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ENGINEERING

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Semester - 7 Electrical & Electronics Engineering

Power System Protection

- Topic-wise coverage of entire syllabus in Question-Answer form.
- Short Questions (2 Marks)

Session 2021-22 Odd Semester

Includes solution of following AKTU Question Papers

2016-17 • 2017-18 • 2019-20 • 2020-21

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KEE-077 : Power System Protection

1

UNIT

Protection Scheme

CONTENTS

PART-1

Need for Protective Systems.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.1. Explain protective system along with its elements.

Answer

A. Protective system :

1. An electrical power system consists of generators, transformers, transmission and distribution lines, etc.
2. Short circuits (faults) and other abnormal conditions often occur in a power system.
3. The high current associated with short circuits is likely to damage the equipments, if the suitable protective system is not provided for each section of the power system.
4. Under fault condition, an automatic protection device is needed to isolate faulty element as quickly as possible to keep the healthy section of the system unaffected.
5. If the faulty element is not isolated with in a fraction of second, the heavy short circuit current may even cause fire. It may spread in the system leading to loss of synchronism between the generators of same power station or different power stations.

B. Elements of protective system :

1. The protective system includes circuit breakers, transducers (PTs and CTs) and protective relays to isolate faulty section from healthy one.
2. Their functions are :

i. A circuit breaker disconnects the faulty element of the system from the healthy sections when actuated by protective relay.

ii. Transducers (CTs and PTs) reduce the actuating quantities (current, voltage etc.) to lower values so as to isolate the protective relays from high voltages of the power system.

iii. The protective relay detects and locates the fault and issues a command to circuit breaker to disconnect the faulty section. It monitors the electrical quantities (current, voltage, phase angle and frequency) that vary under normal and abnormal conditions.

Que 1.2. **What are the needs of protective system employed in power system ?**

Answer

Need of protective system :

1. It is needed for the protection of short circuit condition arising in a power system.
2. To minimize damage to the system components involved in the failure.
3. Protective systems are specialized system that monitors the power system, detecting faults or abnormal conditions and then initiating corrective action.
4. Limit the extent and duration of service interruption whenever equipment failure occurs on any portion of the system.

PART-2

Evolution of Protective Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.3. **Explain the evolution of protective relays.**

Answer

The evolution of protective relays begins with the electromechanical relays. Over the past decade it upgraded from electromechanical to solid state technologies to predominate use of microprocessors and microcontrollers.

A. First generation protective relays (1900-1963) :

1. Electromechanical relays are the first generation relaying system.
2. There were two basic types of operating mechanisms: the electromagnetic-attraction relay and electromagnetic-induction relay.

B. Second generation protective relays (1963-1972) :

1. The static relays are second generation relays.
2. The term 'static' implies that the relay has no moving mechanical parts in it. Compared to the electromechanical relay, the static relays has longer life-span, decreased noise and faster respond speed.

C. Third generation protective relays (1972-1980) :

1. The digital relays are third generation relays. The digital relays use microprocessors and microcontrollers.

2. Instead of using analog signals, the digital relay converts all measured analog quantities into digital signals.

D. Fourth generation protective relays (1980 -1990) :

1. The numerical relays are fourth generation relays. Numerical relays were mainly designed to meet the static relay protection characteristic.
2. Now-a-days modern numeric protection devices are capable of providing complete protection with added functions like control and monitoring.

PART-3

Zone of Protction.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.4. **What is a relay ? Explain the role of contacts in a relay. What is an Auxiliary Switch ?**

Answer

A. Relay :

1. Relay is a device which detects the fault and is responsible for energizing the trip circuit of a circuit breaker. This isolates the faulty part from rest of the system. The relay operates when the resultant torque is positive.
2. Circuit for relay is shown in Fig. 1.4.1. Relay circuit is a 3-phase circuit and its contact circuit is complicated.

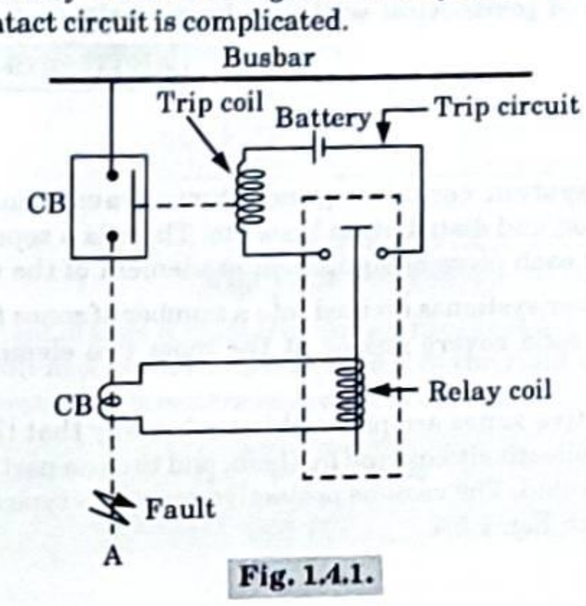

Fig. 1.4.1.

3. Let part *A* is to be protected. The current transformer is connected with its primary around the line to be protected. The secondary of CT is connected in series with the relay coil.
4. Relay contacts are part of the trip circuit of circuit breaker. In addition to trip contacts, trip circuit consists of trip coil and a battery.
5. If the fault is as shown in Fig. 1.4.1, then current through the line connected to *A* increases to a very high value. Accordingly secondary current of the CT increases which is nothing but the current through relay coil.
6. In the influence of such high current, relay contacts mechanically get closed.
7. So trip circuit of circuit breaker gets closed and current starts flowing from battery through trip coil, thus trip coil gets energized making the circuit breaker open. This isolates the faulty part from rest of the healthy part.

B. Auxiliary switch :

1. An important device in trip circuit is auxiliary switch. It is a multipoint switch. This switch is mechanically coupled with the operating mechanism of circuit breaker.
2. So when circuit breaker opens, auxiliary switch also gets open, when this switch gets open, it breaks current through the trip circuit, once the current is interrupted the relay contacts come to normal condition.
3. Advantage of auxiliary switch is that breaking of trip circuit takes place only across the switch, so arcing due to current interruption across relay contacts can be avoided.

Que 1.5. What do you understand by zone of protection? Discuss various zones of protection with the help of single-line diagram.

AKTU 2019-20, Marks 07

Answer

1. A power system contains generators, transformers, bus bars, transmission and distribution lines etc. There is a separate protective scheme for each piece of equipment or element of the power system.
2. Thus, a power system is divided into a number of zones for protection. A protective zone covers one or at the most two elements of a power system.
3. The protective zones are planned in such a way that the entire power system is collectively covered by them, and thus no part of the system is left unprotected. The various protective zones of a typical power system are shown in Fig. 1.5.1.

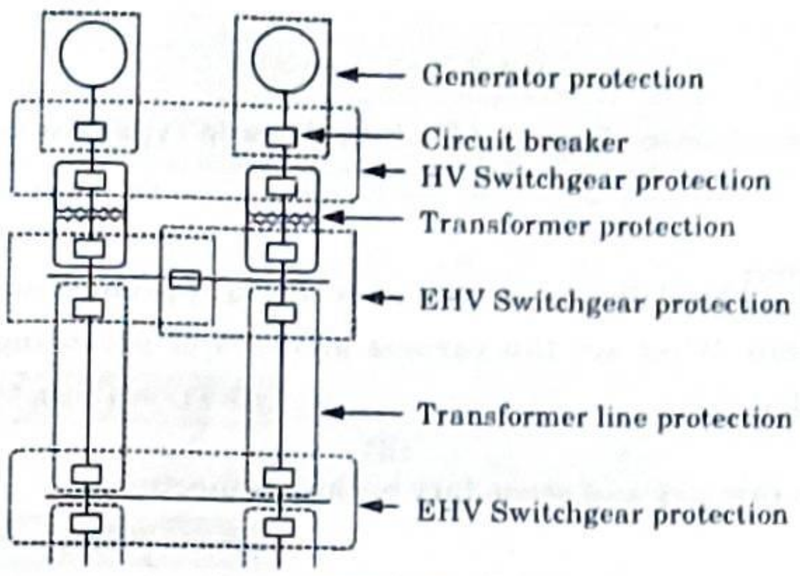

Fig. 1.5.1.

4. Adjacent protective zones must overlap each other, failing which a fault on the boundary of the zones may not lie in any of the zones and hence no circuit breaker would trip. Thus, the overlapping between the adjacent zones is unavoidable.
5. If a fault occurs in the overlapping zone in a properly protected scheme, more circuit breakers than the minimum necessary to isolate the faulty element of the system would trip.
6. A relatively low extent of overlap reduces the probability of faults in this region and consequently, tripping of too many breakers does not occur frequently.
7. As shown in Fig. 1.5.2, when a fault is seen at *X*, the circuit breaker of zone *B*, including breaker *C* will be tripped. This will not interrupt the flow of fault current from zone *A*.

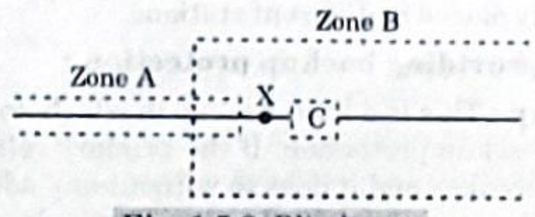

Fig. 1.5.2. Blind spot.

8. Equipment of zone *B* must trip certain breakers in zone *A*. This is alright with fault at *X* but for faults in zone *B* to the right of circuit breaker *C*, the operation of breakers in zone *A* is useless.

PART-4

Primary and Back-up Protection.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.6. **Explain what do you understand by primary and backup protection. What are the various methods of providing backup protection ?** **AKTU 2017-18, Marks 10**

OR

Explain primary and secondary backup protection. **AKTU 2020-21, Marks 07**

Answer

A. Primary and backup protection :

1. A power system is divided into various zones for its protection. There is a particular scheme for each zone.
2. If the fault occurs in a particular zone, it is the duty of primary relays of that zone to isolate the faulty portion.
3. If because of some reason the primary protection fails to clear the faul then the backup protection has to clear it.
4. The backup relays are made independent of those factors because of which the primary relay failed. A backup relay operates after some time delay so as to give the primary relay sufficient time to operate.
5. When a backup relay operates, a large part of the power system is disconnected from the power source, which is unavoidable. A backup relay is usually placed at different stations.

B. Methods of providing backup protection :

1. **Relay backup :** This is a local backup in which an additional relay is provided for backup protection. If the primary relay fails, it trips the same circuit breaker and it does so without any additional delay. This backup is costly, so preferred only when remote backup is not possible.

2. Breaker backup :

i. This is also a local backup. It is necessary for busbar system where a number of circuit breakers are connected to it. When a protective relay operates in response to a fault but circuit breaker fails to operate, the fault is treated as busbar faults.

ii. It is necessary that all the circuit breakers on the busbar should trip. If the proper breaker does not trip within a specified time, the main relay closes the contact of the backup which trips all the circuit breakers.

3. **Remote backup :** When backup relays are located at neighbouring stations, they backup the entire primary scheme which includes relay, circuit breaker, PT and CT. It is the cheapest form of backup protection and used for transmission lines.

PART-5

Essential Qualities of Protection.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.7. **Write the essential qualities of protection.**

Answer

Qualities of protection system :

i. Reliability :

1. A protective relaying should be reliable in its basic quality. It indicates the ability of the relay system to operate under predetermined conditions.
2. Every component and circuit which is involved in the operation of relay plays an important role and reliability of a protection system depends on the reliability of various components like circuit breakers, PTs etc.
3. The reliability is based on the design which can be achieved by factors like :

a. Simplicity
b. Robustness
c. High contact pressure
d. Good workmanship and careful maintenance.

ii. Selectivity : The selectivity is the ability of the relay to identify the faulty part correctly and disconnect that part without affecting the rest of the healthy part of the system.

iii. Discrimination : The discrimination quality of the protective system is the ability to distinguish between normal condition and abnormal condition and also between abnormal conditions within protective zone and elsewhere.

iv. Speed :

1. The protective system must disconnect the faulty system as fast as possible.

2. If the faulty system is not disconnected for a long time, then the device carrying the fault current may get damaged. The high speed protective system avoids the possibility of such undesirable effects.

v. Time :

1. The fault clearing time should be as small as possible (less than a fraction of second) to have high speed operation of the protective system.
2. Although small fault clearing time is preferred but certain time lag is provided to have clear discrimination between primary and backup protection.

vi. Sensitivity :

1. The relay should be sufficiently sensitive so that it can operate reliably when required. Sensitivity of the relay is smallest value of actuating quantity at which the relay starts operating corresponding to the minimum value of the fault current in the protected zone.
2. Mathematically sensitivity is expressed by the factor called sensitivity factor K_s as

$$K_s = \frac{I_s}{I_o}$$

where, K_s = Sensitivity factor

I_s = Minimum short circuit current in the zone

I_o = Minimum operating current for the protection.

vii. Stability : The stability is the quality of the relay due to which it remains inoperative and stable under certain specified conditions such as transients, faults etc.

PART-6

Classification of Protective Schemes.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.8. Give the classification of different types of protective schemes.

Answer

1. A protective scheme is used to protect equipments or a section of the line.

2. The following are the most common protective schemes which are usually used for the protection of a power system :

A. Overcurrent protection :

i. It is used for the protection of distribution lines, large motors and equipment.

ii. It includes one or more overcurrent relays. An overcurrent relay operates when the current exceeds its pick-up value.

B. Distance protection :

i. It is used for the protection of transmission or sub-transmission lines, usually 33 kV, 66 kV and 132 kV lines.

ii. A distance relay measures the distance between the relay location and the point of fault in terms of impedance, reactance, etc.

C. Carrier-current protection :

i. Carrier current protection is the most widely used scheme for the protection of EHV and UHV power lines, generally 132 kV and above. In this scheme a carrier channel of high frequency is employed.

ii. The frequency range of the carrier signal is 50 kHz to 700 kHz. The power level is about 10-20 W. In this scheme, a conductor of the power lines to be protected is used for the transmission of carrier signals.

D. Differential protection :

i. It is used for the protection of generators, transformers and motors of very large size.

ii. In this protection, CTs are placed on both sides of each winding of a machine.

iii. The outputs of their secondaries are applied to the relay coils. The relay compares the current entering a machine winding and leaving the same.

iv. Under normal conditions or during any external fault, the current entering the winding is equal to the current leaving the winding.

v. But in the case of an internal fault on the winding, these are not equal. This difference in the current actuates the relay.

vi. Thus, the relay operates for internal faults and remains inoperative under normal conditions or during external faults.

PART-7

Automatic Reclosing.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.9. **What is auto re-closing ? Explain its various schemes.**

OR

Explain automatic reclosing. **AKTU 2020-21, Marks 07**

Answer

A. Auto re-closing :

1. About 80-90 % of faults on overhead transmission and distribution lines are transient in nature. These faults disappear if the line circuit breakers are tripped momentarily to isolate the line.
2. The disconnection of the line from the system permits the arc to extinguish.
3. The line is reenergized again by reclosing circuit breakers to restore normal supply after the arc path becomes sufficiently deionised. Automatic reclosing of circuit breakers is known as auto re-closing.

B. Types of auto re-closing :

a. Single-shot auto re-closing :

1. Most of the faults on EHV transmission lines are due to flashover across insulators caused by lightning. Because of the height of EHV lines, tree branches are unlikely to cause faults.
2. If some physical conducting objects are dropped on EHV lines by birds, they are vaporized instantly due to large amount of power in the arc.
3. Consequently, there is no need for more than one reclosure in case of EHV transmission lines.
4. In a single-shot auto-reclosing scheme, only one reclosure is made.
5. The reclosure should be made as quickly as possible so that there should not be any appreciable drift in phase angle between the voltages at the two ends of the open line.

b. Multi-shot auto re-closing :

1. A multi shot auto re-closing scheme provides more than one automatic reclosures. On radial lines, one instantaneous reclosure is provided, followed by 2 or 3 more delayed reclosures if necessary.
2. Actually 80 % of the faults are cleared after the first reclosure. The second reclosure is made after a delay of 15 to 45 seconds.
3. About 10 % of the remaining faults are cleared after the second reclosure. The third reclosure is made after 60 to 120 s.
4. Less than 2 % of faults require the third reclosure. If a fault is not cleared after three reclosures, there is an automatic lock-out of the reclosing relay.
5. The usual practice is to reclose the circuit breakers three-times. The fourth reclosure, if required, can be made by hand. If the fourth reclosure fails, there is clear indication of a permanent fault.

c. Single-phase (single-pole) auto re-closing :

1. In a single-phase auto-reclosing (single-pole auto-reclosing) scheme, only the faulty phase pole of the circuit breaker is tripped and reclosed.

2. For any multi-phase fault, all the three phases are simultaneously tripped and reclosed.
3. In a single-phase auto re-closing, each phase of the circuit breaker is segregated and provided with its own closing and tripping mechanism.

d. Three-phase auto re-closing :

1. In a three-phase auto re-closing scheme, all the three phases are tripped and reclosed when a fault occurs on the system, irrespective of types of the fault.
2. Its relaying scheme is simpler and less expensive than the single phase auto re-closing scheme. It is faster because of less deionising time.

e. Delayed auto re-closing scheme :

1. When two sections of a power system are connected through a number of transmission line systems, there is little chance of drifting them apart in phase and losing synchronism.
2. On such a system, delayed auto re-closing can be employed. We employ delayed auto re-closing with dead times of the order of 5-6 s.
3. The fault arc deionisation times and circuit breaker operating characteristics do not present problems in such a scheme. Before reclosing, power swings are allowed to settle down.

PART-8

Current Transformer for Protection, Potential Transformer.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.10. **Discuss about the current transformer for protection of power system.**

Answer

1. Current transformers (CTs) are used to obtain reduced current signals from the power systems for the purpose of measurement, control and protection.
2. They reduce the heavy currents of the power system to lower values that are suitable for the operation of relays and other instruments connected to their secondary windings.
3. Besides reducing the current levels, CTs also isolate the relays and instruments circuits from the primary circuit which is a high voltage power circuit and allow the use of standardized current ratings for relays and meters.
4. The current ratings of the secondary windings of the CTs have been standardized so that a degree of interchangeability among relays and meters of different manufacturers can be achieved.

5. Since the standard current ratings of the secondary windings of the CTs are 5 or 1 ampere the protective relays also have the same current rating.
6. The current transformers are designed to withstand fault currents (which may be as high as 50 times the full load current) for a few seconds.
7. The accuracy of a current transformer is expressed in terms of the departure of its ratio form its true ratio. This is called the ratio error, and is expressed as :

$$\text{Percent error} = \left[\frac{NI_s - I_p}{I_p}\right] \times 100$$

where, N = Nominal CT ratio

$$= \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

$$= \frac{\text{Number of secondary turns}}{\text{Number of primary turns}}$$

I_s = Secondary current

I_p = Primary current

The ratio error of a CT depends on its exciting current.

8. There are three types of current transformers :

i. Electromagnetic ii. Opto-electronic

iii. Rogowski coil type.

Que 1.11. Explain the working of potential transformer.

Answer

1. Voltage transformers (VTs) are also known as potential transformers (PTs).
2. They are used to reduce the power system voltages to lower values and to provide isolation between the high-voltage power network and the relays and other instruments connected to their secondaries.
3. The voltage ratings of the secondary windings of the VTs have been standardized, so that a degree of interchangeability among relays and meters of different manufacturers can be achieved.
4. The secondary windings of the voltage transformers are rated at 110 V line to line.
5. Therefore, the voltage ratings of the voltage (pressure) coils of protective relays and measuring instruments (meters) are also 110 V line to line.
6. The accuracy of voltage transformers is expressed in terms of the departure of its ratio from its true ratio.
7. The percentage ratio error is given by,

$$\text{Percent ratio error} = \left[\frac{KV_s - V_p}{V_p}\right] \times 100$$

where, K = Nominal voltage ratio

$$= \frac{\text{Rated primary voltage}}{\text{Rated secondary voltage}}$$

$$= \frac{\text{Number of primary turns}}{\text{Number of secondary turns}}$$

V_s = Secondary voltage, and

V_p = Primary voltage

8. There are three types of voltage transformers :

i. Electromagnetic type ii. Capacitor type

iii. Opto-electronic type.

