OBJECTIVES:

- To educate the causes of abnormal operating conditions (faults, lightning and switching surges) of the apparatus and system.
- To introduce the characteristics and functions of relays and protection schemes.
- To impart knowledge on apparatus protection
- To introduce static and numerical relays
- To impart knowledge on functioning of circuit breakers

UNIT I PROTECTION SCHEMES

- Principles and need for protective schemes – nature and causes of faults – types of faults – fault current calculation using symmetrical components – Methods of Neutral grounding – Zones of protection and essential qualities of protection – Protection schemes

UNIT II ELECTROMAGNETIC RELAYS

- Operating principles of relays - the Universal relay – Torque equation – R-X diagram –
- Electromagnetic Relays – Overcurrent, Directional, Distance, Differential, Negative sequence and Under frequency relays.

UNIT III APPARATUS PROTECTION

- Current transformers and Potential transformers and their applications in protection schemes - Protection of transformer, generator, motor, busbars and transmission line.

UNIT IV STATIC RELAYS AND NUMERICAL PROTECTION

- Static relays – Phase, Amplitude Comparators – Synthesis of various relays using Static comparators – Block diagram of Numerical relays – Overcurrent protection, transformer differential protection, distant protection of transmission lines.

UNIT V CIRCUIT BREAKERS


TOTAL : 45 PERIODS

OUTCOMES:

- Ability to understand and analyze power system operation, stability, control and protection.

TEXT BOOKS:


REFERENCES:

Unit-1

2 mark

   There are mainly two types of faults in the electrical power system. Those are symmetrical and unsymmetrical faults.
   **Symmetrical faults**
   These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to line to ground (L-L-L-G) and line to line (L-L-L).
   ![symmetrical faults diagram]
   **Unsymmetrical faults**
   These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.
   ![un symmetrical faults diagram]

2. Give the difference between circuit breaker and switch (AU MAY 2017)
   **Circuit Breaker:** A circuit breaker is an auto & manually operated electrical switch by using the contact as a air, thermostatic element, vacuum for protect an electrical circuit overload, short circuit & earth fault. Any fault occurred in the circuit the contact automatically opened.
   **Switch:** A switch is a manually operated by using contactor to open and close the circuit, interrupting the current

3. What is the role (function/need) of protection relay in a modern power system (AU MAY 2016) (AU MAY 2015)
   Relay detect the abnormal condition in the electrical circuit by constantly measuring electrical quantities which are different under normal and fault condition.
   After detecting fault initiating the operation circuit breaker to open faulty section from healthy section

4. What is meant by pick up current (AU MAY 2016) (AU NOV 2014)
   Minimum value of actuating current quantity for relay to operate
5. What is meant by earthing. Mention any two objectives of earthing. (AU NOV 2014)

Earthing means connection of non-current carrying parts of the electrical equipment or the neutral point of the supply system to the general mass of earth in such a manner that at all times an immediate discharge of electrical energy takes place without danger.

6. Differentiate between primary protection and secondary protection (AU NOV 2017)

Primary protection: Is the protection in which the fault occurring in a line will be cleared by its own relay and circuit breaker. It serves as the first line of defence.

Back up protection: A backup relay is the relay which operate after a slight delay, if primary protection fails, it acts as a second line of defence.

7. What is the difference between a short circuit and an overload (AU NOV 2015)

On occurrence of a short-circuit, the voltage at the fault point is reduced to zero and current of abnormally high magnitude flows through the network to the fault point. On the other hand, an overload means that load greater than the designed value have been imposed on the system. In case of an overload, the voltage at the over load point may become low, but cannot be zero. The under voltage conditions may extend to some distance beyond the overload point in the remainder of the system. In the case of an over load, the currents are high but are substantially lower than in the case of a short-circuit.

8. Define protection zone, list the different zone of protection and necessity of dividing into different zones. (AU MAY 2015) (AU MAY 2016)

Protection zone is defined as the part of the power system which is protected by a certain protective scheme. It is established around each power system equipment. When the fault occurs on any of the protection zones then only the circuit breakers within that zone will be opened.

Generator zone
Busbar zone
Transformer zone
Transmission line zone

Are those which are directly protected by a protective system such as relays, fuses or switchgears. If a fault occurring in a zone can be immediately detected and or isolated by a protection scheme dedicated to that particular zone.

9. What are the different types of earthing (AU MAY 2015)

(i) Equipment earthing
(ii) System earthing

Solid, resistance, reactance, arc suppression coil

10. What is Peterson coil (AU May 2009)

It is called as arc suppression coil, it an iron cored tapped reactor connected in neutral to ground connection the reactor is provided with tapping so that it can be tuned to the system capacitance, function is to suppress arcing grounds

11. What are the reasons for failure of main protection?

The dc supply to the tripping circuit fails.
The current or voltage supply to the relay fails.
The tripping mechanism of circuit breakers fails.
The circuit breaker fails to operate.
The main protective relay fails

12. Classify the protective schemes

Over current
Distance
Differential
Carrier current
directional

13. Difference between fuse and CB (AU May 2014)

Fuse is a low current interrupting device. It is a copper or an aluminium wire. Circuit breaker is a high current interrupting device and it act as a switch under normal operating conditions.

14. Write the sources of fault power (AU NOV 2013)
Break down at normal voltage- the deterioration of insulation, perching of birds, short circuit by kite, snake, tree branches.

Break down at abnormal voltage due to switching surges and surges caused by lightning.

15. what is meant by switch gear (AU MAY 2007)

Switchgear is the combination of electrical disconnect switches, fuses or circuit breakers used to control, protect and isolate electrical equipment.

16. list the essential features of switch gear (AU MAY 2009)

Quick in operation. Safely bypassing surges without damaging itself.

17. Define the term dead zone.

Unprotected section of power system.

18. Write why overlapping of protective zones are required

Adjacent zone overlapped to avoid dead zone.

19. State the term arcing ground?

Arcing ground is the surge, which is produced if the neutral is not connected to the earth. The phenomenon of arcing ground occurs in the ungrounded three-phase systems because of the flow of the capacitance current. The capacitive current is the current flow between the conductors when the voltage is applied to it. The voltage across the capacitances is known as the phase voltage. During the fault, the voltage across the capacitance reduces to zero in the faulted phase, while in the other phases the voltage is increased by the factor of $\sqrt{3}$ times.

20. list the essential qualities (requirements) of protective relaying

Reliability, selectivity, fastness of operation, discrimination.

13 MARKS

1. Discuss in detail about different protection schemes (AU MAY 2017)

Directional Relay: Directional relay operates when the fault is driving power to flow in particular direction. It senses the direction of current flowing. For example, consider a three phase synchronous motor. Assume fault on the system. Power supply to motor is not available. But 3-phase armature is rotating in magnetic field due to inertia. So motor starts generating power. Which feeds fault. To avoid this, Directional Relay is used.

Differential Relay

A differential relay operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined amount.

For example, consider the comparison of the current entering a protected line and the current leaving it. If the current enters the protected line is more than the current leaves it, then the extra current must flow in the fault. The difference between the two electrical quantities can operate a relay to isolate the circuit.
Types of differential relay
1. Current Differential Relay
2. Voltage Differential Relay
3. Biased or Percentage Differential Relay
4. Voltage Balance Differential Relay

distance relay
There is one type of relay which functions depending upon the distance of fault in the line. More specifically, the relay operates depending upon the impedance between the point of fault and the point where relay is installed. These relays are known as distance relay or impedance relay.

types of distance relay
Impedance relay.
Reactance relay.
Admittance relay

Over current relay:
in an over current relay, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force. But when the current through the coil increases, the magnetic effect increases, and after a certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force.

Types of Over Current Relay
Depending upon time of operation, there are various types of Over Current relays, such as,
1. Instantaneous over current relay.
2. Definite time over current relay.
3. Inverse time over current relay.

3. Explain how fault current is calculated using symmetrical components (AU MAY 2017)  
For unbalance conditions the calculation of fault currents is more complex. One method of dealing with this is symmetrical components. Using symmetrical components, the unbalance system is broken down into three separate symmetrical systems:  
- Positive sequence – where the three fields rotate clockwise  
- Negative sequence – where the three fields rotate anti-clockwise  
- Zero sequence – a single field which does not rotate  
The positive sequence network rotates clockwise, with a phase and of 120° between phases as per any standard a.c. system. Negative sequence network, rotates anti-clockwise and the zero sequence network with each phase together (0° apart).

Symmetrical Component Theory  
Mathematically, the relationship between the symmetrical networks and the actual electrical systems, make use of a rotational operator, denoted by $a$ and given formally by:

$$a = e^{j\frac{2\pi}{3}} = -\frac{1}{2} + j\frac{\sqrt{3}}{2}$$

Perhaps more simply, the $a$ operator can be looked at as a 120° shift operator. It can also be shown that the following conditions hold true:

$$a = 1 \mid 120^\circ \text{ with } a^3 = 1 \text{ and } a^{-1} = a^2$$
By using the \( a \) operator, any unbalanced any unbalance three phase system \( V_a, V_b, V_c \) can be broken down into three balanced (positive, negative and zero sequence) networks \( V_1, V_2, V_0 \).

<table>
<thead>
<tr>
<th>Unbalanced Network</th>
<th>Symmetrical Network</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_a = V_1 + V_2 + V_0 )</td>
<td>( V_1 = \frac{1}{3}(V_e + aV_b + a^2V_c) )</td>
</tr>
<tr>
<td>( V_b = a^2V_1 + aV_2 + V_0 )</td>
<td>( V_2 = \frac{1}{3}(V_a + a^2V_b + V_c) )</td>
</tr>
<tr>
<td>( V_c = aV_1 + a^2V_2 + V_0 )</td>
<td>( V_0 = \frac{1}{3}(V_a + V_b + V_c) )</td>
</tr>
</tbody>
</table>

The operator \( a \) is the unit 120° vector: \( a = 1|120° \). Note: \( a^3 = 1 \) and \( a^3 = a^2 \)

**Fault Solutions**

Once the sequence networks are known, determination of the magnitude of the fault is relatively straightforward. The a.c. system is broken down into its symmetrical components as shown above. Each symmetrical system is then individually solved and the final solution obtained by superposition of these (as shown above).

For the more common fault conditions, once the sequence networks are known we can jump directly to the fault current.

During a fault and letting \( U_n \) be the nominal voltage across the branch, use of symmetrical components give the following solutions (excluding fault impedance):

<table>
<thead>
<tr>
<th>Type of Fault</th>
<th>Initial Fault Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>three phase</td>
<td>( I''_{k3} = \frac{cU_n}{\sqrt{3}</td>
</tr>
<tr>
<td>phase to phase</td>
<td>( I''_{k2} = \frac{cU_n}{</td>
</tr>
<tr>
<td>phase to phase</td>
<td>( I''_{k1} = \frac{cU_n\sqrt{3}}{</td>
</tr>
<tr>
<td>phase to phase to earth</td>
<td>( I''_{kE2E} = \frac{cU_n\sqrt{3}</td>
</tr>
<tr>
<td>phase to phase to earth</td>
<td>( I''_{k2EL3} = \frac{cU_n</td>
</tr>
<tr>
<td>phase to phase to earth</td>
<td>( I''_{k2EL2} = \frac{cU_n</td>
</tr>
</tbody>
</table>

4. Describe the various methods of neutral grounding (AU NOV 2017)

When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called solid grounding or effective grounding.
solid grounding of the neutral point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at earth potential under all conditions. Therefore, under fault conditions, the voltage of any conductor to earth will not exceed the normal phase voltage of the system.

Advantages. The solid grounding of neutral point has the following advantages:

i) The neutral is effectively held at earth potential.
   • This is a metallic connection made from the neutral of the system to one or more earth electrodes consisting of plates, rods or pipes buried in the ground.

   When earth fault occurs on any phase, the resultant capacitive current $I_C$ is in phase opposition to the fault current $I_F$. The two current completely cancel each other. Therefore, no arcing ground or over-voltage conditions can occur. Consider a line to ground fault in line B as shown in Fig. the capacitive currents flowing in the healthy phase R and Y are $I_R$ and $I_Y$ respectively. The resultant capacitive current $I_C$ is the phasor sum of $I_R$ and $I_Y$. In addition to these capacitive currents, the power source also supplies the fault current $I_F$. This fault current will go from fault point to earth, then to neutral point N and back to the fault point through the faulty phase. The path of $I_C$ is capacitive and that of $I_F$ is inductive. The two currents are in phase opposition and completely cancel each other. Therefore, no arcing ground phenomenon or over-voltage conditions can occur.

   When there is an earth fault on any phase of the system, the phase to earth voltage of the faulty phase becomes zero. However, the phase to earth voltages of the remaining two healthy phases remain at normal phase voltage because the potential of the neutral is fixed at earth potential. This permits to insulate the equipment for phase voltage. Therefore, there is a saving in the cost of equipment.

   iv) It becomes easier to protect the system from earth faults which frequently occur on the system. When there is an earth fault on any phase of the system, a large fault current flows between the fault point and the grounded neutral. This permits the easy operation of earth fault relay.

Disadvantages: The following are the disadvantages of solid grounding:

   Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable.

   The solid grounding results in heavy earth fault currents. Since the fault has to be cleared by the circuit breakers, the heavy earth fault currents may cause the burning of circuit breaker contacts.

   The increased earth fault current results in greater interference in the neighboring communication lines.

Applications.

Solid grounding is usually employed where the circuit impedance is sufficiently high so as to keep the earth fault current within safe limit. This system of grounding is used for voltages upto 33 kV with total power capacity not exceeding 5000 kVA.

Resistance Grounding

In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding.

When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is connected to earth (i.e. soil) through a resistor, it is called resistance grounding.

Shows the grounding of neutral point through a resistor R. The value of R should neither be very low nor very high. If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system. On the other hand, if earthing resistance R is very high, the system conditions become similar to ungrounded neutral system. the value of R is so chosen such that the earth fault current is limited to safe value but still sufficient to permit the operation of earth fault protection system. in practice, that value of R is selected that limits the earth fault current to 2 times the normal full load current of the earthed generator or transformer.

Advantages.
The following are the advantages of resistance earthing:
1. By adjusting the value of $R$, the arcing grounds can be minimised. Suppose earth fault occurs in phase $B$ as shown in Fig. the capacitive currents $I_R$ and $I_Y$ flow in the healthy phases $R$ and $Y$ respectively. The fault current $I_F$ lags behind the phase voltage of the faulted phase by a certain angle depending upon the earthing resistance $R$ and the reactance of the system up to the point of fault. The fault current $I_F$ can be resolved into two components viz.

a) $I_{F1}$ in phase with the faulty phase voltage.
b) $I_{F2}$ lagging behind the faulty phase voltage by $90^o$.

The lagging component $I_{F2}$ is in phase opposition to the total capacitive current $I_C$. If the value of earthing resistance $R$ is so adjusted that $I_{F2} = I_C$, the arcing ground is completely eliminated and the operation of the system becomes that of solidly grounded system. However, if $R$ is so adjusted that $I_{F2} < I_C$, the operation of the system becomes that of ungrounded neutral system.

1. The earth fault current is small due to the presence for earthing resistance. Therefore, interference with communication circuits is reduced.

Disadvantages.
The following are the disadvantages of resistance grounding:
1. Since the system neutral is displaced during earth faults, the equipment has to be insulated for higher voltages.
2. This system is costlier than the solidly grounded system.
3. A large amount of energy is produced in the earthing resistance during earth faults. Some times it becomes difficult to dissipate this energy to atmosphere.

Applications.
It is used on a system operating at voltages between 2.2 kV and 33 kV with power source capacity more than 5000 kVA.

Reactance Grounding:
In this system, a reactance is inserted between the neutral and ground as shown in Figure. The purpose of reactance is to limit the earth fault current. By changing the earthing reactance, the earth fault current can to changed to obtain the conditions similar to that of solid grounding.

This method is not used these days because of the following disadvantages:
In this system, the fault current required to operate the protective device is higher that that of resistance grounding for the same fault conditions.

High transient voltages appear under fault conditions.

Arc Suppression Coil Grounding (or Resonant Grounding)
We have seen that capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth. If inductance $L$ of appropriate value is connected in parallel with the capacitance of the system, the fault current $I_F$ flowing through $L$ will be in phase opposition to the capacitive current $I_C$ of the system. If $L$ is so adjusted that $I_L = I_C$, then resultant current in the fault will be zero. This condition is known as resonant grounding.

When the value of $L$ of arc suppression coil is such that the fault current $I_F$ exactly balances the capacitive current $I_C$ it is called resonant grounding.
Circuit details. An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth as shown in Fig. i) The reactor is provided with tappings to change the inductance of the coil. By adjusting the tappings on the coil, the coil can be tuned with the capacitance of the system i.e. resonant grounding can be achieved.

**Operation.** shows the 3-phase system employing Peterson coil grounding. Suppose line to ground fault occurs in the line B at point F. the fault current \( I_F \) and capacitive currents \( I_R \) and \( I_Y \) will flow as shown in Fig. Note that \( I_F \) flows through the Peterson coil (or Arc suppression coil) to neutral and back through the fault. The total capacitive current \( I_C \) is the phasor sum of \( I_R \) and \( I_Y \) as shown in phasor diagram in Fig. The voltage of the faulty phase is applied across the arc suppression coil. Therefore, fault current \( I_F \) lags the faulty phase voltage by 90°. the current \( I_F \) is in phase opposition to capacitive current \( I_C \) [See Fig(ii)]. By adjusting the tappings on the Peterson coil, the resultant current in the fault can be reduced. If inductance of the coil is so adjusted that \( I_L = I_C \), than resultant current in the fault will be zero.

**Value of \( L \) for resonant grounding.**

For resonant grounding the system behaves as an ungrounded neutral system. therefore, full line voltage appears across capacitors \( C_R \) and \( C_r \).

\[
I_R = I_Y = \frac{\sqrt{3}V_{ph}}{X_C}
\]

\[
I_C = \sqrt{3} I_R = \frac{\sqrt{3}V_{ph}}{X_C} = \frac{3V_{ph}}{X_C}
\]

Here, \( X_C \) is the line to ground capacitive reactance.

Fault current,

\[
I_F = \frac{V_{ph}}{X_L}
\]

Here, \( X_L \) is the inductive reactance of the arc suppression coil.

For resonant grounding, \( I_L = I_C \)

\[
\frac{V_{ph}}{X_L} = \frac{3V_{ph}}{X_C}
\]

Or

\[
X_L = \frac{X_C}{3}
\]

Or

\[
\omega L = \frac{1}{3\omega C}
\]

\[
L = \frac{1}{3\omega^2 C}
\]

Exp. (i) gives the value of inductance \( L \) of the arc suppression coil for resonant grounding.

**Advantages:** The Peterson coil grounding has the following advantages:
1. The Peterson coil is completely effective in preventing and damage by an arching ground.
2. The Peterson coil has the advantages of ungrounded neutral system.

**Disadvantages:** The Peterson coil grounding has the following disadvantages:
1. Due to varying operational conditions, the capacitance of the network changes form time to time. Therefore, inductance \( L \) of Peterson coil requires readjustment.
2. The lines should be transposed.

**Voltage Transformer Earthing:**

In this method of neutral earthing, the primary of a single-phase voltage transformer is connected between the neutral and the earth as shown in Fig
A low resistor in series with a relay is connected across the secondary of the voltage transformer. The voltage transformer provides a high reactance in the neutral earthing circuit and operates virtually as an ungrounded neutral system.

Advantages:
• Arcing grounds are reduced.
• Transient overvoltage are reduced

5. Describe the essential qualities (requirements) of protective relaying (AU NOV 2017) (AU NOV 2014)

(i) selectivity  (ii) speed  (iii) sensitivity
(iv) reliability  (v) simplicity  (vi) economy

(i) Selectivity It is the ability of the protective system to select correctly that part of the system in trouble and disconnect the faulty part without disturbing the rest of the system.

A well designed and efficient relay system should be selective i.e it should be able to detect the point at which the fault occurs and cause the opening of the circuit breakers closest to the fault with minimum or no damage to the system. This can be illustrated by referring to the single line diagram of a portion of a typical power system in fig. It may be seen that circuit breakers are located in the connections to each power system element in order to make it possible to disconnect only the faulty section. Thus, if a fault occurs at some zone, then only breakers nearest to the fault viz. 1, 2 and 3 should open. In fact, opening of any other breaker to clear the fault will lead to a greater part of the system being disconnected.

In order to provide selectivity to the system, it is usual practice to divide the entire system into several protection zones. When a fault occurs in a given zone, then only the circuit breakers within the zone will be opened. This will isolate only the faulty circuit or apparatus, leaving the healthy circuits intact. The system can be divided into the following protection zones:

(a) generators
(b) low-tension switchgear
(c) transformers
(d) high-tension switchgear
(e) transmission lines

It may be seen in fig. that there is certain amount of overlap between the adjacent protection zones. For a failure within the region where two adjacent zones overlap, more breakers will be opened than the minimum necessary to disconnect that faulty section. But if there were no overlap, a failure in the region between zones would not lie in either region and, therefore, no breaker would be opened. For this reason, a certain amount of overlap is provided between the adjacent zones.

(ii) Speed: The relay system should disconnect the faulty section as fast as possible for the following reasons:
Electrical apparatus may be damaged if they are made to carry the fault currents for a long time.

A failure on the system leads to a great reduction in the system voltage. If the faulty section is not disconnected quickly, then the low voltage created by the fault may shut down consumers motors and generators on the system may become unstable.

The high speed relay system decreases the possibility of development of one type of fault into the other more severe type.

(iii) **Sensitivity:** *It is the ability of the relay system to operate with low value of actuating quantity.*

Sensitivity of a relay is a function of the volt-ampere input to the coil of the relay necessary to cause its operation. The smaller the volt-ampere input required to cause relay operation, the more sensitive is the relay. Thus, a 1VA relay is more sensitive than a 3VA relay. It is desirable that relay system should be sensitive so that it operates with low values of volt-ampere input.

\[ K_s = \frac{I_p}{I_o} \]

Where:
- \( K_s \) is the sensitivity factor
- \( I_p \) is the minimum short circuit current in zone
- \( I_o \) is the minimum operating current for protection

(iv) **Reliability:**

It is ability of the relay system to operate under the pre-determined conditions. Without reliability, the protection would be rendered largely ineffective and could even become a liability.

