufficiently sensitive to operate when the operating current just exceeds its pick-up value. **(d) Stability** A protective system should remain stable even when a large current is flowing through its protective zone due to an external fault, which does not lie in its zone. The concerned circuit breaker is supposed to clear the fault. But the protective system will not wait indefinitely if the protective scheme of the zone in which fault has occurred fails to operate. After a preset delay the relay will operate to trip the circuit breaker. **(e) Fast Operation** A protective system should be fast enough to isolate the faulty element of the system as quickly as possible to minimise damage to the equipment and to maintain the system stability. For a modern power system, the stability criterion is very important and hence, the operating time of the protective system should not exceed the critical clearing time to avoid the loss of synchronism. Other points under consideration for quick operation are protection of the equipment from burning due to heavy fault currents, interruption of supply to consumers and the fall in system voltage which may result in the loss of industrial loads. The operating time of a protective relay is usually one cycle. Half-cycle relays are also available. For distribution systems the operating time may be more than one cycle.	
	OR	
11. (b)	**Summarize the effects of fault current due to a phase to ground fault in an ungrounded neutral system. Illustrate how those effects are minimized with the help of resonant grounding.** Resonant grounding is a special case of reactance grounding. In this case an iron-cored reactor connected between the neutral and ground is capable of being tuned to resonate with the capacitance of the system when a line-to-ground (L-G) fault occurs [Fig. a]. The iron-cored reactor is known as arc suppression coil or Peterson coil or ground fault neutralizer. Arc suppression coil (Peterson coil or ground fault neutralizer) is provided with tappings which permit selection of reactance of the coil depending upon the capacitance to be neutralized. The capacitance to be neutralized depends upon the length of the transmission line. The phasor diagram for fault on phase c is shown in Fig. b	**13**



(a) L-G fault on phase *c* (b) Phasor diagram

In case of resonant grounding, the value of the inductive reactance of the arc suppression coil is such that the fault current IL exactly balances the charging current. In an ungrounded system, when a ground fault occurs on any one line, the voltages of the healthy phases is increased by ÷ √3 times (i.e., √3 Vp). Hence the charging currents become √3 Ic per phase, were Ic is the charging current of line to ground of one phase. The resultant charging current Icr which is the phasor sum of the charging currents of the healthy phases (i.e., √3 Ic) becomes 3 times the normal line to neutral charging current of one phase, as shown in phasor diagram of Fig.b.

Hence,

Icr = 3Ic = $3\frac{V_p}{1/wc} = 3V_p wc$ ----(1)

If L is the inductance of the arc suppression coil (Peterson coil or ground-fault neutralizer) connected between the neutral and the ground, then

$I_L = \frac{V_p}{wL}$ ---------------(2)

In order to obtain satisfactory cancellation (neutralization) of arcing grounds, the fault current IL flowing through the arc suppression coil should be equal to resultant charging current Icr

Therefore, for balance condition

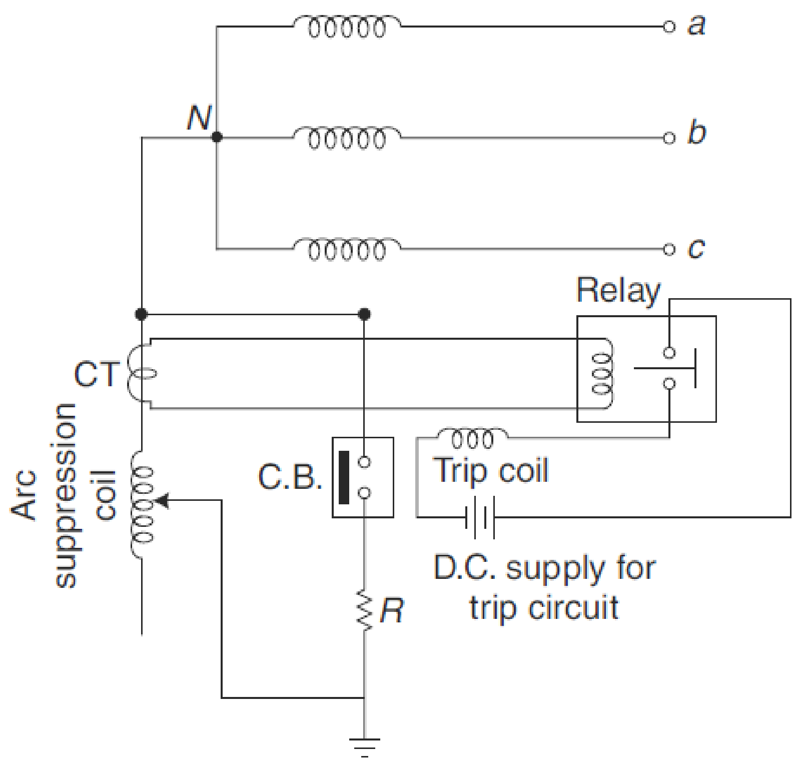
I_L = Icr

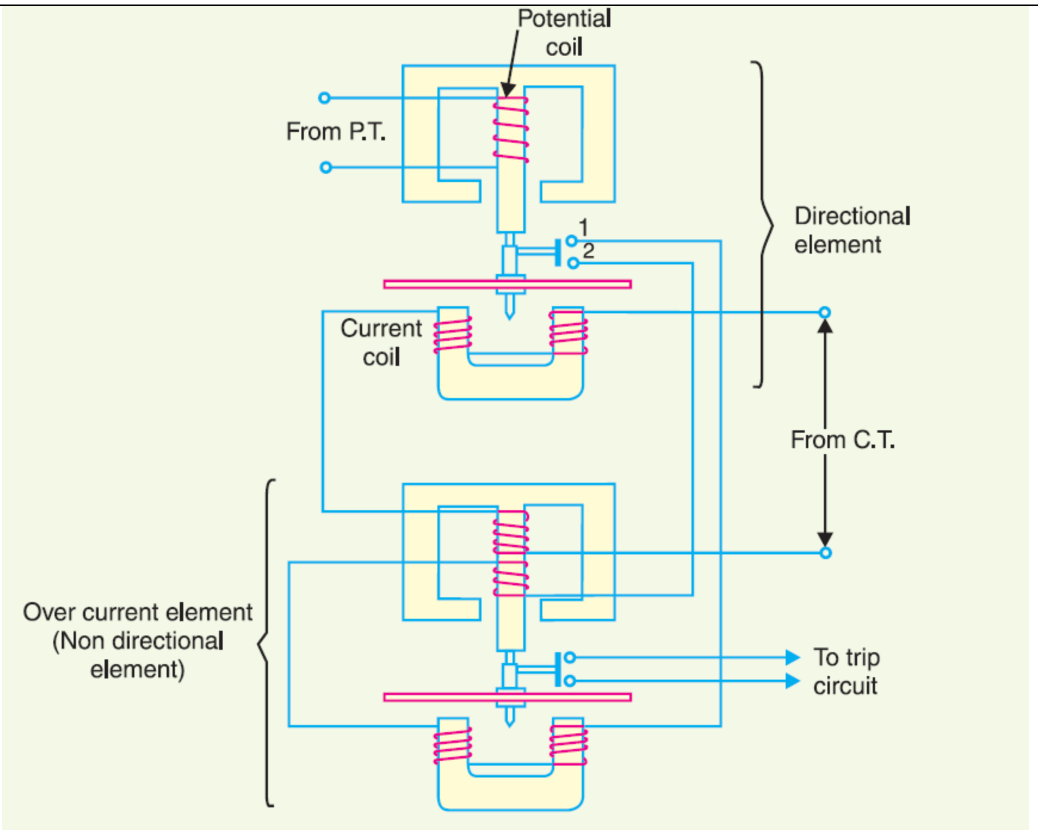
$\frac{V_p}{wL} = 3V_p wc$ [From eqs 1 & 2]

or $L = \frac{1}{3w^2c}$ ---------------- (3)