PART-9

Summation Transformer, Phase Sequence Current-Segregating Network.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 1.12. Describe summation transformer with the help of neat sketch.

Answer

1. Summation transformer is used for converting the three-phase quantities into a single phase quantity.
2. Summation transformer is used during unbalanced or faulty conditions in the system, in order to ensure the relay operates normally.
3. Fig. 1.12.1(a) shows a schematic diagram of a summation transformer where the primary windings are connected to the output terminals of the line CTs, Fig. 1.12.1(b) and Fig. 1.12.1(c) show corresponding phase diagrams.
4. The number of turns between R and Y phases is equal to those between Y and B. But more turns are provided between B and neutral.
5. The output of a summation CT is given by

$$I_{output} = (N + 2)\, I_R + (N + 1)\, I_Y + NI_B \quad \ldots(1.12.1)$$

6. Eq. (1.12.1) can be converted to their symmetrical components. Taking R phase as reference we get,

$$I_{output} = (N + 2)(I_1 + I_2 + I_0) + (N + 1)(a^2 I_1 + aI_2 + I_0) + N(aI_1 + a^2 I_2 + I_0)$$

$$= 3I_0 (N + 1) + I_1 (2 + a^2 + a^2 N + aN + N) + I_2 (2 + a + a^2 N + aN + N)$$

$$= 3I_0 (N + 1) + I_1 (2 + a^2) + I_2 (2 + a)$$

$$= K_0 I_0 + K_1 I_1 + K_2 I_2 \quad \ldots(1.12.2)$$

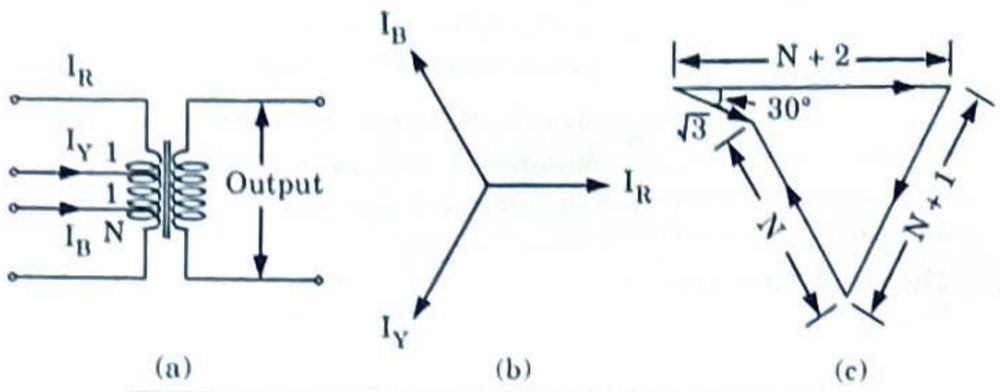

Fig. 1.12.1. (a) Summation transformer
(b) Phasor diagram of 3-phase input current
(c) Phasor diagram of summated output for 3-phase balanced input current.

Que 1.13. **Explain phase sequence current segregating network.**

Answer

1. A simple arrangement of phase sequence current segregating network is shown in Fig. 1.13.1(a).
2. The output of the network or any other kind of summation device can be given by,

$$I_{output} = K_0 I_0 + K_1 I_1 + K_2 I_2$$

3. The constants K_0, K_1 and K_2 depend on the device which is used to derive a single-phase quantity from the 3-phase quantities.
4. The phase-sequence filter giving an output in the form of $I_1 - KI_2$ gives the most uniform response for any type of fault. The value of K may be 5 or 6. Fig. 1.13.1(b) shows a phase sequence filter of this type.

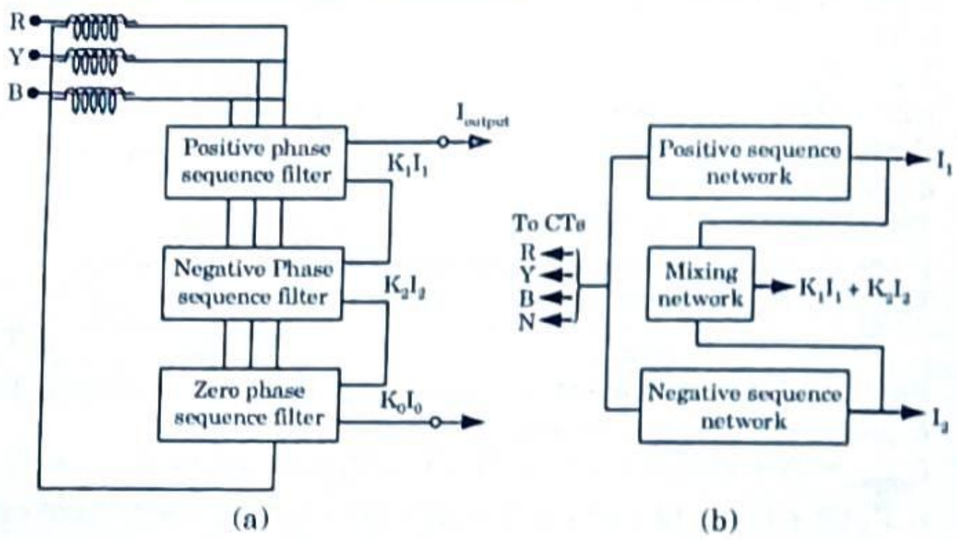

Fig. 1.13.1. (a) Phase sequence filter network
(b) $(K_1I_1 + K_2I_2)$ type phase sequence filter network.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the needs of protective system employed in power system ?
Ans. Refer Q. 1.2.

Q. 2. What do you understand by zone of protection? Discuss various zones of protection with the help of single-line diagram.
Ans. Refer Q. 1.5.

Q. 3. Explain what do you understand by primary and backup protection. What are the various methods of providing backup protection ?
Ans. Refer Q. 1.6.

Q. 4. Write the essential qualities of protection.
Ans. Refer Q. 1.7.

Q. 5. Explain automatic reclosing.
Ans. Refer Q. 1.9.

Q. 6. Explain the working of potential transformer.
Ans. Refer Q. 1.11.

Q. 7. Describe summation transformer with the help of neat sketch.
Ans. Refer Q. 1.12.

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2 UNIT

Relays

CONTENTS

PART-1

Relays : Electromagnetic Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.1. **Explain electro-mechanical relays and show its types.**

AKTU 2020-21, Marks 07

OR

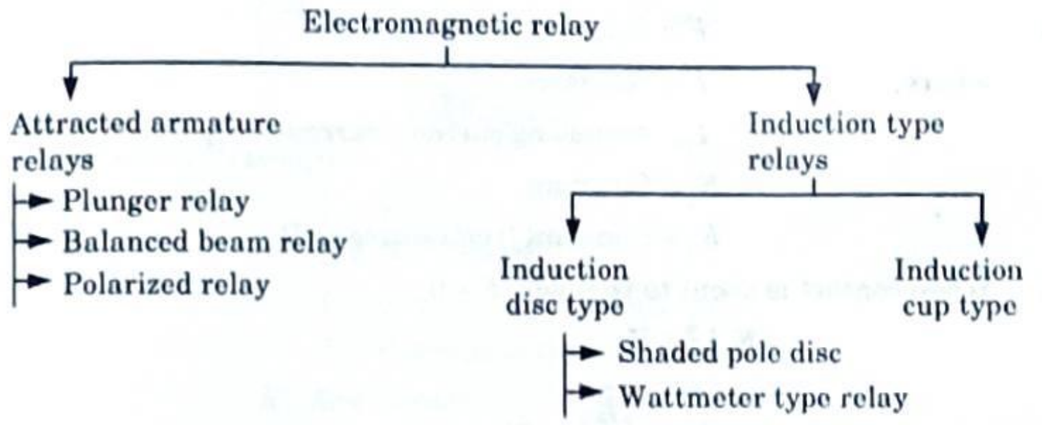
Give the principle and types of electromagnetic relay.

Answer

A. Principle :

1. Electromagnetic relays are those relay which operates on the principle of electromagnetic attraction.
2. It is a type of a magnetic switch which uses the magnet for creating a magnetic field. Then that magnetic field is used for opening and closing the switch and for performing the mechanical operation.

B. Types :



PART-2

Attracted and Induction Type Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.2. **What are the different types of attracted armature type relays ? Explain why they are noisy.** **AKTU 2017-18, Marks 10**

Answer

Attracted armature type relay :

a. Plunger type relay :

1. The plunger moves when the coil is energized. The magnetic force attracts the plunger upwards. The spring pulls the plunger down when the coil is not energized.
2. Under the normal condition, the coil is not energized and contact is open. The plunger is set to move upward. The moving force is proportional to the square of current in coil.
3. The threshold value of current at which plunger start moving upward is called pick up value of current. This relay can operate on AC or DC both. The typical operating time is 5 to 50 nsec.

Operating Principle :

1. Here electromagnetic force $\propto \phi^2$, where ϕ is the flux in air gap under unsaturation
2. Force $\propto I^2$, where I is actuating current and $\phi \propto I$
3. $$F = K_1 I_1^2 - K_2$$

   where, F = Net force

   I_1 = Actuating current (current in operating coil)

   K_1 = Constant

   K_2 = Constant (restraining coil)
4. When contact is about to be made, $F = 0$

$$K_1 I_1^2 = K_2$$

$$I_1 = \sqrt{\frac{K_2}{K_1}} = \text{Constant}$$

For the operation of plunger, current has to be greater than I_1.

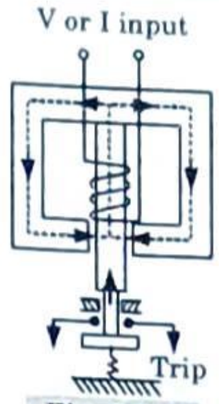


Fig. 2.2.1.

b. Balanced beam type relay :

1. The balanced beam relay operates on the balance principle, by comparing two quantities (two currents, or one current and one voltage). It consists of a beam pivoted centrally (supported at middle).
2. There are two coils on each side, energized by current (current balanced beam relay) or by current and voltage (impedance balanced beam relay). Under normal condition, beam remains horizontal.
3. When the operating torque or force exceeds the restraining torque, a beam is pulled down and its contacts are closed (or tripped).

Fig. 2.2.2.

Operating Principle :

1. $$T = K_1 I_1^2 - K_2 I_2^2$$

   where, T = Net Torque

   I_1 = Current in operating coil

   I_2 = Current in restraining coil

   K_1, K_2 = Constant
2. When, $T = 0$

$$K_1 I_1^2 = K_2 I_2^2$$

$$\frac{I_1}{I_2} = \sqrt{\frac{K_2}{K_1}}$$

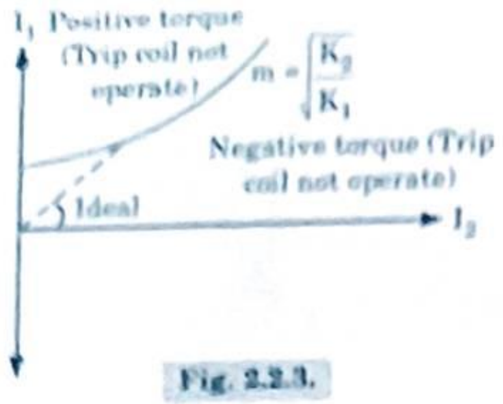


Fig. 2.2.3.

c. Polarized type relay :

1. A relay whose operation depends upon direction of current and polarity of voltage is called polarized relay. The current carrying coil will be the stationary core.
2. A permanent magnet is used for polarization. The contacts are closed if current of operating coil exceeds the pickup value.
3. It is highly sensitive relay with its operating time between 2 msec to 15 msec.
4. It is DC polarized relay meant to be used with DC. This relay operates only when input is applied with correct polarity.

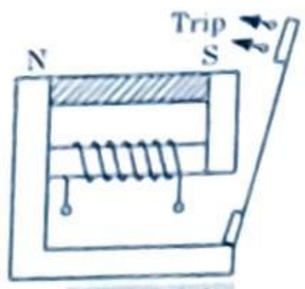


Fig. 2.2.4.

B. Reasons : If restraining force produced with the help of spring is constant then the relay armature will vibrate at double frequency. This causes noise.

Que 2.3. Explain the working principle of electromagnetic relay. Give its advantages and disadvantages along with applications.

AKTU 2016-17, Marks 15

Answer

A. Working principle of electromagnetic relay : Refer Q. 2.1, Page 2-2B, Unit-2.

B. Advantages :

1. It can be used for both AC and DC.
2. They have fast operation and fast reset.
3. High operating speed.

C. Disadvantages :

1. High burden level instrument transformers are required.
2. The directional feature is absent.
3. Requires periodic maintenance and testing.

D. Applications :

1. The protection of various AC and DC equipments.
2. In the definite time lag over current and earth fault protection along with definite time lag over current relay.
3. For the differential protection.

Que 2.4. Explain the operating principle and types of induction relays.

Answer

Operating principle :

1. Induction relays use electromagnetic induction principle for their operation.
2. Their principle of operation is same as that of a single-phase induction motor. Hence they can be used for AC currents only.
3. There are two types of induction relays. In both types of relays, the moving element (disc or cup) is equivalent to the rotor of the induction motor.
4. The moving element acts as a carrier of rotor currents, whereas the magnetic circuit is completed through stationary magnetic elements.
5. Two sources of alternating magnetic flux in which the moving element may turn are required for the operation of induction-type relays. In order to produce an operating torque, the two fluxes must have a phase difference between them.

Types of induction relays :

A. Induction disc type relay :

a. Shaded pole type relay :

1. This relay, on construction point of view is used as a single quantity relay. The actuating quantity may be voltage or current.
2. It consists of an operating coil carrying the current proportional to system current. The main flux produced is splitted into two fluxes displaced in time and space with the help of shaded ring.
3. The air gap flux of shaded pole (ϕ_1) lags behind the flux of unshaded pole.

The shaded ring is made of copper. The moving part is a circular metallic disc (Al disc).

4. The two alternating fluxes (ϕ_1, ϕ_2) displaced in space and time cut the disc and produces eddy current in it.
5. Torques are produced by the interaction of each flux and $\tau \propto \phi_1\phi_2 \sin\theta$ where θ is phase difference between ϕ_1 and ϕ_2. The resultant torque causes the disc to rotate.

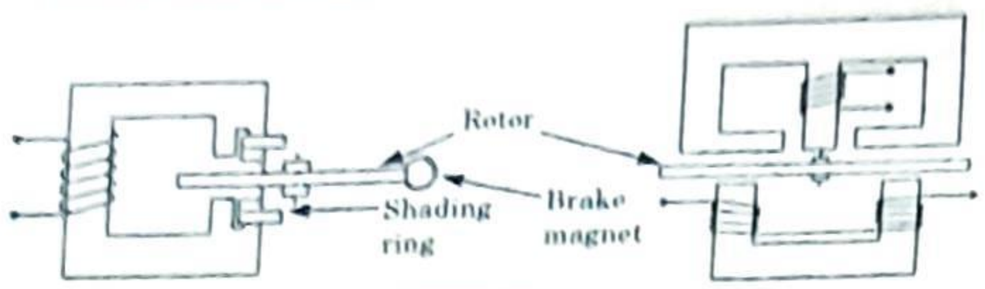


Fig. 2.4.1.

6. Due to rotation of disc, the trip coil contact may be closed. The C shaped brake magnet is used to control the rotation speed.

b. Wattmeter type relay :

1. The construction of this relay is similar to the wattmeter used. It consists of two electromagnets. One is of E shape and other one of C shape and an aluminium disc is there in between which can rotate freely.
2. Each magnet produces displacement between the fluxes because both magnets are energized by two different actuating quantities. If both are energized by quantity, then the resistance and reactance of the two circuits must be different so that sufficient phase difference can be produced between two fluxes.
3. Now the disc rotates due to interaction between two different fluxes and so contact may close and command may go to trip coils.

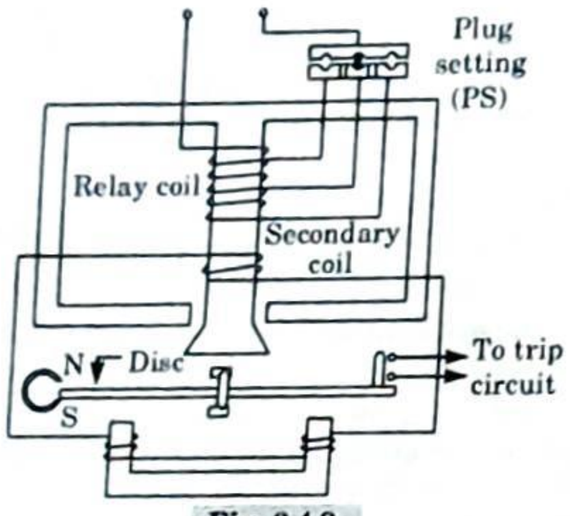


Fig. 2.4.2.

B. Induction cup type relay :

1. It operates on the same principle as that of an induction motor. In this a stationary iron core is placed inside the rotating cup to decrease the air gap without increasing inertia.
2. The spindle of the cup carries an arm which closes the contacts. A spring is employed to provide a resetting torque.
3. When two actuating quantities are employed, one produce operating torque and other restraining torque. Two pair of coils produces a rotating field which induces current in the rotor.
4. Due to the interaction between the rotating flux and induced current, a torque is produced which causes rotation.
5. The magnetic system is more efficient and also reduces the resistance of the induced current path in the rotor.
6. Magnetic saturation can be avoided by proper design and the relay can be made to have its characteristics linear and accurate.

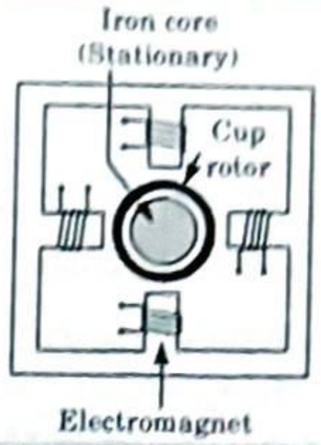


Fig. 2.4.3. Induction cup structure.

Que 2.5. **Derive torque equation for induction type relay.**

AKTU 2016-17, Marks 10

OR

Explain the operating principle of induction type relay. Derive the expression for the force exerted on the plates of induction type relay.

AKTU 2010-20, Marks 07

Answer

A. Operating principle of induction type relay : Refer Q. 2.4, Page 2–6B, Unit-2.

B. Expression :

1. Fluxes ϕ_1 and ϕ_2 are produced in a disc type of shading technique. In wattmetric type construction ϕ_1 is produced by the upper magnet and ϕ_2 by the lower magnet.

2. A voltage is induced in a coil wound on the lower magnet by transformer action. Force is produced in a rotor, which is cut by ϕ_1 and ϕ_2.
3. These fluxes are alternating quantities expressed as :

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

   where θ is the phase difference between ϕ_1 and ϕ_2.

   The flux ϕ_2 leads ϕ_1 by θ.

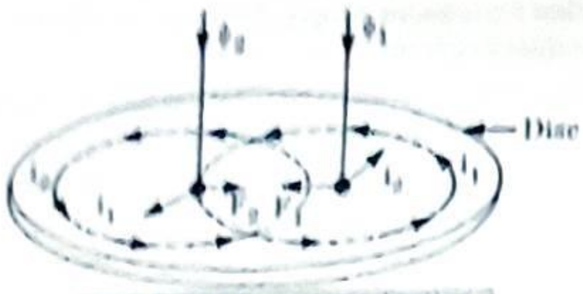


Fig. 2.5.1. Torque production.