(v) **Simplicity:**

The relaying system should be simple so that it can be easily maintained. Reliability is closely related to simplicity. The simpler the protection scheme, the greater will be its reliability.

(vi) **Economy:**

Cost of the protecting system should not exceed 5% of the total cost of equipment to be protected.

6. List the cause and consequence of fault, classify the fault. (AU NOV 2015)

**Causes of fault in power system**
- Break down at normal voltage - the deterioration of insulation
- Perching of birds
- Short circuit by kite, snake, tree branches

**Consequence of fault**
- The heavy current due to fault causes excessive heating which may result in fire or explosion.
- Sometimes the short circuit current takes the form of an arc that may cause considerable damage to the element of the power system.
- The stability of the power system may be adversely affected, and even the complete shutdown of the power system may occur.
- Damage to other apparatus in the system may be caused due to overheating and due to abnormal mechanical forces set up.

**Types of fault**
- There are mainly two types of faults in the electrical power system. Those are symmetrical and unsymmetrical faults.
- **Symmetrical faults**
  - These are very severe faults and occur infrequently in the power systems. These are also called as balanced faults and are of two types namely line to line to ground (L-L-G) and line to line to line (L-L-L).

**Unsymmetrical faults**
- These occur frequently in the power systems. When one phase is in a faulty state, it is called an unsymmetrical fault.
Symmetrical faults
Only 2-5 percent of system faults are symmetrical faults. If these faults occur, system remains balanced but results in severe damage to the electrical power system equipments.
Above figure shows two types of three phase symmetrical faults. Analysis of these fault is easy and usually carried by per phase basis. Three phase fault analysis or information is required for selecting set-phase relays, rupturing capacity of the circuit breakers and rating of the protective switchgear.

Unsymmetrical faults
These are very common and less severe than symmetrical faults. There are mainly three types namely line to ground (L-G), line to line (L-L) and double line to ground (LL-G) faults.

Unsymmetrical faults
Line to ground fault (L-G) is most common fault and 65-70 percent of faults are of this type. It causes the conductor to make contact with earth or ground. 15 to 20 percent of faults are double line to ground and causes the two conductors to make contact with ground. Line to line faults occur when two conductors make contact with each other mainly while swinging of lines due to winds and 5-10 percent of the faults are of this type. These are also called unbalanced faults since their occurrence causes unbalance in the system. Unbalance of the system means that that impedance values are different in each phase causing unbalance current to flow in the phases. These are more difficult to analyze and are carried by per phase basis similar to three phase balanced faults.

7. Explain the overlapping of protective zones with neat sketch (AU NOV 2015)
A protective zone is the separate zone which is established around each system element. The significance of such a protective zone is that any fault occurring within cause the tripping of relays which causes opening of all the circuit breakers within that zone.
The circuit breakers are placed at the appropriate points such that any element of the entire power system can be disconnected for repairing work, usual operation and maintenance requirements and also under abnormal conditions like short circuits. Thus a protective covering is provided around rich element of the system.

The various components which are provided with the protective zone are generators, transformers, transmission lines, bus bars, cables, capacitors etc. No part of the system is left unprotected. The figure below shows the various protective zones used in a system.

**Why Protection Zones are Overlapped**

The boundaries of protective zones are decided by the locations of the current transformer. In practice, various protective zones are overlapped.

The overlapping of protective zones is done to ensure complete safety of each and every element of the system. The zone which is unprotected is called dead spot. The zones are overlapped and hence there is no chance of existence of a dead spot in a system. For the failures within the region where two adjacent protective zones are overlapped, more circuit breakers get tripped than minimum necessary to disconnect the faulty element.

If there are no overlaps, then dead spot may exist, means the circuit breakers lying within the zone may not trip even though the fault occurs. This may cause damage to the healthy system.

The extent of overlapping of protective zones is relatively small. The probability of the failures in the overlapped regions is very low; consequently the tripping of the too many circuit breakers will be frequent. The figure shows the overlapping of protective zones in primary relaying.

**primary protection** is the protection in which the fault occurring in a line will be cleared by its own relay and circuit breaker. It serves as the first line of defence.

**backup protection** A backup relay is the relay which operate after a slight delay, if primary protection fails, it acts as a second line of defence.

Figure shows Overlapping zones in primary relaying. It can be seen from the figure that the circuit breakers are located in the connections to each power system element. This provision makes it possible to disconnect only the faulty element from the system.

Occasionally for economy in the number of circuit breakers, a breaker between the two adjacent sections may be omitted but in that case both the power system are required to be disconnected for the failure in either of the two. Each protective zone has certain protective scheme and each scheme has number of protective systems.

Unit-2

2 mark

1. Why shading ring is provided in an induction disc relay (AU MAY 2017)

To create phase difference between to flux

2. What are the difficulties of differential protection(AU MAY 2017)

Difference in pilot wire length
CT ratio error during short ckt
Saturation of CT magnetic ckt during short ckt condition
3. In what way a distance relay is superior to over current protection for protection of transmission lines (AU MAY 2016) (AU NOV 2015)

- Distance relays are double actuating quantity relays with one coil energized by voltage and the other coil energized by current. The torque produced is where as over current relay is actuated by one parameter, namely current.
- Discrimination/selectivity is possible in the case of distance relaying.
- Stepped time characteristic for each zone of protection is possible.
- Faster is operation.

4. What is negative phase sequence relay and where it is employed (AU MAY 2016) (AU NOV 2017) (AU NOV 2015)

The negative sequence relay is used to protect electrical machine against overheating due to unbalanced current in the stator which is caused by unbalance loading in generators.

Negative sequence relay is employed for the protection of generators and motors against unbalanced loading that may arise due to phase to phase faults.

5. Write the universal torque equation (AU NOV 2017)

\[ T = K_1 I^2 - K_2 V^2 - K_3 \]

K1 relay constant
I current operating quantity
V voltage restraining quantity
K2 constant
K3 spring constant

6. What is the principle of differential relay (AU MAY 2015)

A differential relay operates when the phasor difference of two or more similar electrical quantities exceeds a pre-determined amount.

7. What is under frequency relay and its functions (AU NOV 2014)

An under frequency relay is one which operates when the frequency of the system (usually an alternator or transformer) falls below a certain value.

8. For what purpose distance relay are used (AU NOV 2006)

Distance relays are used in the Distance scheme for the protection of high and extra high Voltage (EHV) transmission and sub-transmission lines at 220kV, 132kV even for 11kV also. The relaying units used in carrier current protection are distance relays.

9. What type of relay is best suited for long distance very high voltage transmission line (AU NOV 2007)

Distance relay specifically mho relay

10. Different types of distance relay (AU MAY 2014)

- Impedance relay.
- Reactance relay.
- Admittance relay

11. Mention the types of Time-Current characteristics of an over-current relay.

Idmt, Inverse time, Instantaneous

12. Types of electromagnetic relay

- Electromagnetic attraction type
- Attracted armature relay
- Solenoid and plunger type relay
- Electromagnetic induction type
- Shaded pole type
- Watt hour meter type
- Induction cup type

13. What are the actuating quantities with respect to relay
14. What is distance relay
Is a double coil and double acting quantity relay with one coil energized by voltage (restraining coil) and other coil by current (operating coil), its operation is based on the measurement of impedance, reactance or admittance of the line between the location of relay and the fault point

15. what is R-X diagram
It is the a representative diagram of impedance or reactance or admittance relay characteristics on R-X plane with R in x axis and X in y axis

16. Mention the application of DC relay
DC trolley- bus system
Motor control
Electroplating

17. what is a direction relay
A relay which respond to flow of power in definite direction with reference to the location of CT and PT. it consist of two coils, energizes by voltage and current respectively.

18. Application of differential relay
Protection of generator
Protection of large motors
Protection of transformer
Protection of bus bar
Protection of transmission line

19. advantage , disadvantage application of Induction cup type relay
**ADVANTAGES:**
- Used for both a.c. and d.c.
- Fast operation and reset.
- High operating speed.
- Compact, simple, reliable, robust.
- Pickup can be high as 90-95% for d.c. and 60-90% for a.c.

**DISADVANTAGES:**
- Directional feature is absent.
- Affected by transients.

**APPLICATIONS:**
- Protection of various equipments.
- For differential protection.
- Used as auxiliary relays in the contact system.

20. Why cup type rotor is preferred
It is the hollow cylindrical rotor which reduce the moment of inertia

13 MARKS

1. Explain the construction and operating principle of impedance, admittance and reactance distance relay with R-X diagram(AU MAY 2017) (AU NOV 2015)

- The operation is dependent on the ratio of the voltage and current, which is expressed in terms of impedance.
- **TYPES:**
  1. Impedance relay.
  2. Reactance relay.
  3. Admittance relay.
  1. **IMPEDANCE RELAY:**
Impedance relay works corresponding to the ratio of V and I.

Two elements in relay, one produces torque proportional to current and another proportional to voltage. Both torque are balanced by each other.

Current element produces operating torque, voltage element produces restraining torque.

Normal condition – V and I denoted as ZL, relay is inoperative.

Fault condition – I increases, Z reduces drastically, makes circuit breaker to open.

TORQUE EQUATION:

\[ T = K_1 I^2 - K_2 V^2 - K_3 \]

\[ 0 = K_1 I^2 - K_2 V^2 - K_3 \]

\[ K_2 V^2 = K_1 I^2 - K_3 \]

Dividing both sides by \( K_2 I^2 \),

\[ \frac{V^2}{I^2} = \frac{K_1}{K_2} - \frac{K_3}{K_2 I^2} \]

\[ Z^2 = \frac{K_1}{K_2} - \frac{K_3}{K_2 I^2} \]

\[ Z = \sqrt{\frac{K_1}{K_2}} - \sqrt{\frac{K_3}{K_2 I^2}} \]

\[ Z = \frac{V}{I} = \text{constant} \]

OPERATING CHARACTERISTICS:

- If fault is near, Z will be low and if it is far then Z will be higher.
- As the effect of spring is dominating for the lower values of currents, the characteristics shows a noticeable bend at lower currents.
- The relay will pickup for any combination of V and I represented by any point above the line in the +ve torque region.
DISADVANTAGES:

- When fault occurs, an arc exists. This affects the performance of this relay.
- It is a non-directional and can operate for faults on both sides of a point where relay is connected. Hence it fails to discriminate between internal and external faults.

Reactance Relay

In this relay the operating torque is obtained by current while the restraining torque due to a current voltage directional relay. The over current element develops the positive torque and directional unit produces negative torque. Thus the reactance relay is an over current relay with the directional restraint.

The directional element is so designed that the maximum torque angle is 90°.

Construction:

The structure used for the reactance relay can be of induction cup type. It is a four pole structure. It has operating coil, polarizing coil and a restraining coil. The schematic arrangement of coils for the reactance relay is shown in the Fig 1.43 See Fig on next page.

The current I flows from pole 1 through iron core stacking to lower pole 3. the winding on pole 4 is fed from voltage V. The operating torque is produced by poles 1, 2 and 3. While the restraining torque is developed due to interaction of fluxes due to the poles 1, 3 and 4. Hence the operating torque is proportional to the square of the current $I^2$ while the restraining torque is proportional to the product of V and I (VI). The desired maximum torque angle is obtained with the help of RC circuit shown in the fig 2.24.

Torque Equation

The driving torque is proportional to the square of the current while the restraining torque is proportional to the product of V and I

Hence the net torque neglecting the effect of spring is given by

$$T = K_1I^2 - K_2VI \cos(\theta - \tau)$$

At the balance point net torque is zero.
\[ 0 = K_1 I^2 - K_2 V I \cos(\theta - \tau) \]
\[ K_1 I^2 = K_2 V I \cos(\theta - \tau) \]
\[ K_1 = K_2 \frac{V}{I} \cos(\theta - \tau) \]
\[ K_1 = K_2 Z \cos(\theta - \tau) \]

Adding capacitor the torque angle is adjusted as 90°

\[ K_1 = K_2 Z \cos(\theta - 90°) \]
\[ K_1 = K_2 Z \sin \theta \]
\[ Z \sin \theta = \frac{K_1}{K_2} \]

Consider an impedance triangle shown in the Fig 1.44

\[ Z \sin \theta = X = \text{react} \tan \text{ce} \]
\[ Z \cos \theta = R = \text{resis} \tan \text{ce} \]
\[ X = \frac{K_1}{K_2} = \text{Constant} \]

Thus the relay operate on the reactance only. The constant X means a straight line parallel to X- axis on R-X diagram. For the operation of the relay the reactance seen by the relay should be smaller than the reactance for which the relay is designed.

**Operating Characteristics**

The operating characteristics of such relay is a straight line parallel to the x axis i.e. R-axis on R-X diagram. All the impedance vectors have their tips lying on the straight line representing constant reactance. The resistance component of the impedance has no effect on the operation of the relay. It responds only to the reactance component of the impedance. The characteristics is shown in the Fig 2.25

The relay will operate for all the impedances whose heads lie below the operating characteristics, whether below or above the R-axis

**Disadvantages**

This relay as can be seen from the characteristics is a non-directional relay. This will not be able discriminate when used on transmission line, whether the fault has taken place in the section where relay is located or it has taken place in the adjoining section. It is not possible to use a directional relay of the type used with basic impedance relay because in that cause the relay will operate even under normal load conditions if the system is operating at or near unity P.f. conditions. The reactance relay with directional feature is called mho relay or admittance relay.

**Mho Relay or Admittance Relay**
In the impedance relay a separate unit is required to make it directional while the same unit cannot be used to make a reactance relay with directional feature. The mho relay is made inherently directional by adding a voltage winding called polarizing winding. This relay works on the measurement of admittance $Y \angle \theta$. This relay is also called angle impedance relay.

**Construction:**
This relay also uses an induction cup type structure. It also has an operating coil, polarizing coil and restraining coil. The schematic arrangement of all the coils

In this relay the operating torque is obtained by $V$ and $I$ element while the restraining torque is obtained by a voltage element. Thus an admittance relay is a voltage restrained directional relay.

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

Thus the restraining torque is proportional to the square of the voltage $V^2$ while the operating torque is proportional to the product of voltage and current $(VI)$ the torque angle is adjusted using series tuning circuit.

**Torque Equation**
The operating torque is proportional to $VI$ while restraining torque is proportional to $V^2$. Hence net torque is given by Where

$$T = K_1 V I \cos(\theta - \tau) - K_2 V^2 - K_3$$

$K_3$ = control spring effect

Generally control spring effect is neglected ($K_3=0$)
And at balance net torque is also zero.

$$0 = K_1 V I \cos(\theta - \tau) - K_2 V^2$$

$$K_1 V I \cos(\theta - \tau) = K_2 V^2$$

$$K_1 \cos(\theta - \tau) = K_2 \frac{V^2}{VI}$$

$$K_1 \cos(\theta - \tau) = K_2 \frac{V}{I}$$

$$Z = \frac{K_1}{K_2} \cos(\theta - \tau)$$

This is the equation of a circle having diameter $K_1/K_2$ passing through origin. And this constant $K_1/K_2$ is the ohmic setting of this relay.

**Operating Characteristics**
The torque equation the characteristics of this relay is a circle passing through origin with diameter as $K_1/K_2$. 

![Fig. 4.12 Schematic arrangement of admittance relay](image-url)
Let \( \frac{K_1}{K_2} = Z_R \) = ohmic setting of relay = diameter

2. With necessary sketches discuss in detail about electromagnetic attraction type relay (AU MAY 2017) (AU MAY 2016) (AU NOV 2017)

They work on the following two main operating principles:

(i) Electromagnetic attraction
(ii) Electromagnetic induction

Electromagnetic Attraction Relays

(i) Attracted armature type relay
(ii) Solenoid type relay
(iii) Balanced beam type relay

Induction Relays / Electromagnetic induction

(i) Induction type overcurrent Relay (Non Directional Relay)
(ii) Induction Cup Relay (Directional Relay)

Attracted Armature Type Relay

There are two types of structures available for attracted armature type relay which are

i. Hinged armature type
ii. Polarised moving iron type

The two types of attracted armature type relays

![Attracted Armature Type Relay Diagrams]
In attracted armature type there exists a laminated electromagnet which carries a coil. The coil is energized by the operating quantity which is proportional to the circuit voltage or current. The armature or a moving iron is subjected to the magnetic force produced by the operating quantity. The force produced is proportional to the square of current hence these relays can be used for a.c as well as d.c. The spring is used to produce restraining force. When the current through coil increases beyond the limit under fault conditions armature gets attracted. Due to this it makes contact with contacts of a trip circuit, which results in an opening of a circuit breaker. The minimum current at which the armature gets attracted to close the trip circuit is called pickup current.

Generally the number of tappings are provided on the relay coil with which its turns can be selected as per the requirement. This is used to adjust the set value of an operating quantity at which relay should operate. An important advantage of such relays is their high operating speed. In modern relays an operating time as small as 0.5 m sec is possible. The current time characteristics of such relays is hyperbolic as shown in the

**Solenoid and Plunger type Relay**

![Image of Solenoid and Plunger type Relay]

The fig shows the schematic arrangement of solenoid and plunger type relay which works on the principle of electromagnetic attraction.

It consists of a solenoid which is nothing but an electromagnet. It also consists a movable iron plunger. Under normal working conditions, the spring holds the plunger in the position such that it cannot make contact with trip circuit contacts.

Under fault conditions when current through relay coil increases the solenoid draws the plunger upwards. Due to this it makes contact with the trip circuit contacts, which results in an opening of a circuit breaker.

**Operating Principle of Electromagnetic Attraction Relays**

The electromagnetic force produced due to operating quantity which is exerted on armature, moving iron or plunger is proportional to the square of the flux in the air gap. Thus neglecting the saturation effect, the force is proportional to the square of the operating current. Hence such relays are useful for a.c. and d.c. both.

For d.c. operation : In d.c. operation, the electromagnetic force is constant. When this force exceeds the restraining force, the relay operates.

\[ F_e = K_1 I^2 \]

Where \( F_e \) = Electromagnetic force  
\( K_1 \) = constant  
\( I \) = Operating current in a coil  

And  \( F_r = K_2 \)

Where \( F_r \) = Restraining force due to spring including friction  
\( K_2 \) = Constant

On the verge of relay operating, electromagnetic force is just equal to the restraining force.

\[ K_1 I^2 = K_2 \]

\[ I^2 = \frac{K_2}{K_1} \]

\[ I = \sqrt{\frac{K_2}{K_1}} = \text{cons} \tan t \]

This is the current at which relay operates in case of d.c. operation.

For a.c. operation : In a.c. electromagnetic relays the electromagnetic force is proportional to square of the current but it is not constant. It is given by

\[ F = K I^2 \]

\[ = \frac{1}{2} K I_m^2 - \frac{1}{2} K I_m^2 \cos 2\omega t \]

Where \( I_m \) = Maximum value of the operating current
K = Constant

It shows that the electromagnetic force consists of two components

- Constant independent of time.
- Pulsating at double the frequency of applied voltage.

The total force thus pulsates at double the frequency. If the restraining force \( F_r \) which is produced by the spring is constant then the armature of relay will be picked up at time \( t_1 \) and it drops off at time \( t_2 \) as shown in

Thus relay armature pulsates at double frequency. This causes the relay to hum and produces a notice. It may cause damage to the relay contacts.

To overcome this difficulty, the air gap flux producing an electromagnetic force is divided into two fluxes acting simultaneously but differing in time phase. This causes resulting electromagnetic force to be always positive. If this is always greater than restraining force \( F_r \), then armature will not vibrate. The phase lag between the two components of flux through the unshaded part.

**Advantages of Electromagnetic Relays**

The various advantages of electromagnetic relays are

- Can be used for both a.c. and d.c.
- They have fast operation and fast reset
- These are almost instantaneous. Through instantaneous, the operating time varies with current. With extra arrangements like dashpot, copper ring etc. Slow operating and resetting times can be obtained.
- High operating speed with operating time in few milliseconds also can be achieved.
- The pickup can be as high as 90-95% for d.c. operation and 60 to 90% for the d.c. operation.
- Modern relays are compact, simple reliable and robust.

**Disadvantages of electromagnetic Relays**

The few disadvantages of these relays are

- The directional feature is absent
- Due to fact operation the working can be affected by the transients. As transients contain d.c. as well as pulsating component, under steady state value less than set value the relay can operate during transients.

**Applications of Electromagnetic Relays**

The various applications of these relays are

1. The protection of various a.c. and d.c. equipments
2. The over under current and over under voltage protection of various a.c. and d.c. equipments.
3. In the definite time lag over current and earth fault protection along with definite time lag over current relay.
4. For the differential protection
5. Used as auxiliary relays in the contact systems of protective relaying schemes.

**Induction type relay:**

Consist of a pivoted aluminium disc free to rotate in the air gap of an electromagnet. One half of each pole of the magnet is surrounded by copper band known as shading ring due to alternating flux \( \phi_s \) emf get induced in the shading ring. This emf drives current causing the flux to exist in shaded portion. This flux lags in the unshaded portion by angle \( \alpha \)

\[ T = \alpha \phi_s I^2 \sin \alpha \]

Assuming flux propositional to I

\[ T = FK \]
**Watt hour meter**
Two electromagnet upper magnet carries two winding primary and secondary
Primary winding carries the relay current $I_1$ which induce emf in the secondary and circulate a current $I_2$
$I_1$ and $I_2$ produces a fluxes $\phi_1$ and $\phi_2$
$T \propto \phi_1 \phi_2 \sin \alpha$

**Cup type rotor**
It most closely resembles an induction motor, except that the rotor iron is stationary, only the rotor conductor portion being free to rotate.
The moving element is a hollow cylindrical rotor which turns on its axis. The rotating field is produced by two pairs of coils wound on four poles as shown.
The rotating field induces currents in the cup to provide the necessary driving torque.