The inductance of the arc suppression coil is calculated from Eq. (3)

The method of resonant grounding is usually confined to medium-voltage overhead transmission lines which are connected to the system generating source through intervening power transformers. The use of this method of grounding reduces the line interruption due to

	transient line-to-ground faults which will not be possible with other methods of grounding. In this method of grounding, the tendency of a single phase to ground fault developing into two or three-phase fault is decreased. Normal time-rating of arc suppression coils used on systems on which permanent ground faults can be located and removed promptly is ten minutes whereas continuous time-rated coils are used on all other systems. In such cases, it is also usual to provide automatic means as shown in Fig. c to bypass the arc suppression coil after some time. If for any reason more current flows through the arc suppression coil, a circuit breaker closes after a certain time-lag and the ground-fault current flows through the parallel circuit by-passing the arc-suppression coil.  Fig. C – Connection of Arc Suppression Coil The circuit breaker (C.B.) which is normally open is closed by the trip coil when the relay operates after a predetermined time. Thus the fault current is by-passed through the resistor branch.	
12. (a)	**With a neat diagram, explain the working principle of a directional overcurrent relay. Derive an expression for the deflecting torque produced in it.** The directional power relay discussed above is unsuitable for use as a directional protective relay under short-circuit conditions. When a short-circuit occurs, the system voltage falls to a low value and there may be insufficient torque developed in the relay to cause its operation. This difficulty is overcome in the directional overcurrent relay which is designed to be almost independent of system voltage and power factor.	**13**



Constructional details. Fig. 21.19 shows the constructional details of a typical induction type directional ovecurrent relay. It consists of two relay elements mounted on a common case viz. (i) directional element and (ii) non-directional element.

(i) Directional element. It is essentially a directional power relay which operates when power flows in a specific direction. The potential coil of this element is connected through a potential transformer (P.T.) to the system voltage. The current coil of the element is energised through a C.T. by the circuit current. This winding is carried over the upper magnet of the non-directional element.

The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the overcurrent element. Therefore, the latter element cannot start to operate until its secondary circuit is completed. In other words, the directional element must operate first (i.e. contacts 1 and 2 should close) in order to operate the overcurrent element.

(ii) Non-directional element. It is an overcurrent element similar in all respects to a non-directional overcurrent relay described in Art. 21.11. The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element.

It may be noted that plug-setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity. The tappings are provided on the upper magnet of overcurrent element and are connected to the bridge.

Operation. Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, directional power relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) unenergised. However, when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the *upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element. The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section. The two relay elements are so arranged that final

	tripping of the current controlled by them is not made till the following conditions are satisfied: **(i)** current flows in a direction such as to operate the directional element. **(ii)** current in the reverse direction exceeds the pre-set value. **(iii)** excessive current persists for a period corresponding to the time setting of overcurrent element. **Deflecting Torque:** To understand the production of torque in an induction relay, refer to the elementary arrangement shown in Fig. (i). The two a.c. fluxes Ø1 and Ø2 differing in phase by an angle α induce e.m.f.s' in the disc and cause the circulation of eddy currents i2 and i1 respectively. These currents lag behind their respective fluxes by 90°. Referring to Fig. 21.6 (ii) where the two a.c. fluxes and induced currents are shown separately for clarity, let $\emptyset_1 = \emptyset_{1max} Sin\omega t$ $\emptyset_2 = \emptyset_{2max} Sin(\omega t + \propto)$ where $\emptyset_1$ and $\emptyset_2$ are the instantaneous values of fluxes and $\emptyset_2$ leads $\emptyset_1$ by an angle $\propto$. Assuming that the paths in which the rotor currents flow have negligible self-inductance, the rotor currents will be in phase with their voltages. $i_1 \alpha \frac{d\emptyset_1}{dt} = \frac{d}{dt}(\emptyset_{1max} Sin\omega t)$ $\alpha\ \emptyset_{1max} Cos\omega t$ And $i_2 \alpha \frac{d\emptyset_2}{dt} = \emptyset_{2max} Cos(\omega t + \alpha)$ Now $F_1 = \emptyset_1 i_2$ and $F_2 = \emptyset_2 i_1$ Fig. (*ii*) shows that the two forces are in opposition. Net force *F* at the instant considered is F α F_2 - F_1 $\alpha\ \emptyset_2 i_1 - \emptyset_1 i_2$ $\alpha\ \emptyset_{2max} Sin(\omega t + \alpha) \emptyset_{1max} Cos\omega t - \emptyset_{1max} Sin\omega t \emptyset_{2max} Cos(\omega t + \alpha)$ $\alpha\ \emptyset_{1max} \emptyset_{2max} [Sin(\omega t + \alpha)\ Cos\omega t - Sin\omega t\ Cos(\omega t + \alpha)$ F $\alpha\ \emptyset_1 \emptyset_2 Sin\alpha$	
OR		
12. (b)	**With the help of phasor diagram, discuss the function of negative sequence relay used for the detection of current in electrical machines.** A negative phase sequence relay (or phase unbalance) is essentially provided for the protection of generators and motors against unbalanced loading that may arise due to phase-to-phase faults.	**13**

Essentially such a relay has a filter circuit which is responsive only to the negative sequence components. Since small magnitude overcurrent can cause dangerous conditions, it becomes necessary to have low setting of such relays. No doubt, an earth relay can also provide the desired protection but only in case when there is a fault between any phase and earth. For phase-to-phase faults an earth relay cannot provide necessary protection and hence negative phase sequence relay is required.

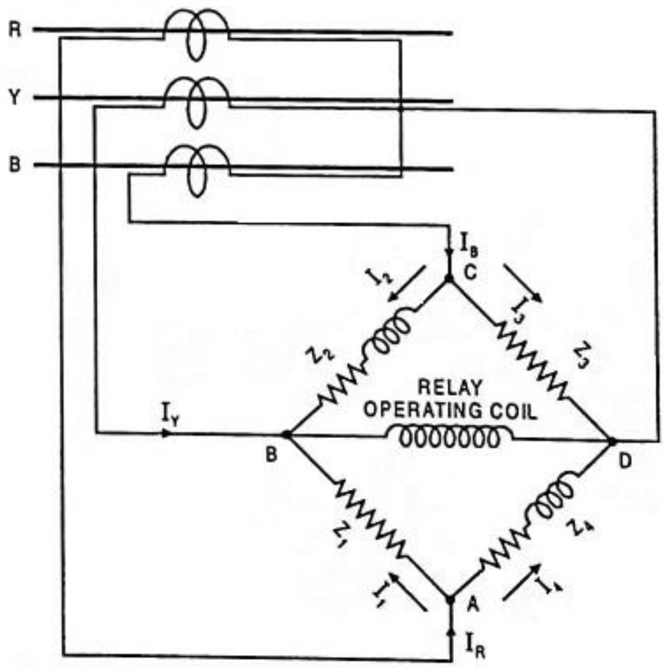
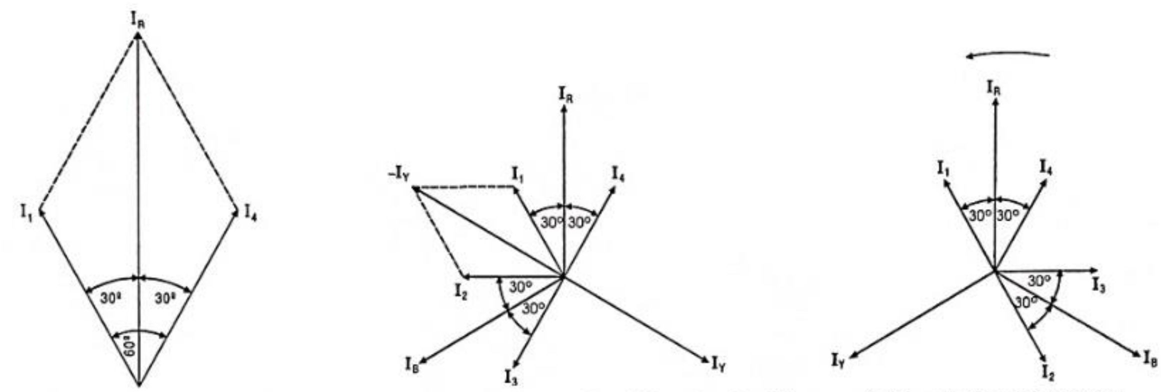