4. Currents induced in the rotor are

$$i_1 \propto \frac{d\phi_1}{dt} \propto \phi_{1m} \cos \omega t$$

$$i_2 \propto \frac{d\phi_2}{dt} \propto \phi_{2m} \cos (\omega t + \theta)$$

5. The current produced by the flux interacts with the other fluxes and forces produced are

$$f_1 \propto \phi_1 i_2 \propto \phi_{1m} \sin \omega t \, \phi_{2m} \cos (\omega t + \theta)$$
$$\propto \phi_{1m} \phi_{2m} \cos (\omega t + \theta) \sin \omega t$$
$$f_2 \propto \phi_2 i_1 \propto \phi_{2m} \sin (\omega t + \theta) \, \phi_{1m} \cos \omega t$$
$$\propto \phi_{1m} \phi_{2m} \sin (\omega t + \theta) \cos \omega t$$

6. As these forces are in opposition, the resultant force is

$$f = (f_2 - f_1)$$
$$\propto \phi_{1m} \phi_{2m} [\sin (\omega t + \theta) \cos \omega t - \cos (\omega t + \theta) \sin \omega t]$$
$$\propto \phi_{1m} \phi_{2m} \sin \theta$$
$$f = k \phi_1 \phi_2 \sin \theta$$

   where ϕ_1 and ϕ_2 are rms values.

7. If the same current produces ϕ_1 and ϕ_2, force produced is given by

$$f = k I_1 I_2 \sin \theta,$$

   where θ is the angle between ϕ_1 and ϕ_2.

8. The net force of torque acting on disc is same at every instant. The action of relay under such force is free from vibrations.
9. If θ is zero, the net force is zero and disc cannot rotate. Hence there must exist a phase difference between two fluxes. The torque is maximum when phase difference θ is 90°.

PART-3

Thermal Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.6. **Discuss the working principle, types and applications of thermal relays.** **AKTU 2017-18, Marks 10**

Answer

A. Working principle :

1. Thermal relays utilize the electrothermal effect of the actuating current for their operation.
2. The thermal element is bimetallic element which consists of two metal strips of different co-efficient of thermal expansion.
3. When this bimetallic strip is heated up, one strip expands more than the other. This results in bending of the strip.
4. When the bimetallic element heats up, it bends and gets deflected there by closing the relay contacts.
5. Unimetallic strips are also used as thermal elements in a hair pin like shape as shown in Fig. 2.6.1. When the strip gets heated, it expands and closes the contacts.

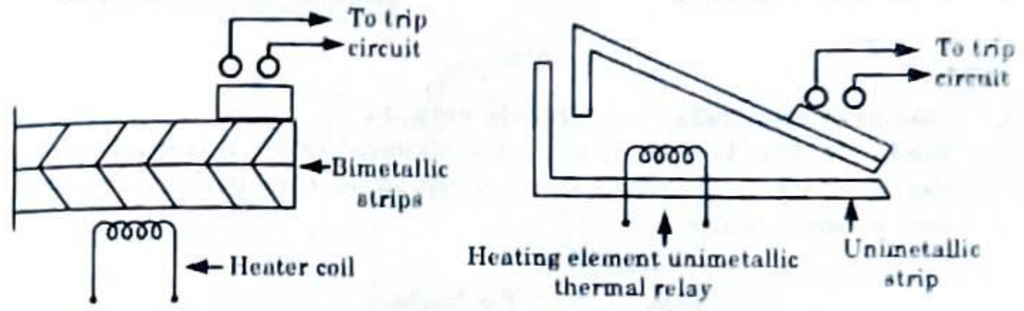


Fig. 2.6.1.

6. For the protection of 3-phase motors, three bimetallic strips are used. They are energized by currents from the three phases.
7. Their contacts are arranged in such a way that if any one of the spirals moves differently from the others, due to unbalance exceeding 12 %, their contacts meet and cause the circuit breaker to trip. These spirals also protect motors, against overloading.

8. The elements form an arm of balancing bridge. In normal conditions, the bridge is balanced. When the temperature exceeds a certain limit, the bridge becomes unbalanced.
9. The change in the balance current energizes a relay which trips the circuit breakers. Thermocouple and RTD are also used in protection. In the protection of large generator, such elements are placed in stator slots.

B. Types :

1. Bimetallic thermal relay.
2. Bimetallic spiral type thermal relay.
3. Unimetallic thermal relay.

C. Applications :

1. For protection of small motors.
2. For protection of 3-ϕ motors.

PART-4

Gas Actuated Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.7. **Explain how gas actuated relay operates. Also write down its applications.** **AKTU 2019-20, Marks 07**

Answer

A. Gas actuated relay (Buchholz relay) :

1. Buchholz relay is nothing but a gas actuated relay. It is used to detect the faults which are minor initially but as the time increases they may lead to major faults.

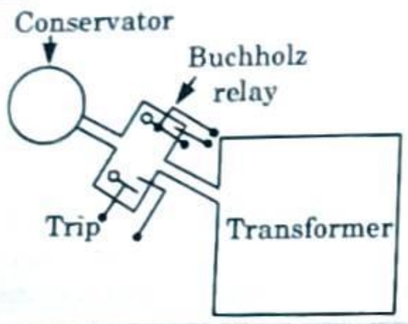


Fig. 2.7.1. Location of Buchholz relay.

2. Whenever a fault takes place in a transformer, the oil of the tank gets overheated and gases are formed.
3. The generation of the gases may be slow depending upon whether the fault is incipient, minor or heavy short circuit. The generated gas is used as a means of fault detection.
4. Buchholz relay is the simplest form of protection which is commonly used. It consists of two hinged floats in a metallic chamber which is connected in the upper side of the pipe run between the oil conservator and the transformer tank.

B. Operation :

1. Under normal conditions the floats are up, but when the fault occurs between the winding's turns, bubbles produced by the breakdown of the oil flow in the direction of conservator.
2. This is a slow fault and warming is given. However if the fault is heavy, the surge of gas and oil up the pipe engages the lower float, which engages associated contacts, which in turn trip the circuit breaker.
3. Whenever a fault occurs it produces heat and thus decomposes transformer fluid or solid insulating material which produces inflammable gases.
4. When a specified amount of gas is formed this relay gives an alarm. If we analyze the accumulated gas we can find out the type of fault.
5. Whenever gas accumulates the oil level falls down, thus the floats come down. It causes an alarm to sound and alert an operator. The accumulated gas can be taken out with the help of a pipe through petcock.
6. If there is a severe fault then the large amount of gases will be accumulated which cause the lower float to operate. It finally trips the circuit breaker of transformer.

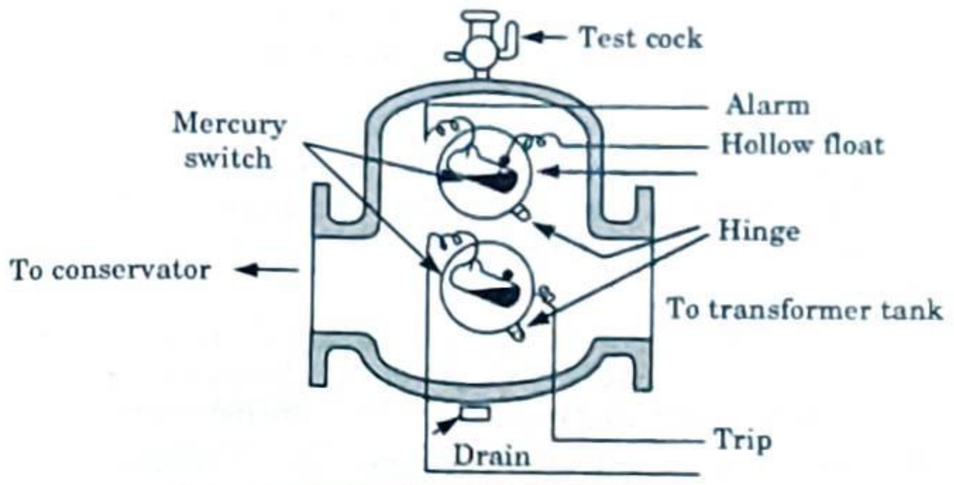


Fig. 2.7.2. Buchholz relay.

7. This relay is a slow acting device. The minimum operating time is 0.1 sec; the average time is 0.2 sec.

8. Main advantage of this relay is that it indicates incipient faults between turns or core heating, so transformer may be taken out of service before major problem occurs.

C. Applications :

1. Winding short circuit
2. Bushing puncture
3. Winding earth faults.

PART-5

Design Considerations of Electromagnetic Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.8. Explain the design considerations of electromagnetic relay.

AKTU 2020-21, Marks 07

Answer

The design of an electromagnetic relay is based on the construction of various components of that relay. The design considerations for the various components of an electromagnetic relay are :

1. **Coils :** The coils carry the currents and should be designed by considering temperature rise associated with the coil. The temperature rise limits the current rating of the coil.
2. **Movable assembly :** The inertia of the movable assembly must be as low as possible for the fast operation of the relay. Thus the parts used are very light for the movable assembly. Similarly for the fast operation, the distance of travel is also minimized.
3. **Relay contacts :**

i. The relay contacts must be robust as the contacts must perform 'make and break' duty successfully. This is difficult because for making relay sensitive, the parts used in moving system are light in weight.

ii. Hence seal in contact arrangement is used. This arrangement prevents opening of relay contacts for the flow of trip current.

iii. The materials which are preferred for the relay contacts are silver due to low resistance and self cleaning property, alloys of silver such as

cadmium silver oxide for high current applications, gold-silver-platinum alloys for low current applications.

4. **Bearings :** The 'pivot and jewel' bearings are preferred for induction relays. The jewels absorb the shocks as spring mounted. The pin bearings and knife edge bearings are used for armature relays.
5. **Cases :** The cases used are of same width and depth. The length depends on the type and application of the relay. The cases are usually flush mounted. Presently cases of pressed steel cast aluminium or plastic are used. These are dust proof cases.
6. **Operation indicator :** This is a coloured flag. When relay operates, it is mechanically moved to indicate that the relay is operated. When the relay is reset, the flag is reset manually. When the flag is operated, the corresponding operation of the circuit breaker is assumed.
7. **Adjustment of reset :** The adjustment of reset is achieved using tapped auxiliary potential transformers and resistors. In some relays, adjusting spring tension or air gap length adjustment is used for adjustment of reset.

PART-6

Relay Application and Characteristics : Amplitude and Phase Comparators.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

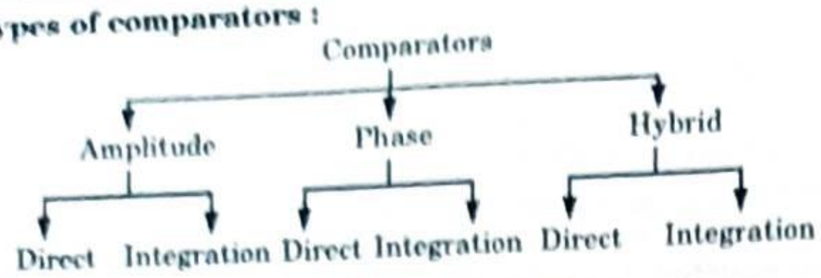
Que 2.9. What is comparator and explain its types ?

Answer

A. Comparator :

1. Many relay operations are based on the resultant of the comparison of two quantities.
2. The comparator is that part of a relay which receives two inputs and produces the output based on the comparison of two inputs.
3. In some relays, the amplitudes of the two quantities entering and leaving a protected zone are compared. It is called amplitude comparator.
4. While in some relays, the phase angles between the sending end quantities and receiving end quantities are compared. They are called phase comparators.

B. Types of comparators :



Que 2.10. What is amplitude comparator ?

Answer

1. An amplitude comparator compares the amplitudes of the two input quantities, irrespective of phase angle of the quantities.

Fig. 2.10.1. Basic operation of amplitude comparator.

2. $\bar{R}$ is positive if $|\bar{P}| > |\bar{Q}|$
   $\bar{R}$ is negative if $|\bar{P}| < |\bar{Q}|$
   $\bar{R}$ is zero if $|\bar{P}| = |\bar{Q}|$
3. In some comparators, the ratio of amplitudes is obtained and resultant is decided based on the value of ratio.
4. Let $$\frac{|\bar{P}|}{|\bar{Q}|} = \bar{R}$$
   Then, $\bar{R} > 1$ if $|\bar{P}| > |\bar{Q}|$
   $\bar{R} < 1$ if $|\bar{P}| < |\bar{Q}|$
   $\bar{R} = 1$ if $|\bar{P}| = |\bar{Q}|$

Que 2.11. What are the different types of amplitude comparators ? Discuss the operating principle of rectifier bridge amplitude comparator. **AKTU 2017-18, Marks 10**

Answer

Amplitude comparator is of two types :

A. Rectifier bridge comparator :

1. The inputs are sinusoidal currents. Each input is given to full wave rectifier which rectifies it. The output is the difference of the amplitudes of the two inputs.
2. The output relay is connected in parallel with the two rectifier circuits. A filter circuit is used at the output to make it smoother.

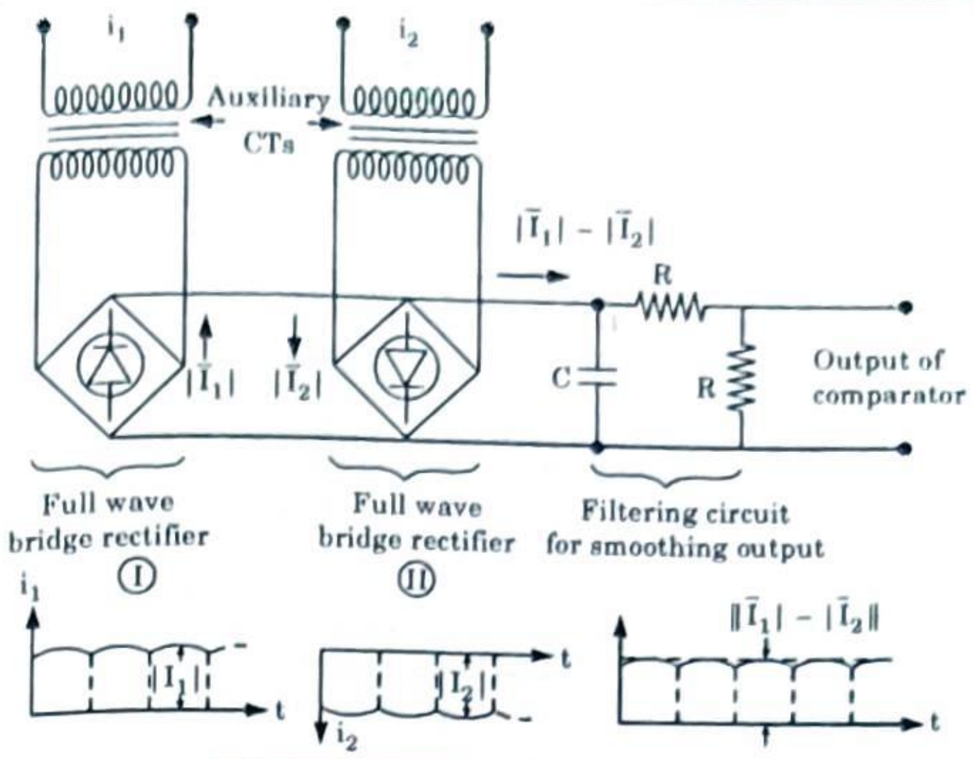


Fig. 2.11.1. Rectifier bridge comparator.

3. The output is continuous and a DC equivalent to $|\bar{I}_1| - |\bar{I}_2|$. When $|\bar{I}_1| - |\bar{I}_2|$ exceeds the threshold value, the relay operates.

B. Integrating amplitude comparator :

1. In this, the output of the comparator is given to an integrator and the circuit integrates the output with time.
2. When integrated value reaches threshold value, the output relay operates.

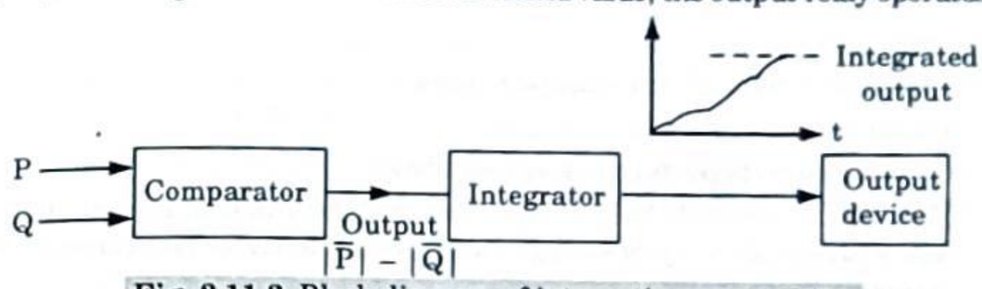


Fig. 2.11.2. Block diagram of integrating comparator.

Que 2.12. What is phase comparator ?

OR

Describe amplitude and phase comparators. **AKTU 2020-21, Marks 07**

Answer

A. Amplitude comparator : Refer Q. 2.10, Page 2–15B, Unit-2.

B. Phase comparator :

1. If the two input signals are S_1 and S_2 the output occurs when the inputs have a phase relationship lying within specified limits.
2. Both inputs must exist for an output to occur; ideally, operation is independent of their magnitudes, and is dependent only on their phase relationship. Fig. 2.12.1 illustrates the phase comparator in its simple form.
3. The function is defined by the boundary of marginal operation and represented by two straight lines from the origin of the complex plane.

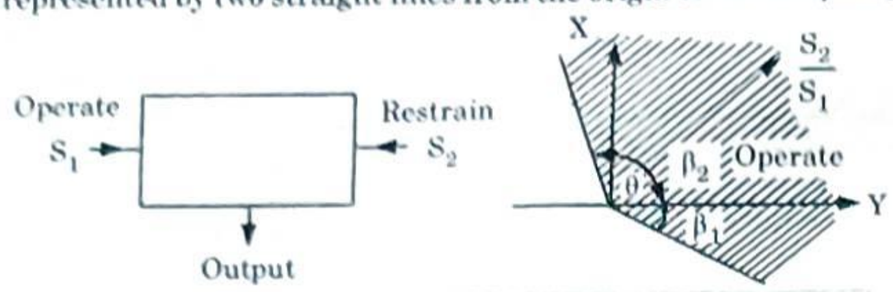


Fig. 2.12.1. Phase comparator output when angle θ between S_1 and S_2 is within limits β_1 and β_2.

4. The condition of operation can be put mathematically as
$$-\beta_1 \leq \theta \leq +\beta_2$$
where θ is the angle by which S_2 leads S_1.
5. If $\beta_1 = \beta_2 = 90°$ then the comparator is known as cosine comparator and if $\beta_1 = 0$ and $\beta_2 = 180°$ then it is a sine comparator.

Que 2.13. What are types of phase comparator ? Explain any one.

OR

Discuss the coincidence principle used in phase comparators.

Answer

Types of static phase comparators :

A. Vector product phase comparator.

B. Coincidence type phase comparator :

1. The basic concept of phase comparison is simpler in that it is possible to deal with signals of equal strength whose coincidence (or non-coincidence) is readily measurable.
2. Considering two sinusoidal signals S_1 and S_2, the period of coincidence of S_1 and S_2 will depend on the phase difference between S_1 and S_2. Fig. 2.13.1 illustrates the coincidence of signals for different phase relationships.
3. It can be seen that the period of coincidence is equal to the period of non-coincidence for a phase difference of ± 90°, the period of coincidence is less than the period of non-coincidence and vice versa when the phase difference is less than ± 90°.