3. Explain with the help of neat diagram the construction and working of induction type over current relay

**Working principle:**
The over current relay operates when the current in the circuit exceeds a certain preset value.

**Construction:**
The induction type non directional overcurrent relay has a construction similar to a watt-hour meter with slight modification. The fig shows the constructional details of non directional induction type over current relay.

It consists of two electromagnets. The upper is E shaped while the lower in U shaped. The aluminum disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts and when the disc rotates the moving contacts come in contact. With fixed contacts which are the terminals of a trip circuit.
The upper magnet has two windings, primary and secondary. The primary is connected to the secondary of C.T on the line to be protected. This winding is tapped at intervals. The tappings are connected to plug setting bridge. With the help of this bridge, number of turns of primary winding can be adjusted. Thus the desired current setting for the relay can be obtained. There are usually seven section of tapping to have the overcorrect range from 50% to 200% in steps of 25%. These values are percentages of the current rating of the relay. Thus a relay current rating may be 10A, i.e. it can be connected to C.T with secondary current rating of 10A but with 50% setting the relay will start operating at 5A. So adjustment of the current setting the relay will start operating at 5A. So adjustment of the current setting is made by inserting a pin between spring loaded jaw of the bridge socket, at the proper tap value required. When the pin is withdrawn for the purpose of changing the setting while relay is in service then relay automatically adopts a higher current setting thus secondary of C.T is not open circuited. So relay remains operative for the fault occurring during the process of changing the setting.

The secondary winding on the central limb of upper magnet is connected in series with winding on the lower magnet. This winding is energized by the induction from primary. By this arrangement of secondary winding, the leakage fluxes of upper and lower magnets are sufficiently displaced in space and time to produce a rotational torque on the aluminum disc. The control torque is provided by the spiral spring.

When current exceeds its preset value, disc rotates and moving contacts on spindle make connection with trip circuit thermals. Angle through which the disc rotates is between 0° to 360°. The travel of the moving contacts can be adjusted by adjusting bangle of rotation of disc. This gives the relay any desired time setting which is indicated by a pointer on a time setting dial. The dial is calibrated from 0 to 1. This does not give direct operating time but it gives multiplier which can be used along with the time plug setting multiplier curve to obtain actual operating time of the relay. The time plug setting multiplier curve is provided by the manufacturer.

**Time Current characteristics**

Time required to rotate the disc depends on a torque. The torque varies as current in the primary circuit. More the torque, lesser is the time required hence relay ha inverse time characteristics. The Fig 1.23 see on next page shows the time current characteristics for the over current relay. Such characteristics are called inverse Definite Minimum Type (I.D.M.T) characteristics. This is because the characteristics shows inverse relation between time and current for small values of current. But as current increases, some definite time is required by the relay. So the characteristics becomes straight line for higher values of currents. Such I.D.M.T characteristics can be obtained by saturating the iron in the upper magnet so that there cannot be increase in the flux once current achieves certain high value.

The P.S.M can be obtained as

\[
P.S.M = \frac{\text{Fault current in relay coil}}{\text{Rated secondary C.T. current x Current setting}}
\]

Fault current in relay coil = Line fault current x C.T ratio

**Operation:**

The torque is produced due to induction principle. This torque is opposed by restraining force produced by spiral springs. Under normal conditions the restraining force is more than driving force hence disc remains stationary. Under fault conditions when current becomes high, the disc rotates through the preset angle.


**DIRECTIONAL INDUCTION TYPE OVERCURRENT RELAY:**

- Not suitable to use as a protective relay under short circuit conditions.
- Because under short circuit conditions the voltage falls drastically and such a reduced voltage may not be sufficient to produce the driving torque required for the relay operation.
- Operates almost independent of system voltage and power factor.

**DIRECTIONAL ELEMENT:**

i) Directional power relay which operates when power in the circuit flows in a particular direction.
ii) Voltage coil – system voltage through potential transformer.

**Current coil** – system current through a current transformer.

iii) Trip circuit are connected in series with secondary winding of nondirectional element.

**NONDIRECTIONAL ELEMENT:**

i) Current coil of the directional element is connected in series with the primary winding of nondirectional element.
ii) The movement of the nondirectional element is controlled by the directional element.
OPERATION:

- Under normal condition – power flows in proper direction, relay is inoperative.
- Under fault condition – power flow in reverse direction, produces the flux.
- Current in the voltage coil produces another flux.
- Two fluxes interact to produce torque due to which the disc rotates.
- So sensitive it can operate even at 2% of power flow in reverse direction.
- Current in primary winding of nondirectional element produce flux, which induces the e.m.f. in the secondary winding.
- This induced e.m.f. drives the current and produce another flux.
- These two fluxes produce driving torque, rotates the disc.
- The contacts of the trip circuit get closed and it opens the circuit breaker.

**Directional characteristics:**

![Diagram of Directional Overcurrent Relay]
6. What is universal torque equation (AU MAY 2016)

Universal Relay Torque Equation
The universal relay torque equation can be given as where \( I \) = RMS value of current in current coil
\[
T = K_1 I^2 + K_2 V^2 + K_3 I V \cos (\phi - \tau) + K
\]
\( V \) = RMS value of voltage fed to the voltage coil
\( \phi \) = Electrical angle between \( V \) and \( I \)
\( T \) = The maximum torque angle \( K_1, K_2 \) and \( K_3 \) = Relay constant
Distance Protection:
\[
T = K_1 I^2 + K_2 V^2
\]
Reactance Relay In universal torque equation, putting \( k = 0 \)
\[
T = K_1 I^2 + K_3 I V \cos (\phi - \tau)
\]
Over current relay
\[
T = K_1 I^2 - K_3
\]

7. Explain the various differential protection (AU NOV 2017)

DIFFERENTIAL RELAY:
- It is defined as the relay that operates when the phasor difference of two or more similar electrical quantities exceeds a predetermined value.
- Types:
  2. Biased beam relay or percentage differential relay.

i) CURRENT DIFFERENTIAL RELAY:

- Two current transformers are used having same ratio are connected on the either side of the section to be protected.
- Let current I is flowing through the primary of C.T. towards the external fault.
- No current will flow through the operating coil for the relay, remains inoperative. So relay cannot operate if there is an external fault.

![Action of differential relay](image)

- Consider an internal fault occurs at point A, as shown in fig as above.
- Current flows through the fault from both sides (I1 + I2), current in secondary are not equal.
- High current causes the relay to operate.
- Some current flowing out of one side while a large current entering the other side can cause differential relay to operate.

**DISADVANTAGES:**

1. Sensitive relay can operate to a very small difference in the two currents, though there is no fault existing.
2. Under heavy current flows, pilot cable capacitances may cause inaccurate operation for the relay.

**ii) BIASED BEAM RELAY:**

- To operate to the differential current in terms of its fractional relation with the actual current flowing through the protected circuit.

![Biased beam relay](image)

- Operating coil of the relay carries a differential current (I2 – I1)
- Restraining coil carries the current proportional to (I1 + I2)/2.
- Under normal condition, the bias force produced due to the restraining coil > operating force produced by operating coil, relay is inoperative.
- When internal fault occurs, the operating force becomes more than the bias force.
- Due to this, beam moves and the trip contacts are closed to open the circuit breaker.

\[
N = \text{Total number of turns of restraining coil} \\
\text{Effective ampere turns} = \frac{I_1 N}{2} + \frac{I_2 N}{2} = N \left( \frac{I_1 + I_2}{2} \right)
\]
• Differential operating current / average restraining current = fixed percentage.
• Increasing slope type relays cost is more but it require less accuracy in the performance of their current transformers.

iii) VOLTAGE BALANCE DIFFERENTIAL RELAY:

• Opposed voltage method.
• Under normal condition, currents at the two ends to be protected is same.
• Fault condition, currents at the two ends are different, causes voltage drop across the relay.
• Large current flows through relay due to which the relay operates to open the circuit breaker.

8. write a short note on under frequency relay (AU NOV 2014)

UNDER FREQUENCY RELAY:
• Frequency of the induced e.m.f. is related to the speed of the synchronous generators by the relation, 
  \[ f = \frac{(N_s P)}{120} \]
• Ferraris measuring system
• Frequency relay is connected to secondary of voltage transformer.
• Two pair of coils are connected in parallel to the supply voltage through the impedances.
• At normal frequency, impedances are tuned balancing each other.
• No torque is experienced by the cup type rotor at normal frequency.
Frequency decreases – unbalance in the impedance, torque say anticlockwise in nature is exerted on the rotor.
Frequency decreases beyond the setting = under frequency relay.

8. write a short note on negative sequence protection (AU MAY 2015)

NEGATIVE SEQUENCE RELAY:
- Also called phase unbalance relays because these relays provide protection against negative sequence component of unbalanced currents existing due to unbalanced loads.
- Used to give protection to generators and motors against unbalanced currents.
- This relay has a filter circuit.
- Provides protection against phase to phase faults.

Consists of resistance bridge network.
Magnitudes of the impedances of all the branches of the network are equal.
\[ OB = \frac{I_R}{2} \]

Now in triangle OAB,
\[ \cos 30 = \frac{OB}{OA} \]
\[ \frac{\sqrt{3}}{2} = \frac{\frac{I_R}{2}}{I} \]
\[ I = \frac{I_R}{\sqrt{3}} = I_1 \]

\[ I_1 = I_2 \]
Similarly \( IB/(3)^{1/2} = I_3 = I_4 \)

\( I_1 \) leads \( IR \) by 30 degree, \( I_2 \) lags \( IR \) by 30 degree.
\( I_4 \) leads \( IB \) by 30 degree, \( I_3 \) lags \( IB \) by 30 degree.

\[ I_{\text{relay}} = I_1 + I_3 + I_Y \]
\[ = I_Y + \frac{I_R}{\sqrt{3}} \text{ (leads } I_R \text{ by } 30^\circ) + \frac{I_R}{\sqrt{3}} \text{ (lags } I_R \text{ by } 30^\circ) \]

\[ I_1 + I_3 = -I_Y \]
\[ I_1 + I_3 + I_Y = 0 \]

Resultant current at D is zero.
Relay is inoperative for a balanced system.
\( I_1 \) and \( I_3 \) cancel each other because they are equal and opposite to each other.
Relay coil carries current \( I_Y \).
Total current through relay is $I_1 + I_3 + I_Y$.
Thus relay operates to open the circuit breaker.

9. Explain with the help of neat diagram the construction and working of induction directional relay

**Constructional details:**
It consists of two electro magnets
1) upper magnet which is E-shaped
2) lower magnet which is U-shaped.

- The upper magnet consists of primary winding on the central limb which is energised by voltage from secondary of P.T.
- Lower magnet houses secondary winding which is energised by current of the circuit from secondary of C.T.

Further lower magnet is connected to PSM as previous case (not shown).
Due to phase difference between two flux quantities i.e.,

$$\alpha = 90 - \theta$$

$\Phi_1 \alpha V \& \varphi \alpha I$

Hence $T = \varphi_1 \varphi_2 \sin \alpha$
when power flows in normal direction both driving torque and restraining torque twists in same direction and relay does not operates.

- when the power flow is in reverse direction, driving torque and restraining torque acts in opposite direction and relay operates. therefore CB operates and disconnects faulty section.

**Unit-3**

**2 mark**

1. **What is the need for instrument transformer (AU MAY 2017)**

   Most common usage of instrument transformers is to operate instruments or metering from high voltage or high current circuits, safely isolating secondary control circuitry from the high voltages or currents. The primary winding of the transformer is connected to the high voltage or high current circuit, and the meter or relay is connected to the secondary circuit.

2. **What are the limitations of buchholz relay? (AU MAY 2017)**

   - Only fault below the oil level are detected.
   - Mercury switch setting should be very accurate, otherwise even for vibration, there can be a false operation.
   - The relay is of slow operating type, which is unsatisfactory.

3. **why secondary of CT should not be left open circuited. (AU NOV 2017) (AU NOV 2014)**

   If it is left open, then current the secondary becomes 0 hence the ampere luring produced by secondary which generally oppose primary amphere turn becomes 0, there is no counter mmf unopposed primary mmf produce high flux in the core. This produces excessive core losses, heating the core beyond limits heavy em’f’s will be induced on the primary and secondary mide. This may damage the insulation winding.

4. **List the types of busbar protection (AU NOV 2017) (AU NOV 2014)**

   i. Frame leakage protection
   ii. Circuiting current protection.
   iii. High impedance differential protection.

5. **what are the short comings of coming of differential protection scheme as applied to power transformer (AU NOV 2015)**

   - Difference in lengths of pilot wires on either sides of the relay. This is overcome by connecting adjustable resistors to pilot wires to get equipotential points on the pilot wires.
   - Difference in CT ratio error difference at high values of short circuit currents that makes the relay to operate even for external or through faults. This is overcome by introducing bias coil.
   - Tap changing alters the ratio of voltage and currents between HV and LV sides and the relay will sense this and act. Bias coil will solve this.
   - Magnetizing inrush current appears wherever a transformer is energized on its primary side producing harmonics. No current will be seen by the secondary.
   - CT’s as there is no load in the circuit. This difference in current will actuate the differential relay. A harmonic restraining unit is added to the relay which will block it when the transformer is energized.

6. **give an example for unit and non unit schemes system of protection. (AU NOV 2015)**

   Non pilot- no pilot wire
   - Directional time and current graded scheme
   - Distance protection using high speed distance relay

   Unit type
   - Translay relay
   - Carrier current pilot protection
   - Micro pilot protection

7. **what are the various faults that would affect an alternator (AU MAY 2015)**

   - Internal Faults
     a. Phase and/or ground faults in the stator and associated protection zone
     b. Ground faults in the rotor (field winding)
   - Abnormal Operating Conditions.
a. Loss of field.
b. Overload.
c. Overvoltage.
d. Under and over frequency
e. Unbalanced Operation e.g. single phasing.
f. Loss motoring i.e. loss of prime mover.
g. Loss of synchronization (out of step).
h. Subsynchronous oscillation.

8. list the application of CT (AU MAY 2014)
   - Circulating current differential protection.
   - Over current phase fault protection.
   - Difference Protection.
   - Intermediate CTs for feeding protective devices, measuring systems, relays etc.

9. what type of relay best suited for generator protection (AU NOV 2007)
   Percentage differential protection

10. busbar protection need special attention why? (AU MAY 2008)
   - Fault level at busbar is high
   - b) The stability of the system is affected by the faults in the bus zone.
   - c) A fault in the bus bar causes interruption of supply to a large portion of the system network.

11. why it is complex to give protection to generator?
   The most expensive equipment of the power system, if generator are shut off then it lead to power shut down and affect stability of power system, it is associated with many auxiliary system such cooling, field exciter, etc., failure in any one the system also leads to failure in generator

12. protection scheme for transmission line
   Over current protection
   a. Time graded overcurrent protection
   b. Current graded overcurrent protection
   Non unit protection( no pilot wired
   a. Directional time and current graded scheme
   b. Distance protection using high speed distance relay
   Unit type
   a. Translay
   b. Carrier current pilot wire
   c. Micro wave pilot protection.

13. What are the methods used for reduction of Ratio and phase angle errors?
   - As the errors depend on components of exiting currents reduce the magnetizing and loss components of emitting current. This requires to provide smaller magnetic path, good core material and low firm density in core.
   - Reduction of resistance and leakage reactance. The values decide the secondary circuit power factor which affects the errors. This can be achieved by providing thick conductors and smaller length of mean turn.
   - Providing turns compensation at no load the actual ratio exceeds the turns ratio thus the solution to this in to reduce primary turns or increasing secondary turns and to make attract ratio equal to normal rations for one particular value of load.

14. What are the possible transformer faults occur?
   (i) Over heating.
   (ii) Winding faults.
   (iii) Open circuits.
   (iv) Through faults
   (v) Over flowing

15. state what type of protection is suitable for
   a) Medium length feeder
   b) Short length
   c) Very long feeder (Nov/Dec 2007)
a. For medium feeder-impedance type  
b. Short length feeder-Reactance relay  
c. Very long feeder-Mho relay  

17. What is line trap unit?  
   Line trap unit is a parallel turned circuit comprising L & C. It has a low impedance (less than 0.1 ohm) to 50 Hz and offers high impedance to carrier frequencies. Line trap unit is connected between bush bar and connection of coupling capacitor to the line. It is one of the components of a power line carrier communication used in power system.

18. Define CT. burden. How it is specified?  
The value of load ie, relay coil, connecting leads and resistance of the secondary windings connected across the secondary of C.T is called burden of a CT. It is specified in VA or Ohms at rated secondary current. i.e 12.5 VA at 5 amps. Or 0.5 Ohm at 5 amps. (both are same because impedance of secondary X secondary winding^2 = power in VA)

19. Give two methods of protection of transformer?  
a) Buchholz relay protection  
b) Differential protection.  
c) Over load protection.

20. State two method of protection of feeders?  
a) Over current protection  
b) Distance or impedance protection.

13 MARKS
1. give a detailed explanation for protection of transformer using differential protection which includes associated faults(AU MAY 2017) (AU MAY 2016) (AU NOV 2014)  
Refer to Q12  
2. give a detailed explanation about CT’s and PT’s and its application to power system(AU MAY 2017)  
Current Transformer (C.T.):  
The large alternating currents which can not be sensed or passed through normal ammeters and current coils of watt meters, energy meters can easily be measured by use of current transformers along with normal low range instruments.

A transformer is a device which consists of two windings called primary and secondary. It transfers energy from one side to another with suitable change in the level of current or voltage. A current transformer basically has a primary coil of one or more turns of heavy cross-sectional area. In some, the bar carrying high current may act as a primary. This is connected in series with the line carrying high current.

![Current transformer diagram]

Bar type current transformer  
The secondary of the transformer is made up of a large number of turns of fine wire having small cross-sectional area. This is usually rated for 5A. This is connected to the coil of normal range ammeter. Symbolic representation of a current transformer is as shown in the figure.

Working Principle:  
These transformers are basically step up transformers i.e. stepping up a voltage from primary to secondary. Thus the current reduces from primary to secondary. So from current point of view, these are step down transformers, stepping down the current value considerably from primary to secondary.
In this type of current transformer, the primary winding is nothing but a bar of suitable size. The construction is shown in the image.

The stampings used for the laminations in current transformers must have high cross-sectional area than the ordinary transformers. Due to this, the reluctance of the interleaved corners remains as low as possible. Hence the corresponding magnetizing current is also small. The windings are placed very close to each other so as to reduce the leakage reactance. To avoid the corona effect, in bar type transformer, the external diameter of the tube is kept large.

The windings are so designed that without damage, they can withstand short circuit forces which may be caused due to short circuit in the circuit in which the current transformer is inserted.

For small line voltages, the tape and varnish are used for insulation. For line voltages above 7 kV the oil immersed or compound filled current transformers are used.

**Why Secondary of C.T. Should not be Open**

It is very important that the secondary of C.T. should not be kept open. Either it should be shorted or must be connected in series with a low resistance coil such as current coils of wattmeter, coil of ammeter etc. If it is left open, then current through secondary becomes zero hence the ampere turns produced by secondary which generally oppose primary ampere turns becomes zero. As there is no counter m.m.f., unopposed primary m.m.f. (ampere turns) produce high flux in the core. This produces excessive core losses, heating the core beyond limits. Similarly, heavy e.m.fs will be induced on the primary and secondary side. This may damage the insulation of the winding. This is danger from the operator point of view as well. It is usual to ground the C.T. on the secondary side to avoid a danger of shock to the operator.

Hence never open the secondary winding circuit of a current transformer while its primary winding is energized.

Thus most of the current transformers have a short circuit link or a switch at secondary terminals. When the primary is to be energised, the short circuit link must be closed so that there is no danger of open circuit secondary.

**The working Principle of Potential Transformer,**

**Potential Transformers (P.T.)**

The basic principle of these transformers is same as current transformers. The high alternating voltage are reduced in a fixed proportion for the measurement purpose with the help of potential transformers. The construction of these transformers is similar to the normal transformer. These are extremely accurate ratio step down transformers. The windings are low power rating windings. Primary winding consists of large number of turns while secondary has less number of turns and usually rated for 110V, irrespective of the primary voltage rating. The primary is connected across the high voltage line while secondary is connected to the low range voltmeter coil. One end of the secondary is always grounded for safety purpose. The connections.

As a normal transformer, its ratio can be specified as,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}$$

So if voltage ratio of P.T. is known and the voltmeter reading is known then the high voltage to be measured, can be determined.

**Construction:**
The potential transformer use larger core and conductor sizes compared to conventional power transformer. In potential transformer, economy of material is not an important consideration at the time of design. The accuracy is an important consideration.

The shell type or core type construction is preferred for potential transformer. The shell type is used for low voltage while core type for high voltage transformers. At the time of assembly special core is required to reduce the effect of air gap at the joints.

The coaxial primary and secondary windings are used, to reduce the leakage reactance. The secondary winding which is a low voltage winding is always next to the core. The primary winding is a single coil in low voltage transformers. For high voltages, insulation is the main problem. Hence in high voltage potential transformers, primary is divided into number of small sections of short coils to reduce the need of insulation between coil layers.

The cotton tape and varnished cambric are used as the insulations for windings. Hard fiber separators are used in between the coils. The oil immersed potential transformers are used for the voltage levels above 7 kV.

For oil filled potential transformers, oil filled bushings are used. Two bushings are required when no side of the line is at earth potential.

The overall construction of single phase, two winding potential transformer is shown in the

**Comparison of C.T. and P.T.**

The comparison of C.T. and P.T is given in the following table.