Figure illustrates the scheme used for negative phase sequence relay. A network consisting of four impedances Z_1, Z_2, Z_3 and Z_4 of equal magnitude connected in a bridge formation is energized from three CTs. A single pole relay having an inverse-time characteristic is connected across the circuit, as illustrated in the figure. Z_1 and Z_3 are non-inductive resistors while Z_2 and Z_4 are composed of both resistance and inductance. The values of Z_2 and Z_4 are so adjusted that currents flowing through them lag behind those in impedances Z_3 and Z_1 by 60°. The relay is assumed to have negligible impedance. The current from phase R at junction A is equally divided into two branches as I_1 and I_4 but I_4 will lag behind I_1 by 60°.



(a) Division of Current in Phase R *(b) Positive Sequence Currents in Normal Operating Condition* *(c) Negative Sequence Currents*

From Fig. A, B & C

$$I_1 = I_4 = \frac{I_R}{\sqrt{3}} \quad \because \quad I_R^2 = I_1^2 + I_4^2 + 2I_1 I_4 \cos 60°$$

Similarly the current from phase B divide at junction C into two equal components I_3 and I_2;

I_2 lagging behind I_3 by 60°.

$$I_2 = I_3 = \frac{I_B}{\sqrt{3}}$$

Note that I_1 leads I_R by 30° while I_4 lags behind I_R by 30°. Similarly I_2 lags behind I_B by 30°, whereas I_3 leads I_B by 30°.

The current through relay operating coil at junction B will be equal to phasor sum of I_1, I_2 and I_Y.

$$\textit{i.e.,}\quad I_{RELAY} = I_1 + I_2 + I_Y$$

$$= \frac{I_R}{\sqrt{3}} \text{ leading } I_R \text{ by } 30° + \frac{I_B}{\sqrt{3}} \text{ lagging behind } I_B \text{ by } 30° + I_Y \qquad ...(9.24)$$

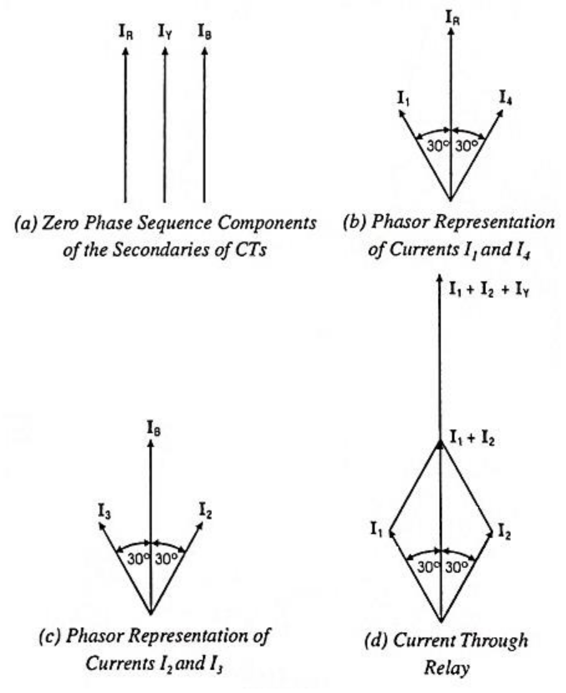
Flow of + ve Sequence Currents:

Figure (b) represents the phasor diagram when the load is balanced or when there is no negative sequence current. Since the current through the relay is $I_1 + I_2 + I_Y = 0$ because $I_1 + I_2 = -I_Y$

So the relay remains in operative for a balanced system.

Flow of – ve Sequence Currents:

Figure (c) represents the phasor diagram for negative sequence currents. It is noted that at junction B current I_1 and current I_2 are equal but opposite to each other, so they cancel each other and current I_Y flows through the relay operating coil. Thus the relay operates due to flow of current I_Y through it. A low setting value well below the normal full-load rating of the machine is provided since comparatively small values of unbalance currents produce a great danger.



(a) Zero Phase Sequence Components of the Secondaries of CTs

(b) Phasor Representation of Currents I_1 and I_4

(c) Phasor Representation of Currents I_2 and I_3

(d) Current Through Relay

Flow of Zero Sequence Currents:

The current at junction B of the relay is represented in phasor diagram [Fig. (d)] from which it is observed that the currents I_1 and I_2 are displaced from each other by 60°, so that the resultant of these currents is in phase with the current in phase Y. Thus a total current of twice the zero sequence current would flow through the relay and would therefore cause its operation.

13. (a) **Classify different protection schemes normally used for protection of a power transformer from internal faults. Discuss one of them in brief.** **13**

(i) Buchholz devices providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.

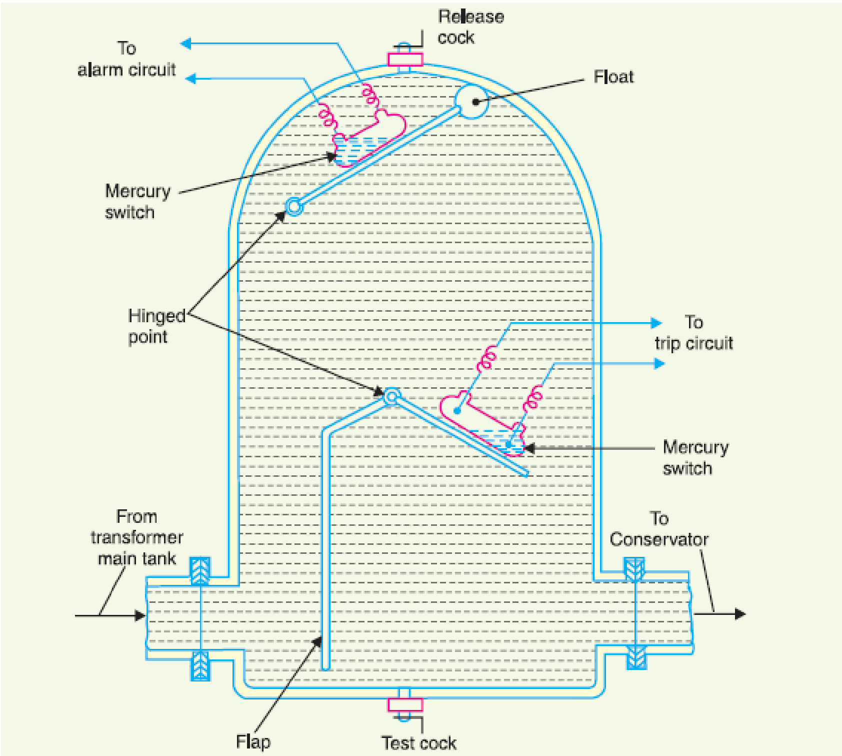
(ii) Earth-fault relays providing protection against earth-faults only.

(iii) Overcurrent relays providing protection mainly against phase-to-phase faults and overloading.

(iv) Differential system (or circulating-current system) providing protection against both earth and phase faults.