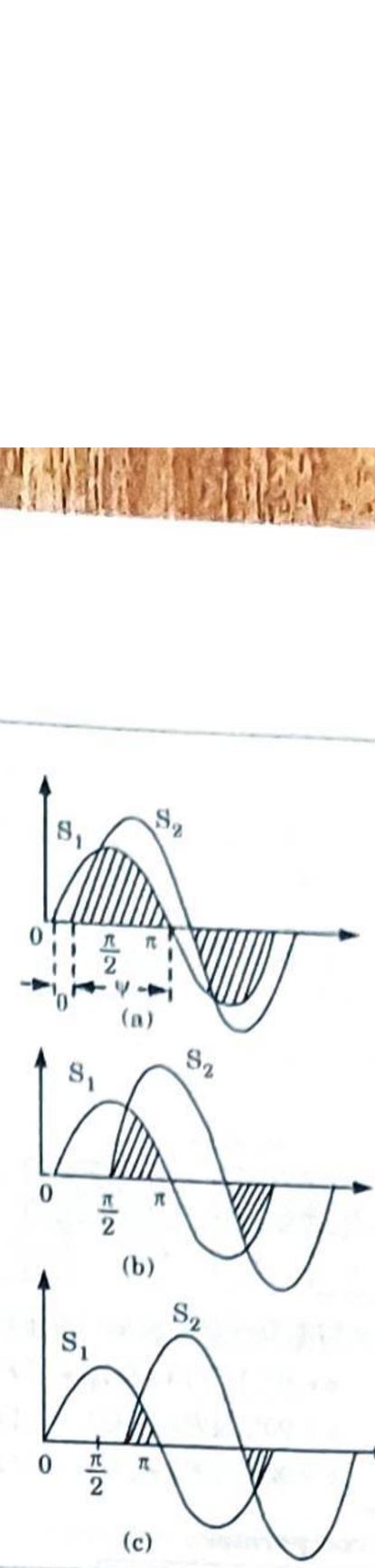


Fig. 2.13.1. Coincidence of signals :
(a) S_2 lagging S_1 by less than π/2;
(b) S_2 lagging S_1 by π/2; (c) S_2 lagging S_1 by more than π/2.

4. Depending upon the phase relation of the input signals it is possible to design the circuit to give an output a *Yes* or a *No*, by measuring the period of coincidence.
5. The period of coincidence of two signals with a phase difference of θ is $\phi = 180 - \theta$. Different techniques can be employed to measure the period of coincidence.

Que 2.14. Draw neat diagrams to demonstrate 'Trip', 'Restrain' and 'Threshold' conditions for the sine and the cosine type of comparators.

OR

Describe various types of phase compensators used in static relays.

Answer

1. In phase comparator, the phase angle ϕ between the two inputs is considered. The sinusoidal inputs are converted to rectangular waveforms

before application to the comparator. Thus $[\bar{P}]$ is rectangular equivalent of $\bar{P}$ while $[\bar{Q}]$ is the rectangular equivalent of $\bar{Q}$.

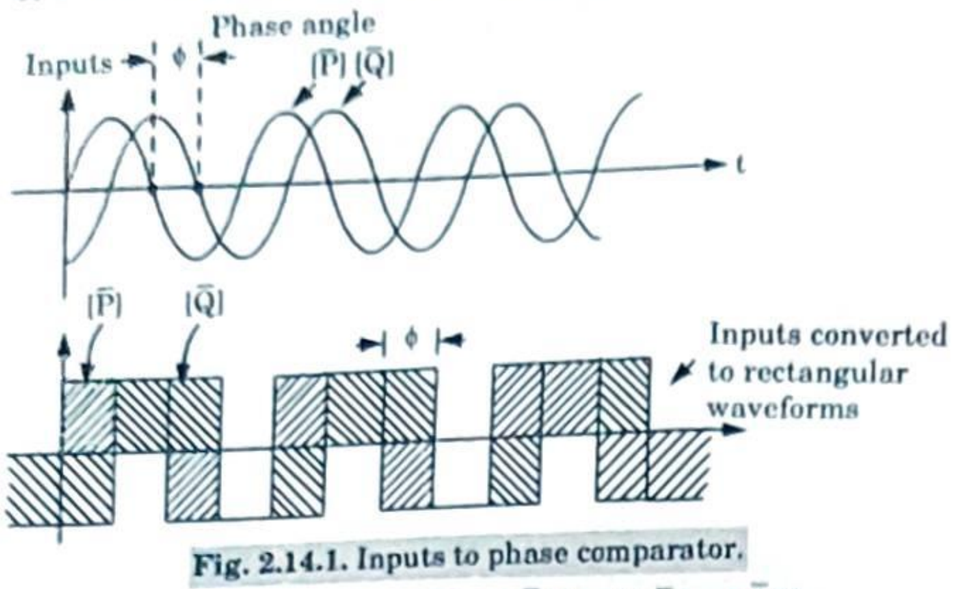


Fig. 2.14.1. Inputs to phase comparator.

Thus, $\phi = 0°$, $|[\bar{P}] + [\bar{Q}]| = |[\bar{P}] - [\bar{Q}]|$

$\phi < 90°$, $|[\bar{P}] + [\bar{Q}]| > |[\bar{P}] - [\bar{Q}]|$

$\phi > 90°$, $|[\bar{P}] + [\bar{Q}]| < |[\bar{P}] - [\bar{Q}]|$

2. **It is of two types :**

a. **Sine type phase comparator :**

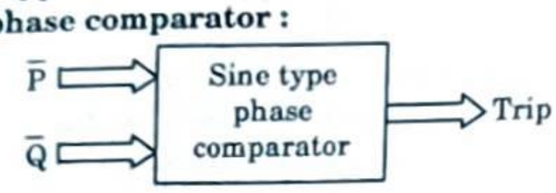


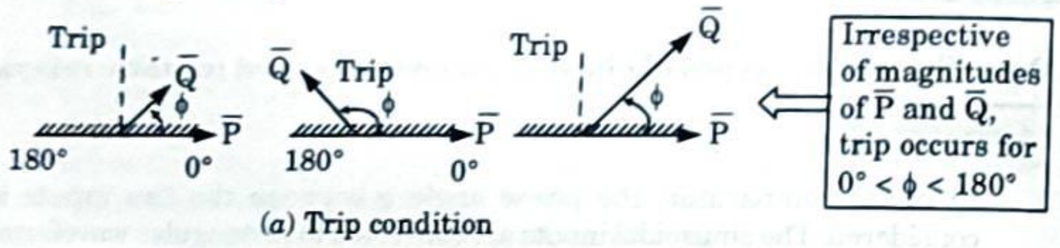
Fig. 2.14.2.

$\bar{P}$ = Reference input

$\bar{Q}$ = Measured input

i. The phase angle is $\angle\left(\frac{\bar{P}}{\bar{Q}}\right)$ and the sine type phase comparator follows the trip law.

ii. If $0° < \left[\angle\left(\frac{\bar{P}}{\bar{Q}}\right)\right] < 180°$, then it will trip otherwise restrain.



(*a*) Trip condition

(*b*) Restrain condition

(*c*) Threshold condition

Fig. 2.14.3. Sine type phase comparator.

b. **Cosine type phase comparator :**

Fig. 2.14.4.

Due to cosine nature, the trip law changes as

If $-90° < \left[\angle\left(\frac{\bar{P}}{\bar{Q}}\right)\right] < +90°$, then it will trip otherwise restrain.

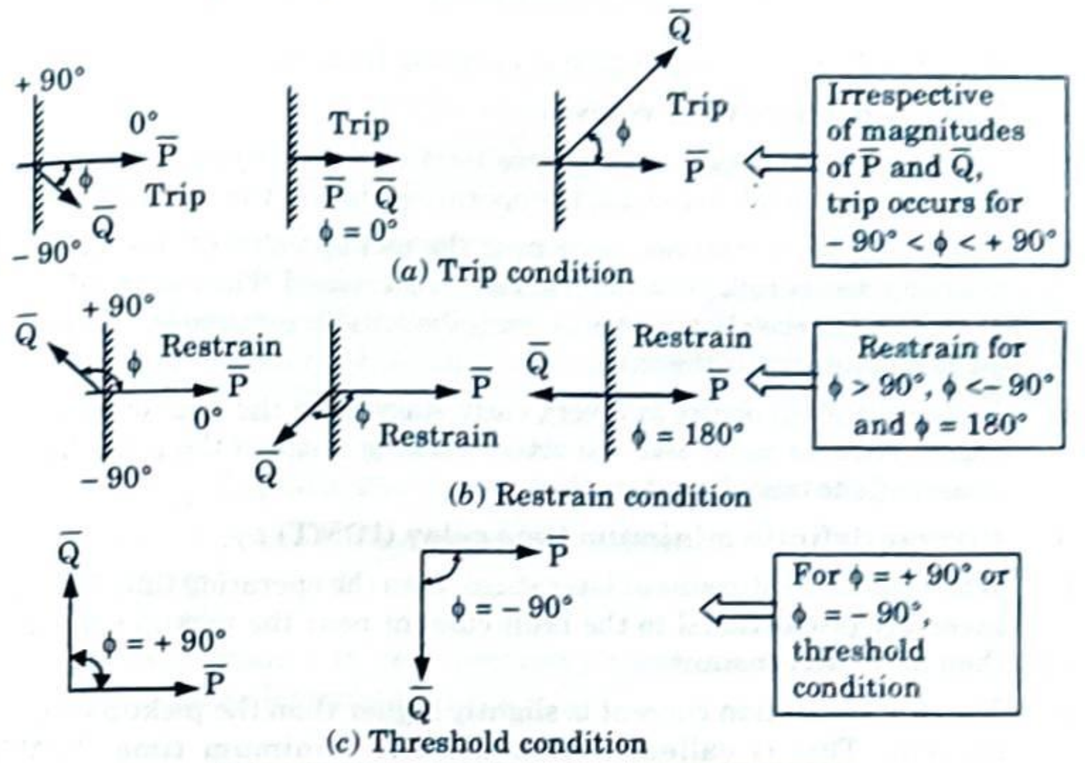


Fig. 2.14.5. Cosine type phase comparator.

PART-7

Overcurrent Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.15. **What are the various types of overcurrent relays ? Discuss their area of applications.** **AKTU 2017-18, Marks 10**

Answer

The overcurrent relays are classified depending upon the time of operation. These are classified as :

1. **Instantaneous overcurrent relays :**

i. These relays operate very fast and there is no time delay. The operating time can be as low as 0.01 sec. This speed of operation can be achieved by hinged armature type electromagnetic relay.

ii. These are effective only when the impedance between the relay and source Z_s is very small as compared to the impedance of protected section Z_L.

Applications : For protection of outgoing feeders.

2. **Inverse definite time relays :**

i. All overcurrent relay have inverse time characteristics means as the fault current level increases, the operating time of the relay decreases.

ii. These characteristics are more near the pickup value of the actuating quantity and become less inverse as it is increased. The nature of these characteristics can be obtained by using the suitable core and by varying the point of saturation of this core.

iii. If the saturation occurs at a very early stage, then the time of operation almost remains same over the active working range of the relay. This is called definite time characteristics.

3. **Inverse definite minimum time relay (IDMT) :**

i. When the core saturates at later stage, then the operating time becomes inversely proportional to the fault current near the pickup value and then becomes constant.

ii. The core saturation current is slightly higher than the pickup value of current. This is called inverse definite minimum time (IDMT) characteristics.

Applications : Used in utility and industrial circuits.

4. **Very inverse relays :** As the core saturation occurs at a further later stage, then the inverse nature of characteristics continues for longer range and takes the shape. This is called very inverse time characteristics. After saturation, the curve tends to definite time.

5. **Extremely inverse relays :** In this, the saturation occurs at very later stage and the curve has an inverse nature for almost entire working range. The equation is $I^2t = K$ where I is the operating current and t is the operating time. This characteristic is called extremely inverse time characteristics.

Applications : Suitable for protection of distribution feeders with peak currents during switching ON (refrigerators, pumps, water heaters etc.).

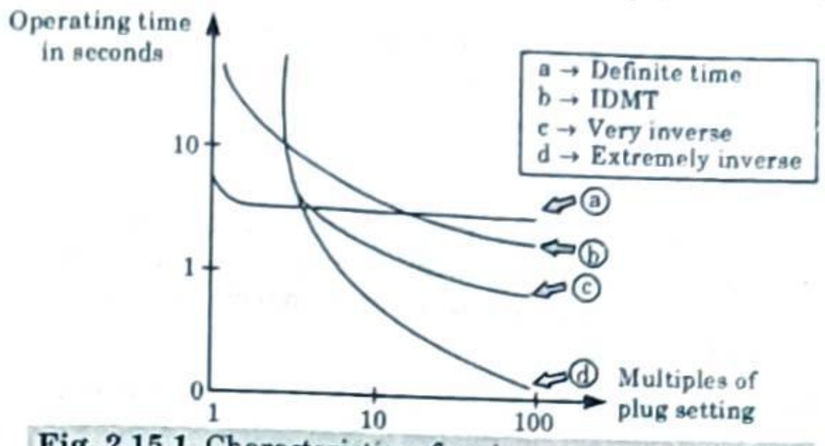


Fig. 2.15.1. Characteristics of various overcurrent relays.

PART-8

Directional Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.16. **Explain the construction and operating principle of overcurrent relay with directional scheme.**

Answer

A. **Construction :** It uses two relay elements mounted on a common case, these elements are :

i. Directional element :

1. It is a directional power relay which operates when power in the circuit flows in a particular direction. The voltage coil of this element is energized by a system voltage through a potential transformer.
2. The current coil on the lower magnet is energized by the system current through a CT. The trip contacts of this relay (1-1') are connected in series with the secondary winding of non-directional element.

ii. Non-directional element :

1. The current coil of directional element is connected in series with the primary winding of non-directional element. The plug setting bridge is provided in this element to adjust current setting as per requirement.
2. The trip contacts (1-1') are in series with winding on lower magnet of non-directional element. When the contacts are closed, the non-directional element cannot operate.

B. Operation :

1. Under normal conditions, power flows in proper direction and hence directional element of the relay is inoperative. Thus the secondary winding on lower magnet of non-directional element is open and hence it is also inoperative.
2. When fault takes place, current or power flows in reverse direction. The current flows through current coil of directional element which produces flux.
3. The current in voltage coil produces another flux. The two fluxes interact to produce the torque due to which the disc rotates and the trip contacts (1-1') get closed.
4. The current also flows through the primary winding on the upper magnet of non-directional element. This energizes the winding to produce the flux.
5. This flux induces the emf in the secondary winding of the non-directional element according to induction principle. As the contacts are closed, the secondary winding has a closed path.
6. Hence the induced emf drives the current through it, producing another flux. The two fluxes interact to produce the driving torque which rotates the disc. Thus the contacts of trip circuit get closed and it opens the circuit breaker to isolate faulty section.

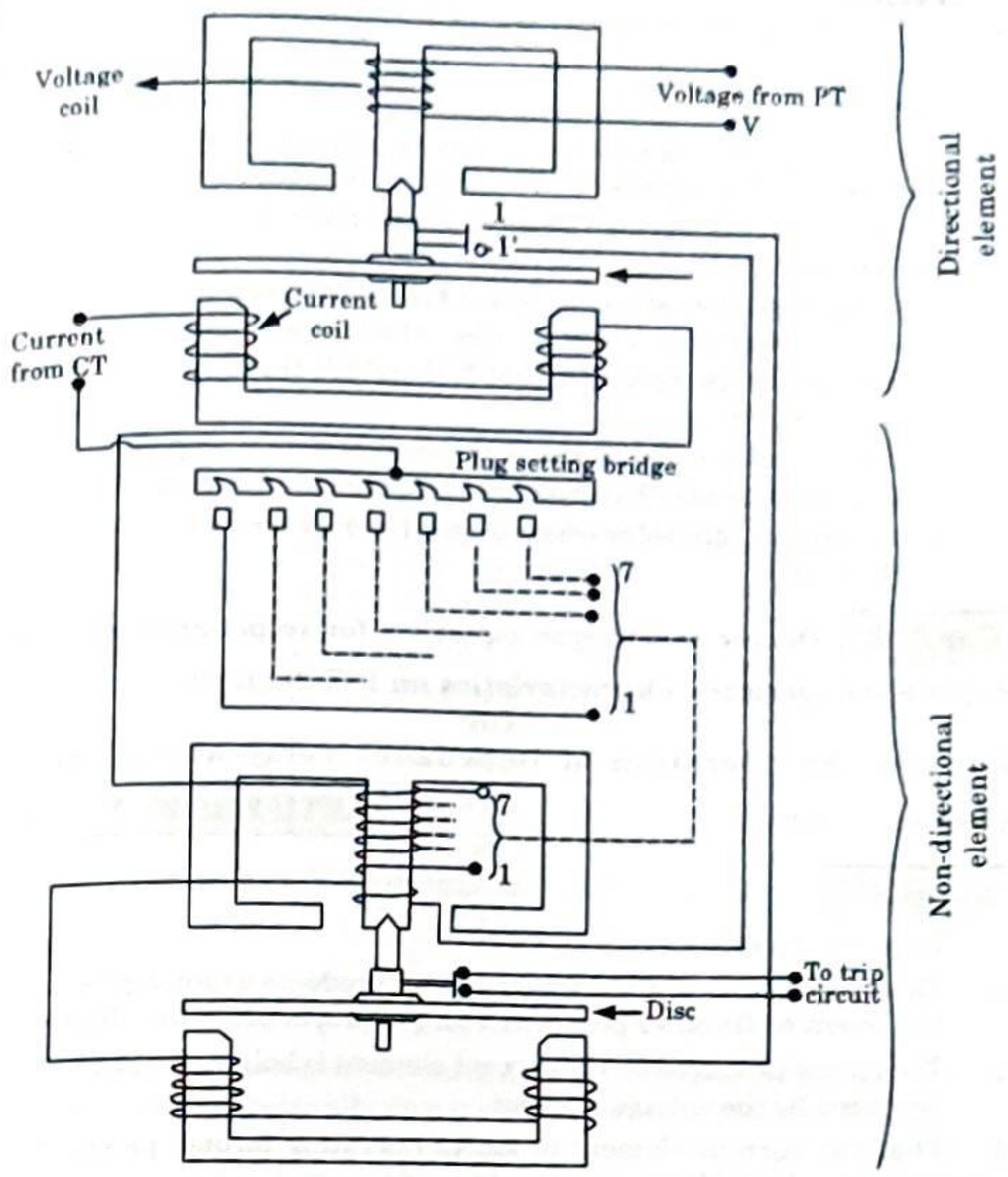


Fig. 2.16.1. Directional overcurrent relay.

PART-9

Distance Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.17. What are distance relays ?

Answer

1. In this relay the operation is dependent on the ratio of voltage and current, which is expressed in terms of impedance.
2. The impedance is nothing but an electrical measure of distance along a transmission line.
3. The relay operates when the ratio V/I, *i.e.*, impedance is less than a predetermined value. These are also called ratio relays.
4. Depending on the ratio of V and I, there are three types of distance relays which are :

i. Impedance relay which is based on measurement of impedance Z.
ii. Reactance relay which is based on measurement of reactance X.
iii. Admittance or Mho relay which is based on measurement of component of admittance Y.

Que 2.18. Derive the torque equation for impedance relay and explain its operating characteristics on R-X diagram.

OR

Explain the operation of impedance relay along with its characteristics. **AKTU 2019-20, Marks 07**

Answer

Impedance relay :

1. There are two elements in this relay; one produces a torque proportional to current while other produces a torque proportional to voltage.
2. The torque produced by the current element is balanced against torque produced by the voltage element.
3. Thus the current element produces operating torque, pickup torque which can be said to be positive torque.
4. The voltage element produces restraining torque, reset torque which can be said to be negative torque. So this relay is voltage restrained overcurrent relay.