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Current Transformer</th>
<th>Potential Transformer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>It can be treated as series transformer under virtual short circuit conditions</td>
<td>It can be treated as parallel transformer under open circuit secondary.</td>
</tr>
<tr>
<td>2.</td>
<td>Secondary must be always shorted.</td>
<td>Secondary is nearly under open circuit conditions.</td>
</tr>
<tr>
<td>3.</td>
<td>A small voltage exists across its terminals as connected in series.</td>
<td>Full line voltage appears across its terminals.</td>
</tr>
<tr>
<td>4.</td>
<td>The winding carries full line current.</td>
<td>The winding is impressed with full line voltage.</td>
</tr>
<tr>
<td>5.</td>
<td>The primary current and excitation varies over a wide range.</td>
<td>The line voltage is almost constant hence exciting current and flux density varies over a limited range.</td>
</tr>
<tr>
<td>6.</td>
<td>The primary current is independent of the secondary circuit conditions.</td>
<td>The primary current depends on the secondary circuit conditions.</td>
</tr>
<tr>
<td>7.</td>
<td>Needs only one bushing as the two ends of primary winding are brought out through the same insulator. Hence there is saving in cost.</td>
<td>Two bushings are required when neither side of the line is at ground potential.</td>
</tr>
</tbody>
</table>

3. describe with neat sketch the percentage protection of modern alternator (AU NOV 2014)  
Refer to Q10

4. discuss the various fault occurring in transformer (AU NOV 2017)  
Refer to Q12

5. explain the operation of buchholz relay (AU NOV 2017)

**Buchholz relay**

All faults below the oil in transformer result in the localized heating & breakdown of the oil, some degree of arcing will always take place in a winding fault & the resulting decomposition of it will release gases such as hydrogen, carbon monoxide & hydrocarbons.

- When the fault is of a very minor type, such as hot joints gas is released slowly, but a major fault involving severe arcing causes rapid release of large volumes of gas as well as oil vapour.
- Such incipient faults of smaller or larger magnitudes can be detected by a gas actuated relay known as Bucholtz Relay.

The Bucholtz Relay is contained in a cast housing which is connected as shown below between the conservator tank and main tank of the transformer.
Under normal conditions, the Buchholz relay is full of oil. It consists of a cast housing containing a hinged hollow float. A mercury switch is attached to a float. The float being rotated in the upper part of the housing. Another hinged flap valve is located in the lower part which is directly in the path of the oil between tank and the conservator. Another mercury switch is attached to a flap valve. The float closes the alarm circuit while the lower flap valve closes the trip circuit in case of internal faults.

**Operation**

There are many types of internal faults such as insulation fault, core heating, bad switch contacts, faulty joints etc. which can occur. When the fault occurs the decomposition of oil in the main tank starts due to which the gases are generated. As mentioned earlier, major component of such gases is hydrogen. The hydrogen tries to rise up towards conservator but in its path it gets accumulated in the upper part of the Buchholz relay. Through passage of the gas is prevented by the flap valve.

When gas gets accumulated in the upper part of housing, the oil level inside the housing falls. Due to which the hollow float tilts and closes the contacts of the mercury switch attached to it. This completes the alarm circuit to sound an alarm. Due to this operator knows that there is some incipient fault in the transformer. The transformer is disconnected and the gas sample is tested. The testing results give the indication, what type of fault is started developing in the transformer. Hence transformer can be disconnected before grows into a serious one. The alarm circuit does not immediately disconnect the transformer but gives only an indication to the operator. This is because sometimes bubbles in the oil circulating system may operate the alarm circuit even though actually there is no fault.

However if a serious fault such as internal short circuit between phases, earth fault inside the tank etc. occurs then the considerable amount of gas gets generated. In that case, due to a fast reduction in the level of oil, the pressure in the tank increases. Due to this the oil rushes towards the conservator. While doing so it passes through the relay where flap valve is present. The flap valve gets deflected due to the rushing oil and operates the mercury switch, thereby energizing the trip circuit which opens the circuit breaker of transformer is totally disconnected from the supply.

The connecting pipe between the tank and the conservator should be as straight as possible and should slope upwards conservator at a small angle from the horizontal. This angle should be around 10°.

For the economic considerations, Buchholz relays are not provided for the transformer having rating below 500 KVA.

**Advantages**
The various advantages of the Buchholz relay are,
1. Normally a protective relay does not indicate the appearance of the fault. It operates when fault occurs. But Buchholz relay gives an indication of the fault at very early stage, by anticipating the fault and operating the alarm circuit. Thus the transformer can be taken out of service before any type of serious damage occurs.
2. It is the simplest protection in case of transformers.

**Limitations**
The various limitation of the Buchholz relay are,
1. Can be used only for oil immersed transformers having conservator tanks.
2. Only faults below oil level are detected.
3. Setting of the mercury switches cannot be kept too sensitive otherwise the relay can operate due to bubbles,
vibration, earthquakes mechanical shocks etc.
4. The relay is slow to operate having minimum operating time of 0.1 seconds and average time of 0.2 seconds.
Applications
The following types of transformer faults can be protected by the Buchholz relay and are indicated by alarm:
1. Local overheating
2. Entrance of air bubbles in oil
3. Core bolt insulation failure
4. Short circuited laminations
5. Loss of oil and reduction in oil level due to leakage
6. Bad and loose electrical contacts
7. Short circuit between phases
8. Winding short circuit
9. Bushing puncture
10. Winding earth fault

Refer Q11

7. Draw and explain differential protection of transmission line (AU May 2015)
Refer Q11

8. Briefly explain types of stator fault protection of alternator (AU May 2015)
Refer Q10

9. Write a brief note on busbar protection (AU May 2014)
Busbar Faults
- Majority of bus faults involve one phase and earth, but faults arise from many causes and a significant number are inter-phase clear of earth.
- With fully phase-segregated metal clad gear, only earth faults are possible, and a protective scheme needs have earth fault sensitivity only.
- For outdoor busbars, protection schemes ability to respond to inter-phase faults clear of earth is an advantage.

Busbar Protection Need Special Attention
- Fault level at busbar is high
- b) The stability of the system is affected by the faults in the bus zone.
- c) A fault in the bus bar causes interruption of supply to a large portion of the system network.

Types of Protection Schemes
- Differential protection/circulating current protection
- Frame leakage protection
- High impedance differential protection

Frame Leakage Protection
This is purely an earth fault system, and in principle involves simply measuring the fault current flowing from the switchgear frame to earth. To this end a current transformer is mounted on the earthing conductor and is used to energize a simple instantaneous relay.

Differential protection/circulating current protection
During normal or external fault condition summation of current entering the bus is equal to summation of current leaving the busbar
\[ I_1 + I_2 + I_3 + I_4 + I_5 + I_6 = 0 \]

**High impedance differential protection**

During normal condition current following through high impedance is zero and relay inoperative
During abnormal condition unbalance current flow through high impedance causing voltage drop, CTis connected to secondary of transformer which measure this drop and trip the relay

10. Explain the Faults occurs in a Generator and their corresponding protection?

**Generator Faults**

The various faults which can occur associated with a generator can be classified as,
1. **Stator faults**: The faults associated with the stator of the generator.
2. **Rotor faults**: The faults associated with the rotor of the generator.
3. **Abnormal running conditions**: This includes number of abnormal conditions which may occur in practice, from which the generator must be protected.

Let us discuss these faults in detail.

**Stator Faults**

The stator faults means faults associated with the three phase armature windings of the generator. These faults are mainly due to the insulation failure of the armature windings. The main types of stator faults are,
1. Phase to earth faults
2. Phase to phase faults
3. Inter-turn faults involving turn of same phase winding.

The most important and common fault is phase to earth fault. The other two are not very common while inter-turn fault is very difficult to detect.

**Phase to Earth Faults**

These faults mainly occur in the armature slots. The faults are dangerous and can cause severe damage to the expensive machine. The fault currents less than 20 A cause negligible burning of core if machine is tripped quickly. But if the fault currents are high, severe burning of stator core can take place. This may lead to the requirement of replacing the laminations which is very costly and time consuming. So to avoid the damage due to phase to earth faults, a separate, sensitive earth fault protection is necessary for the generators along with the earthing resistance.

**Phase to Phase Faults**

The phase to phase faults means short circuit between two phase windings. Such faults are uncommon because the insulation used between the coils of different phases in a slot is large. But once phase to earth fault occurs, due to the over heating phase to phase
fault also may occur. This fault is likely to occur at the end connections of the armature windings which are overheating parts outside the slots. Such a fault causes severe arcing with very high temperatures. This may lead to melting of copper and fire if the insulation is not fire resistant.

**Stator Inter-turn Faults**

The coils used in the alternators are generally multiturn coils. So short circuit between the turns of one coil may occur which is called an inter-turn fault. This fault occurs due to current surges with high value of \( \frac{dL}{dt} \) voltage across the turns. But if the coils used are single turn then this fault can not occur. Hence for the large machines of the order of 50 MVA and more, it is a normal practice to use single turn coils. But in some countries, multi turn coils are very commonly used where protection against inter-turn faults is must.

**Rotor Faults**

The rotor of an alternator is generally a field winding as most of the alternators are of rotating field type. The field winding is made up of number of turns. So the conductor to earth faults and short circuit between the turns of the field winding, are the commonly occurring faults with respect to a rotor. These faults are caused due to the severe mechanical and thermal stresses, acting on the field winding insulation.

The field winding is generally not grounded and hence single line to ground fault does not give any fault current. A second fault to earth will short circuit the part of the field winding and may there by produce an unsymmetrical field system. Such an unsymmetrical system gives rise to the unbalanced forces on the rotor and results in excess pressure on the bearings and the shaft distortion, if such a fault is not cleared very early. So it is very much necessary to know the existence of the first occurrence of the earth fault so that corrective measures can be taken before second fault occurs.

The unbalanced loading on the generator is responsible to produce the negative sequence currents. These currents produce a rotating magnetic field which rotates opposite direction to that of rotor magnetic field. Due to this field, there is induced e.m.f. the rotor winding. This causes overheating of the rotor.

Roter earth fault protection and rotor temperature indicators are the essential and are provided to large rating generators.

**Abnormal Running Conditions**

In practice there are number of situations in which generator is subjected to some abnormal running conditions. The protection must be provided against the abnormal conditions. These abnormal conditions include,

1. Overloading
2. Over speeding
3. Unbalanced loading
4. Over voltage
5. Failure of prime mover
6. Loss of excitation (Field failure)
7. Cooling system failure

**Overloading:**

Due to the continuous overloading, the overheating of the stator results. This may increase the winding temperature. If this temperature rise exceeds certain limit, the insulation of the winding may get damaged. The degree of overloading decides the effects and temperature rise. The over current protection is generally set to very high value hence continuous overloads of less value than the setting cannot be sensed by over current protection.

**Over speeding:**

In case of hydraulic generators a sudden loss of load results in over speeding of the generator. This is because the water flow to the turbine cannot be stopped or reduced.

**Biased Differential scheme (Merz-Price Scheme) for protection of Generators.**

This is most commonly used protection scheme for the alternator stator windings. The scheme is also called biased differential protection and percentage differential protection.

The figure below shows a schematic arrangement of Merz-Price protection scheme for a star connected alternator.
The differential relay gives protection against short circuit fault in the stator winding of a generator. When the neutral point of the windings is available then, the C.T.s may be connected in star on both the phase outgoing side and the neutral earth side, as shown in the above figure. But, if the neutral point is not available, then the phase side CTs are connected in a residual connection, so that it can be made suitable for comparing the current with the generator ground point CT secondary current. The restraining coils are energized from the secondary connection of C.T.s in each phase, through pilot wires. The operating coils are energized by the tappings from restraining coils and the C.T. neutral earthing connection.

The similar arrangement is used for the delta connected alternator stator winding, as shown below.

This scheme provides very fast protection to the stator winding against phase to phase faults and phase to ground faults. If the neutral is not grounded or grounded through resistance then additional sensitive earth fault relay should be provided.

The advantages of this scheme are:
1. Very high speed operation with operating time of about 15 nsec.
2. It allows low fault setting which ensures maximum protection of machine windings.
3. It ensures complete stability under most severe through and external faults.
4. It does not require current transformers with air gaps or special balancing features.

**Earth fault protection of Generators.**

The neutral point of the generator is usually earthed, so as to facilitate the protection of the stator winding and associated system. Impedance is inserted in the earthing lead to limit the magnitude of the earth fault current. Generators which are directly connected to the transmission or distribution system are usually earthed through a resistance which will pass approximately rated current to a terminal earth fault. In case of generator-transformer unit, the generator winding and primary winding of a transformer can be treated as an isolated system that is not influenced by the earthing requirements of the transmission system.

Modern practice is to use a large earthing transformer (5-100 KVA) – the secondary winding which is designed for 100-500V is loaded with a resistor of a value, which when referred through the transformer ratio, will pass a suitable fault current. The resistor is therefore of low value and can be of rugged construction. It is important that the earthing transformer never becomes saturated, otherwise a very undesirable condition of ferro resonance may occur.

**EARTH FAULT PROTECTION**

- Earth fault protection can be obtained by applying a relay to measure the transformer secondary current by connecting a voltage measuring relay in parallel with the load resistor.
2.5.1 Restricted earth fault protection

Generally Merz-Price protection based on circulating current principle provides the protection against internal earth faults. But for large costly generators, an additional protection scheme called restricted earth fault protection is provided. When the neutral is solidly grounded then the generator gets completely protected against earth faults. But when neutral is grounded through earth resistance, then the stator windings get partly protected against earth faults. The percentage of windings protected depends on the value of earthing resistance and the relay setting. In this scheme, the value of earth resistance, relay setting, current rating of earth resistance must be carefully selected. The earth faults are rare near the neutral point as the voltage of neutral point with respect to earth is very less. But when earth fault occurs near the neutral point, then the insufficient voltage across the fault results in a low fault current, that is less than the pickup current of relay coil. Hence the relay coil remains unprotected in this scheme. As it is able to protect a restricted portion of generator winding from earth faults, it is called a restricted earth fault protection. It is usual practice to protect 85% of the winding. The restricted earth fault protection scheme is shown in the above figure. Consider that earth fault occurs on phase B due to breakdown of its insulation to earth, as shown in the Fig. 1. The fault current $I_f$ will flow through the core, frame of machine to earth and complete the path through the earthing resistance. The C.T. secondary current $I_k$ flows through the operating coil and the restricted earth fault relay coil of the differential protection. The setting of restricted earth fault relay and setting of overcurrent relay are independent of each other. Under this secondary current $I_k$, the relay operates to trip the circuit breaker. The voltage $V_{BX}$ is sufficient to drive the enough fault current $I_f$ when the fault point x is away from the neutral point. If the fault point x is nearer to the neutral point then the voltage $V_{BX}$ is small and not sufficient to drive enough fault current $I_f$. And for this $I_f$, relay can’t operate. Thus part of the winding from the neutral point remains unprotected. To overcome this, if relay setting is chosen very low to make it sensitive to low fault currents, then wrong operation of relay may result. The relay can operate under the conditions of heavy through faults, inaccurate C.T.s, saturation of C.T.s etc. Hence practically 15% of winding from the neutral point is kept unprotected, protecting the remaining 85% of the winding against phase to earth faults. Let us see the effect of earth resistance on the percentage of winding which remains unprotected. Consider the earth resistance $R$ is used to limit earth fault current. If it is very small i.e. the neutral is almost solidly grounded, then the fault current is very high. But high fault currents are not desirable hence small R is not preferred for the large machines. For low resistance $R$, the value of $R$ is selected such that full load current passes through the neutral, for a full line to neutral voltage V. In medium resistance $R$, the earth fault current is limited to about 200A for full line to neutral voltage V, for a 60 MW machine.

In high resistance $R$, the earth fault current is limited to about 10 A. This is used for distribution transformers and generator-transformer units. Now higher the value of earth resistance $R$, less is the earth fault current and less percentage of winding gets protected. Large percentage of winding remains unprotected.

Let

$V$ = Full line to neutral voltage
$I$ = Full load current of largest capacity generator
$R$ = Earth resistance

The value of the resistance $R$ is, $R = \frac{V}{I}$

And the percentage of winding unprotected is given by,

$\% \text{ of winding unprotected} = \left(\frac{I_0}{I}\right) \times 100$

Where, $I_0$ = Maximum operating current in the primary of C.T.

If relay setting used is 15% then $I_0$ is 15% of full load current of the largest machine and so on.
1. The unrestricted earth fault protection

The unrestricted earth fault protection uses a residually connected earth fault relay. It consists of three C.T.s, one in each phase. The secondary windings of three C.T.s are connected in parallel. The earth fault relay is connected across the secondaries which carries a residual current. The scheme is shown in the figure below.

Where there is no fault, under normal conditions, vector sum of the three line currents is zero. Hence the vector sum of the three secondary currents is also zero.

So if \( I_{RS} \), \( I_{YS} \) and \( I_{BS} \) C.T. secondary currents then under normal conditions we can write,

\[ I_{RS} + I_{YS} + I_{BS} = 0 \]

The sum of the three currents is residual current \( I_{RS} \) which is zero under normal conditions. The earth fault relay is connected in such a way that the residual current flows through the relay operating coil. Under normal condition, residual current is zero so relay does not carry any current and is inoperative. However in presence of earth fault condition, the balance gets disturbed and the residual current \( I_{RS} \) is no more zero. If this current is more than the pickup value of the earth fault relay, the relay operates and opens the circuit breaker through tripping of of the trip circuit.

In the scheme shown in the figure, the earth fault at any location near or away from the location of C.T.s can cause the residual current. Hence the protected zone is not definite. Such a scheme is hence called unrestricted earth fault protection.

2. Generator and Transformer Unit Biased Differential Protection

In a high voltage transmission system, the bus bars are at very high voltages than the generators. The generators are directly connected to step up transformer to which it is connected, together from a generator transformer unit. The protection of such a unit is achieved by differential protection scheme using circulating current principle. While providing protection to such a unit, it is necessary to consider the phase shift and current transformation in the step up transformer.

The figure in the following page, shows a biased differential protection scheme used for generator transformer unit. The zone of such a scheme includes the stator windings, the step up transformer and the intervening connections.

The transformer is delta-star hence the current transformers on high voltage side are delta connected while those on generator side are star connected. This cancels the displacement between line currents introduced by the delta connected primary of the transformer. Where there is no fault, the secondary currents of the current transformer connected on generator side are equal to the currents in the pilot wires from the secondaries of the delta connected current transformers on the secondary of main transformer. When a fault occurs, the pilot wires carry the differential current to operate the percentage differential relay.

For the protection against the earth faults, an earth fault relays is put in the secondary winding of the main step up transformers as shown. In such a case, differential protection acts as a backup protection to the restricted earth fault protection. This overall differential protection scheme does not include unit transformer as a separate differential scheme is provided ti it.
PHASE FAULT

- Phase-phase faults clear of earth are less common. They may occur on the end portion of stator coils or in the slots if the winding involves two coil sides in the same slot. In the later case the fault will involve earth in a very short time.
  - Phase fault current is not controlled by the method of earthing the neutral point. INTERTURN FAULTS
  - Interturn faults are also uncommon, but not unknown

- A greatest danger arising from failure to deal with interturn faults quickly is fire. A large portion of the insulation is inflammable

**Negative sequence relay : refer to unit 2 Q8**

**Stator Protection Against Interturn Faults**

The Merz-Price protection system gives protection against phase to phase faults and earth faults. It does not give protection against interturn faults. The interturn fault is a short circuit between the turns of the same phase winding. Thus the current produced due to such fault is a local circuit current and it does not affect the currents entering and leaving the winding at the two ends, where C.T.s are located. Hence Merz-Price protection can not give protection against interturn faults.

In single turn generator, there is no question of interturn faults but in multimum generators, the interturn fault protection is necessary. So such interturn protection is provided for multimum generators such as hydroelectric generators. These generator have double winding armatures. This means, each phase winding is divided into two halves, due to the very heavy currents which they have to carry. This splitting of single phase winding into two is advantageous in providing interturn fault protection to such hydroelectric generators. The Fig. 1 shows the interturn fault protection scheme used for the generator with double winding armatures.

The schemes uses cross differential principle. Each phase of the generator is doubly wound and split into two parts S1 and S2 as shown in the Fig.1. The current transformers are connected in the two parallel paths of the each phase winding. The secondaries of the current transformers are cross connected. The current transformers work on circulating current principle. The relay is connected across the cross connected secondaries of the current transformers.

Under normal operation conditions, when the two paths are sound then currents in the two parallel paths S1 and S2 are equal. Hence currents in the secondaries of the current transformers are also equal. The secondary current flows round the loop and is same at all the points. Hence no current flows through the relay and the relay is inoperative.

If the short circuit is developed between the adjacent turns of the part S1 of the winding say then currents through S1 and S2 no longer remain same. Thus unequal currents will be induced in the secondaries of the current transformers. The difference of these currents flows through the relay R. Relay then closes its contacts to trip the circuit breaker which isolates the generator from the system.
Such an interturn fault protection system is extremely sensitive but it can be applied to the generators having doubly wound armatures.

11. Write a short on transmission line (feeder) protection.

Pilot wire schemes for feeder protection

In differential protection scheme, the current entering at one end of the line and leaving from other end of the line is compared. The pilot wires are used to connect the relays. Under normal working condition, the two currents at both ends are equal and pilot wires do not carry any current, keeping relays inoperative. Under an internal fault condition, the two currents at both the ends are no longer same, this causes circulating current flow through pilot wires and makes the relay to trip.

The various schemes used with this method of protection are,

1. Merz-Price Voltage Balance System
2. Translay Scheme

Merz-Price Voltage Balance System

The figure below shows Merz-Price voltage balance system used for the three phase feeders.

Under normal condition, current entering the line at one end is equal to current leaving from the other end. Therefore, equal and opposite voltages are induced in the secondaries of C.T.s. at the two ends resulting in no current flow, through the relay.

Under fault condition, two currents at the two ends are different. Thus the secondary voltages of both the end C.T.s differ from each other. This circulates a circulating current through the pilot wires and the relays. Thus the relays trip the circuit breakers to isolate the faulty section.

The advantages of this method are as follows
1. It can be used for parallel as well as ring main system.
2. It provides instantaneous protection to ground faults.

The limitations of this method are as follows
1. The C.T. s used must match accurately.
2. The pilot wires must be healthy without discontinuity.
3. Economically not suitable as the cost is high due to long pilot wires.
4. Due to long pilot wires, capacitive effects adversely bias the operation of the relays.
5. The large voltage drop in the pilot wires requiring better insulation.

Translay Scheme

The translay relay is another type of differential relay. The arrangement is similar to overcurrent relay but the secondary winding is not closed on itself. Additionally copper ring or copper shading bands are provided on the central limb as shown in the figure below.
In this scheme, two such relays are employed at the two ends of feeder as shown in the figure below.