(i) Buchholz Realy

Buchholz relay is a gas-actuated relay installed in oil immersed transformers for protection against all kinds of faults. Named after its inventor, Buchholz, it is used to give an alarm in case of incipient (i.e. slow-developing) faults in the transformer and to disconnect the transformer from the supply in the event of severe internal faults. It is usually installed in the pipe connecting the conservator to the main tank as shown in Fig. It is a universal practice to use Buchholz relays on all such oil immersed transformers having ratings in excess of 750 kVA



Construction. Fig. shows the constructional details of a Buchholz relay. It takes the form of a domed vessel placed in the connecting pipe between the main tank and the conservator. The device has two elements. The upper element consists of a mercury type switch attached to a float. The lower element contains a mercury switch mounted on a hinged type flap located in the direct path of the flow of oil from the transformer to the conservator. The upper element closes an alarm circuit during incipient faults whereas the lower element is arranged to trip the circuit breaker in case of severe internal faults.

Operation.

In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conserva- tor and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to

cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.

If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator *via* the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

(ii) Earth fault relay

An earth-fault usually involves a partial breakdown of winding insulation to earth. The resulting leakage current is considerably less than the short-circuit current. The earth-fault may continue for a long time and cause considerable damage before it ultimately develops into a short-circuit and removed from the system. Under these circumstances, it is profitable to employ earth-fault relays in order to ensure the disconnection of earth-fault or leak in the early stage. An earth-fault relay is essentially an overcurrent relay of low setting and operates as soon as an earth-fault or leak develops. One method of protection against earth-faults in a transformer is the *core-balance leakage protection shown in Fig.

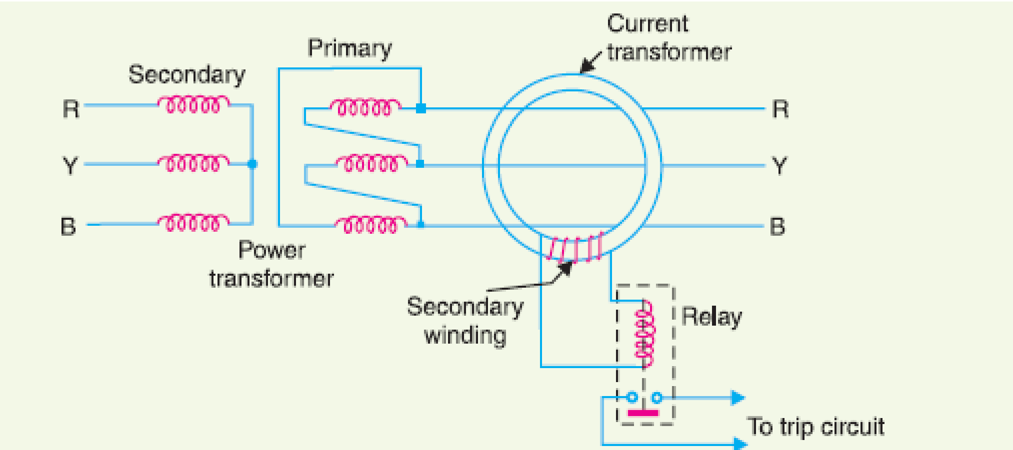


Fig. 22.13

The three leads of the primary winding of power transformer are taken through the core of a current transformer which carries a single secondary winding. The operating coil of a relay is connected to this secondary. Under normal conditions(i.e. no fault to earth), the vector sum of the three phase currents is zero and there is no resultant flux in the core of current transformer no matter how much the load is out of balance. Consequently, no current flows through the relay and it remains inoperative. However, on the occurrence of an earth-fault, the vector sum of three phase currents is no longer zero. The resultant current sets up flux in the core of the

C.T. which induces e.m.f. in the secondary winding. This energises the relay to trip the circuit breaker and disconnect the faulty transformer from the system.

(iii) Circulating current scheme or Merz Price Protection

Fig. shows Merz-Price circulating-current scheme for the protection of a 3- phase delta/delta power transformer against phase-toground and phase-to-phase faults. Note that CTs on the two sides of the transformer are connected in star. This compensates for the phase difference between the power transformer primary and secondary. The CTs on the two sides are connected by pilot wires and one relay is used for each pair of CTs.

During normal operating conditions, the secondaries of CTs carry identical currents. Therefore, the currents entering and leaving the pilot wires at both ends are the same and no current flows through the relays. If a ground or phase-to-phase fault occurs, the currents in the secondaries of CTs will no longer be the same and the differential current flowing through the relay circuit will clear the breaker on both sides of the transformer. The-protected zone is limited to the region between CTs on the high-voltage side and the CTs on the low-voltage side of the power transformer. It is worthwhile to note that this scheme also provides protection for short-circuits between turns on the same phase winding. When a short-circuit occurs between the turns, the turn-ratio of the power transformer is altered and causes unbalance between current transformer pairs. If turn-ratio of power transformer is altered sufficiently, enough differential current may flow through the relay to cause its operation. However, such short-circuits are better taken care of by Buchholz relays.

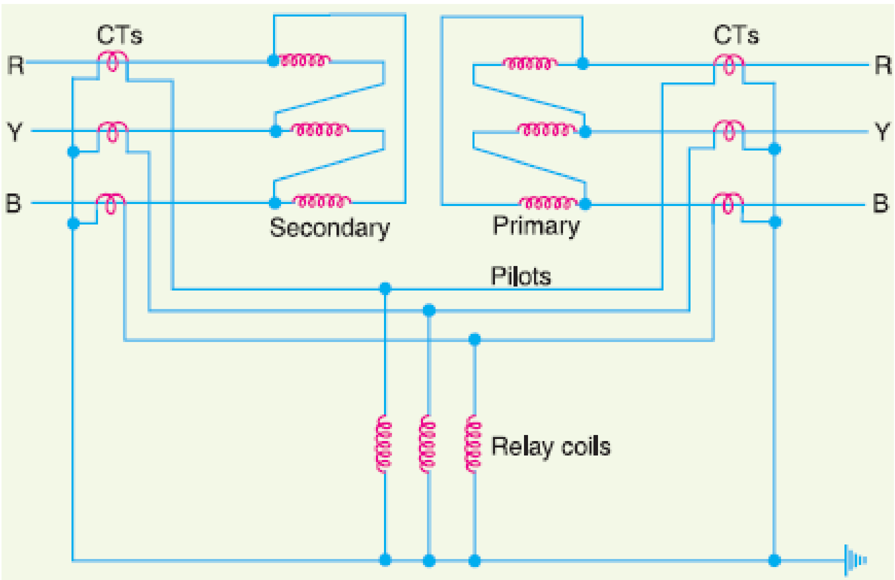
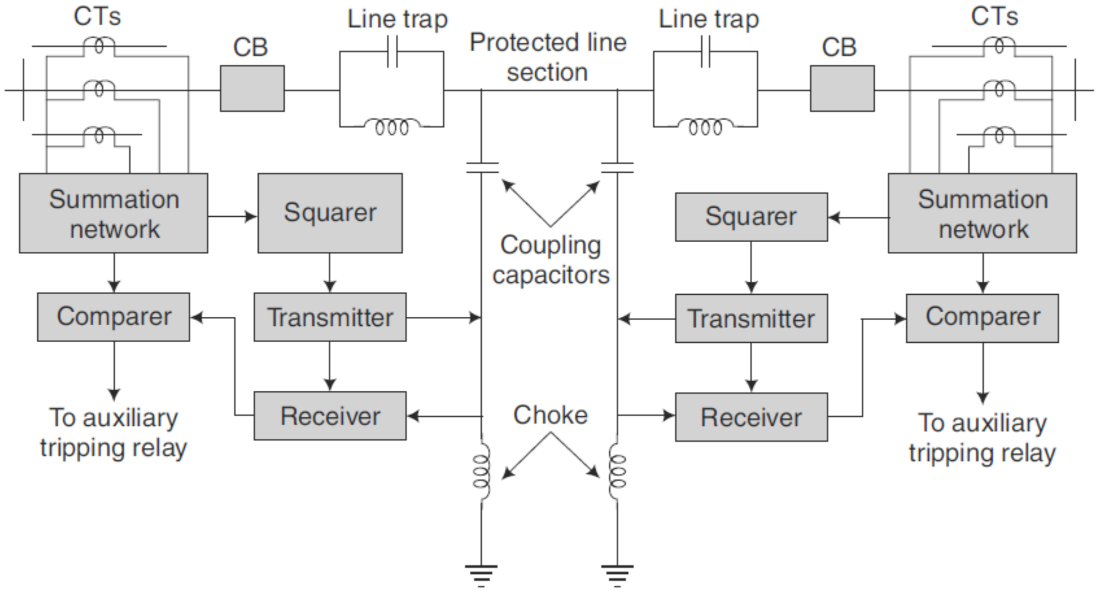