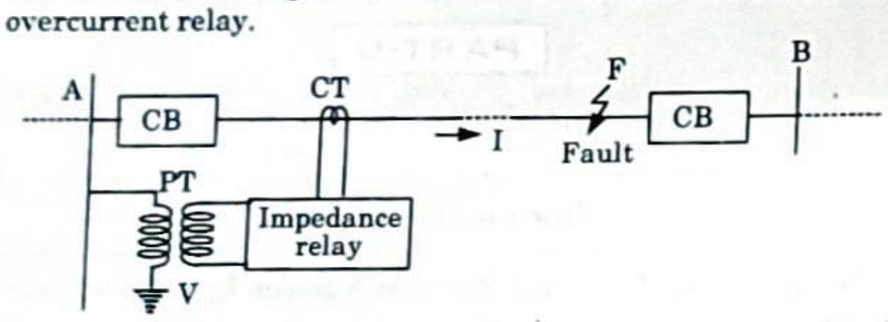


Fig. 2.18.1. Basic operation of impedance relay.

5. The current element is energized by current through CT while voltage element is energized by voltage through PT.
6. The section AB of line is protected zone. When fault occurs at point F in the protected zone, the voltage drops while current increases.
7. Thus the ratio V/I reduce drastically. So, when the impedance reduces than its predetermined value Z_L, it trips and makes the circuit breaker open.
8. The positive torque produced by the current element is proportional to I^2 while the negative torque produced by the voltage element is proportional to V^2.
9. Let control spring effect produces a constant torque of $-K_3$. Hence the torque equation becomes,

$$T = K_1 I^2 - K_2 V^2 - K_3 \qquad ...(2.18.1)$$

where K_1, K_2 are the constants, while V and I are rms values.

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

$$0 = K_1 I^2 - K_2 V^2 - K_3$$

$$\therefore \quad K_2 V^2 = K_1 I^2 - K_3 \qquad ...(2.18.2)$$

11. Dividing eq. (2.18.2) both sides by $K_2 I^2$,

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

$$\therefore \quad Z^2 = \frac{K_1}{K_2} - \frac{K_3}{K_2 I^2}$$

$$\therefore \quad Z = \sqrt{\frac{K_1}{K_2} - \frac{K_3}{K_2 I^2}} \qquad ...(2.18.3)$$

12. Generally the spring effect is neglected as its effect is dominant at low currents which generally do not occur in practice. So with $K_3 = 0$,

$$Z = \sqrt{\frac{K_1}{K_2}} = \frac{V}{I} = \text{Constant} \qquad ...(2.18.4)$$

Operating characteristics :

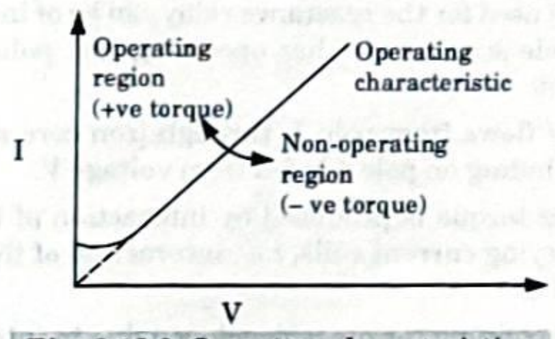


Fig. 2.18.2. Operating characteristics.

Operating characteristics on R-X diagram : The diagram in Fig. 2.18.3, is shown in a plane having X-axis as R (resistance) while Y-axis as X (reactance), this plane is called R-X plane.

$$\therefore \quad |Z| = \sqrt{R^2 + X^2}$$

and
$$\tan \phi = \frac{X}{R}$$

$$\therefore \quad \phi = \tan^{-1} \frac{X}{R}$$

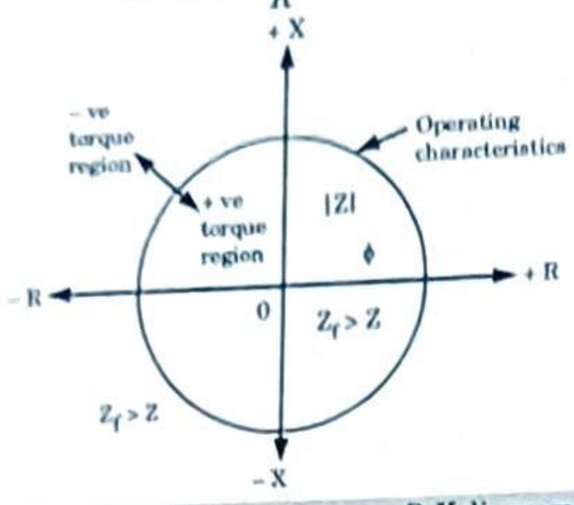


Fig. 2.18.3. Characteristics on R-X diagram.

Que 2.19. Explain the construction, working, torque equation and operating characteristics of reactance relay.

Answer

Reactance relay :

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

Construction, working and torque equation :

1. 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.
2. 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.
3. The operating torque is produced by interaction of fluxes due to the windings carrying current coils, *i.e.*, interaction of fluxes produced by poles 1, 2 and 3.
4. While the restraining torque is developed due to interaction of fluxes due to the poles 1, 3 and 4.

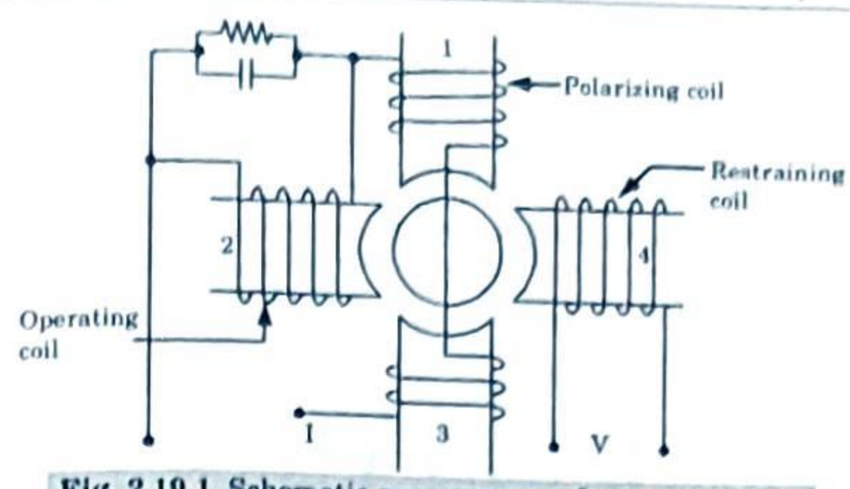


Fig. 2.19.1. Schematic arrangement of reactance relay.

5. Hence the operating torque is proportional to square of current while restraining torque is proportional to the product of V and I.
6. The driving torque is proportional to the square of the current while the restraining torque is proportional to the product of V and I.
7. Hence the net torque neglecting the effect of spring is given by,
$$T = K_1 I^2 - K_2 VI \cos(\theta - \tau)$$
8. At the balance point, net torque is zero.
$$\therefore \quad 0 = K_1 I^2 - K_2 VI \cos(\theta - \tau)$$
$$\therefore \quad K_1 I^2 = K_2 VI \cos(0 - \tau)$$
$$\therefore \quad K_1 = K_2 \frac{V}{I} \cos(0 - \tau)$$
$$\therefore \quad K_1 = K_2 Z \cos(0 - \tau)$$
9. Adding capacitor, the torque angle is adjusted as 90°,
$$\therefore \quad K_1 = K_2 Z \cos(0 - 90°)$$
$$\therefore \quad K_1 = K_2 Z \sin\theta$$
$$\therefore \quad Z \sin\theta = \frac{K_1}{K_2}$$
10. Consider an impedance triangle shown in the Fig. 2.19.2.
$$Z \sin\theta = X = \text{Reactance}$$
$$Z \cos\theta = R = \text{Resistance}$$

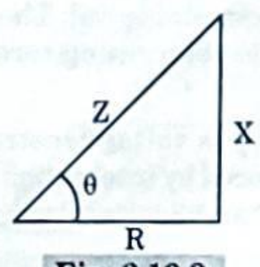


Fig. 2.19.2.

$$X = \frac{K_1}{K_2} = \text{Constant}$$

11. Thus the relay operates on the reactance only. The constant X means a straight line parallel to X-axis on R-X diagram.
12. 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 :

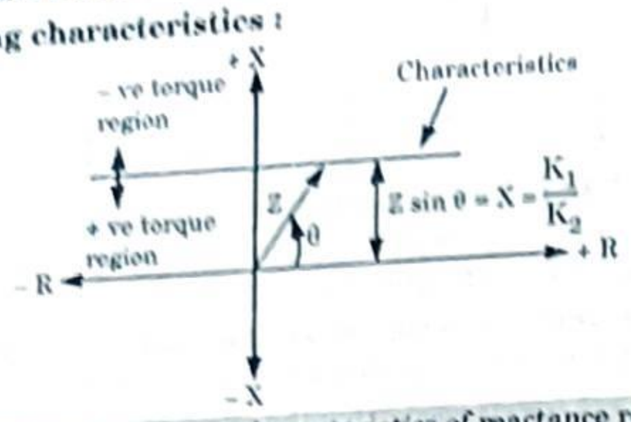


Fig. 2.19.3. Operating characteristics of reactance relay.

Que 2.20. Explain different types of distance relays along with their operating characteristics. **AKTU 2016-17, Marks 15**

Answer

A. Impedance relay : Refer Q. 2.18, Page 2–25B, Unit-2.

B. Reactance relay : Refer Q. 2.19, Page 2–27B, Unit-2.

C. Mho relay :

1. It is also called 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.
2. 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 :

1. This relay uses an induction cup type structure. It has an operating coil, polarizing coil and restraining coil. The operating torque is obtained by V and I element while restraining torque is obtained by a voltage element.
2. Thus an admittance relay is voltage restrained directional relay. The operating torque is produced by interaction of fluxes due to the windings carried by the poles 1, 2 and 3.

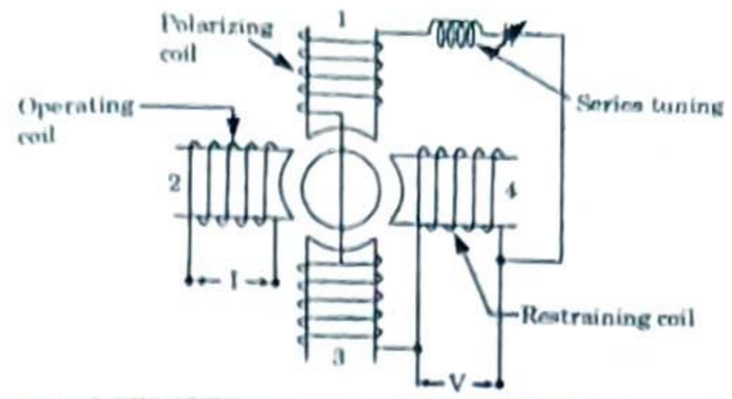


Fig. 2.20.1. Schematic arrangement of admittance relay.

3. While the restraining torque is produced by the interaction of fluxes due to the windings carried by the poles 1, 3 and 4.
4. Thus the restraining torque is proportional to the square of the voltage while operating torque is proportional to the product of voltage and current. Torque angle is adjusted using series tuning circuit.
5. The operating torque is proportional to VI while restraining torque is proportional to V^2. Hence net torque is given by,

$$T = K_1 VI \cos(0 - \tau) - K_2 V^2 - K_3$$

where, K_3 = Control spring effect.

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

$$\therefore \quad 0 = K_1 VI \cos(0 - \tau) - K_2 V^2$$

$$\therefore \quad K_1 VI \cos(0 - \tau) = K_2 V^2$$

$$\therefore \quad K_1 \cos(0 - \tau) = K_2 \frac{V^2}{VI}$$

$$\therefore \quad K_1 \cos(0 - \tau) = K_2 \frac{V}{I}$$

$$\therefore \quad Z = \frac{K_1}{K_2} \cos(0 - \tau)$$

7. 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.

Characteristics of Mho relay on R-X diagram :

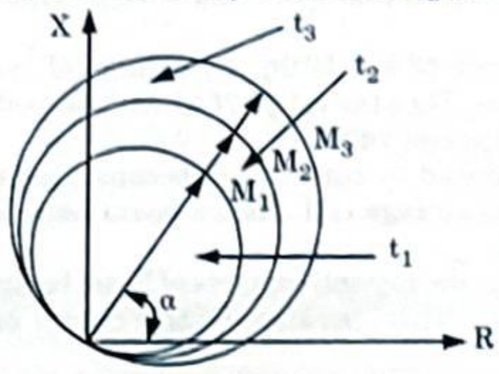


Fig. 2.20.2. Characteristics of MHO relay.

1. The characteristics of Mho relay is shown in Fig. 2.20.2.
2. Mho relay characteristic, when plotted on the impedance diagram (R-X) is a circle, passing through the origin.

Que 2.21. Explain the construction and operation of definite distance type impedance relay.

Answer

Definite distance type impedance relay :

a. Construction :

1. The construction of this relay can be balanced beam type or induction disc type.

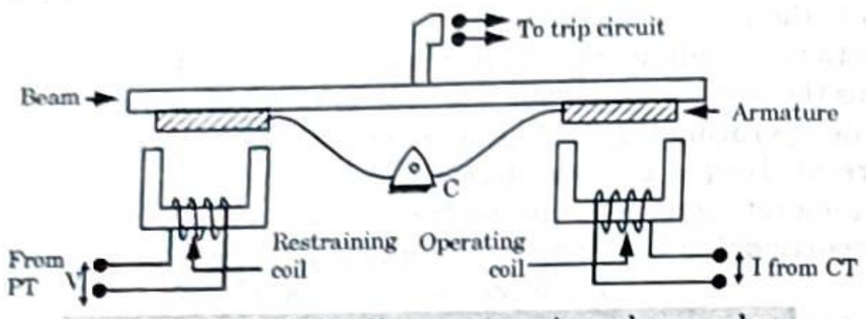


Fig. 2.21.1. Definite distance type impedance relay.

2. It consists of a balanced beam pivoted at the central point *C*. The beam carries the armatures of the two electromagnets. The two electromagnets are energized by a current from CT and voltage from PT, which are located in the circuit to be protected.
3. The voltage coil acts as restraining coil while the current coil acts as operating coil. The beam also carries the moving contacts which can bridge the two fixed contacts of a trip circuit when the relay operates.

b. Operation :

1. The torque produced by voltage coil is proportional to square of the voltage (K_1V^2) while the torque produced by current coil is proportional to the square of the current (K_2I^2).
2. Under normal operating conditions, the torque produced by voltage coil is more than the torque produced by the current coil. Thus restraining torque is more than the operating torque and hence the relay is inoperative.
3. On the occurrence of any fault, the voltage of system decreases and current increases. Thus the ratio *V/I* which is impedance also decreases, it falls below its preset value.
4. The torque produced by current coil becomes greater than the torque produced by the voltage coil. Hence beam experiences a pull on the current coil side.
5. As the beam tilts, the moving contacts of beam bridges the fixed contacts of the trip circuit. This operates the trip circuit and opens the circuit breaker.

PART-10

Differential Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.22. Explain various differential relays.

OR

Define differential protection. With the help of neat sketch explain the operation of differential relay. **AKTU 2020-21, Marks 07**

Answer

A. Differential protection : Refer Q. 1.8, Page 1–9B, Unit-1.

B. Differential relay :

Differential relay is a suitably connected overcurrent relay which operates in a condition when the phasor difference of currents at the two ends of a protected element exceeds a particular value. Various types of differential relays are :

a. Simple differential relay :

1. As $I_1 = I_2 = I_L$ and $I_{1s} = I_{2s} = I_L$, so $I_{1s} - I_{2s} = 0$
2. Simple differential relay is an overcurrent relay having operating coil which carries the phasor difference of currents at the two ends of a protected element.

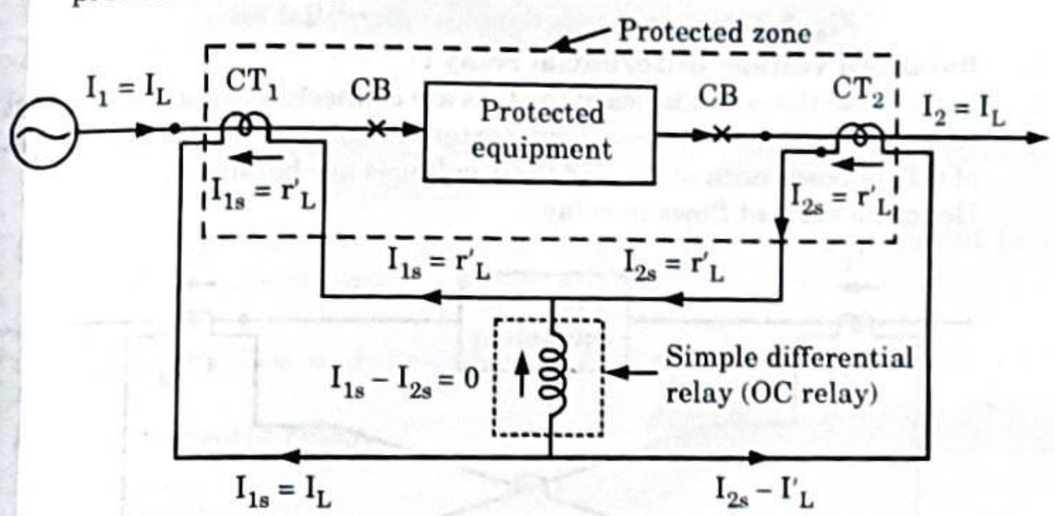


Fig. 2.22.1. Simple differential protection scheme behaviour under normal condition.

3. It operates when the phasor difference of secondary current of the CTs exceeds a predetermined value.

4. The secondary of the CTs at the two ends of the protected element are connected together by the pilot wire circuit.
5. The problem associated with simple relay is during heavy external faults; it occurs because of CT errors and is overcome by percentage differential protection.

b. Percentage differential relay :

1. The differential relay operates if the operating torque produced by the operating coil is more than the restraining torque produced by the restraining coil.
2. Torque is proportional to ampere turns. So when the ampere turns of the operating coil will be greater than ampere turns of restraining coil, the relay will operate.

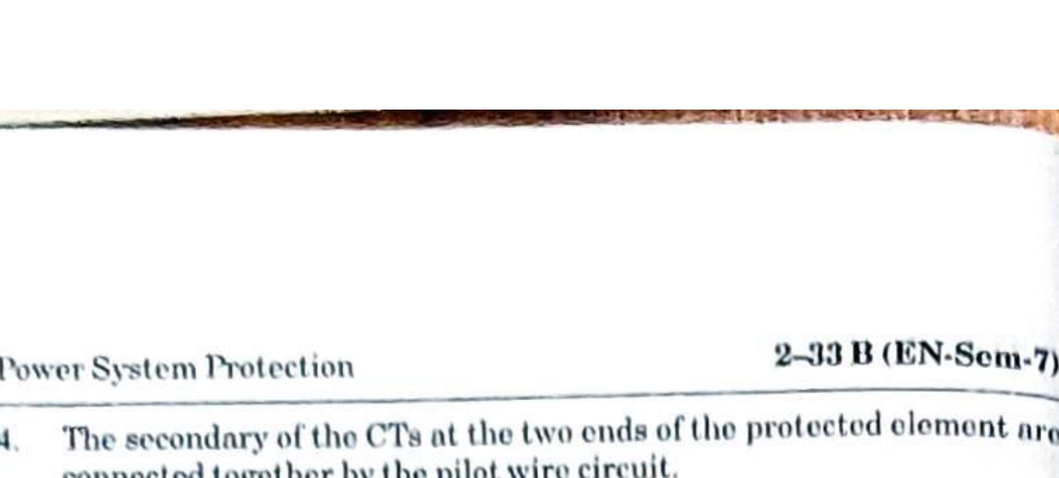
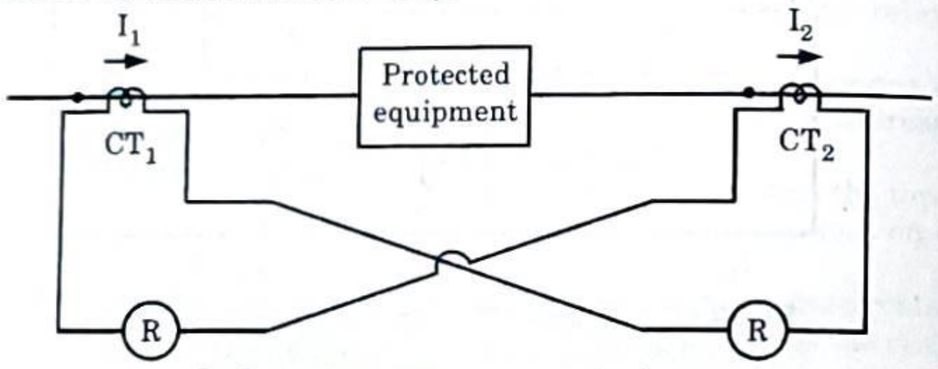


Fig. 2.22.2. Percentage (biased) differential relay.

c. Balanced voltage differential relay :

1. In this case the secondaries of the CTs are connected in such a way that under normal conditions and during external faults the secondary current of CTs opposes each other and their voltages are balanced. Hence no current flows in relay.