The secondaries of the two relays are connected to each other using pilot wires. The connection is such that the voltages induced in the two secondaries oppose each other. The copper coils are used to compensate the effect of pilot wire capacitance currents and unbalance between two currents transformers.

Under normal operating conditions, the current at the two ends of the feeder is same. The primaries of the two relays carry the same currents inducing the same voltage in the secondaries. As these two voltages are in opposition, no current flows through the two secondaries circuits and no torque is exerted on the discs of both the relays.

When the fault occurs, the currents at the two ends of the feeder are different. Hence unequal voltages are induced in the secondaries. Hence the circulating current flows in the secondary circuit causing torque to be exerted on the disc of each relay. But as the secondaries are in opposition, hence torque in one relay operates so as to close the trip circuit while in other relay the torque restricts the operation. Care must be taken so that, at least one relay operates under the fault condition.

**Role of copper ring:** Mainly relays may operate because of unbalance in the current transformers. The copper rings are so adjusted that the torque due to current induced in the copper ring due to primary winding of relay is restraining and do not allow the disc to rotate. It is adjusted just to neutralize the effect of unbalance existing between the current transformers. The copper rings also neutralize the effect of pilot capacitive currents. Though the feeder current is same at two ends, a capacitive current may flow in the pilots. This current leads the secondary voltage by 90°. The copper rings are adjusted such that no torque is exerted on the disc, due to such capacitive pilot currents. Therefore in this scheme the demerits of pilot relaying scheme is somewhat taken care of.

The advantages of this scheme are,
1. Only two pilot wires are required.
2. The cost is very low.
3. The current transformers with normal design can be employed.
4. The capacitive effects of pilot wire currents do not affect the operation of the relays.

**Carrier Current unit protection system**

The basic block diagram and various components
The schematic diagram of the carrier current scheme is shown below. Different basic components of the same are discussed below.

The Coupling capacitor

These coupling capacitors (CU) which offer low reactance to the higher frequency carrier signal and high reactance to the power frequency signal. Therefore, it filters out the low (power) frequency and allows the high frequency carrier waves to the carrier current equipments. A low inductance is connected to the CU, to form a resonant circuit.

Wave Traps

The Wave traps (also known as Line Trap) are inserted between the busbar and the connection of the CU. These traps are L and C elements connected in parallel, and they are tuned in such a manner that they offer low reactance to the power frequency signals and high reactance to the carrier waves. They ensure that neither of these different frequency signals get mixed up before being received at the bus bar.

Both the CU and the Wave traps are protected from switching and lightening surges, with the help suitably designed Spark Gaps or Varistors.

Frequency spacing

Different frequencies are used in adjacent lines and the wave traps ensure that carrier signals of other lines do not enter a particular line section. Therefore, proper choice of frequency bands for different lines are adopted.

Transmitter Unit

In a Transmitter unit, the carrier frequency in the range of 50 to 500 KHz of constant magnitude is generated in the oscillator, which is fed to an amplifier. Amplification is required to overcome any loss in the coupling equipments, weather conditions, Tee connections in the lines of different size and length. The amplifier and the oscillators are constantly energized and a connection is made between the two with the help of a control unit.
The Receiver unit consists of an attenuator and a Band pass filter, which restricts the acceptance of any unwanted signals. The unit also has matching transformer to match the line impedance and that of the receiver unit.

The Modulator modulates, the 50 Hz power signals with high frequency carrier waves and the modulated signal is fed to an amplifier. The amplifier output is transmitted via a CU. It takes half a cycle of power signal to produce requisite Blocks of carrier as shown above.

The Schematic of CCE

The CTs connected to the transmission line feed the Summation block which consist of Network sequence filters. It transforms the CT output to a single phase voltage signal that is representative of the fault condition. The voltage signal is used to control the output from
the local transmitter unit, through the starting relay known as Starter. It therefore initiates comparison between the local transmitter output and the signal received from the remote receiver in the comparator. The comparator output condition then initiates the Trip relay.

The principle of Phase Comparison is one of the methods that involve decision of tripping. As shown above, the presence of blocks of carrier signals abort any tripping and its absence initiates the tripping. Therefore, in a section of transmission line, where CTs at both end buses are connected 180 degree out of phase, an absence of carrier signal can only be possible if an internal fault has occurred. However, it can be seen that such absences of carrier blocks is not possible for an external fault.

12.Write a short note on protection of power transformer
Protection of Transformers:
The transformers are static devices without having any rotating part and are totally enclosed. Hence the chances of faults occurring on transformers are much rare as compared to the faults occurring on generators. Similarly possibilities of running on abnormal conditions are also less in transformers compared to the generators.
But though the fault possibility is rare, if fault occurs, the transformer must be quickly disconnected from the system. The rare faults if not cleared quickly can get developed into the major faults which may be very serious for the transformer. Hence the protection must be provided to the transformers against possible faults.
The use of series fuses is very common in case of small distribution transformers instead of circuit breakers. Hence it is not necessary to install any automatic protective relaying equipments with the distribution transformers. But the power transformers having large ratings always need some type of automatic protective relaying equipments, to give protection against the possible faults.
Possible Transformer Faults:
The generators are subjected to the number of faults and abnormal conditions but the transformers are not. The various possible transformer faults are,
1. Over heating
2. Winding faults
3. Open circuits
4. Through faults
5. Over fluxing
Let us discuss these faults.
Overheating:
The overheating of the transformer is basically of sustained overloads and short circuits. The permissible overload and the corresponding duration is dependent on the type of transformer and class of insulation used for the transformer. Higher loads are permissible for very short duration of time. The overloading which continues for longer time is dangerous as it causes overheating of the transformer. Similarly the failure of the cooling system, though rare, is another possible cause of overheating. Generally the thermal overload relays and temperature relays, sounding the alarm are used to provide protection against overheating. Similarly temperature indicators are also provided. On the transformers, when temperature exceeds the permissible limits, the alarm sounds and the fans are started. The thermocouples or resistance temperature indicators are also provided near the winding. These are connected in a bridge circuit. When temperature exceeds the limiting safe value, the bridge balance gets disturbed and alarm is sounded. If the corrective action is not taken within certain period of time then the circuit breaker trips.

Winding Faults

The winding faults are called internal faults. These faults are,

i. Phase to phase faults
ii. Earth faults
iii. Interterm faults

The overheating or mechanical shocks cause to deteriorate the winding insulation. If the winding insulation is weak, there is a possibility of short circuit between the phases or between the phase and ground. Also the possibility of short circuit between the adjacent turns of the same phase winding is also possible.

When such an internal fault occurs, the transformer must be quickly disconnected from the system. If such a fault persists for longer time, there is possibility of oil fire. The differential protection is very commonly used to provide protection against such faults. But this protection is not economical for the transformers below 5 MVA for which an over current protection is used. For the high capacity transformers in addition to main differential protection, the over current protection is also provided as a backup protection. For earth fault protection, the restricted earth fault protection system, neutral current relays, or leakage to frame protection system is used.

Open Circuits:

The open circuit in one of the three phases is dangerous as it causes the undesirable heating of the transformer. A separate relay protection is not provided for the open circuits as open circuits are much harmless compared to other faults. In case of such faults, the transformer can be manually disconnected from the system.

Through Faults

Through faults are the external faults which occur outside the protected zone. Through faults are not detected by the differential protection. If the through faults persists for long period of time, the transformer may get subjected to the thermal and mechanical stresses which can damage the transformer. The over current relays with under voltage blocking, zero sequence protection and negative sequence protection are used to give protection against through faults. The setting of the over current protection not only protects the transformer but also covers the station busbar and portion of a transmission line. Such a protection acts as a backup protection for the differential protection.

Over fluxing

The flux density in the transformer core is proportional to the ratio of the voltage to frequency i.e. V/f. The power transformers are designed to work with certain value of flux density in the core. In the generator transformer unit, if full excitation is applied before generator reaches its synchronous speed then due to high V/f the over fluxing of core may result. Higher core flux means more core loss and overheating of the core. The saturation of magnetic circuit is also the probable cause for the over fluxing operation. The V/f relay called volts/hertz relay is provided to give the protection against over fluxing operation. This relay does not allow exciting current to flow till the generator reaches to a synchronous speed and runs to produce voltage of proper frequency. The over fluxing relays with enough time lag also can be provided.

Apart from these faults, some other faults like tap-changer faults, high voltage surges due to lightning and switching, incipient faults i.e. slow developing faults may also occur in the transformers. The Buchholz relay is used for oil immersed transformers to give the protection against incipient faults.

Transformer differential protection

Basic discussions related to the Merz-Price Scheme and its limitations which are taken care by the biased differential scheme, are omitted for repetition.

Basic considerations

a. Transformation ratio

The nominal currents in the primary and secondary sides of the transformer vary in inverse ratio to the corresponding voltages. This should be compensated for by using different transformation ratios for the CTs on the primary and secondary sides of the transformer.

b. Current Transformer Connections

When a transformer is connected in star/delta, the secondary current has a phase shift of $30^\circ$ relative to the primary

- This phase shift can be offset by suitable secondary CT connections
- The zero sequence currents flowing on the star-side of the transformer will not produce current outside the delta on the other side. The zero sequence current must therefore be eliminated from the star-side by connecting the CTs in delta.
- The CTs on delta side should be connected in star in order to give $30^\circ$ phase shift.
- When CTs are connected in delta, their secondary ratings must be reduced to 1/3 times the secondary ratings of the star-
connected transformer, in order that the currents outside the delta may balance with the secondary currents of the star-connected CTs.

- If transformers were connected in star/star, the CTs on both sides would need be connected in delta-delta.

c. Bias to cover tap-changing facility and CT mismatch

- If the transformer has the benefit of a tap changer, it is possible to vary its transformation ratio for voltage control.
- The differential protection system should be able to cope with this variation.
- This is because if the CTs are chosen to balance for the mean ratio of the power transformer, a variation in ratio from the mean will create an unbalance proportional to the ratio change. At maximum through fault current, the spill output produced by the small percentage unbalance may be substantial
- Differential protection should be provided with a proportional bias of an amount which exceeds in effect the maximum ratio deviation. This stabilizes the protection under through fault conditions while still permitting the system to have good basic sensitivity.

d. Magnetization Inrush

- The magnetizing inrush produces a current flow into the primary winding that does not have any equivalent in the secondary winding. The net effect is thus similar to the situation when there is an internal fault on the transformer.
- Since the differential relay sees the magnetizing current as an internal fault, it is necessary to have some method of distinguishing between the magnetizing current and the fault current using one or all of the following methods.
  - Using a differential relay with a suitable sensitivity to cope with the magnetizing current, usually obtained by a unit that introduces a time delay to cover the period of the initial inrush peak.
  - Using a harmonic-restraint unit, or a supervisory unit, in conjunction with a differential unit.
  - Inhibiting the differential relay during the energizing of the transformer.

Compared to the differential protection used in generators, there are certain important points discussed below which must be taken care of while using such protection for the power transformers.

1. In a power transformer, the voltage rating of the two windings is different. The high voltage winding is low current winding while low voltage winding is high current winding. Thus there always exists difference in current on the primary and secondary sides of the power transformer. Hence if C.T.s of same ratio are used on two sides, then relay may get operated through there is no fault existing.

   To compensate for this difficulty, the current ratios of C.T.s on each side are different. These ratios depend on the line currents of the power transformer and the connection of C.T.s. Due to the different turns ratio, the currents fed into the pilot wires from each end are same under normal conditions so that the relay remains inoperative. For example if K is the turns ratio of a power transformer then the ratio of C.T.s on low voltage side is made K times greater than that of C.T.s on high voltage side.

2. In case of power transformers, there is an inherent phase difference between the voltages induced in high voltage winding and low voltage winding. Due to this, there exists a phase difference between the line currents on primary and secondary sides of a power transformer. This introduces the phase difference between the C.T. secondary currents, on the two sides of a power transformer. Through the turns ratio of C.T.s are selected to compensate for turns ratio of transformer, a differential current may result due to the phase difference between the currents on two sides. Such a different current may operate the relay though there is no fault. Hence it is necessary to correct the phase difference.

   To compensate for this, the C.T. connections should be such that the resultant currents fed into the pilot wires from either sides are displaced in phase by an angle equal to the phase shift between the primary and secondary currents. To achieve this, secondaries of C.T.s on star connected side of a power transformer are connected in delta while the secondaries of C.T.s on delta connected side of a power transformer are connected in star.

   The table I gives the way of connecting C.T. secondaries for the various types of power transformer connections.

   ![Diagram](image)

<table>
<thead>
<tr>
<th>Power Transformer Connections</th>
<th>C. T. Connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>Secondary</td>
</tr>
<tr>
<td>Star</td>
<td>Delta</td>
</tr>
<tr>
<td>Delta</td>
<td>Star</td>
</tr>
<tr>
<td>Star</td>
<td>Delta</td>
</tr>
<tr>
<td>Delta</td>
<td>Star</td>
</tr>
</tbody>
</table>

With such an arrangement, the phase displacement between the currents gets compensated with the oppositely connected C.T.
secondaries. Hence currents fed to the pilot wires from both the sides are in phase under normal running conditions and the relay is ensured to be inoperative.

3. The neutrals of C.T. star and power transformer stars are grounded.

4. Many transformers have tap changing arrangement due to which there is a possibility of flow of differential current. For this, the turns ratio of C.T.s on both sides of the power transformer are provided with tap for of C.T.s on both sides of the power transformer are provided with tap for their adjustment.

For the sake of understanding, the connection of C.T. secondaries in delta for star side of power transformer and the connection of C.T. secondaries in star for delta

**STAR/DELTA UNIT**

Let us study the Differential protection for the star-delta power transformer. The primary of the power transformer is star connected while the secondary is delta connected. Hence to compensate for the phase difference, the C.T. secondaries on primary side must be connected in delta while the C.T. secondaries on delta side must be connected in star.

![Diagram](image)

The star point of the power transformer primary as well as the star connected C.T. secondaries must be grounded. The restraining coils are connected across the C.T. secondary windings while the operating coils are connected between the tapping points on the restraining coils and the star point of C.T. secondaries.

With the proper selection of turns ratio of C.T.s the coils are under balanced condition during normal operating conditions. The C.T. secondaries carry equal currents which are in phase under normal conditions. So no current flows through the relay and the relay is inoperative.

It is important to note that this scheme gives protection against short circuit faults between the turns i.e. interturn faults also. This is because when there is an interturn fault, the turns ratio of power transformer gets affected. Due to this the currents on both sides of the power transformer become unbalanced. This causes an enough differential current which flows through the relay and the relay operates.
STAR/STARUNIT
The figure above shows the Merz-Price protection system for the star-star power transformer. Both primary and secondary of the power transformer are connected in star and hence C.T. secondaries. The operating coils are connected between the tapping on the restraining coil and the ground. The operation of the scheme remains same for any type of power transformer as discussed for star-star power transformer.

Frame leakage protection

This is purely an earth fault system, and in principle involves simply measuring the fault current flowing from the transformer frame to earth. To this end a current transformer is mounted on the earthing conductor and is used to energize a

Buchholz relay refer to Q5

Unit-4

2 mark

1. Define sampling theorem (AU MAY 2017)
A continuous time signal can be represented in its samples and can be recovered back when sampling frequency $f_s$ is greater than or equal to the twice the highest frequency component of message signal.

2. Write about numerical transformer differential protection (AU MAY 2017)
3. Define static relay (AU NOV 2017)
An electrical relay in which the designed response is developed by electronic, magnetic, optical or other components without mechanical motion.

4. Define phase comparator and amplitude comparator (AU NOV 2017)

Amplitude Comparator
Comparing the magnitudes of two quantities means the operating quantity and restraining quantity regardless of the value of phase angle when magnitude of operating quantity exceed that of restraining quantity the relay operate and send trip signal to circuit breaker

Types: integrating amplitude, instantaneous amplitude, sampling amplitude

Phase Comparator
A phase comparator compares the phase angle of two input quantities, regardless of their amplitude, and output appears when the phase angle between them is lying within specified limits (<90°) examples are directional relay distance relay excluding impedance type relay and other phase comparison relays.

5. Mention the advantages and disadvantage of static relay (AU NOV 2014)

Advantages:
- The moving parts are absent. The moving parts are present only in the actual tripping circuit and not in the control circuit.
- The burden on current transformers gets considerably reduced thus smaller C.T's can be used.
- The power consumption is very low as most of the circuits are electronic.
- The response is very quick
- As moving parts are absent, the minimum maintenance is required. No bearing friction or contact troubles exist.
- The resetting time can be reduced and overshots can be reduced due to absence of mechanical inertia and thermal storage.
- The sensitivity is high as signal amplification can be achieved very easily.
- The use of printed circuits eliminates the wiring errors and mass production is possible.
- As electronic circuits can be used to perform number of functions, the wise range of operating characteristics can be obtained which almost approach to ideal requirements.
- The low energy levels required in the measuring circuits make the relays smaller and compact in size.

Disadvantages:
- The characteristics of electronic components such as transistors, diodes etc. are temperature dependent. Hence relay characteristics vary with temperature and ageing.
- The reliability is unpredictable as it depends on a large number of small components and their electrical connections
- These relays have low short time overload capacity compared to electromagnetic relays.
- Additional d.c. supply is required for various transistor circuits.
- Susceptible to the voltage fluctuations and transients.
- Less robust compared to electromagnetic relays.

6. What is the use of multiplexer in Microprocessor based relays?
Analog inputs such as currents and voltage are multiplexed in the multiplier and then converted into digital signals in A/d converter.
7. Comparison of static and Electromagnetic relays?
- The electromagnetic relays to the moving parts as an armature.
- These relays are robust and mighty reliable.
- The current and potential transformers are subjected to high burdens in case of electromagnetic relays.
- Static relays are using the transistors circuits called transistor relay.
- The transistor circuits can perform like summation, integration, comparison etc.

8. Limitation of numerical relay
Often relay on non-proprietary software, exposing the system to risk of hacking
Has exposure to externally sourced transient interference that would not affect conventional technology

9. Draw the block diagram of static relay/list the main parts of static relay

10. Draw the block diagram of numerical relay

11. Define numerical relay
is the relay in which measured AC quantities are subsequently sampled and converted into numerical data that is mathematically AND/OR logically processed to make trip decision

12. State the role of comparator in static relay
Is apart of static relay which receives two or more inputs to be compared and gives output based on comparison
Types
Amplitude comparator
Phase comparator
Hybrid comparator

13. List the various electronic components in static relay
Rectifier, RMU: (relay measuring unit consist of level detector, filter, comparator, voltage stabilizer), unijunction transistor, thyristor, amplifier, trip circuit, logic circuit, time delay circuit, multivibrator etc

14. List the various amplitude and phase comparator in static relay
Phase comparator (i) cosine type, (ii) sine type
Amplitude comparator (i) integrated comparator (ii) instantaneous comparator (iii) sampling comparator

15. State the advantage (features) of numerical relay
Flexible, fast in operation, compact, multi function, highly reliable

16. State the role level detector in static relay
level detector circuits are very often employed in static relay circuits as a final stage before the trip coil circuit of the circuit breaker. The name level detector is derived from the fact that the circuit operates abruptly when the input level exceeds a predetermined value.
17. state the role of time delay in static relay
Time delay is defined as the controlled period between the functioning of two events. A Time delay relay is a combination of an electromechanical output relay and a control circuit. The control circuit is comprised of solid state components and timing circuits that control operation of the relay and timing range.

18. basic components of numerical relay
Digital processor, signal conditioners, anti aliasing filters, multiplexers, sample hold ckt ect

19. state the role sample and hold ckt
In electronics, a sample and hold (S/H, also "follow-and-hold"[1]) circuit is an analog device that samples (captures, takes) the voltage of a continuously varying analog signal and holds (locks, freezes) its value at a constant level for a specified minimum period of time. Sample and hold circuits are used in linear systems. In some kinds of analog-to-digital converters, the input is compared to a voltage generated internally from a digital-to-analog converter (DAC).

20. state the features of numerical relay
Flexible, fast in operation, compact, multi function , highly reliable

13 MARKS

1. explain the block diagram of numerical relay with necessary diagram (AU MAY 2017)

Define numerical relay
is the relay in which measured AC quantities are subsequentially sampled and converted into numerical data that is mathematically AND/OR logically processed to make trip decision

**Basic components of numerical relay:**
Signal conditioning subsystem
Conversion subsystem
Digital processing relay

**Digital relay comprises both hardware and software. The hardware is described briefly here.**

**CPU:** responsible for processing the protection algorithms including digital filtering

**Memory:** made up of two memory components:
- **RAM** (random access memory) which has various functions, including retaining the incoming data which is input to the CPU and is necessary for storing information during the compilation of the protection algorithm.
- **ROM** (read only memory) which is used for storing programs permanently.
2. with a neat sketch discuss in detail about the synthesis of reactance relay using phase comparator (AU MAY 2017)

Refer Q8

3. draw and explain the block diagram of a static relay and state its advantage (AU MAY 2016) (AU NOV 2017)

The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc are called static relays. The circuits such as comparators, level detectors, zero crossing detectors etc. designed using electronic components are used in the static relays for measurement and comparison of electrical quantities. The static relay is designed in such a way that whenever a quantity under consideration exceeds a particular level, the static circuit produces a response without any moving parts such as armature. This response is then manipulated and given to tripping circuit which may be electronic. Thus static relay response circuit does not have moving parts and made up of electronic components but its tripping circuit may be electronic or electromagnetic.

The relaying quantity can be the output of C.T or P.T or it may be combination of various signals. Thus an electronic circuit such as rectifier is required as an input element to get the input signal in a convenient form before applying it to a measuring element. Some mixing circuits such as op-amp adder may also be required as an input element.

1. Input Element

The relaying quantity can be the output of C.T or P.T or it may be combination of various signals. Thus an electronic circuit such as rectifier is required as an input element to get the input signal in a convenient form before applying it to a measuring element. Some mixing circuits such as op-amp adder may also be required as an input element.