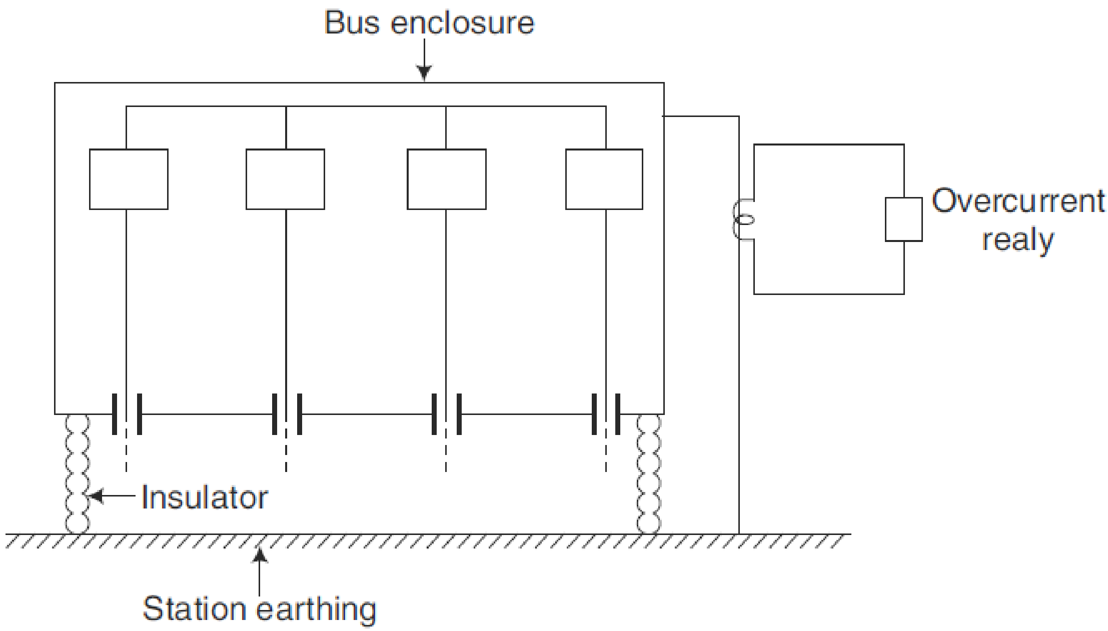
Fig. 22.15

OR

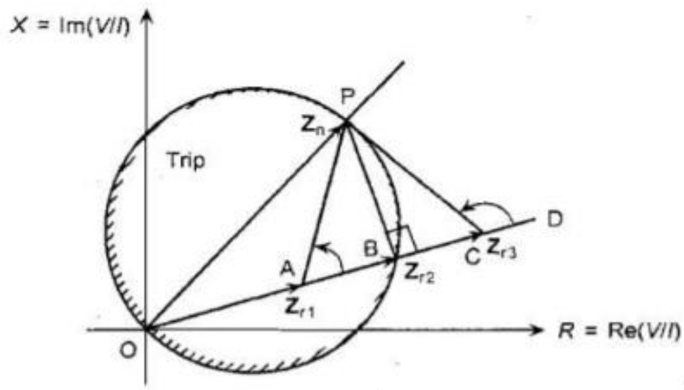
13. (b) **(i) Discuss the working principle of directional comparison carrier current protection of transmission lines.** **07**

In this scheme, the phase angle of the current entering one end of the protected line section is compared with the current leaving the other end. Figure shows the schematic diagram of the phase comparison scheme. The line trap is a parallel resonant circuit tuned to the carrier frequency connected in series with the line conductor at each end of the protected line section. This keeps carrier signal confined to the protected line section and does not allow the carrier signal to flow into the neighbouring sections. It offers very high impedance to the carrier signal but negligible impedance to the power frequency current. There are carrier transmitter and receives at both the end of the protected line. The transmitter and receiver are connected to

	the power line through a coupling capacitor to withstand high voltage and grounded through an inductance.  The coupling capacitor consists of porcelain-clad, oil-filled stack of capacitors connected in series. It offers very high impedance to power frequency current but low impedance to carrier frequency current. On the other hand, the inductance offers a low impedance to power frequency current and high impedance to carrier frequency current. Thus the transmitter and receiver are insulated from the power line and effectively grounded at power frequency current. But at carrier frequency they are connected to the power line and effectively insulated from the ground. For the transmission of carrier signal either one phase conductor with earth return or two phase conductors can be employed. The former is called phase to earth coupling and the latter is called phase to phase coupling. The phase to earth coupling is less expensive as the number of coupling capacitors and line traps required is half of that needed for phase to phase coupling. However the performance of phase to phase coupling is better compared to phase to earth coupling because of lower attenuation and lower interference levels. The half-cycle blocks of carrier signals are injected into the transmission line through the coupling capacitor. Fault detectors control the carrier signal so that it is started only during faults. **(ii) Write short notes on frame leakage protection of busbars.** This is more favoured for indoor than outdoor installations. This is applicable to metal clad type switchgear installations. The frame work is insulated form the ground. The insulation is light, anything over 10 ohms is acceptable. This scheme is most effective in case of isolated-phase construction type switchgear installations in which all faults involve ground. To avoid the undesired operation of the relay due to spurious currents, a check relay energised from a CT connected in the neutral of the system is employed. An instantaneous overcurrent relay is used in the frame leakage protection scheme if a neutral check relay is incorporated. If neutral check relay is not employed, an inverse time delay relay should be used.	**06**



14. (a) **Interpret phase and amplitude comparators. Synthesis Mho relay using static comparators.** **13**



OA = $|Z_{r1}| \rightarrow$ Trip

OB = $|Z_{r2}| \rightarrow$ Threshold

OC = $|Z_{r3}| \rightarrow$ Restrain

AP = $|Z_n - Z_{r1}|$

BP = $|Z_n - Z_{r2}|$

CP = $|Z_n - Z_{r3}|$

$$\text{Arg} \frac{|Z_n - Z_{r1}|}{|Z_{r1}|} = \angle BAP < 90° \quad \rightarrow \quad \text{Trip}$$

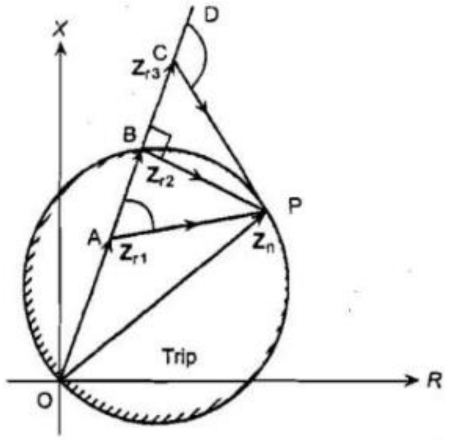
$$\text{Arg} \frac{|Z_n - Z_{r2}|}{|Z_{r2}|} = \angle CBP = 90° \quad \rightarrow \quad \text{Threshold}$$

$$\text{Arg} \frac{|Z_n - Z_{r3}|}{|Z_{r3}|} = \angle DCP > 90° \quad \rightarrow \quad \text{Restrain}$$

Trip law:

$$\text{If} \quad \text{Arg} \frac{|Z_n - Z_r|}{|Z_r|} < 90°; \quad \text{then trip}$$

Similar analysis shows that even if the impedance seen by the relay is on the other i side of Z, as shown in Figure 10.13, as long as it is in the trip region, the angle between (Z, - Z,) and Z, is always greater than -90". The angle hits 90" for boundary conditions.