R : Instantaneous overcurrent relays

Fig. 2.22.3. Balanced (opposed) voltage differential protection.

2. During internal fault, differential current is proportional to $(I_1 - I_2)$ in case of single end fed system and is proportional to $(I_1 + I_2)$ in case of double end fed system.
3. If the differential current flowing through the relay coil is higher than the pickup value the relay operates.

PART-11

Static Relays : Comparison with Electromagnetic Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.23. What do you understand b static relays ? Also write its advantages and disadvantages.

Answer

A. Static relay : The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc., are called static relays.

B. Advantages :

1. It has fast response and long life.
2. Greater sensitivity as amplification can be provided easily.
3. Quick resetting and absence of overshoot.

C. Disadvantages :

1. Static relays are sensitive to voltage transients. Voltage spikes can damage semiconductor components.
2. They need an auxiliary power supply, which can be supplied by a stabilized power supply or a battery.

Que 2.24. Give a detailed comparison between static and electromagnetic relay. **AKTU 2019-20, Marks 07**

Answer

Comparison between static and electromagnetic relays :

S. No.	Points	Static relays	Electromagnetic relays
1.	Power consumption	Very less 1 milliwatt	High 2 watt
2.	Moving contacts	No moving contacts.	Moving contacts are present.
3	Effect of gravity (Gravitational force)	No effect of gravity on operation of static relay.	Gravitational force can affect the relay.
4.	Position of relay	Relay can be installed at any location and at any position.	This relay has to be installed straight only and away from magnetic field.
5.	Technology standard	2nd generation relays.	1st generation relays.
6.	Relay size	Small	Large
7.	Accuracy and speed	High	Less

PART-12

Classification and their Description.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.25. **Give the classification of static relays.**

Answer

Classification of static relays :

A. Transductor (magnetic amplifier relays) :

1. The restraining voltage is applied to the control winding through an impedance Z_R and a rectifier.
2. The restraining current so obtained is rectified and partially smoothed by the short-circuit effect of the rectifier on the control winding and also due to the short-circuited coupling winding.
3. The effect of this is to drive both the limbs on which the operating winding is wound into saturation.

4. The operating winding is wound in such a way that the ampere-turns so produced opposes the restraining ampere-turns in one limb and strengthen them in the other.
5. Assuming equality of restraining and operating turns, and neglecting the finiteness of permeability the operating current would drive out of saturation the limb in which operating current opposes the restraining ampere-turns, when the peak value of the operating current exceeds the magnitude of restraining current.
6. When this happens a voltage is induced in the output winding and the relay gets energized. The same operation is repeated on the other limb during next half cycle.

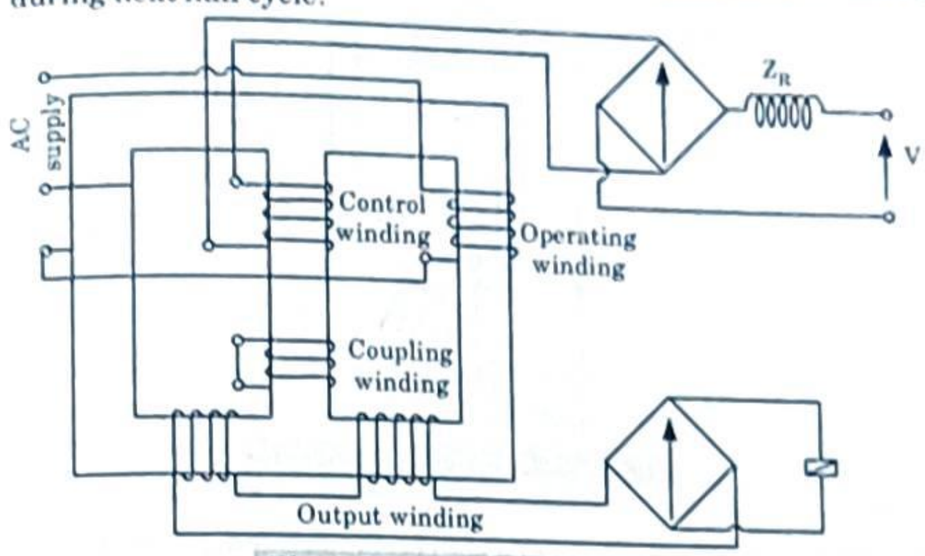


Fig. 2.25.1. Transductor relays.

B. Rectifier bridge relays : This relay consists of two rectifier bridges and a moving coil or polarized moving iron relay. The most common are relay comparators based on rectifier bridges, which can be arranged as either amplitude or phase comparators.

C. Transistor relays :

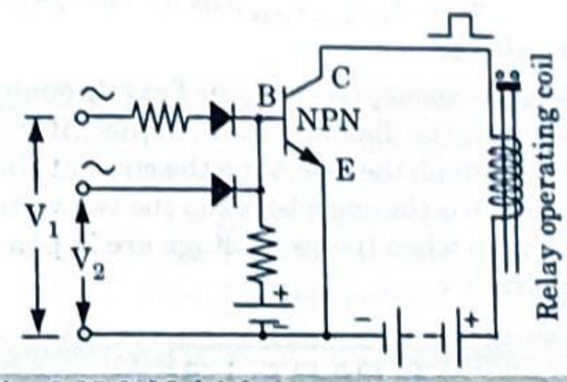


Fig. 2.25.2. Multiple inputs to transistor base.

1. Current of constant magnitude flows in the collector circuit only when the input AC quantities are simultaneously positive.

2. A relay in the collector circuit will pick-up when the overlap angle exceeds a certain value, i.e., when the mean DC level in the collector circuit exceeds the relay pick-up as a consequence of phase coincidence.

D. Hall effect relays :

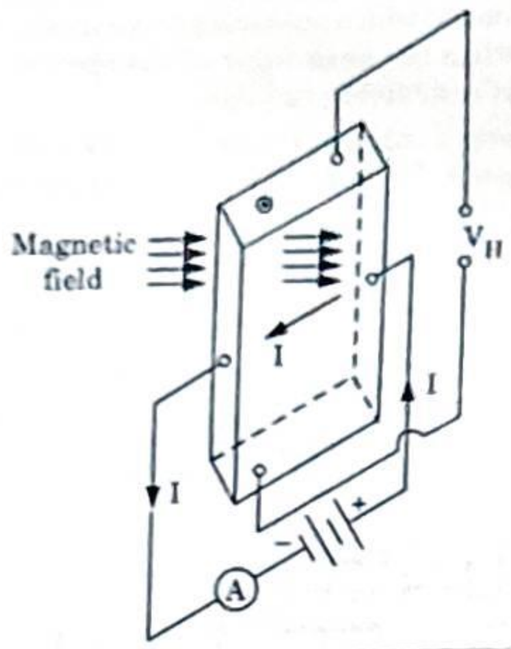


Fig. 2.25.3. Basic hall generator.

1. The Hall crystal in the form of a slab is connected to a battery so that a current I flows through the slab in the manner shown in the Fig. 2.25.3 and the magnetic field is applied so that it is perpendicular to the slab of the Hall crystal.
2. A potential difference V_H, called the Hall voltage, is developed between the top and bottom of the slab. The magnitude of the voltage is proportional to the product of strength of the magnetic field and current.

$$V_H = K_H \phi_{max} I_{max} [\cos \alpha - \cos (2\omega t - \omega)]$$

E. Gauss effect relays :

If one AC voltage V_1 develops a magnetic field through the crystal in the form of the having large diameter and another AC voltage V_2 sends a current radially through the disc, then the current will be proportional to $V_1 V_2 \cos \theta$ where θ is the angle between the two voltage V_1 and V_2 *i.e.*, current is maximum when the two voltage are in phase and zero when they are in quadrature.

PART-13

Static Overcurrent Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.26. Explain static overcurrent relays.

Answer

1. In overcurrent relay secondaries of the line CTs are connected to a summation circuit. The output of the summation CT is fed to an auxiliary CT whose output is rectified, smoothened and applied to the measuring unit (a level detector).
2. When the input current to the level detector is less than the threshold value (set value), the output of the level detector is zero.
3. For the overcurrent relay :

   If $I_{input} < I_{threshold}$, $I_{out} = 0$

   If $I_{input} \geq I_{threshold}$, I_{out} = +ve quantity
4. The output of the level detector is simplified and applied to the output device to cause trip/alarm. If time delay is desired, a timing circuit may be introduced before the level detector.
5. A filter may be installed at the input of the CT in order to get required output.

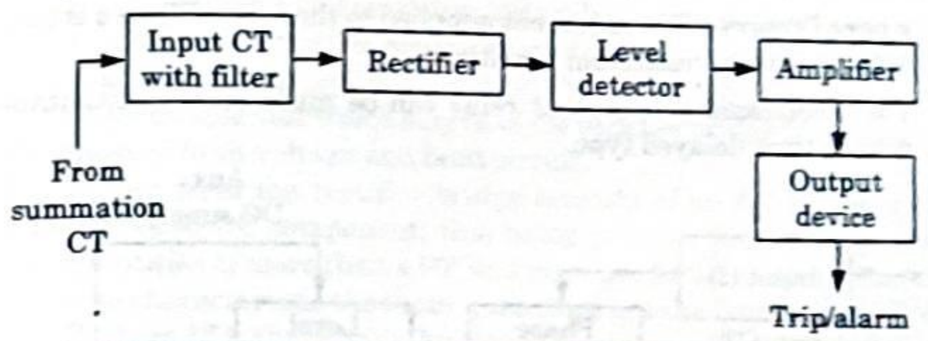


Fig. 2.26.1. Block diagram of static overcurrent relay.

6. The general operation equation of the time characteristic is given by

$$I^n t = K = \text{Constant} \quad \text{...(2.26.1)}$$

where, I = Relaying current
t = Time of operation
n = A design index.

PART-14

Static Directional Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.27. Discuss static directional relay.

Answer

1. Directional relay being a double actuating quantity with input current I from CT and input voltage V from PT.
2. The two inputs are supplied to phase comparator. A phase shifter is included in the voltage input circuit.
3. The output of it is applied to a phase comparator whose output, in its turn is applied to a level detector.
4. The output of the level detector is amplified and in case a timer is necessary, the output is applied to the output device through the timer.
5. The directional static overcurrent relay is a double actuating quantity relay and senses its phase angle between V and I, the two actuating quantities.
6. Let this angle be ϕ while the relay characteristic angle be θ. Let I_S be the set current magnitude. Relay will operate provided

$$I_S \leq I \cos(\phi - \theta)$$

where I represents the current supplied to the relay. When ϕ is equal to θ, the relay has maximum sensitivity.

7. The directional overcurrent relay can be made either instantaneous type or time delayed type.

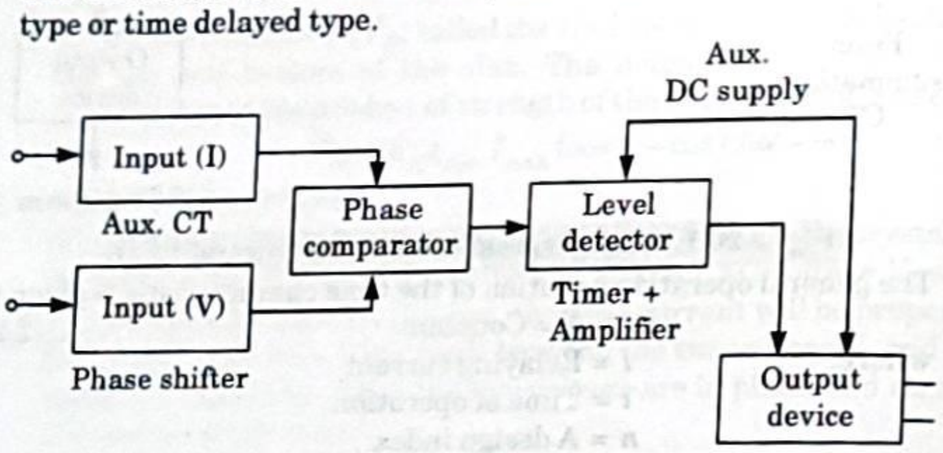


Fig. 2.27.1. Block diagram of directional overcurrent relay.

PART-15

Static Distance Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.28. What is static distance relay ?

Answer

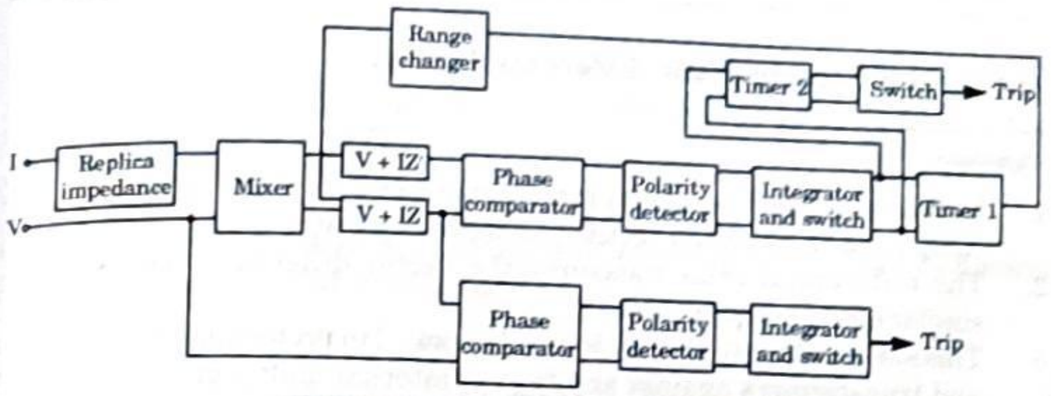


Fig. 2.28.1. Static distance relay.

1. In this relay the operating current I is supplied by the current transformer through the replica impedance while the restraining current is supplied by PT.
2. The relay operates when the ratio of restraining voltage and replica voltage is less than a certain value. This relay becomes directional when the inputs have particular combination of current and voltage through a mixing transformer.
3. The phase comparator which may be of the rectifier bridge type compares the phase of fault voltage and fault circuit.
4. The output from the rectifier bridge consists of an AC signal with a superimposed DC component; this being positive for angles between two quantities of more than ± 90° and negative for angles less than 90°.
5. For Mho characteristic the input quantities are the fault voltage V and $V - IZ$ where IZ is the voltage developed across a replica impedance unit energized by the fault current.
6. When the angle between V and $V - IZ$ is less than 90° the relay will restrain and when the angle is greater than 90°, the relay will operate.
7. The output from the comparator is fed into a polarity detector where, when the input currents to the comparator are 90° apart, the output device will be turned ON for + 90° and turned OFF for – 90° and hence the output wave will be a square wave with equal space ratios.
8. The output from the polarity detector is fed into an integrating circuit. If the mean input to polarity detector is positive it indicates a fault within the boundary. The build-up of current is faster leading to faster relay operation.

PART-16

Static Differential Relay.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 2.29. Explain static differential relay.

Answer

1. In this relay, the two similar input quantities (*I* or *V*) are compared. The comparator is usually a rectifier bridge comparator.
2. The differential relay measures the vector difference between two similar electrical quantities.
3. This static differential relay is mostly applied in protection of generators and transformers against any type of internal fault similar to that of electromagnetic type differential relay.

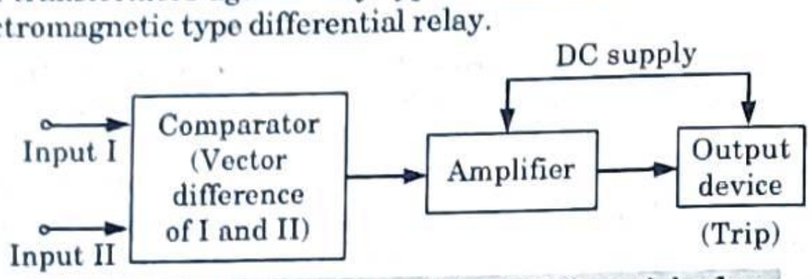


Fig. 2.29.1. Block diagram of static differential relay.

4. The relay is advantages from the electromagnetic differential relay as it is very compact, highly sensitive for internal faults, high stability, very first operation, low power consumption, lower *VA* burden, inrush current proof characteristic.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What are the different types of attracted armature type relays ? Explain why they are noisy.

Ans. Refer Q. 2.2.

Q. 2. Explain the working principle of electromagnetic relay. Give its advantages and disadvantages along with applications.

Ans. Refer Q. 2.3.

Q. 3. Derive torque equation for induction type relay.

Ans. Refer Q. 2.5.

Q. 4. Explain how gas actuated relay operates. Also write down its applications.

Ans. Refer Q. 2.7.

Q. 5. What are the different types of amplitude comparators ? Discuss the operating principle of rectifier bridge amplitude comparator.

Ans. Refer Q. 2.11.

Q. 6. What are the various types of overcurrent relays ? Discuss their area of applications.

Ans. Refer Q. 2.15.

Q. 7. Explain the construction and operating principle of overcurrent relay with directional scheme.

Ans. Refer Q. 2.16.

Q. 8. Explain different types of distance relays along with their operating characteristics.

Ans. Refer Q. 2.20.

Q. 9. Define differential protection. With the help of neat sketch explain the operation of differential relay.

Ans. Refer Q. 2.22.

Q. 10. Give a detailed comparison between static and electromagnetic relay.

Ans. Refer Q. 2.24.

Q. 11. Discuss static directional relay.

Ans. Refer Q. 2.27.

☺☺☺

3

UNIT

Protection of Components

CONTENTS

PART-1

Types and Detection of Faults and their Effects.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.1. **Explain the different types of fault in power system.**

OR

What are the different types of faults in electrical components and the method used for their protection ?

Answer

A. **Types of fault :** In the electrical power system, the faults are classified into two types :

1. **Symmetrical faults :**

i. A three-phase fault is called a symmetrical type of fault. In a 3-ϕ fault, all the three phases are short circuited.

ii. The symmetrical faults are of two types,

a. L-L-L

b. L-L-L-G

2. **Unsymmetrical faults :**

i. **Single-phase to ground (L-G) fault :** A short circuit between any one of the phase conductors and earth is called a single phase to ground fault.

ii. **Two-phase to ground (2L-G) fault :** A short circuit between any two phases and the earth is called a double line to ground or a two-phase to ground fault.

iii. **Phase-to-phase (L-L) fault :** A short circuit between any two phases is called a line to line or phase-to-phase fault.