2. Measuring Element

This is heart of the static relay. It compares the output of an input element with a set value and decides the signal to be applied to the output element which ultimately drives the tripping circuit. Thus measuring elements is a deciding signal generator.
Measuring element can be classified as
1. Single input device
2. Two input device
3. Multi input device

The single input devices depending on the protection and control schemes are further classified as

a. **Non critical Repeat Function All or Nothing Relay**
   
   As the name suggest, these devices are completely unenergized or energized much higher than the marginal condition required, to produce very fast response. It can be represented as shown in the fig 1.21. The input R is either zero or too higher than the marginal operating level. Such devices are instantaneous with response time less than 20 ms. The switching power gain associated with them is generally $10^3$. Such devices have multiple output contacts. The main functions of such devices in the protection are
   1. To produce final tripping signal to the circuit breaker.
   2. To produce signals to perform supplementary functions such as alarming intertripping etc.
   3. To act as intermediate switching stages in a complex protection scheme.

b. **Critical measuring function:**
   
   This device is a sort of on off controller. It activates when the input signal reaches to some critical level decided by the protection scheme. Such a device is shown in the fig 2.22
   
   Thus when input $R$ is greater than some critical value $P$, it operates, while for reset input $R$ must be less than $K_p (k \leq 1)$
   
   It has only one output and switching gain need not be high. The output of such device then can be connected to instantaneous non-critical to obtain multiple outputs.
   
   The various requirements of critical function devices are
   1. High accuracy
   2. Long term consistency
   3. Fast and reliable operation
   4. High controllable reset ration

   c. **Definite of fixed function:** This is nothing but a delay function element. It produces a define time delay between its input and the output. The delay may be provided between the application of input and activation of output or between removal of input and resetting of output. It is shown in the Fig 2.22

   The input is non-critical type i.e. either zero or too high than the marginal requirement. Practically charging time of a capacitor is controlled to obtain fixed time delay.

   d. **Input Dependent Time Function:**
   
   This function depends on the input characteristics and decides the time accordingly. The common form of input dependent time function characteristics is
   
   $t = f(R^n)$ where $R =$input $t$
   
   and $n =$negative
   
   The function and its characteristics are shown in the fig 2.23
   
   As $n$ is negative as the input increase the operating time decreases. So operating time is inversely proportional to some power of the input. The examples of such relays are inverse definite minimum time lag over current and earth fault relays.
   
   The two input devices are very common such as comparators, level detectors etc. While multiple input devices are extension of two input devices to extend the range of characteristics.

   **Output Element**
   
   The signals obtained from the measuring element are required to be amplified before applying to the tripping circuit. Thus output element is an amplifier. Sometimes this element not only amplifies the signals but multiplies them or combines them with other signals to delay them.

   **Feed Element**
   
   The measuring element uses electronic circuits consisting transistors, diodes etc. The output element uses transistor as an amplifier. All these components, circuits along with the tripping circuit require d.c. supply for the proper functioning. The feed element provides the d.c. Voltage required by the various elements.

   **Comparison of static and Electromagnetic Relays**
The conventional electromagnetic relays use the moving parts such as an armature, disc etc. Thus they are bulky in size. These relays are robust and highly reliable. These are subjected to differential forces under fault conditions and hence required to have delicate setting of small contact gaps, special bearing arrangements, clutch assemblies etc. Thus there are lot of manufacturing difficulties and problems related to mechanical stability associated with electromagnetic relays. The current and potential transformers are subjected to high burdens in case of electromagnetic relays.

The static relays are commonly using the transistor circuits and called transistor relays. This is because transistor can be used as an amplifying device as well as a switching device. Hence any functional characteristics as per the requirement can be obtained. By the static relays. The transistor circuits can perform functions like summation, integration, comparison etc.

Advantages of Static relays
The various advantages of static relays are
1. The moving parts are absent. The moving parts are present only in the actual tripping circuit and not in the control circuit,
2. The burden on current transformers gets considerably reduced thus smaller C.T’s can be used.
3. The power consumption is very low as most of the circuits are electronic.
4. The response is very quick
5. As moving parts are absent, the minimum maintenance is required. No bearing friction or contact troubles exist.
6. The resetting time can be reduced and overshoots can be reduced due to absence of mechanical inertia and thermal storage.
7. The sensitivity is high as signal amplification can be achieved very easily.
8. The use of printed circuits eliminates the wiring errors and mass production is possible.
9. As electronic circuits can be used to perform number of functions, the wise range of operating characteristics can be obtained which almost approach to ideal requirements.

1. The low energy levels required in the measuring circuits make the relays smaller and compact in size.

Limitations of Static Relays
In spite of various advantages, the static relays suffer from the following limitations.
2. The characteristics of electronic components such as transistors, diodes etc. are temperature dependent. Hence relay characteristics vary with temperature and ageing.
3. The reliability is unpredictable as it depends on a large number of small components and their electrical connections
4. These relays have low short time overload capacity compared to electromagnetic relays.
5. Additional d.c. supply is required for various transistor circuits.
6. Susceptible to the voltage fluctuations and transients.
7. Less robust compared to electromagnetic relays.

Now a days effect of temperature on the semiconductor devices can be compensated by careful design of the circuits.

4. describe the operation static over current relay (AU NOV 2017)

- The secondaries of CT are connected to the summation circuit
- Output of summation CT is given to the input CT, input CT is called auxiliary CT which has taps on the primary for selecting the required pickup and current range
- The input CT is called auxiliary which has taps on the primary for selecting the required pickup and current range
- Then the output of auxiliary CT is rectified and smoothened
- It is then applied to overload detector and RC timing circuit
- When the voltage across the timing capacitor reaches critical value then it trigger the level detector. output of level detector is amplified and given to trip circuit

Fig. 8.12 Block diagram of time current static relay
5. Discuss in detail about numerical over current relay

![Block Schematic Diagram of proposed NPR for Over Current Protection](image-url)
6. Discuss in detail about numerical transformer differential relay

Algorithm
- Read percentage bias B and minimum pick up current $I_{pu}$
- Read $I_p$ samples estimate $I_p$ phasor using any tech
- Read $I_s$ sample estimate $I_s$ phasor using any technique
- Compute spill current $I_{p} - I_{s}$
- Compute circulating current $=(I_p + I_s)/2$
- $I_{p} - I_{spill} > (B \times I_{cir} + I_{pu})$ then trip, else restrain

7. Discuss in detail about numerical distance protection of transmission line
8. With neat sketch discuss in detail about the synthesis of distance relay.

In the distance relay, the operation is dependent on the ratio of the voltage and current, which is expressed in terms of an impedance. The relay operates when the ratio \( V/I \) i.e. impedance is less than a predetermined value. The distance relays include impedance, reactance and admittance relays as discussed earlier. In static relays the comparison of voltage and current is achieved by electronic comparator circuits.

The line voltage \( V_L \) and line current \( I_L \) are given as the inputs to the two measuring circuits. The circuits produce the outputs \( S_1 \) and \( S_2 \) depending upon their characteristics. Thus,

\[
S_1 = K_1 V_L + K_2 I_L \\
S_2 = K_3 V_L + K_4 I_L
\]

where \( K_1, K_2, K_3 \) and \( K_4 \) are to be selected according to the requirement of the characteristics.

Now depending upon whether the comparator is amplitude or phase comparator and the constants \( K_1 \) to \( K_4 \), the various characteristics of the distance relay can be obtained.

The various types of derived voltages \( S_1 \) and \( S_2 \) for amplitude and phase comparators to obtain particular characteristics are given in the Table 8.1.

<table>
<thead>
<tr>
<th>No.</th>
<th>Amplitude comparator</th>
<th>Phase comparator</th>
<th>Distance relay scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operating</td>
<td>Restraining</td>
<td>Operating</td>
</tr>
<tr>
<td></td>
<td>(</td>
<td>I_L + \frac{V_L}{Z_a}</td>
<td>)</td>
</tr>
<tr>
<td>1</td>
<td>( I_L )</td>
<td>( \frac{V_L}{Z_a} )</td>
<td>( I_L Z_a - V_L )</td>
</tr>
<tr>
<td>2</td>
<td>(</td>
<td>I_L - \frac{V_L}{Z_a}</td>
<td>)</td>
</tr>
<tr>
<td>3</td>
<td>( I_L )</td>
<td>( \frac{V_L}{Z_a} )</td>
<td>( I_L Z_a - V_L )</td>
</tr>
<tr>
<td>4</td>
<td>(</td>
<td>I_L</td>
<td>)</td>
</tr>
</tbody>
</table>
9. with neat sketch discuss in detail about the synthesis of differential relay

A differential relay is the relay which operates when the phasor difference of two or more similar electrical quantities exceed a predetermined value.

In static differential relay, two similar quantities either voltages or currents are compared. The comparator measures the vector difference between the two similar input signals. The rectifier bridge type comparator is generally used in the static differential relay. The block diagram is shown in the Fig. 8.17.

In normal conditions, the two quantities balance each other and the comparator output is zero and the relay is inoperative.

For any internal fault conditions, the comparator senses the phase difference between the two quantities and produces the output. This is amplified and given to the trip circuit which operates the relay.

This scheme is used for protection of the generators and transformers against any type of internal fault.

The various advantages of static differential relay over electromagnetic differential relay are, highly sensitive, compact, very fast in operation, low power consumption, less burden on input CTs and inrush current proof characteristics.
10. Discuss in details various electronic components of static relay

**Semiconductor diodes**: This includes the conventional p-n junction diode, zener diode, avalanche diode and the circuits using these diodes such as rectifiers, regulators, references etc.

**Transistors**: This includes bipolar junction transistors (BJT) and field effect transistors (FET). The transistors are used as amplifiers or as switches in the static relays. The direct coupled amplifiers using transistors are also used in the static relays.

**Logic circuits**: Most of the relays are bistable devices i.e. they are operated in two stable states either ON or OFF. The logic circuit also has two states high i.e. ON and low i.e. OFF. Hence logic circuits play an important role in the static relays.

**Filter circuits**: The RC and LC filters are also used in static relays after rectifiers to obtain smoothing of d.c. voltage generated. To obtain fast smoothing instead of conventional capacitor filter, the phase splitting before the rectification is used in static relays.

**Multivibrators**: The various multivibrators using transistors are used to produce square waveforms in static relays. The diode clippers also can be used to obtain square waveforms.

**Time delay circuits**: The variety of time delay circuits such as delay lines, RC circuits, timer circuits, resonant circuits using transistors, thyristors and ICs are used in static relays. Depending upon the requirement of time delay, the particular circuit is chosen. The delay lines are used for shorter delays while RC charging and discharging circuits are used for longer delays. The time delays of the order of micro secs to hours can be achieved using such time delay circuits.

**Level detectors**: In static relays, it is necessary to detect the operating levels of various signals and used it to produce the necessary actuating signals. The level detector circuits using the diodes, rectifier and RC elements are commonly used in static relays.

11. Discuss in detail about the various comparator in static relay

**Comparator**

The magnitude of voltage & current and phase angle between them may change when a fault occurs. Static relay senses the change in these parameters to differentiate between healthy and faulty conditions. This is achieved by comparing either the magnitudes of voltage & current or the phase angle between them. The circuitry which performs this function is called comparator.

**Two types** – amplitude comparator and phase comparator

**Circulating current Comparator**

10. Discuss in details various electronic components of static relay

Let $n_o$ and $n_r$ be the number of turns of operating and restraining coils respectively. Then the relay operates when,

$$k_1 n_o I_o > k_2 n_r I_r + K'$$

where $k_1$ and $k_2$ are design constants while $K'$ is the spring control torque.

$10. \text{discuss in details various electronic components of static relay}$

$11. \text{Discuss in detail about the various comparator in static relay}$

$\textbf{Comparator}$

The magnitude of voltage & current and phase angle between them may change when a fault occurs. Static relay senses the change in these parameters to differentiate between healthy and faulty conditions. This is achieved by comparing either the magnitudes of voltage & current or the phase angle between them. The circuitry which performs this function is called comparator.

$\textbf{Two types} – \text{amplitude comparator and phase comparator}$

$\textbf{Circulating current Comparator}$

$I_o$ and $I_r$ are operating and restraining currents.

Under no fault condition, $I_r > I_o$. The differential current flows through the relay in $-ve$ direction.
During a fault, $i_o > i_r$. Hence the differential current flows through the relay in +ve direction to trip C.B

**Opposed Voltage Comparator**

$V_O$ and $V_r$ are operating and restraining voltages. Under no fault condition, $V_r > V_O$. The differential current flows through the relay in -ve direction. During a fault, $V_o > V_r$. Hence the differential current flows through the relay in +ve direction to trip C.B.

**Phase Comparator**

Period of coincidence of +ve polarity of 2 signals are compared with a reference angle. (usually 90 degree)

If the 2 signals have a phase difference of $\phi$, then the angle of coincidence $\psi = 180 - \phi$.

If $\phi < 90^\circ$, then $\psi > 90^\circ$. The phase comparator may be designed to trip the C.B, when $\psi > 900$.

The period of coincidence is measured by different

**Block and Spike Phase Comparator**

In this method, one of the two input signals is converted into a square wave and the other is converted into a spike during its peak. Square wave and spike are given to an AND gate whose output is 1 when both square wave and spike are coinciding. Coincidence will happen only when the angle between the input signals are less than 900 which indicates a fault. Output of AND gate is used to trip the C.B

**Phase Splitting Comparator**

- In this method, two phase shifted (+/-45°) components are obtained for each of the input signals.
- These 4 components are fed into an AND gate.
- Output will be 1 if all 4 signals are positive at a time. This happens only during a faulty condition.
- Output of AND gate is used to trip the C.B
Unit-5
2 mark

1. Define restricking voltage and recovery voltage (AU MAY 2017) (AU NOV 2017)
recovery voltage: The power frequency rms voltage appearing across the breaker contacts after the arc is extinguished and transient oscillations die out is called recovery voltage.
restricking voltage: It is the transient voltage appearing across the breaker contacts at the instant of arc being extinguished.

2. What is rupturing (breaking) capacity? (AU MAY 2017)
It is the RMS current that a C.B is capable of breaking at given recovery voltage and under specified condition.

3. Write the inference of resistance switching (AU MAY 2016)
It is the method of connecting a resistance in parallel with the contact space (arc). The resistance reduces the restricking voltage frequency and it diverts part of the arc current. It assists the circuit breaker in interrupting the magnetizing current and capacity current.

4. List out the various methods of arc interruption (AU MAY 2016)
High resistance interruption: the arc resistance is increased by elongating, and splitting the arc so that the arc is fully extinguished.
Current zero method: The arc is interrupted at current zero position that occurs 100 times a second in case of 50Hz power system frequency in ac.

5. How do you classify the circuit breakers (AU MAY 2016) (AU NOV 2014)
- Air break circuit breaker
- Oil circuit breaker
- Minimum oil circuit breaker
- Air blast circuit breaker
- SF6 circuit breaker
- Vacuum circuit breaker

6. What are the advantages and disadvantage of SF6 circuit breaker (AU MAY 2016) (AU MAY 2015)
Advantages:
- Due to superior arc quenching property of SF6, such breakers have very short arcing time
- Dielectric strength of SF6 gas is 2 to 3 times that of air, such breakers can interrupt much larger currents.
- Gives noiseless operation due to its closed gas circuit
- Closed gas enclosure keeps the interior dry so that there is no moisture problem
- There is no risk of fire as SF6 is non-inflammable
- There are no carbon deposits
- Low maintenance cost, light foundation requirements and minimum auxiliary equipment
• sf6 breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists

Disadvantages:
• sf6 breakers are costly due to high cost of sf6
• sf6 gas has to be reconditioned after every operation of the breaker, additional equipment is required for this purpose

7. what are the different types of testing in circuit breakers (AU MAY 2016) (AU MAY 2015)
   _ Type test
   _ Routine test
   _ Reliability test
   _ Commissioning test

8. define theories of arc interruption (AU NOV 2017)
   Slepian theory/recovery theory: If the rate of rising of re-striking voltage is rapid than the dielectric strength then the space breaks down and arc persists
   Cassies theory/energy balance theory: If the energy lost from the arc column at current zero exceeds the energy input from the external electrical circuit, the electrical current will cease to flow.

9. what is meant by making and breaking capacity (AU NOV 2015) (AU NOV 2014)
   Making capacity
   The peak value of current including DC component during the first cycle of current wave after the closure of C.B
   breaking capacity
   It is the RMS current that a C.B is capable of breaking at given recovery voltage and under specified condition

10. What are the characteristic of SF6 gas?
    It has good dielectric strength and excellent arc quenching property. It is inert, non-toxic, noninflammable and heavy. At atmospheric pressure, its dielectric strength is 2.5 times that of air. At three times atmospheric pressure, its dielectric strength is equal to that of the transformer oil.

11. name the material used for contact of vaccum circuit breakers (AU NOV 2015)
    Silver coating to limit the emission of electrons

12. What are the characteristic of SF6 gas?
    It has good dielectric strength and excellent arc quenching property. It is inert, non-toxic, noninflammable and heavy. At atmospheric pressure, its dielectric strength is 2.5 times that of air. At three times atmospheric pressure, its dielectric strength is equal to that of the transformer oil.

13. what is RRRV? (AU MAY 2015)
    It is the rate of rise of restriking voltage, expressed in volts per microsecond. It is closely associated with natural frequency of oscillation

14. mention advantages of vacuum CB
    advantages:
    • They are compact, reliable and have longer life.
    • There are no fire hazards
    • There is no generation of gas during and after operation
    • They can interrupt any fault current. The outstanding feature of a VCB is that it can break any heavy fault current perfectly just before the contacts reach the definite open position.
    • They require little maintenance and are quiet in operation
    • Can withstand lightning surges
    • Low arc energy
    • Low inertia and hence require smaller power for control mechanism.

15. What is meant by electro negativity of SF6 gas?
    SF6 has high affinity for electrons. When a free electron comes and collides with a neutral gas molecule, the electron is absorbed by the neutral gas molecule and negative ion is formed. This is called as electro negativity of SF6 gas.

16. what is meant by current chopping (AU NOV 2014)
    When interrupting low inductive currents such as magnetizing currents of the transformer, shunt reactor, the rapid deionization of the contact space and blast effect may cause the current to be interrupted before the natural current zero. This phenomenon of interruption of the current before its natural zero is called current chopping.

17. critical resistance
R ≤ 0.5√(1/c) resistance across contact to suppress the transient oscillation

18. define the operating time of CB (AU MAY 2014)
Time start from closing of the circuit breaker trip circuit and the opening of the circuit breaker contacts to the final arc extinction.

19. What is the main problem of the circuit breaker?
When the contacts of the breaker are separated, an arc is struck between them. This arc delays the current interruption process and also generates enormous heat which may cause damage to the system or to the breaker itself. This is the main problem.

20. what are the problems encountered in DC CB (AU MAY 2008)
No natural zero crossing
Have to dissipate more energy
Cost is very high

13 MARKS


(i) current chopping
While interrupting highly inductive current, like no-load current of transformer, the rapid deionization of contact space and blast effect may cause current interruption before its natural zero. Such an interruption of current before its natural zero is termed as “current chopping”. This phenomenon is more pronounced in case of air-blast circuit breakers which exerts the same deionizing force for all currents within its short-circuit capacity. Even though, the instantaneous value of current being interrupted may be less than the normal current rating of the breaker, it is quite dangerous from the point of view of overvoltages which may result in the system.

Let,
L = Inductance of the system
C = Capacitance of the system
i = Instantaneous value of arc current
V = Instantaneous value of capacitor voltage (which appears across the breaker when it opens)
The electromagnetic energy stored in the system at the instant before interruption is 1/2(Li²) As soon as the current is interrupted the value of i becomes zero. But, the electromagnetic energy stored in the system [1/2(Li²)] cannot become zero instantaneously and so it is converted into electrostatic energy [1/2(CV²)] as the system has some capacitance. According to the principle of energy conversion we have,
1/2(Li²)=1/2(CV²)
V=i√(L/C)
This theoretical value of V is called as “prospective Voltage or Arc Voltage”. If this voltage is very high when compared with the gap withstanding voltage, then the gap breakdowns and so “the arc restrikes. Again the current is chopped (interrupted) because of high quenching force and so, restriking occurs. This process repeats until the current is suppressed finally without any restrike and this occurs near current zero as shown in the figure.
In actual proactive the voltage across the breaker does not reach dangerously high prospective values of voltage. It is due to the fact that as soon as the breaker voltage increases beyond the gap withstanding voltage, it breaks down and the arc restrikes due to which the voltage across breaker falls to a very low value of arc voltage which can also be seen in the figure. Hence, it can be said that the arc is not an undesirable phenomenon and instead it protects the power system from severe stress on insulation due to overvoltages.

(ii) interruption of capacitive current

![Diagram](image-url)
Interruption of capacitive current poses a rather difficult problem for the circuit breakers. Example of such instances are opening a long transmission line on no load, disconnecting a capacitor bank etc. To understand the features of this process, let us consider the simple circuit shown in figure.