OA = $|Z_{r1}|$ → Trip $\quad$ AP = $|Z_n - Z_{r1}|$

OB = $|Z_{r2}|$ → Threshold $\quad$ BP = $|Z_n - Z_{r2}|$

OC = $|Z_{r3}|$ → Restrain $\quad$ CP = $|Z_n - Z_{r3}|$

$$\text{Arg } \frac{|Z_n - Z_{r1}|}{|Z_{r1}|} = \angle PAB > -90° \quad \Rightarrow \quad \text{Trip}$$

$$\text{Arg } \frac{|Z_n - Z_{r2}|}{|Z_{r2}|} = \angle PBC = 90° \quad \Rightarrow \quad \text{Threshold}$$

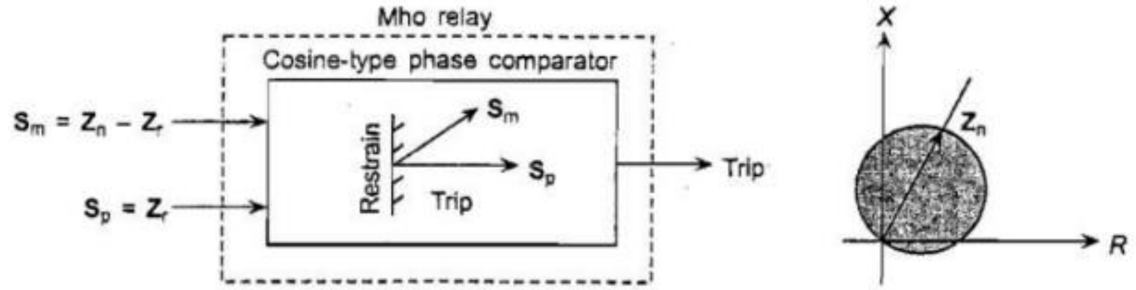
$$\text{Arg } \frac{|Z_n - Z_{r3}|}{|Z_{r3}|} = \angle PCD < -90° \quad \Rightarrow \quad \text{Restrain}$$

Trip law:

$$\text{If} \quad \text{Arg } \frac{|Z_n - Z_r|}{|Z_r|} > -90°; \quad \text{then trip}$$

Thus, the phasors (Z, - &) and Z, obey the law of cosine-type phase comparison. Therefore, if (Z, - Z,) and Z, are used as inputs to a cosine comparator, the resulting entity would behave exactly like a mho relay.

However, there is a practical problem here. The problem is that the electronic circuit of the comparator accepts only voltage signals at its input. We, therefore, need to convert these two impedance phasors into voltage signals.



$$(Z_n - Z_r)I_r = Z_n I_r - V_r = S_m$$
$$Z_r I_r = V_r = S_p$$

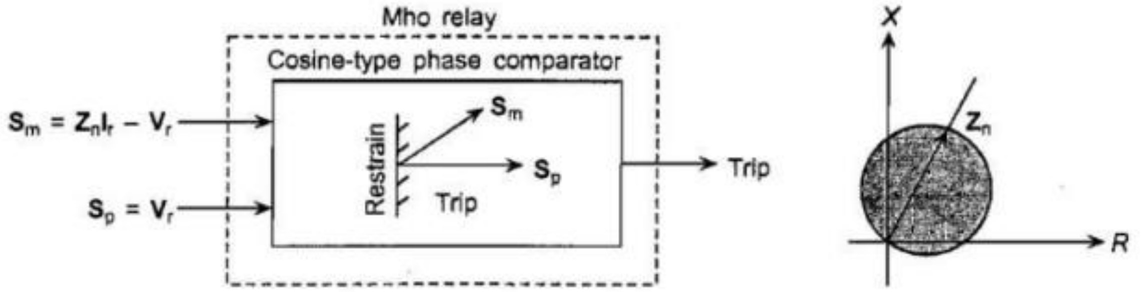


Figure Deriving practical signals for mho relay synthesis.

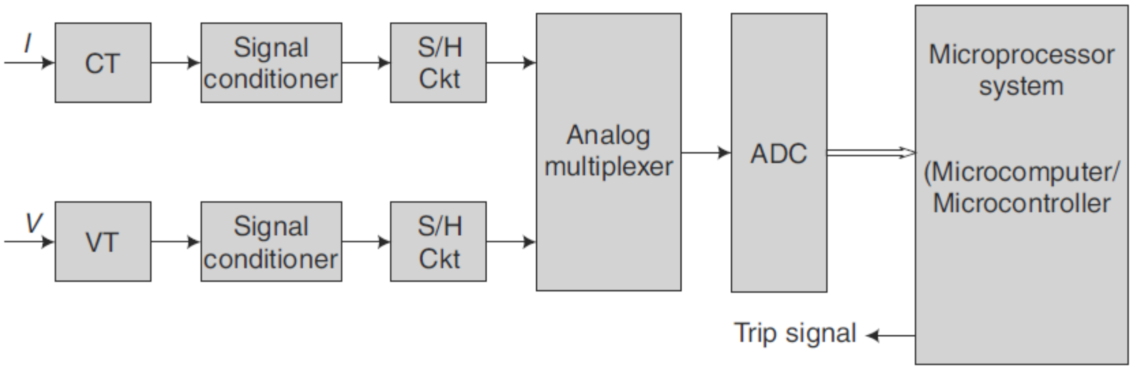
At the relay location, we have the signals V, and I, readily available. In order to form Sp and S, inputs suitable for synthesis of mho relay, we will have to mix them using suitable hardware to get the required signals.

OR

14. (b) Illustrate the distance protection of transmission lines using static and numerical relays with necessary diagram. **13**

Distance protection is a widely used protective scheme for the protection of transmission and sub-transmission lines. It employs a number of distance relays which measure the impedance or some components of the line impedance at the relay location. Since the measured quantity is proportional to the distance (line-length) between the relay location and the fault point, the measuring relay is called a distance relay. A distance protection scheme which incorporates numerical distance relays for the protection of lines is known as a numerical distance protection scheme or numerical distance protection. In a numerical distance relay, the analog voltage and current signals monitored through primary transducers (VTs and CTs) are conditioned, sampled at specified instants of time and converted to digital form for numerical manipulation, analysis display and recording. The voltage and current signals in the form of discrete numbers are processed by a numerical filtering algorithm to extract the fundamental frequency components of the voltage and current signals and make trip decisions. The extraction of the fundamental frequency components from the complex postfault voltage and current signals that contain transient dc offset component and harmonic frequency components, in addition to the power frequency fundamental components, is essential because the impedance of a linear system is defined in terms of the fundamental frequency voltage and current sinusoidal waves.

Using the computed values of R and X, the relay examines whether the fault point lies within the defined protective zone or not. If the fault point lies in the protective zone of the relay, the relay issues a trip signal to the circuit breaker.