B. **Detection of fault :** Detection of faults in components and their protection :

1. **In generator, there are two types of faults :**

i. Stator faults.

ii. Rotor faults.

a. **Protection of stator faults :** By using percentage differential protection method.

b. **Protection of rotor faults :** By using loss of excitation protection method.

2. **In transformer, there are two types of faults :**

i. Internal faults.

ii. External faults.

a. **Protection of internal faults :** By using percentage differential protection method.

b. **Protection of external faults :** By using time graded over current relays.

3. **Protection of transmission line :** By using distance protection method.

Que 3.2. **What are the effects of fault occurring in the power system ?**

Answer

1. Faults give rise to abnormal operating conditions, usually excessive voltages and currents at certain points on the system.
2. Faults can cause the three-phase system to become unbalanced with the result that three-phase equipment operates improperly.
3. Faults can cause system to become unstable.
4. There may be reduction in the supply voltage of the healthy feeders, resulting in the loss of industrial loads.
5. Heavy short circuit current may cause damage to equipment or any other element of the system due to overheating and high mechanical forces set up due to heavy current.

PART-2

Alternator Protection Scheme (Stator, Rotor, Reverse Power Protection etc.)

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.3. **What are the various protections adopted to protect generators ?**

OR

Write brief note on generator protection.

Answer

1. A generator is very important and costly equipment in power system. It is accompanied by prime mover, excitation system, voltage regulator, cooling system etc. Its protection is very complex and elaborate.

2. **A generator set is provided with following protective schemes :**

i. **Stator Protection :**

a. Percentage differential protection.

b. Protection against stator interturn faults.

c. Stator-overheating protection.

ii. **Rotor Protection :**

a. Field ground fault protection.

b. Loss of excitation protection.

c. Protection against rotor overheating because of unbalanced three phase stator currents.

iii. **Miscellaneous :**

a. Over voltage protection.

b. Over speed protection.

c. Protection against motoring.

d. Protection against vibration.

e. Bearing overheating protection.

f. Protection against auxiliary failure.

g. Protection against voltage regulator failure.

Que 3.4. **Give the complete protection scheme for alternator.**

OR

Describe the principle of Merz-Price scheme of protection applied to the alternator. What are the shortcomings of this scheme and how are they overcome ?

Answer

A. Merz-Price scheme is used for the protection of alternator stator windings. It is also called biased differential protection and percentage differential protection.

B. Construction :

1. The differential relay gives protection against short circuit fault in the stator winding of a generator.

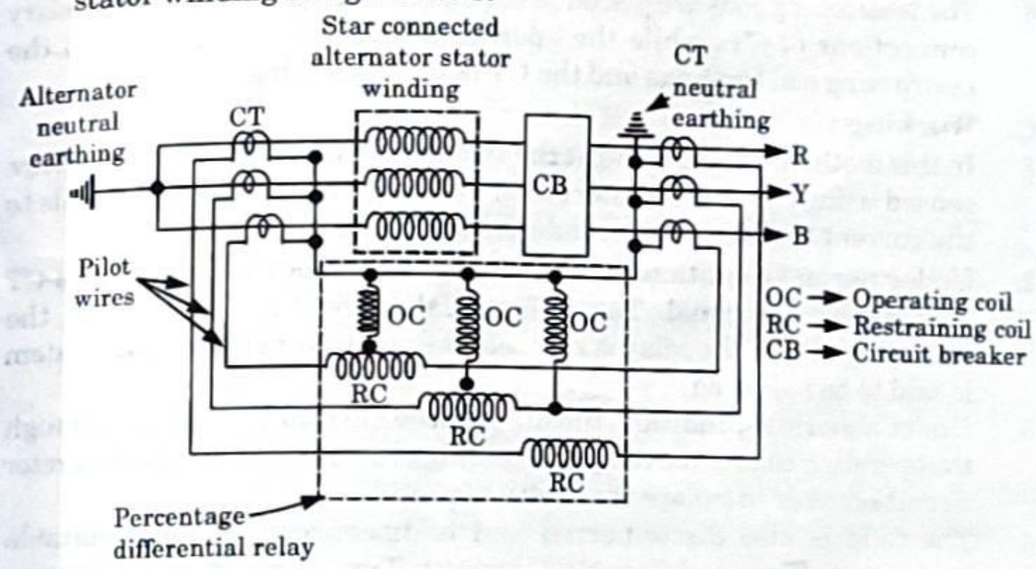


Fig. 3.4.1. Merz-Price protection for star connected alternator.

2. The CTs are connected in star and are provided on both, the outgoing side and machine winding connections to earth side.

3. The restraining coils are energized from the secondary connection CTs in each phase through pilot wires.
4. The operating coils are energized by the tapping from restraining co and the CT neutral earthing connection.
5. The CTs on the delta connected machine winding side are connected delta while the CTs at outgoing ends are connected in star.

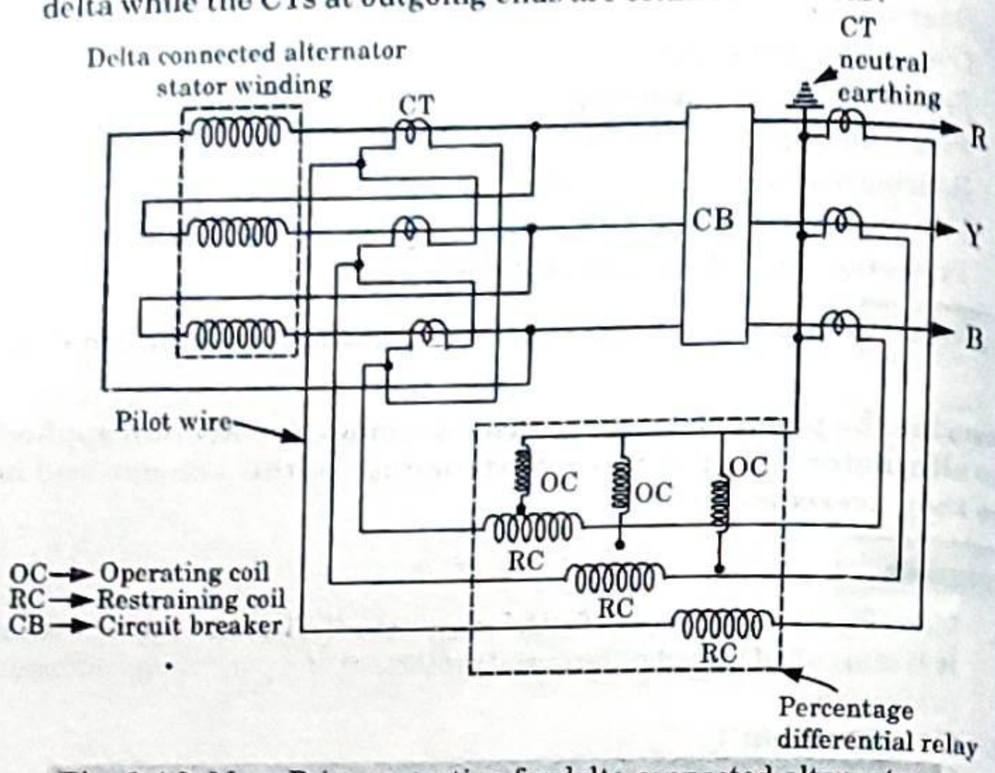


Fig. 3.4.2. Merz-Price protection for delta connected alternator.

6. The restraining coils are placed in each phase energized by the secondar connections of CTs while the operating coils are energized from th restraining coil tappings and the CT neutral earthing.

C. Working :

1. In this method, the currents at the two ends of the protected section ar sensed using current transformers. The wires connecting relay coils t the current transformer secondaries are called pilot wires.
2. Under normal conditions, the currents in the pilot wires fed from C secondaries are equal. The differential current $i_1 - i_2$ through th operating coils of the relay is zero and the relay is operative. The syste is said to be balanced.
3. Under abnormal condition, the differential current $i_1 - i_2$ flows throug the operating coils of the relay and relay operates. This trips the generate circuit breaker to isolate the faulty section.
4. The field is also disconnected and is discharged through suitabl impedance. Thus a differential current flows through the operatin coils which are responsible to trip the relay and open the circuit breaker

D. Shortcoming : There can be flow of current through relay even durin normal operating conditions.

E. To overcome : Use of two identical CTs can solve this problem.

Que 3.5. Explain the restricted earth fault protection of generators. What is the effect of earth resistance on percentage of winding unprotected ?

Answer

A. Restricted earth fault :

1. When the neutral is solidly grounded, then the generator gets completely protected against earth faults. But when it is grounded through earth resistance, then the stator windings get partly protected against earth faults.
2. The earth faults are rare near the neutral point. The voltage of neutral point with respect to earth is very less.
3. But when they occur, the insufficient voltage across the fault drives very low fault current than the pickup current of relay coil.
4. Hence the relay coil remains inoperative. Thus 15 % to 20 % winding from the neutral side remains unprotected in this scheme.
5. Hence it is called restricted earth fault protection. It is usual practice to protect 85 % of the winding.

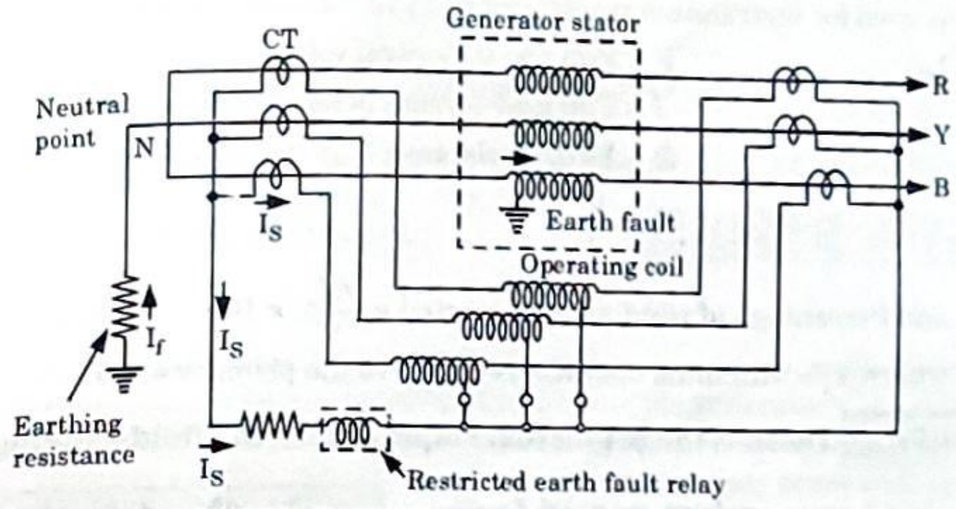


Fig. 3.5.1. Restricted earth fault protection.

6. Consider that earth fault occurs on phase *B* due to breakdown of its insulation to earth as shown in Fig. 3.5.1.
7. The fault current I_f will flow through the core, frame of machine to earth and complete the path through the earthing resistance.
8. The CT secondary current I_s flows through the operating coil and the restricted earth fault relay coil of differential protection due to which the relay operates to trip the circuit breaker.
9. The voltage V_{bx} is sufficient to drive the enough fault current I_f when any fault point x is away from the neutral point.

10. When fault point is nearer to neutral point, then voltage V_{fn} is small and current I_f is not sufficient for relay operation.
11. Hence the winding remains unprotected. Hence, practically 15 % of winding from neutral point is kept unprotected.

B. Effect of earth resistance on perventage of winding unprotected :

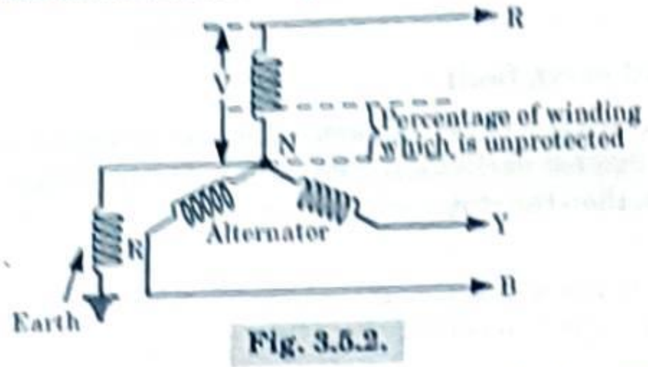


Fig. 3.5.2.

1. The value of R limits the earth fault current. 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.
2. In medium resistance R, the earth fault current is limited to about 200 A for full line to neutral voltage V, for a 60 MW machine.
3. In high resistance R, the earth fault current is limited to about 10 A. This is used for distribution transformers and generator-transformer units.
4. Let V = Full line to neutral voltage
   I = Full load current of largest capacity generator
   R = Earth resistance

$$\therefore \quad R = \frac{V}{I}$$

and Percentage of winding unprotected $= \frac{RI_o}{V} \times 100$

where, I_o = Minimum operating current in the primary of CT.

Que 3.6. Discuss the protection employed for the field winding of the alternator against ground faults. **AKTU 2017-18, Marks 10**

Answer

1. Rotor earth fault protection includes DC injection method and AC injection method. The arrangement is shown in Fig. 3.6.1.
2. In this arrangement either DC or AC voltage is impressed between the field circuit and ground through a sensitive overvoltage relay and current limiting resistor or capacitor (in case of AC voltage).
3. A single earth fault in the rotor circuit will complete the circuit comprising the voltage source (AC or DC), sensitive overvoltage relay and earth fault and thus earth fault will be sensed by the relay.

4. DC injection method is simple and has no problems of leakage events.
5. If direct current is used the overvoltage relay can be more sensitive than if alternating current is used.
6. With AC, the relay must not pickup on the current that flows normally through the capacitance to ground, and care must be taken to avoid resonance between the capacitance and the relay inductance.

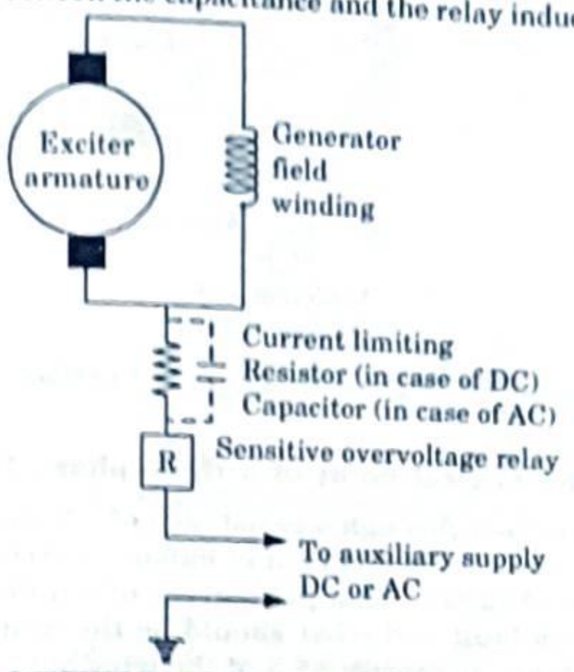


Fig. 3.6.1. Rotor earth fault protection.

Que 3.7. Discuss the protection employed against loss of excitation of the alternator. **AKTU 2017-18, Marks 10**

Answer

1. When a generator loses excitation, it draws reactive power from the system amounting as much as 2 to 4 times the generator's rated load.
2. Thus, this large reactive load suddenly thrown on the system, together with the loss of generator's reactive power output may cause wide spread voltage reduction, which in turn, may cause extensive instability.
3. Undercurrent moving coil relay connected across a shunt in series with the field winding for loss of excitation protection is shown in Fig. 3.7.1.
4. In case of large generators which operate over a wide range of field excitation such a relay may be a problem.
5. Furthermore, field failure due to failure of exciter may not be detected by it as it may be held in by AC induced from the stator.
6. An undercurrent relay fast enough to drop out on AC cannot be employed as it would be affected by AC induced during synchronising and during external faults.

7. The most selective type of loss of excitation relay is a directional distance type relay operated from alternating current and voltage at the main generator terminals.

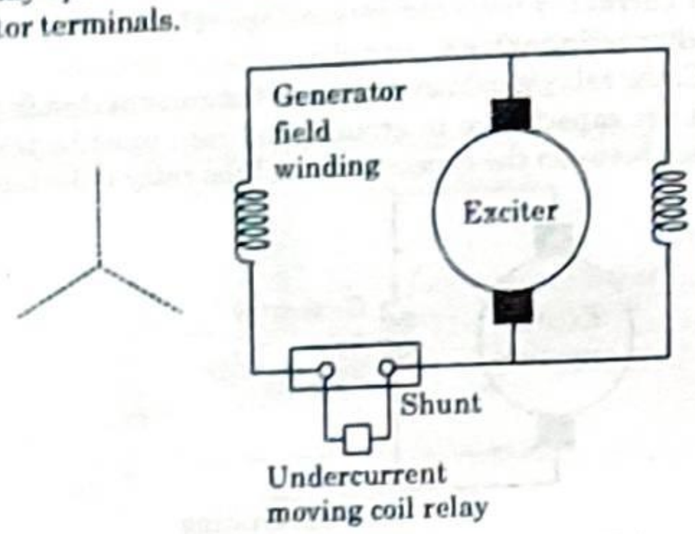


Fig. 3.7.1. Loss of excitation protection.

Que 3.8. **The neutral point of a three-phase 10 MVA, 11 kV alternator is earthed through a resistance of 4.5 ohms, the relay is set to operate when there is an out of balance current of 1.3 A. The CTs have ratio of 1500/5. What percentage of winding is protected against an earth fault and what should be the minimum value of earthing resistance to protect 85 % of the winding ?**

Answer

1. The primary CT current for relay operation

$$= 1.3 \times \frac{1500}{5}$$

$$\therefore \quad I_s = 390 \text{ A}$$

2. $\therefore$ % of winding unprotected $= \frac{I_s R}{V} \times 100$

$$= \frac{390 \times 4.5\sqrt{3}}{11000} \times 100 = 27.63\ \%$$

3. $\therefore$ % of winding protected $= 100\ \% - 27.63\ \% = 72.37\ \%$

4. Resistance required for protecting 85 % of winding is given by

$$100 - 85 = \frac{I_s R \times 100}{V}$$

$$15 = \frac{390 \times R \times 100\sqrt{3}}{11000}$$

$$R = \frac{15 \times 11000}{390 \times 100 \times \sqrt{3}} = 2.44\ \Omega$$

PART-3

Power Transformer Protection (External and Internal Faults Protection)

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.9. **With a neat schematic diagram, explain the protection of transformer with differential protection scheme.**

AKTU 2020-21, Marks 07

Answer

1. Percentage differential protection is used for the protection of large transformers (5 MVA and above). If there are internal short circuits in the transformer, then this scheme is used.

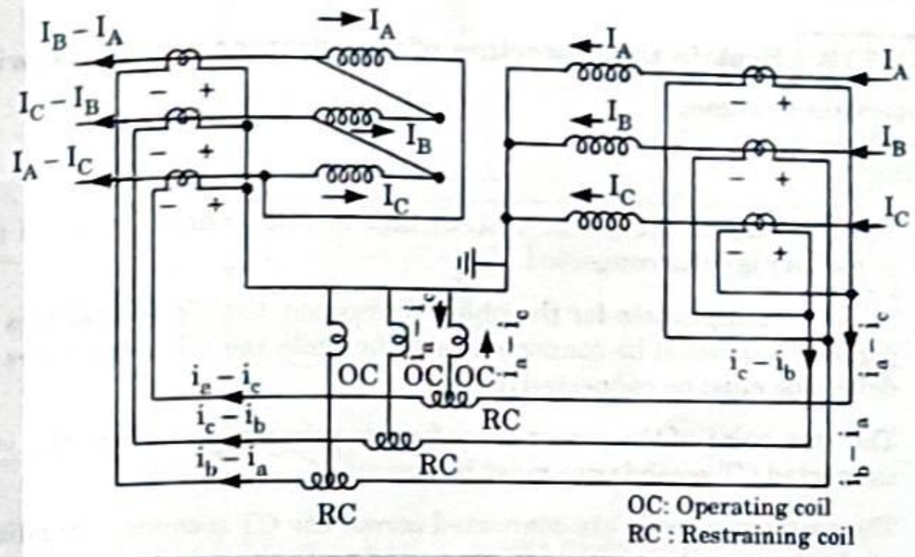


Fig. 3.9.1. Percentage differential protection for Y-Δ connected transformer.