The value of capacitance $C_L$ is much more than $C$. Referring to figure, we see that the charging current is easily interrupted near its passage through zero (point a) because the current is low and the rate of rise of recovery voltage at the beginning is also low and increases relatively slowly. The opening of the circuit leaves a charge trapped in the capacitance $C_L$. The voltage $V_{CL}$ across this capacitance remains at the value it had when circuit was opened i.e. the peak value of the voltage $V$. After opening the circuit, the voltage $V_C$ across the capacitance $C_L$. The voltage $V_{CL}$ across this capacitance remains at the value it had when circuit was opened i.e., the peak value of the supply voltage $V$. After opening the circuit, the voltage $V_C$ across the capacitance $C$ oscillates and approaches the new steady state value. However, since the capacitance $C$ is quite small; the new value of voltage across it will be assumed to be approximately equal to the supply voltage $V$. After opening the circuit, the voltage $V_C$ across the capacitance $C$ oscillates and approaches the new steady state value. However, since the capacitance $C$ is quite small; the new value of voltage across it will be assumed to be approximately equal to the supply voltage $V$. The recovery voltage $V_r$ is equal to the difference between $V_C$ and $V_{CL}$. Its initial value is zero (point a) and increases slowly in the beginning. But half a cycle later when $V_C$ reverses, the recovery voltage reaches twice the normal peak value (point $v$). At this instant ($b'$) or even earlier it is possible that the are restrikes because the electrical strength between the contacts of the circuit breaker may not have attained sufficiently high value. This will re-clue the circuit and $V_{CL}$ will oscillated with a high frequency about the supply voltage $V$. At this moment, the supply voltage is at its negative peak (point 2); therefore a high frequency oscillation will occur between $+1$ and $-3$ times the peak value of supply voltage. AT the instant when the arc is re-struck recover voltage $V_r$ becomes zero (point $b'$). If we assume that at the first zero of the high frequency current arc extinction takes place (point $c'$), the voltage across the capacitance $C_L$ attains $–3$ times the peak value of normal voltage and remains there. Due to this the recovery voltage reaches point $C$ and starts to increase slowly upto point $d$. If at this instant a restrike occurs again, a high frequency oscillation of $V_{CL}$ about the supply voltage (point 3) will take places between $–3 + 5$ times its peak value. Several repetitions of the restriking cycle can theoretically increase the voltage across capacitance $C_L$ to exceedingly high value (at a rate of nearly 2 times normal peak value of supply voltage per half a cycle). However, in practical cases over-voltage are limited to about 4 times the normal peak of the supply voltage.

(iii) resistance switching (AU MAY 2016)

It is the method of connecting a resistance in parallel with the contact space(arc). The resistance reduces the restriking voltage frequency and it diverts part of the arc current. It assists the circuit breaker in interrupting the magnetizing current and capacity current.

Principle of Arc Extinction in Air-Blast CKT Breaker:

These breakers employ a high pressure air-blast as an arc quenching medium. The contacts are opened in a flow of air-blast established by the opening of blast valve. The air-blast cools the arc and sweeps away the arcing products to the atmosphere. This rapidly increases the dielectric strength of the medium between contacts and prevents from re-establishing the arc. Consequently, the arc is extinguished and flow of current is interrupted.

Depending upon the direction of air-blast in relation to the arc, air blast circuit breakers can be different types i.e. axial, cross-blast type or radial-blast type.

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Depending upon the direction of air-blast in relation to the arc, air blast circuit breakers can be different types i.e. axial, cross-blast type or radial-blast type.
An axial blast type of C.B is also an air blast circuit breaker.

In axial-blast type circuit breaker, the flow of air is longitudinal along the arc.

The essential components of a typical axial-blast circuit breaker are shown in fig. The fixed and moving contacts are held in closed position by spring pressure under normal operating conditions. The air reservoir tank is connected to the arc chamber through an air valve, which is opened by a tripping impulse.

On occurrence of a fault, the tripping impulse causes opening of the air valve connecting the reservoir to the arcing chamber. The air entering the arc chamber exerts pressure on the moving contacts which moves when the arc pressure exceeds the spring force. The moving contact is separated and an arc is struck. The air flowing at a high speed axially along the arc causes removal of heat from the
periiphery of the arc and the diameter of the arc reduces to a low value at current zero. At this instant the arc is interrupted and the contact-space is flushed with fresh air following through the nozzle.

The flow of fresh air through the contact space ensures removal of hot gases and rapid building up of dielectric strength. After the brief duration of air flow, the interrupter is filled with high pressure air. The dielectric strength of air increases with pressure. Thus the fresh high pressure air in the contact space is capable of withstanding the transient recovery voltage.

**Advantages:**

The axial blast circuit breaker gives high speed clearance because of the small gap required for interruption. This is desirable for improving transient stability on hv transmission and interconnection networks.

An air-blast circuit breaker has the following advantages over an oil circuit breaker:

- The risk of fire is eliminated.
- The arcing products are completely removed by the blast whereas the oil deteriorates with successive operations; the expense of regular oil replacement is avoided.
- The growth of dielectric strength is so rapid that final contact gap needed for arc extinction is very small. This reduces the size of the device.
- The arcing time is very small due to the rapid build up of dielectric strength between contacts. Therefore, the arc energy is only a fraction of that in oil circuit breakers, thus resulting in less burning of contacts.
- Due to lesser arc energy, air-blast circuit breakers are very suitable for conditions where frequent operation is required.
- The energy supplied for arc extinction is obtained from high pressure air and is independent of the current to be interrupted.

**Disadvantages:**

The use of air as the arc quenching medium offers the following disadvantages:

- The air has relatively inferior arc extinguishing properties.
- The air-blast circuit breakers are very sensitive to the variations in the rate of rise of restriking voltage.
- Considerable maintenance is required for the compressor plant which supplies the air-blast.

The air blast circuit breakers are finding wide applications in high voltage installations. Majority of the circuit breakers of voltages beyond 110 kV are of this type.

3. with the necessary diagram explain vacumb CB(AU MAY 2016) (AU MAY 2015)

**Principle.** The production of arc in a vacuum circuit breaker and its extinction can be explained as follows: When the contacts of the breaker are opened in vacuum (10⁻⁷ to 10⁻⁵ torr), an arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc rapidly diffuse on the surfaces of the circuit breaker contacts, resulting in quick recovery of dielectric strength. The reader may note the salient feature of vacuum as an arch quenching medium. As soon as the arc is produced in vacuum, it is quickly extinguished due to the fact rate of recovery of dielectric strength in vacuum.

**Construction.** Fig. shows the parts of a typical vacuum circuit breaker. It consists of fixed contact, moving contact and arc shield mounted inside a vacuum chamber. The movable member is connected to the control mechanism by stainless steel bellows. This enables the permanent sealing of the vacuum chamber so as to eliminate the possibility of leak. A glass vessel or ceramic vessel is used as the outer insulating body. The arc shield prevents the deterioration of the internal dielectric strength by preventing metallic vapours falling on the inside surface of the outer insulating cover.

![Diagram of Vacuum Circuit Breaker](image)

**Working.** When the breaker operates, the moving contact separates from the fixed contact and an arc is struck between the contacts. The production of arc is due to the ionization of metal ions and a depends very much upon the material of contacts. The arc is quickly extinguished because the metallic vapours, electrons and ions produced during arc are diffused in a short time and seized by the surfaces of moving and fixed members and shields. Since vacuum has very fast rate of recovery of dielectric strength, the arc extinction in a vacuum breaker occurs with a short contact separation (say 0.625 cm).

**Applications.** Vacuum circuit breakers are being employed for outdoor applications ranging from 22 kV to 66 kV. Even with limited rating of say 60 to 100 MVA. They are suitable for a majority of applications in rural areas. Where distances are quite large and accessibility to those remote areas is difficult, for installation and maintenance.

- Where voltages are high and current to be interrupted is low, these breakers have definite superiority over the oil or air circuit breakers.
  - For low fault interrupting capacities the cost is low in comparison to other interrupting devices.
  - The vacuum switches can be employed for capacitor switching which is a very difficult task for oil circuit breakers.

These can be used along with static over current relays and given an overall clearance time of less than 40 ms on phase-to-phase faults.
4. Discuss in detail the different types of rating of circuit breaker bringing out clearly their physical significance (AU MAY 2016) (AU NOV 2015) (AU NOV 2014)

The different rating of circuit breakers based upon the major duties are as below.

1) The breaking capacity
2) Making capacity.
3) Short time capacity (short-time current ratings.)
4) Rated Voltage.
5) Normal current ratings.
6) Operating duty.
7) Thermal parameters.
8) Rated Interrupting time.

1. The Breaking Capacity

It is the highest current that the circuit-breaker is capable of breaking at a stated recovery voltage (mostly equal to the rated voltage).

2) Making Capacity:

The making current of a circuit breaker is the peak value of the maximum current wave (including the d-c component) in the first cycle of the current after the circuit is closed by the circuit breakers.

Rated making capacity = \(1.8 \times \sqrt{2} \times \text{the corresponding rated symmetrical breaking capacity.}\)

3) Short time capacity:

As per IEC specification, a short-time current equal to the rated symmetrical breaking capacity corresponding to the lower rated voltage marked on the name plate which can be carried by the c-b for a period of one second.

4) Rated Voltage

Standard voltage ratings of power circuit breakers are in terms of three phase line-to-line voltage.

5) Normal Current Rating

The rated normal current of a C.B is the rms value of the current which the C.B shall be able to carry continuously at its rated frequency under specified testing condition.

6) Operating Duty:

The operating duty of a C.B consists of a prescribed number of unit operations at stated intervals CO C CO: closing operation followed immediately an opening operations.

7) Thermal Parameters:

It is the maximum temperature rise that is permissible for the individual parts of the equipment.

8) Rated Interrupting Time

It is the mean time for interruption of any current not exceeding the rated interrupting current of the breaker.

5. Describe the construction, operation and application minimum oil circuit breaker. (AU NOV 2015)

A low oil circuit breaker employs solid materials for insulation purposes and uses a small quantity of oil which is just sufficient for arc extinction. As regards quenching the arc, the oil behaves identically in bulk as well as low oil circuit breaker. By using suitable arc control devices, the arc extinction can be further facilitated in a low oil circuit breaker. Construction, Fig 5.10 shows the cross section of a single phase low oil circuit breaker. There are two compartments separated from each other but both filled with oil. The upper chamber is the circuit breaking chamber while the lower one is the supporting chamber. The two chambers are separated by a partition and oil from one chamber is prevented from mixing with the other chamber. This arrangement permits two advantages. Firstly, the circuit breaking chamber requires a small volume of oil which is just enough for arc extinction. Secondly, the amount of oil to be replaced is reduced as the oil in the supporting chamber does not get contaminated by the arc.

Supporting chamber. It is a porcelain chamber mounted on a metal chamber. It is filled with oil which is physically separated from the oil in the circuit breaking compartment.

It is filled with oil which is physically separated from the oil in the circuit breaking compartment. The oil inside the supporting chamber and the annular space formed between the porcelain insulation and bakelised paper is employed for insulation purposes only.

1) Circuit-breaking chamber. It is a porcelain enclosure mounted on the top of the supporting compartment. It is filled with oil and has the following parts:

(a) upper and lower fixed contacts
(b) moving contact
(c) tabulator.
The moving contact is hollow and includes a cylinder which moves down over a fixed piston. The turbulator is an arc control device and has both axial and radial vents. The axial venting ensures the interruption of low currents whereas radial venting helps in the interruption of heavy currents.

II) **Top chamber.** It is a metal chamber and is mounted on the circuit-breaking chamber. It provides expansion space for the oil in the circuit breaking compartment. The top chamber is also provided with a separator which prevents any loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

**Operation.** Under normal operating conditions, the moving contact remains engaged with the upper fixed contact. When a fault occurs, the moving contact is pulled down by the tripping springs and an arc is struck. The arc energy vaporizes the oil and produces gases under high pressure. This action constrains the oil to pass through a central hole in the moving contact and results in forcing series of oil through the respective passages of the turbulator. The process of turbulation is orderly one, in which the sections of the arc are successively quenched by the effect of separate streams of oil moving across each section in turn and bearing away its gases.

**Advantages.** A low oil circuit breaker has the following advantages over a bulk oil circuit breaker:

(i) It requires lesser quantity of oil
(ii) It requires smaller space.
(iii) There is reduced risk of fire.
(iv) Maintenance problems are reduced.

**Disadvantages.** A low oil circuit breaker has the following disadvantages as compared to a bulk oil circuit breaker:

(i) Due to smaller quantity of oil, the degree of carbonization is increased.
(ii) There is a difficulty of removing the gases from the contact space in time.
(iii) The dielectric strength of the oil deteriorates rapidly due to high degree of carbonisation.


sulphur hexafluoride (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.4.9 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 reservoir. 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 with 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 system after each operation of the breaker.

**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 noiseless 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 SF
to gas is non-inflammable.
VI) There are no carbon deposits so that tracking and insulation problems are eliminated.
VII) The SF
breakers have low maintenance cost, light foundation requirements and minimum auxiliary equipment.
VIII) Since SF
breakers are totally enclosed and sealed from atmosphere, they are particularly suitable where explosion hazard exists e.g., coal mines.

**Disadvantages**

Problems associated with SF
breakers are given below:
I) Sealing problems. Imperfect joints lead to leakage of SF
to gas.
II) SF
to gas is suffocating to some extent. In case of leakage in the breaker tank, SF
being heavier than air settles in the surroundings and may lead to suffocation of the operating personnel. However, it is non-poisonous.
III) Arced SF
gas is poisonous and should not be inhaled or let-out.
IV) Influx of moisture in the breaker is very harmful to SF
breakers. Several failures are reported because of it.

7. derive the expression for RRRV(AU MAY 2015) (AU NOV 2014)

The power system contains an appreciable amount of inductance and some capacitance. When a fault occurs, the energy stored in the system can be considerable. Interruption of fault current by a circuit breaker will result in most of the stored energy dissipated within the circuit breaker, the remainder being dissipated during oscillatory surges in the system. The oscillatory surges are undesirable and, therefore, the circuit breaker must be designed to dissipate as much of the stored energy as possible.

Fig. 19.17 (i) shows a short-circuit occurring on the transmission line. Fig. 19.17 (ii) shows its equivalent circuit where L is the inductance per phase of the system up to the point of fault and C is the capacitance per phase of the system. The resistance of the system is neglected as it is generally small.

**Rate of rise of re-striking voltage:**

It is the rate of increase of re-striking voltage and is abbreviated by R.R.R.V. usually; the voltage is in kV and time in microseconds so that R.R.R.V. is in kV/µ sec.

Consider the opening of a circuit breaker under fault conditions Shown in simplified form in Fig. 19.17 (ii) above. Before current interruption, the capacitance C is short-circuited by the fault and the short-circuit current through the breaker is limited by Inductance L of the system only. Consequently, the short-circuit current will lag the voltage by 90° as shown in Fig. 19.18, where I Represents the short-circuit current and ea represents the arc voltage. It may be seen that in this condition, the *entire generator voltage appears across inductance L.

When the contacts are opened and the arc finally extinguishes at some current zero, the generator voltage e is suddenly applied to the inductance and capacitance in series.

2Π LC

This LC combination form a series oscillatory circuit and voltage across capacitance which is restriking voltage rises and oscillates.

The natural frequency of oscillations is given by

\[ f_n = \frac{1}{2\pi\sqrt{LC}} \]

The voltage across the capacitance which is the voltage across the contacts of the circuit breaker can be calculated in terms of L, C, \( f_n \) and system voltage. The mathematical expression for transient condition is as follows.

\[ E = L\frac{di}{dt} + \frac{1}{C}\int idt \]

\[ i = \frac{dq}{dt} = (CV_i) / dt \]

\[ \frac{di}{dt} = (C^2V_i)/dt^2 = C\frac{d^2V_c}{dt^2} \]

\[ E = LC\frac{d^2V_c}{dt^2} + V_c \]

\[ E/S = LCS^2V_c + V_c(S) \]

\[ E/S[LC^2S^2 + 1] = V_c(S) \]

\[ V_c(S) = E/LCS[LC^2S^2 + 1] = E_\omega^2S/[(S^2 + \omega_n^2)] \]

\[ V_c(t) = E(1 - cos\omega_n t) = E(1 - cos1/\sqrt{LC} t) = \text{restriking voltage} \]

The maximum value of restriking voltage = \[ \frac{dv_c(t)}{dt} = 0 \]
The rate of rise of restriking voltage (RRRV)
\[ = \omega_n E \sin \omega t \]
The maximum value of RRRV = \( \omega_n E = \omega_n E_{\text{peak}} \)

Which appears across the capacitor C and hence across the contacts of the circuit breaker. This transient voltage, as already noted, is known as re-striking voltage and may reach an instantaneous peak value twice the peak phase-neutral voltage i.e. \( 2 E_m \). The system losses cause the oscillations to decay fairly rapidly but the initial overshoot increases the possibility of re-striking the arc. It is the rate of rise of re-striking voltage (R.R.R.V.) which decides whether the arc will re-strike or not. If

- The potential difference between the contacts is quite small and is just sufficient to maintain the arc.
- The arc provides a low resistance path and consequently the current in the circuit remains UN interrupted so long as the arc persists.
- During the arcing period, the current flowing between the contacts depends upon the arc resistance. The greater the arc resistance, the smaller the current that flows between the contacts.

**The arc resistance depends upon the following factors:**
1. **Degree of ionization** - the arc resistance increases with the decrease in the number of ionized particles between the contacts.
2. **Length of the arc** — the arc resistance increases with the length of the arc i.e., separation of contacts.
3. **Cross-section of arc** — the arc resistance increases with the decrease in area of X-section of the arc.

**Principles of Arc Extinction:**
Before discussing the methods of arc extinction, it is necessary to examine the factors responsible for the maintenance of arc between the contacts. These are:
1. Potential difference between the contacts.
2. Ionized particles between contacts taking these in turn.

- When the contacts have a small separation, the Potential difference between them is sufficient to maintain the arc. One way to extinguish the arc is to separate the contacts to such a distance that Potential difference becomes inadequate to maintain the arc. However, this method is impracticable in high voltage system where a separation of many meters may be required.
- The ionized particles between the contacts tend to maintain the arc. If the arc path is demonized, the arc extinction will be facilitated. This may be achieved by cooling the arc or by bodily removing the ionized particles from the space between the contacts.

**Methods of Arc Extinction (or) Interruption:**
There are two methods of extinguishing the arc in circuit breakers viz.
1. **High resistance method.**
2. **Low resistance or current zero method**

**High resistance method:**
In this method, arc resistance is made to increase with time so that current is reduced to a value insufficient to maintain the arc. Consequently, the current is interrupted or the arc is extinguished.

- The principal disadvantage of this method is that enormous energy is dissipated in the arc. Therefore, it is employed only in D.C. circuit breakers and low-capacity a.c. circuit breakers.
The resistance of the arc may be increased by:

1. **Lengthening the arc**: The resistance of the arc is directly proportional to its length. The length of the arc can be increased by increasing the gap between contacts.

   ![Diagram of arc lengthening](image)

   In this method, the arc length is increased by using arc runners which are horn like blades of conducting material. The arc runners are connected to arcing contacts and it is in the shape of letter V. The arc is initiated at the bottom and blows upwards due to electromagnetic force. Due to this arc length increases and consequently arc is extinguished.

2. **Cooling the arc**: Cooling helps in the deionization of the medium between the contacts. This increases the arc resistance. Efficient cooling may be obtained by a gas blast directed along the arc.

3. **Reducing X-section of the arc**: If the area of X-section of the arc is reduced, the voltage necessary to maintain the arc is increased. In other words, the resistance of the arc path is increased. The cross-section of the arc can be reduced by letting the arc pass through a narrow opening or by having smaller area of contacts.

4. **Splitting the arc**: The resistance of the arc can be increased by splitting the arc into a number of smaller arcs in series. Each one of these arcs experiences the effect of lengthening and cooling. The arc may be split by introducing some conducting plates between the contacts.

![Diagram of arc splitting](image)

**Low resistance or Current zero method:**

In this method, arc extinction in a.c. circuits only. In this method, arc resistance is kept low until current is zero where the arc extinguishes naturally and is prevented from restriking in spite of the rising voltage across the contacts. All Modern high power a.c. circuit breakers employ this method for arc extinction.

- **In an a.c. system, current drops to zero after every half-cycle. At every current zero, the arc extinguishes for a brief moment.**
- **Now the medium between the contacts contains ions and electrons so that it has small dielectric strength and can be easily broken down by the rising contact voltage known as restriking voltage.**
- **If such a breakdown does occur, the arc will persist for another half cycle.**
- **If immediately after current zero, the dielectric strength of the medium between contacts is built up more rapidly than the voltage across the contacts, the arc fails to re-strike and the current will be interrupted.**

**The rapid increase of dielectric strength of the medium near current zero can be achieved by:**

- **Causing the ionized particles in the space between contacts to recombine into neutral molecules.**
- **Sweeping the ionized particles away and replacing them by un ionized particles.**

   Therefore, the real problem in a.c. arc interruption is to rapidly de-ionize the medium between contacts as soon as the current becomes zero so that the rising contact voltage or restriking voltage cannot breakdown the space between contacts.

**The de-ionization of the medium can be achieved by:**

1. **Lengthening of the gap**: The dielectric strength of the medium is proportional to the length of the gap between contacts. Therefore, by opening the contacts rapidly, higher dielectric strength of the medium can be achieved.

2. **High pressure**: If the pressure in the vicinity of the arc is increased, the density of the particles constituting the discharge also increases. The increased density of particles causes higher rate of de-ionization and consequently the dielectric strength of the medium between contacts is increased.

3. **Cooling**: Natural combination of ionized particles takes place more rapidly if they are allowed to cool. Therefore, dielectric strength of the medium between the contacts can be increased by cooling the arc.
4. Blast effect: If the ionized particles between the contacts are swept away and replaced by UN ionized particles, the dielectric strength of the medium can be increased considerably. This may be achieved by a gas blast directed along the discharge or by forcing oil into the contact space.

9. Describe the operating principle of DC CB (AU NOV 2014)

D.C Circuit Breaking

The breaking in case of d.c circuits can be explained as follows. For this, we will consider a circuit which will consist of generator with voltage \( E \), resistance \( R \), inductor \( L \) and the circuit breaker as shown in fig

![Image](image.png)

The voltage-current relationship can be represented as shown in fig

From the fig it could be seen that curve AB represents the voltage \( E - iR \), \( i \) is nothing but current at any instant. The curve XY represents the voltage-current characteristics of the arc for decreasing currents.

When the circuit breaker starts opening it carries the load current \( I = \frac{E}{R} \). In the graph shown the current is shown to be reduced to \( i_1, i_2 \) and \( i_3 \) respectively. Section pr represents voltage drop \( i_3 \) R whereas qs represents arc voltage which is greater than available voltage. The arc becomes unstable and the difference in voltage is supplied by inductance \( L \) across which the voltage

\[
\frac{di}{dt} = L - -------------
\]

For decreasing values of currents this voltage is negative and according to lenz’s law it tries to maintain the arc.