15. (a) **(i) Compare the performances of different types of circuit breaker used for protection.** **06**

Circuit Breaker Type	Performance Characteristics	Applications
Air Circuit Breakers (ACBs)	Versatile; reliable protection against overloads and short circuits; adjustable tripping settings; quick reset after tripping.	Industrial, commercial, and residential applications.
Molded Case Circuit Breakers (MCCBs)	Reliable protection against overloads and short circuits; available in various trip characteristics; suitable for low-voltage systems.	Distribution panels, motor control centers, low-voltage applications.
Miniature Circuit Breakers (MCBs)	Protection against overloads and short circuits; thermal and magnetic trip mechanisms; suitable for residential and light commercial applications.	Branch circuits, lighting circuits, small appliances.
Vacuum Circuit Breakers (VCBs)	High reliability; efficient arc quenching; suitable for medium to high-voltage applications; high-speed operations.	Medium-voltage switchgear, transformers, industrial applications.
SF6 Circuit Breakers	High dielectric strength; excellent arc quenching properties; low maintenance; suitable for high-voltage applications.	High-voltage substations, power transmission networks, industrial plants.
Oil Circuit Breakers (OCBs)	Reliable performance; uses mineral oil as arc extinguishing medium; requires regular maintenance; being replaced by newer technologies.	High-voltage substations, power systems (historical usage).

(ii) Write short notes on the various tests done on circuit breakers. **07**

Routine Tests:

- **Visual Inspection**: Examination for any visible damage or irregularities.
- **Mechanical Operation Test**: Testing the mechanical operation of the circuit breaker to ensure smooth functioning of moving parts.

Type Tests:

- **Dielectric Test**: Measures insulation resistance and dielectric strength to ensure proper insulation between live parts and the enclosure.

- **Short-Circuit Test**: Simulates short-circuit conditions to evaluate the breaking capacity and performance of the circuit breaker.
- **Temperature Rise Test**: Determines the temperature rise of the circuit breaker under normal operating conditions to ensure it remains within safe limits.
- **Endurance Test**: Evaluates the long-term performance and durability of the circuit breaker by subjecting it to repeated operations under various conditions.

Special Tests:

- **Mechanical Endurance Test**: Checks the mechanical endurance of the circuit breaker by subjecting it to a large number of mechanical operations.
- **Contact Resistance Test**: Measures the resistance across the contacts to ensure low contact resistance for efficient current interruption.
- **Arc Resistance Test**: Evaluates the ability of the circuit breaker to withstand the arc produced during current interruption.
- **Voltage Drop Test**: Measures the voltage drop across the circuit breaker during operation to ensure it remains within acceptable limits.
- **Dynamic Stability Test**: Assesses the dynamic stability of the circuit breaker under fault conditions to ensure reliable operation.

Acceptance Tests:

- **Functional Test**: Verifies the proper functioning of the circuit breaker under normal operating conditions.
- **Trip Time Test**: Measures the time taken for the circuit breaker to trip in response to various fault conditions.
- **Overcurrent Protection Coordination Test**: Checks the coordination between the circuit breaker and other protective devices in the system.

OR

15. (b) **Describe the constructional details and operation of Sulfur Hexafluoride circuit breaker. Mention its advantages and disadvantages.** **13**

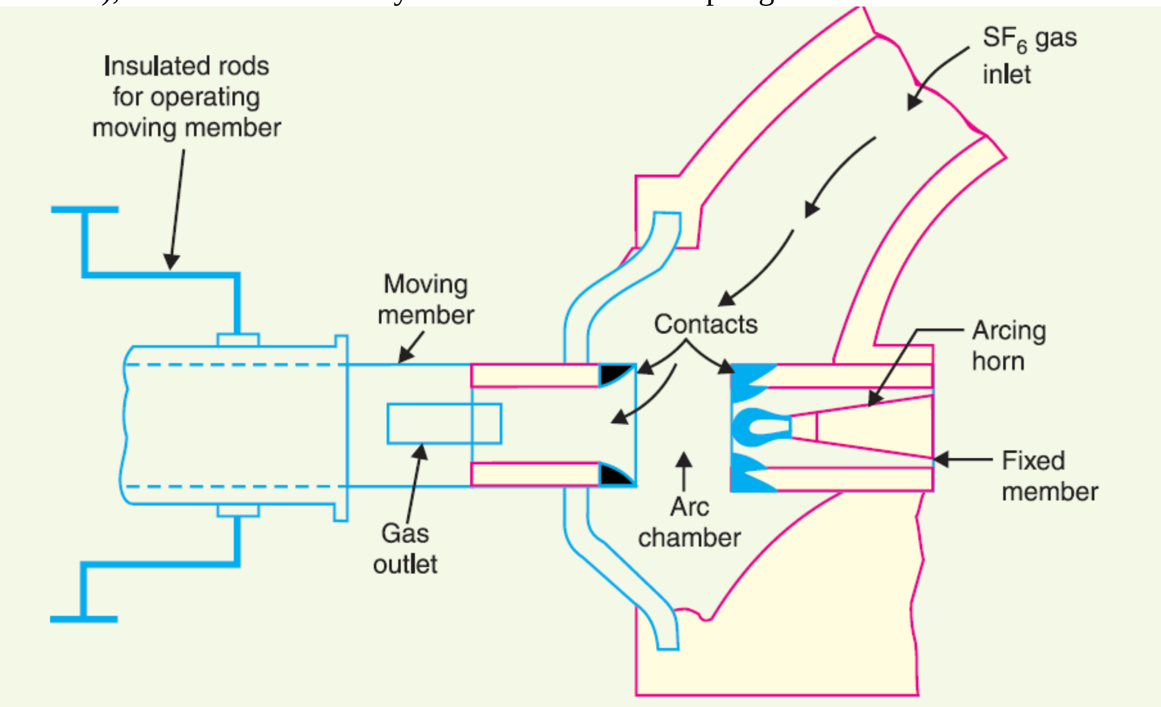
In such circuit breakers, sulphur hexaflouride (SF6) gas is used as the arc quenching medium. The SF6 is an electro-negative gas and has a strong tendency to absorb free electrons. The contacts of the breaker are opened in a high pressure flow of SF6 gas and an arc is struck between them. The conducting free electrons in the arc are rapidly captured by the gas to form relatively immobile negative ions. This loss of conducting electrons in the arc quickly builds up enough insulation strength to extinguish the arc. The SF6 circuit breakers have been found to be very effective for high power and high voltage service.

Construction.

Fig. shows the parts of a typical SF6 circuit breaker. It consists of fixed and moving contacts enclosed in a chamber (called arc interruption chamber) containing SF6 gas. This chamber is connected to SF6 gas reservior. When the contacts of breaker are opened, the valve mechanism permits a high pressure SF6 gas from the reservoir to flow towards the arc interruption chamber. The fixed contact is a hollow cylindrical current carrying contact fitted with an arc horn. The moving contact is also a hollow cylinder with rectangular holes in the sides to permit the SF6 gas to let out through these holes after flowing along and across the arc. The tips of fixed contact, moving contact and arcing horn are coated with copper-tungsten arc resistant material. Since SF6 gas is costly, it is reconditioned and reclaimed by suitable auxiliary sytem after each operation of the breaker.

Working:

In the closed position of the breaker, the contacts remain surrounded by SF6 gas at a pressure of about 2·8 kg/cm2. When the breaker operates, the moving contact is pulled apart and an arc is struck between the contacts. The movement of the moving contact is synchronised with the opening of a valve which permits SF6 gas at 14 kg/cm2 pressure from the reservoir to the arc interruption chamber. The high pressure flow of SF6 rapidly absorbs the free electrons in the arc path to form immobile negative ions which are ineffective as charge carriers. The result is that the medium between the contacts quickly builds up high dielectric strength and causes the extinction of the arc. After the breaker operation (i.e., after arc extinction), the valve is closed by the action of a set of springs.



Advantages. Due to the superior arc quenching properties of SF6 gas, the SF6 circuit breakers have many advantages over oil or air circuit breakers. Some of them are listed below :

(*i*) Due to the superior arc quenching property of SF6, such circuit breakers have very short arcing time.

(*ii*) Since the dielectric strength of SF6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.

(*iii*) The SF6 circuit breaker gives noiselss operation due to its closed gas circuit and no exhaust to atmosphere unlike the air blast circuit breaker.

(*iv*) The closed gas enclosure keeps the interior dry so that there is no moisture problem.

(*v*) There is no risk of fire in such breakers because SF6 gas is non-inflammable.

(*vi*) There are no carbon deposits so that tracking and insulation problems are eliminated.

(*vii*) The SF6 breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.

(*viii*) Since SF6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists *e.g.*, coal mines.

Disadvantages

(*i*) SF6 breakers are costly due to the high cost of SF6.

(*ii*) Since SF6 gas has to be reconditioned after every operation of the breaker, additional equipment is requried for this purpose.

Applications. A typical SF6 circuit breaker consists of interrupter units each capable of dealing with currents upto 60 kA and voltages in the range of 50—80 kV. A number of units are connected in series according to the system voltage. SF6 circuit breakers have been developed for voltages 115 kV to 230 kV, power ratings 10 MVA to 20 MVA and interrupting time less than 3 cycles.

PART C- (1*15 = 15 Marks)

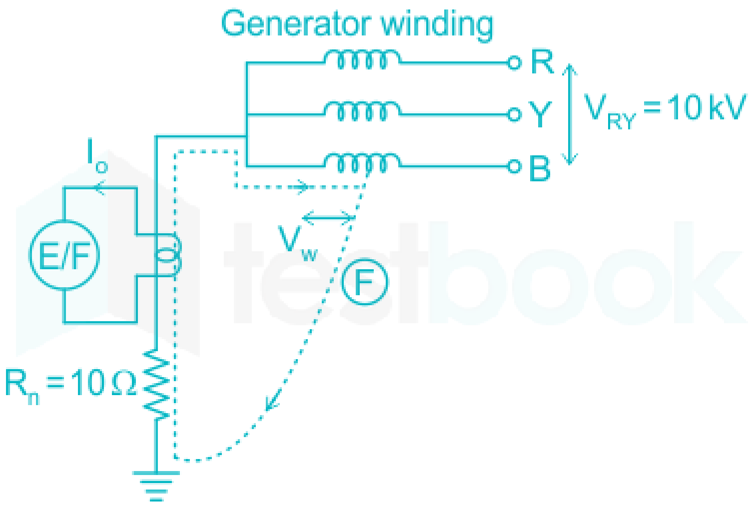
16. (a) An alternator rated at 10 kV protected by the balanced circulating current system has its neutral grounded through a resistance of 10 ohms. The protective relay is set to operate when there is an out of balance current of 1.8 A in the pilot wires which are connected to the secondary windings of 1000/5 CT ratio. Determine the percentage of winding which remains unprotected and minimum value of earthing resistance required to protect 80% of the winding. **15**

Voltage = 10 kV

Resistance = 10 Ω

Relay current = 1.8 A

C.T Ratio = 1000/5



I_0 = pick up current of Relay × C.T Ratio

$= 1.8 \times \frac{1000}{5}$

= 1.8 × 200 = 360 A

Percentage of unprotected winding of Generator.

$\% \ U_w = \frac{I_0 R_n}{V_{ph}} \times 100$

Phase value $= \frac{10000}{\sqrt{3}} = 5773.5 \ V$

$\% \ U_w = \frac{360 \ \times \ 10}{5773.5} \times 100$

= 62.35 %

Percentage winding 62.35% remains unprotected.

(ii) Let *r* ohms be the minimum earthing resistance required to provide protection for 80% of stator winding. Then 20% winding would be unprotected *i.e.* *x* = 20%.

$360 = \frac{57.735 \ X}{r}$

	r = $\frac{57.735*20}{360}$ = 3.20 Ω	
	OR	
16. (b)	From the following data of 50 Hz generator: e.m.f to neutral 7.5 kV (rms), reactance of generator and connected system 4 ohms, distributed capacitance to neutral 0.01 µF, resistance negligible; find (a) the maximum voltage across the contacts of the circuit breaker when it breaks a short-circuit current at zero current, (b) the frequency of transient oscillations (c) rate of rise of restriking voltage and (d) the average rate of rise of voltage up to the first peak of the oscillation. Consider the p.f of the fault as 0.3. Given data: • Generator frequency (f) = 50 Hz • E.m.f to neutral (V) = 7.5 kV (rms) = 7500 V • Reactance of generator and connected system (X) = 4 ohms • Distributed capacitance to neutral (C) = 0.01 µF = 0.01 × 10^(-6) F • Power factor (p.f) of the fault = 0.3 **(a) Maximum voltage across the contacts of the circuit breaker when it breaks a short-circuit current at zero current:** The maximum voltage across the contacts of the circuit breaker during a short-circuit condition can be calculated using the formula: $V_{\max} = V + 2\pi f X C$ $V_{\max} = 7500 + 2\pi \times 50 \times 4 \times 0.01 \times 10^{-6}$ $V_{\max} = 7500 + 2\pi \times 50 \times 4 \times 0.01 \times 10^{-6}$ $V_{\max} \approx 7500 + 0.0157 \approx 7500V$	**15**

(b) Frequency of transient oscillations:

The frequency of transient oscillations can be calculated using the formula:

$f_{\text{transient}} = \frac{1}{2\pi\sqrt{LC}}$

Given that L = X and C = distributed capacitance,

$f_{\text{transient}} = \frac{1}{2\pi\sqrt{XC}}$

$f_{\text{transient}} = \frac{1}{2\pi\sqrt{4\times0.01\times10^{-6}}}$

$f_{\text{transient}} = \frac{1}{2\pi\times0.02\times10^{-3}}$

$f_{\text{transient}} \approx \frac{1}{1.26\times10^{-4}} \approx 7937.01\ \text{Hz}$

(c) Rate of rise of restriking voltage:

The rate of rise of restriking voltage can be calculated using the formula:

$R = \frac{V}{t}$

Where V is the voltage and t is the time.

For simplicity, let's consider t = 1 cycle (1/50 seconds).

$R = \frac{7500}{1/50}$

$R = 7500 \times 50$

$R = 375,000\ \text{V/s}$

(d) Average rate of rise of voltage up to the first peak of the oscillation:

The average rate of rise of voltage up to the first peak of the oscillation can be calculated using the formula:

$$R_{\text{avg}} = \frac{V}{\tau}$$

Where V is the voltage and τ is the time constant.

The time constant (τ) can be calculated as:

$$\tau = \frac{L}{R}$$

Given that L = X and R is the reactance of the generator and connected system, we'll use the given reactance value.

$$\tau = \frac{4}{50}$$

$$\tau = 0.08 \text{ seconds}$$

$$R_{\text{avg}} = \frac{7500}{0.08}$$

$$R_{\text{avg}} = 93,750 \text{ V/s}$$

So, the solutions are:

(a) The maximum voltage across the contacts of the circuit breaker when it breaks a short-circuit current at zero current is approximately 7500 V.

(b) The frequency of transient oscillations is approximately 7937.01 Hz.

(c) The rate of rise of restriking voltage is approximately 375,000 V/s.

(d) The average rate of rise of voltage up to the first peak of the oscillation is approximately 93,750 V/s.