The voltage across inductance \( L \) is seen to be positive in the region of currents \( i_1 \) and \( i_2 \); this is shown in fig

It can be seen that arc voltage is greater than \( E - iR \) and the balance between the voltages is supplied by the voltage across the inductance \( E_L \), which is proportional to rate of change of current \( di/dt \)

Thus the function of the circuit breaker is to raise the arc characteristics without affecting its stability. This is done by reducing the arcing time which is the time from contact separation to final extinction of arc. But it will increase extinction voltage. Hence compromise between arcing time and arc extinction voltage is made.

10. Explain about interruption Theories?

Arc Interruption Theories

There are two theories to explain the Zero current interruption of the Arc:

1. Recovery rate theory (Slepain’s Theory)
2. Energy balance theory (Cassie’s Theory)

Recovery rate theory (Slepain’s Theory):

The arc is a column of ionized 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 in to 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 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 ionization persists and breakdown of the gap occurs, resulting in an arc for another half cycle.
Energy balance theory (Cassie’s Theory):
The space between the contacts contains some ionized gas immediately after current zero and hence, it has a finite post-zero moment, power is zero because restriking voltage is zero. When the arc is finally extinguished, the power gain becomes zero, the gap is fully de-ionized 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 figure. 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 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.

I. Write a short note on bulk oil circuit breaker
Types of Oil Circuit Breakers:
The oil circuit breakers find extensive use in the power system. These can be classified into the following types:
- Bulk oil circuit breakers
- Low oil circuit breakers
- Bulk oil circuit breakers:
  - Which use a large quantity of oil. The oil has to serve two purposes. Firstly, it extinguishes the arc during opening of contacts and secondly, it insulates the current conducting parts from one another and from the earthed tank. Such circuit breakers may be classified into:
    - Plain break oil circuit breakers
    - Arc control oil circuit breakers.
  - In the former type, no special means is available for controlling the arc and the contacts are directly exposed to the whole of the oil in the tank. However, in the latter type, special arc control devices are employed to get the beneficial action of the arc as efficiently as possible.

Plain Break Oil Circuit Breakers

A plain-break oil circuit breaker involves the simple process of separating the contacts under the whole of the oil in the tank. There is no special system for arc control other than the increase in length caused by the separation of contacts. The arc extinction occurs when a certain critical gap between the contacts is reached. The plain-break oil circuit breaker is the earliest type from which all other circuit breakers have developed. It has a very simple construction. It consists of fixed and moving contacts enclosed in a strong weather-tight earthed tank containing oil up to a certain level and an air cushion above the oil level. The air cushion provides sufficient room to allow for the reception of the arc gases without the generation of unsafe pressure in the dome of the circuit breaker. It also absorbs the mechanical shock of the upward oil movement. Fig. 19.3
shows a double break plain oil circuit breaker. It is called a double break because it provides two breaks in series.
Under normal operating conditions, the fixed and moving contacts remain closed and the breaker carries the normal circuit Current.
When a fault occurs, the moving contacts are pulled down by the protective system and an arc is struck which vaporizes the oil mainly into hydrogen gas.
The arc extinction is facilitated by the following processes:
1. The hydrogen gas bubble generated around the arc cools the arc column and aids the deionization of the medium between the contacts.
2. The gas sets up turbulence in the oil and helps in eliminating the arcing products from the arc path.
As the arc lengthens due to the separating contacts, the dielectric strength of the medium is increased.
The result of these actions is that at some critical gap length, the arc is extinguished and the circuit current is interrupted.
Disadvantages:
1. There is no special control over the arc other than the increase in length by separating the moving contacts. Therefore, for successful Interruption, Long arc length is necessary.
2. These breakers have long and inconsistent arcing times. These breakers do not permit high speed interruption.
Due to these disadvantages, plain-break oil circuit breakers are used only for low voltage applications where high breaking-capacities are not important. It is a usual practice to use such breakers for low capacity installations for Voltages not exceeding 11 kV.
Arc Control Oil Circuit Breakers:
In case of plain-break oil circuit breaker discussed above, there is very little artificial control over the arc. Therefore, comparatively long arc length is essential in order that turbulence in the oil caused by the gas may assist in quenching it. However, it is necessary and desirable that final arc extinction should occur while the contact gap is still short. For this purpose, some arc control is incorporated and the breakers are then called arc control circuit breakers.
There are two types of such breakers, namely:
Self-blast oil circuit breakers—in which arc control is provided by internal means i.e. the arc itself is employed for its own extinction efficiently.
Forced-blast oil circuit breakers—in which arc control is provided by mechanical means external to the circuit breaker.
Self-blast oil circuit breakers:
In this type of circuit breaker, the gases produced during arcing are confined to a small volume by the use of an insulating rigid pressure chamber or pot surrounding the contacts. Since the space available for the arc gases is restricted by the chamber, a very high pressure is developed to force the oil and gas through or around the arc to extinguish it. The magnitude of pressure developed depends upon the value of fault current to be interrupted. As the pressure is generated by the arc itself, therefore, such breakers are some times called self-generated pressure oil circuit breakers.
The pressure chamber is relatively cheap to make and gives reduced final arc extinction gap length and arcing time as against the plain-break oil circuit breaker. Several designs of pressure chambers (sometimes called explosion pots) have been developed and a few of them are described below:
Plain explosion pot:

![Fig. 19.4](image)

It is a rigid cylinder of insulating material and encloses the fixed and moving contacts (See Fig. 19.4). The moving contact is a cylindrical rod passing through a restricted opening (called throat) at the bottom. When a fault occurs, the contacts get separated and an arc is struck between them. The heat of the arc decomposes oil into a gas at very high pressure in the pot. This high pressure forces the oil and gas through and round the arc to extinguish it. If the final arc extinction does not take place while the moving contact is still within the pot, it occurs immediately after the moving contact leaves the pot. It is because emergence of the moving contact from the pot is followed by a violent rush of gas and oil through the throat producing rapid extinction.
The principal limitation of this type of pot is that it cannot be used for very low or for very high fault currents. With low fault currents, the pressure developed is small, thereby increasing the arcing time. On the other hand, with high fault currents, the gas is produced so rapidly that explosion pot is liable to burst due to high pressure. For this reason, plain explosion pot operates well on moderate short-circuit currents only where the rate of gas evolution is moderate.
Cross jet explosion pot:
This type of pot is just a modification of plain explosion pot and is illustrated in Fig. 19.5. It is made of insulating material and has channels on one side which act as arc splitters. The arc splitters help in increasing the arc length, thus facilitating arc extinction. When a fault occurs, the moving contact of the circuit breaker begins to separate. As the moving contact is withdrawn, the arc is initially struck in the top of the pot. The gas generated by the arc exerts pressure on the oil in the back passage. When the moving contact uncovers the arc splitter ducts, fresh oil is forced across the arc path. The arc is, therefore, driven sideways into the —arc splitters—which increase the arc length, causing arc extinction.

The cross-jet explosion pot is quite efficient for interrupting heavy fault currents. However, for low fault currents, the gas pressure is small and consequently the pot does not give a satisfactory operation.

Self-compensated explosion pot:

This type of pot is essentially a combination of plain explosion pot and cross jet explosion pot. Therefore, it can interrupt low as well as heavy short circuit currents with reasonable accuracy. Fig. 19.6 shows the schematic diagram of self-compensated explosion pot. It consists of two chambers; the upper chamber is the cross-jet explosion pot with two arc splitter ducts while the lower one is the plain explosion pot. When the short-circuit current is heavy, the rate of generation of gas is very high and the device behaves as a cross-jet explosion pot. The arc extinction takes place when the moving contact uncovers the first or second arc splitter duct. However, on low short-circuit currents, the rate of gas generation is small and the tip of the moving contact has the time to reach the lower chamber. During this time, the gas builds up sufficient pressure as there is very little leakage through arc splitter ducts due to the obstruction offered by the arc path and right angle bends. When the moving contact comes out of the throat, the arc is extinguished by plain pot action.

It may be noted that as the severity of the short circuit current increases, the device operates less and less as a plain explosion pot and more and more as a cross-jet explosion pot. Thus the tendency is to make the control self-compensating over the full range of fault currents to be interrupted.

Forced-blast oil circuit breakers:

In the self-blast oil circuit breakers discussed above, the arc itself generates the necessary pressure to force the oil across the arc path. The major limitation of such breakers is that arcing times tend to be long and inconsistent when operating against currents considerably less than the rated currents. It is because the gas generated is much reduced at low values of fault currents. This difficulty is overcome in forced-blast oil circuit breakers in which the necessary pressure is generated by external mechanical means independent of the fault currents to be broken.

In a forced -blast oil circuit breaker, oil pressure is created by the piston-cylinder arrangement. The movement of the piston is mechanically coupled to the moving contact. When a fault occurs, the contacts get separated by the protective system and an arc is struck between the contacts. The piston forces a jet of oil towards the contact gap to extinguish the arc. It may be noted that necessary oil pressure produced does not in any way depend upon the fault current to be broken.

Advantages:

Since oil pressure developed is independent of the fault current to be interrupted, the performance at low currents is more consistent than with self-blast oil circuit breakers.

The quantity of oil required is reduced considerably.
Unit-1

1. What are symmetrical components
   It is a mathematical tool to resolve unbalanced components into balanced components.
   Three sequence components:
   Positive sequence components, negative sequence components and zero sequence components.

2. Define positive sequence component and zero sequence component
   Positive sequence: has 3 vectors equal in magnitude and displaced from each other by an angle 120 degrees and having the phase sequence as original vectors
   Zero sequence component: They have 3 vectors having equal magnitudes and displaced from each other by an angle zero degrees. It is a mathematical tool to resolve unbalanced components into balanced components.

   Selectivity or discrimination
   It is the ability of a relay to discriminate between faulty conditions and normal conditions (or between a fault within the protected section by which it distinguished between those conditions for which it should operate and those for which it should not.
   Sensitivity
   A protective relay should be sensitive enough to operate when the magnitude of the actuating quantity exceeds its pick-up value.

4. What is neutral earthing or neutral grounding? Why are modern power systems operated with grounded neutral?
   Connecting the neutral point (or star point) of star-connected 3-phase winding of power transformers, generators, motors, earthing transformers to low resistance earth is called neutral earthing. Modern power systems are operated with grounded neutral because of safety to personnel and equipment, improved service reliability, lengthy insulation life etc.

5. What is the difference between system earthing (or neutral earthing) and equipment earthing (or safety earthing)?
   System earthing deals with earthing of the system neutral to ensure system security and protection. Equipment earthing deals with earthing of non-current carrying parts of the equipment to ensure safety of personnel and protection against lightning.

6. Define solid grounding or effective grounding.
   In solid grounding a direct metallic connection or a wire of negligible resistance and reactance is made from the system neutral to one or more earth electrodes.

7. What are unit system and non unit system?
   A unit protective system is one in which only faults occurring within its protected zone are isolated. Faults occurring elsewhere in the system have no influence on the operation of a unit system. A non unit system is a protective system which is activated even when the faults are external to its protected zone.

8. What is meant by ‘Reach’ or balance point of a relay.
   This term is mostly used in connection with distance relays. A distance relay operates when the impedance (or a component of the impedance) as seen by the relay is less than a preset value. This preset impedance (or a component of impedance) or corresponding distance is called the reach of the relay. In other words, it is the maximum length of the line up to which the relay can protect.

   Operation of (distance) relay for a fault beyond its set protected distance (say 130%). Fault point is beyond its present reach (i.e. its protected length).

Unit 2
1. operating principle of ELECTROMAGNETIC ATTRACTION TYPE relay
There is a coil which energizes an electromagnet. When the operating current becomes large, the magnetic field produced by an electromagnet is so high that it attracts the armature or plunger, making contact with the trip circuit.

2. operating principle of ELECTROMAGNETIC INDUCTION TYPE relay
Principle – induction motor or an energy meter.
Metallic disc is rotated between 2 electromagnets.
Coils of electromagnet energized by alternating currents.
Torque is produced due to interaction of one alternating flux with eddy currents induced in the rotor by another alternating flux.

3. operating principle Shaded pole induction type relay
Consists of aluminium disc – to rotate in an air gap of an electromagnet.
Part of pole face of each pole is shaded with the help of copper band or ring – shading ring.
Total flux is produced, e.m.f. gets induced in the shading ring.
E.m.f. drives current causing flux to exist in shaded portion.

\[
T = \phi \sin \alpha \\
T = P \sin \alpha \\
T = kI^2
\]

4. R-X diagram for impedance, reactance and admittance relay

5. Explain how you provide directional feature to reactance relay?
The voltage restrained reactance relay provides directional feature to the reactance relay. A separate directional element is incorporated in the scheme which gives a positive or negative torque.

6. Define frequency relay?
The frequency of the induced emf is related to the speed of the synchronous generators.

\[
f = \frac{PSN}{120}
\]

While load increases speed decreases and the frequency decrease. Frequency relay are required if frequency changes from its normal value and are used in the generator protection and for load frequency control.

7. What are the features of directional relay?
High speed operation; high sensitivity; ability to operate at low voltages; adequate short-time thermal ratio; burden must not be excessive.

8. Define reach.
It is the distance upto which the relay will cover for protection.

9. Define the terms pickup value, current setting, time setting multiplier and plug setting multiplier.
Minimum value of actuating quantity for relay to operate
Setting of pick up value
It is the measure of travel of disc of the relay which can be adjusted to vary the relay operating time.
Ratio of fault current to pick of current

10. Define burden
The power consumed by the the relay ckt, expressed in volt ampere,

Unit-3

1. Explain why carrier protection is suitable for important inter connected lines?
   a. Fast and simultaneous operation of circuit breakers at both ends.
   b. Auto reclosing is possible for faults.
   c. Fast fault clearance leads to maintenance of stability.
   d. Carrier current protection provide easy discrimination
   e. Power line is used as channel for transmitting / receiving trip signals.
2. What purposes are served by line trap and coupling capacitors in carrier channels. ( AU. N/D 04)
   Line trap is an IC network inserted between bus bar and connection of coupling capacitor to the line and tuned
   to resonance at the high frequency and are used to prevents the high frequency and the carrier currents flow only
   in the protected line.
   The coupling capacitor is used to connect the high frequency (carrier ) equipment to one of the line conductors
   and simultaneously serves to isolate the carrier equipment from the high power line voltage.

2. What are the requirements of CTs for differential protections?
   • The secondary current should be true replica of primary current.
   • It should be of PS class is protection special CTs should be governed by knee point voltage higher knee
     print voltage to avoid saturation during fault.

3. Distinguish between through faults and internal faults?
   Through faults are faults external to the zone of protection. i.e. external to the transformer for which the
   differential relay should not act. Whereas internal faults are fault inside the transformer which is within the
   protection zone for which the differential relay is to operate.

4. What is the consequences of loss of field or field failure in the case of generators?
   If it is a simple generator supplying local load, the loss of field causes loss of terminal voltage and subsequently
   loss of synchronizing depending upon the load conditions. It the generator is connected in parallel with other
   units; it can draw magnetizing currents from the bus bars and continue to run as induction generator. The
   magnetizing current being large, and are to be supplied by other units, the stability of the system is affected.

5. Under the what condition, restricted earth fault protection is employed for protection of alternators??
   What is the draw back?
   Since neutral of alternators is earthed through resistance to limit the earth fault current, it is not possible to
   protect complete winding from earth fault. Differential protection takes care only 80 to 85% of the generator
   winding. Hence, restricted earth fault protection is provided to take care of the complete winding against earth
   faults.

6. What is biased differential bus zone reduction?
   The biased beam relay is designed to respond to the differential current in terms of its fractional relation to the
   current flowing through the protected zone. It is essentially an over-current balanced beam relay type with an
   additional restraining coil. The restraining coil produces a bias force in the opposite direction to the operating
   force.

7. What are the various faults to which a turbo alternator is likely to be subjected?
   Failure of steam supply; failure of speed; overcurrent; over voltage; unbalanced loading; stator winding fault.

8. Define the term pilot with reference to power line protection.
   Pilot wires refers to the wires that connect the CT’s placed at the ends of a power transmission line as part of its
   protection scheme. The resistance of the pilot wires is usually less than 500 ohms.

9. What are the uses of Buchholz’s relay?
10. What are the causes of over speed and how alternators are protected from it?
Sudden loss of all or major part of the load causes over-speeding in alternators. Modern alternators are provided with mechanical centrifugal devices mounted on their driving shafts to trip the main valve of the prime mover when a dangerous over-speed occurs.

11. Give the limitations of Merz Price protection of alternator.
Since neutral earthing resistances are often used to protect circuit from earth-fault currents, it becomes impossible to protect the whole of a star-connected alternator. If an earth-fault occurs near the neutral point, the voltage may be insufficient to operate the relay. Also it is extremely difficult to find two identical CT’s. In addition to this, there always an inherent phase difference between the primary and the secondary quantities and a possibility of current through the relay even when there is no fault.

12. What are the main safety devices available with transformer?
Oil level guage, sudden pressure delay, oil temperature indicator, winding temperature indicator.

13. Why neutral resistor is added between neutral and earth of an alternator?
In order to limit the flow of current through neutral and earth a resistor is introduced between them.

14. What is REF relay?
It is restricted earth fault relay. When the fault occurs very near to the neutral point of the transformer, the voltage available to drive the earth circuit is very small, which may not be sufficient to activate the relay, unless the relay is set for a very low current. Hence the zone of protection in the winding of the transformer is restricted to cover only around 85%. Hence the relay is called REF relay.

15. What are the causes of bus zone faults?
- Failure of support insulator resulting in earth fault
- Flashover across support insulator during over voltage
- Heavily polluted insulator causing flashover
- Earthquake, mechanical damage etc.

16. What is over fluxing protection in transformer?
If the turns ratio of the transformer is more than 1:1, there will be higher core loss and the capability of the transformer to withstand this is limited to a few minutes only. This phenomenon is called over fluxing.

17. What are the merits of carrier current protection?
Fast operation, auto re-closing possible, easy discrimination of simultaneous faults.

18. What are the errors in CT?
Ratio error
- Percentage ratio error = [(Nominal ratio – Actual ratio)/Actual ratio] x 100 The value of transformation ratio is not equal to the turns ratio.
Phase angle error:
- Phase angle = \(180/\pi\times[\tan^{-1}\frac{\omega}{\omega_{s}}]\)

Unit V
1. short time capacity
Depends upon its ability to withstand the electromagnetic force effect and temperature rise

2. factor for selecting the C.B
Maximum current to be carried momentarily
Maximum fault current which is to be interrupted by the breaker

3. rating of C.B
Breaking capacity
Making capacity
Short time capacity
When a long unloaded line or a capacitive bank is switched off, capacitive current produced high voltage transient across the breaker contact.

4. **what are the factor on which RRRV depends upon**
   Em which is peak value of recovery voltage phase to neutral in volt
   Values of inductance and capacitance

5. **mention the methods of high resistance are interruption**
   Lengthening of arc, splitting of arc, cooling of arc

6. **differentiate AC and DC circuit breaker**
   AC circuit breaking: the current passes through zero twice in one complete cycle. When the current are reduced to zero the breaker are operated to cut off the current. but DC doesn’t have nature zero crossing.

7. **basic requirement of C.B**
   Short circuit current must be safely operated
   Quick isolation
   Should not operate for over current at healthy condition
   Must isolate faulty section only

8. **factors affecting restriking voltage**
   Configuration of the N/W
   Natural freq of the N/W
   The resistance in series and parallel with capacitance of the N/W

9. **How direct tests are conducted in circuit breakers?**
   Using a short circuit generator as the source.
   Using the power utility system or network as the source.

10. **What is dielectric test of a circuit breaker?**
    It consists of overvoltage withstand test of power frequency lightning and impulse voltages. Tests are done for both internal and external insulation with switch in both open and closed conditions.

11. **What are the indirect methods of circuit breaker testing?**
    Unit test
    Synthetic test
    Substitution testing
    Compensation testing
    Capacitance testing

12. **What are the advantages of synthetic testing methods?**
    The breaker can be tested for desired transient recovery voltage and RRRV.
    Both test current and test voltage can be independently varied. This gives flexibility to the test.
    The method is simple. With this method a breaker capacity (MVA) of five times of that of the capacity of the test plant can be tested.

12. **What are demerits of MOCB?**
   - Short contact life
   - Frequent maintenance
   - Possibility of explosion
   - Larger arcing time for small currents
   - Prone to restricts

13. **What are the advantages of oil as arc quenching medium?**
    It absorbs the arc energy to decompose the oil into gases, which have excellent cooling properties.
    It acts as an insulator and permits smaller clearance between line conductors and earthed components.

14. **What are the hazards imposed by oil when it is used as an arc quenching medium?**
    There is a risk of fire since it is inflammable. It may form an explosive mixture with arc. So oil is preferred as an arc quenching medium.
15. What are the advantages of MOCB over a bulk oil circuit breaker?  
It requires lesser quantity of oil  
It requires smaller space  
There is a reduced risk of fire  
Maintenance problem are reduced

16. What are the disadvantages of MOCB over a bulk oil circuit breaker?  
The degree of carbonization is increased due to smaller quantity of oil  
There is difficulty of removing the gases from the contact space in time  
The dielectric strength of the oil deteriorates rapidly due to high degree of carbonization.

17. What are the types of air blast circuit breaker?  
- Arial-blast type  
- Cross blast  
- Radial-blast

18. What are the advantages of air blast circuit breaker over oil circuit breaker?  
The risk of fire is diminished  
The arcing time is very small due to rapid buildup of dielectric strength between contacts  
The arcing products are completely removed by the blast whereas oil deteriorates with successive operations

19. What are the demerits of using oil as an arc quenching medium?  
The air has relatively inferior arc quenching properties  
The air blast circuit breakers are very sensitive to variations in the rate of rise of restriking voltage  
Maintenance is required for the compression plant which supplies the air blast

20. What is circuit breaker?  
It is a piece of equipment used to break a circuit automatically under fault conditions. It breaks a circuit either manually or by remote control under normal conditions and under fault conditions.

21. What are the methods of capacitive switching?  
• Opening of single capacitor bank  
• Closing of one capacitor bank against another

22. What is an arc?  
Arc is a phenomenon occurring when the two contacts of a circuit breaker separate under heavy load or fault or short circuit condition.