2. The polarity of CT voltage and current directions are taken for a particular instant. For both upper and lower CTs, the current at entering end is marked as positive and current at leaving end is marked as negative.

3. '*OC*' are the operating coils and '*RC*' are the restraining coils of the rel in Fig. 3.9.1. The connections are made in such a way that in case external faults or normal operation, the current flows in the operati coils of the relay.
4. Due to this, CTs of primary side are in opposition to the CTs of th secondary side and under this condition, the relay will not operate.
5. If a fault occurs in the winding, the polarity of the induced voltage of th CT of the secondary side is reversed.
6. The currents in the operating coil from CTs of both primary an secondary side are in the same direction and hence relay operates.
7. The CTs which are on the star side of the transformer are connected delta to supply the matching current in the operating winding.
8. The CTs which are on the delta side of the transformer are connected *Y*.
9. In case of *Y*-Δ connected transformer there is a phase shift of 30° in th line currents.
10. The zero sequence currents in *Y* side of transformer does not produ current on the Δ side. Thus zero sequence currents must be eliminate using above mentioned connections.

Que 3.10. Explain the protection of transformer with Merz-pric protection scheme.

Answer

1. The primary of the power transformer is star connected while th secondary is delta connected.
2. Hence to compensate for the phase difference, the CT secondaries o primary side must be connected in delta while the CT secondaries o delta side must be connected in star.
3. The star point of the power transformer primary as well as the sta connected CT secondaries must be grounded.
4. The restraining coils are connected across the CT secondary winding while the operating coils are connected to the tapping points on th restraining coils and the star point of CT secondaries.
5. With the proper selection of turns ratio of CTs, the coils are under balanced condition during normal operating conditions.
6. Under normal conditions no current flows through the relay and th relay is inoperative.

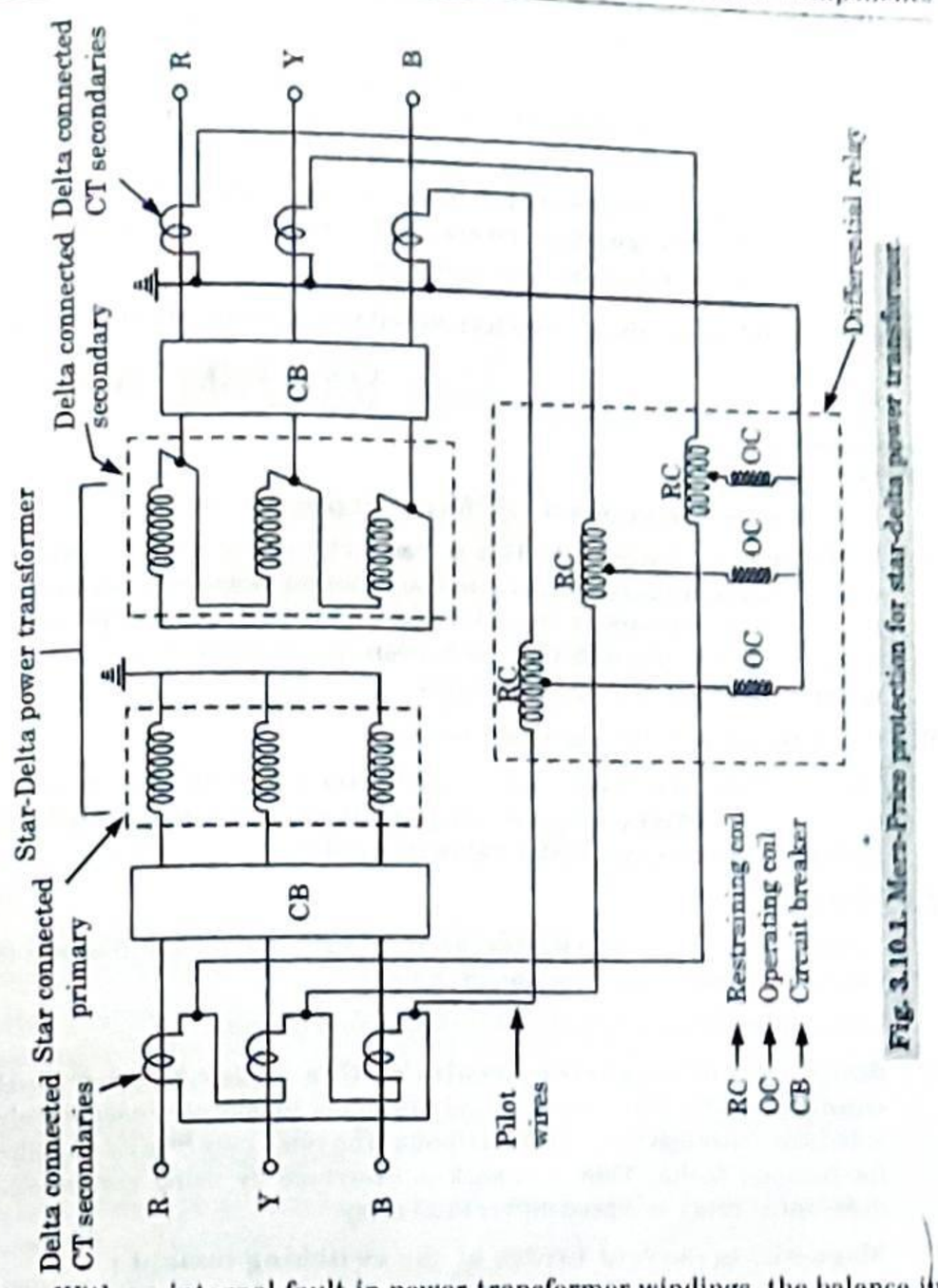


Fig. 3.10.1. Merz-Price protection for star-delta power transformer

7. With an internal fault in power transformer windings, the balance in the CTs gets disturbed.
8. The operating coils of differential relay carry currents proportional to the difference of current between the two sides of a power transformer.
9. This causes the relay operation which trips the main circuit breakers on both the sides of the power transformer.
10. **The basic requirements of the differential relay are :**

i. The differential relay must not operate on load or external faults.

ii. It must operate on severe internal faults.

The relay satisfying these requirements is used in Merz-Price protection.

11. This scheme gives protection against short circuit faults between the turns *i.e.*, interturn faults. This is because when there is an interturn fault, the turns ratio of power transformer gets affected.

12. 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.

Que 3.11. What are the problems related to differential protection ?

AKTU 2016-17, Marks 10

Answer

Problems associated with differential protection :

A. Difference in length of pilot wires : The power system element under protection and CTs are located at different places and normally it is not possible to connect the relay operating coil to the equipotential points. However, this difficulty can be overcome by connecting adjustable resistors in series with the pilot wires.

B. CT ratio errors during short circuits :

1. The CTs used may have almost equal ratio at normal currents, bu during short-circuit conditions, the primary currents are unduly large and the ratio errors of CTs on either side differ.

2. This is due to :

i. Inherent difference in characteristic of CTs arising out of difference in magnetic circuit, saturation conditions etc.

ii. Unequal DC components in the short-circuit currents.

C. Saturation of magnetic circuits of CTs under short-circuit condition : The differential relays are likely to operate inaccurately with heavy through (*i.e.*, external) faults. The relay may lose its stability for through faults. This drawback is overcome by using percentage differential relay or biased differential relay.

D. Magnetizing current inrush at the switching instant :

1. When the power transformer is connected to the supply, a large current (about 6 to 10 times full-load current) inrush takes place.

2. The differential relay operates due to such inrush current, though the transformer has no fault.

3. However, this difficulty is overcome by providing harmonic restraint for the differential relay. This relay filters the harmonic component from the inrush current and supplies it to the restraining coil.

4. The harmonic content of the magnetizing current is used to obtain restraining torque during switching ON of transformer.

E. Tap changing :

1. Transformer transformation ratio is changed whenever the taps are changed.

2. Due to this CT ratios do not match with the new tap settings and result in flow of current in pilot wires even during healthy condition.

3. This problem is overcome by employing biased differential relay.

PART-4

Generator-Transformer Unit Protection Scheme.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.12. With a neat sketch, discuss the protection of generator-transformer unit.

Answer

1. A biased differential protection scheme is used for generator- transformer unit.

2. The zone of such a scheme includes the stator windings, the step up transformer and the intervening connections.

3. In this protection, the generators are directly connected to step up transformer to which it is connected, together from a generator-transformer unit.

4. The protection of such a unit is achieved by differential protection scheme using circulating current principle.

5. While providing protection to such a unit, it is necessary to consider the phase shift and current transformation in the step up transformer.

6. In this protection under normal operation, the two currents at both ends are equal and pilot wires do not carry any current, keeping relays inoperative.

7. When fault occurs, both the currents are different, this causes circulating current to flow and relays trip which operate the circuit breakers to isolate the faulty section.

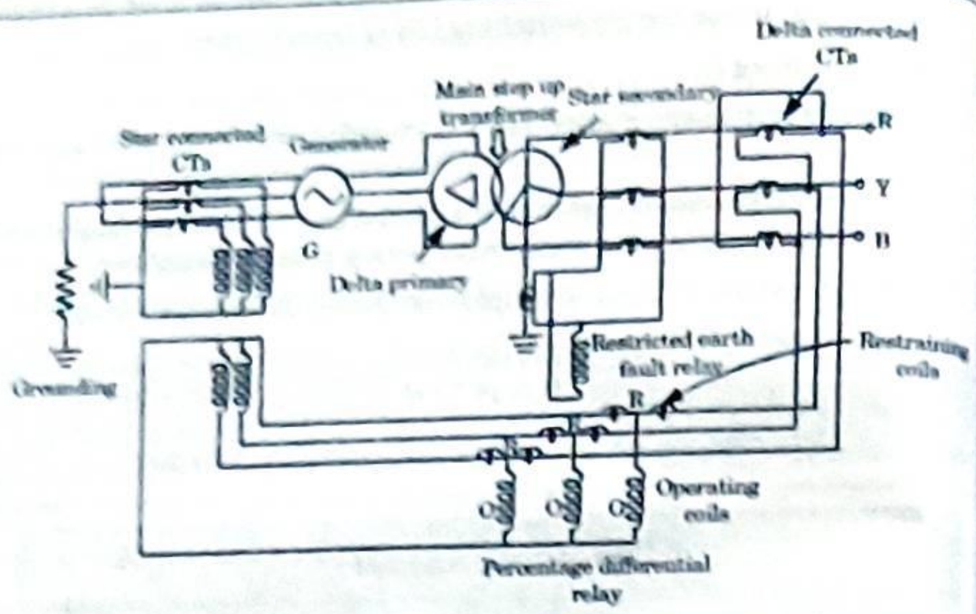


Fig. 3.12.1. Differential protection of generator-transformer unit.

PART-5

Bus-Bar Protection.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.13. **What are the faults which occur in busbar and how is it protected ?**

OR

With a neat sketch, discuss the differential scheme for bus-zone protection. **AKTU 2017-18, Marks 10**

Answer

A. The various busbar faults are :

i. Failure of circuit breaker.

ii. Earth fault due to failure of support insulator.

iii. Accidents due to foreign bodies falling across the busbar.

iv. Flashover due to heavily polluted insulator.

v. Errors in the operation and maintenance of switchgear.

B. The various protection schemes are :

a. Frame Leakage Protection of Busbar :

1. Metal supporting framework known as fault bus is earthed through a CT. When the fault is there, a contact between conductor and earth results.
2. This derives current through this CT and energizes the frame leakage relay.
3. The CT energizing the check relay is mounted in neutral earth of the transformer.
4. The contacts of check relay and frame leakage relay are in series.

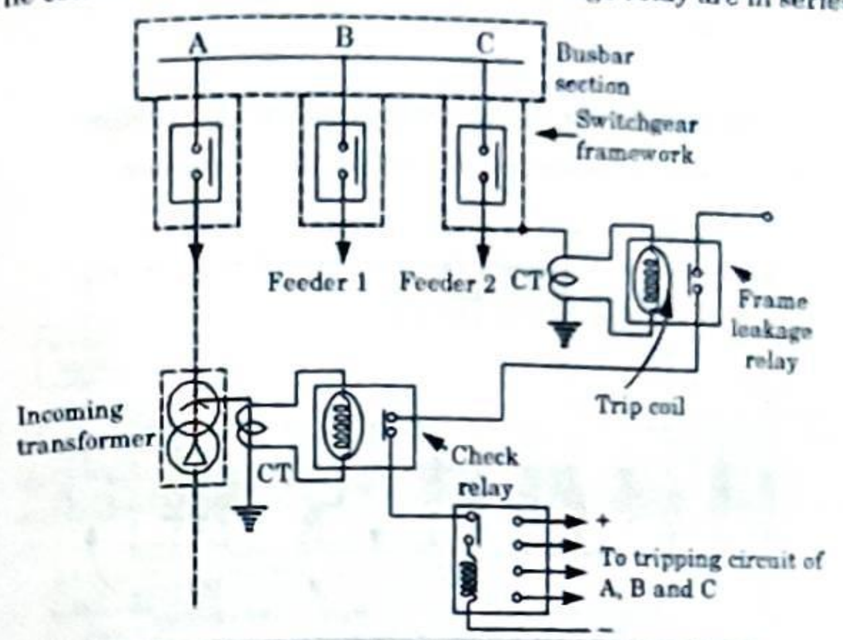


Fig. 3.13.1. Frame leakage protection of busbar.

4. Thus before tripping circuit gets energized, both the relays operate and due to this, all the breakers will trip connecting the equipment to the busbar.

b. Circulating current protection of Busbar :

1. $\bar{I}_1, \bar{I}_2, \bar{I}_3, \ldots \bar{I}_6$ are the currents in the circuits connected to the busbar.

   Under normal condition, $\Sigma I = 0 \Rightarrow \bar{I}_1 + \bar{I}_2 + \ldots + \bar{I}_6 = 0$

   Hence relays remain inoperative.
2. Under fault conditions,

$$\bar{I}_1 + \bar{I}_2 + \ldots + \bar{I}_6 = \bar{I}_f$$

   where $\bar{I}_f$ = Fault current
3. Hence, the relay operates.

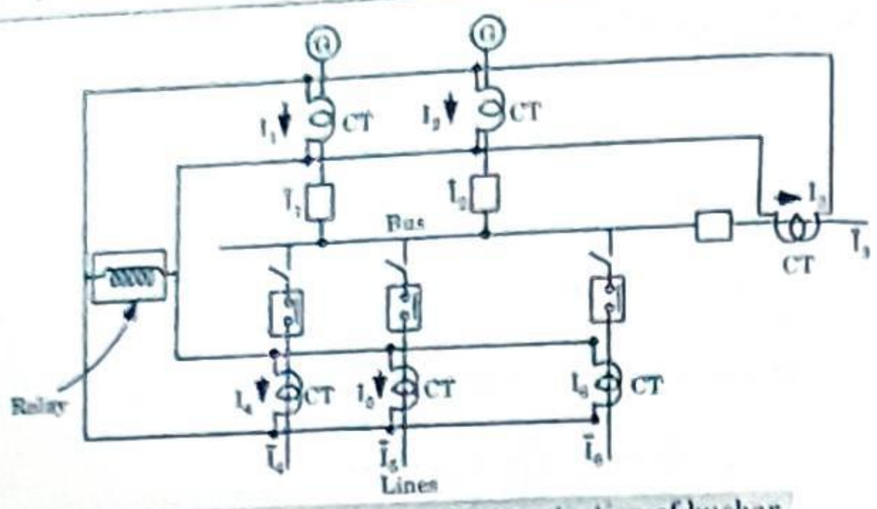


Fig. 3.13.2. Circulating current protection of busbar.

c. High impedance differential protection of busbar :

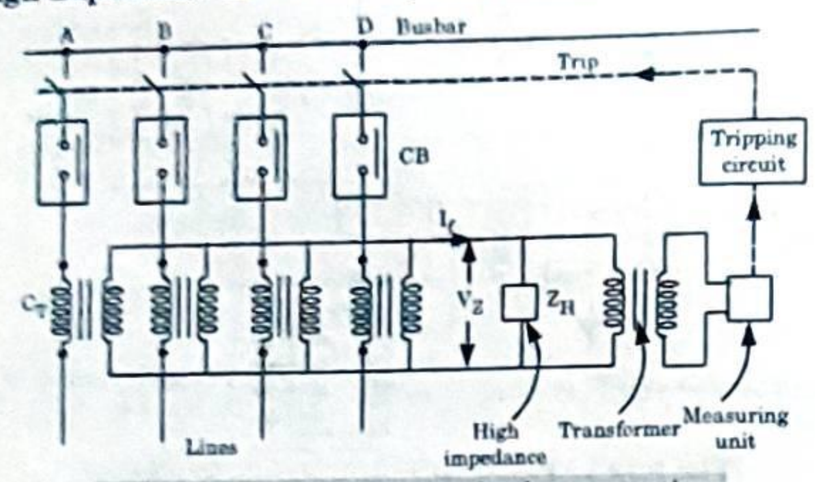


Fig. 3.13.3. High impedance busbar protection.

1. Under normal conditions, relay is inoperative. During fault conditions unbalanced current exists. Such an out of balance current I_f flows through Z_H causing a high voltage drop V_Z across it. It is given to transformer.
2. A measuring unit is connected to the secondary of this transformer which measures this drop and trips the relay accordingly.
3. Main advantage is that as voltage drop is sensed, saturation of core of one of the CT has no effect on the protection scheme.

d. Differential protection of bus using linear couplers :

1. In differential protection of bus, the main drawback is the difference in saturation condition of different iron cored CT.
2. The different magnetic conditions of iron cored CT may result in false operation of the relay at the time of an external fault.

3. Even by using identical CT having large iron cores to avoid saturation with maximum fault currents, this problem is not solved because of the presence of DC transient components swing to their slow decay.
4. Biasing of differential relays though improves stability considerably but is not a complete solution. Thus, a special type of CT having no iron core, also called linear coupler is employed to overcome the above mentioned difficulties.
5. In case of linear couplers, secondary voltage is proportional to the primary current and the secondary windings of all coupler on the same bus section are connected in series to the relay as shown in the Fig. 3.13.4.

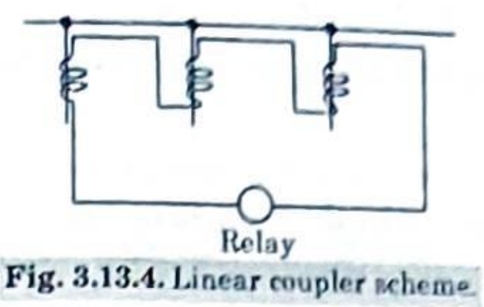


Fig. 3.13.4. Linear coupler scheme.

PART-6

Transmission Line Protection (Current/Time Grading, Distance).

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.14. What is overcurrent protection ?

OR

Enumerate the concept of ring feeder.

Answer

Overcurrent protection is divided into two methods :

A. Non-directional time and current graded method :

1. It is mainly used for the radial feeders. Definite time relays are used in this method.
2. The basic principle used in this method is that the minimum time of operation of the relay decreases from the generating power station to the remote substation.

3. Fig. 3.14.1 shows the overcurrent protection of a radial feeder. For a fault beyond *D*, Circuit Breaker at *D* operates first with relay time of 0.3 sec.

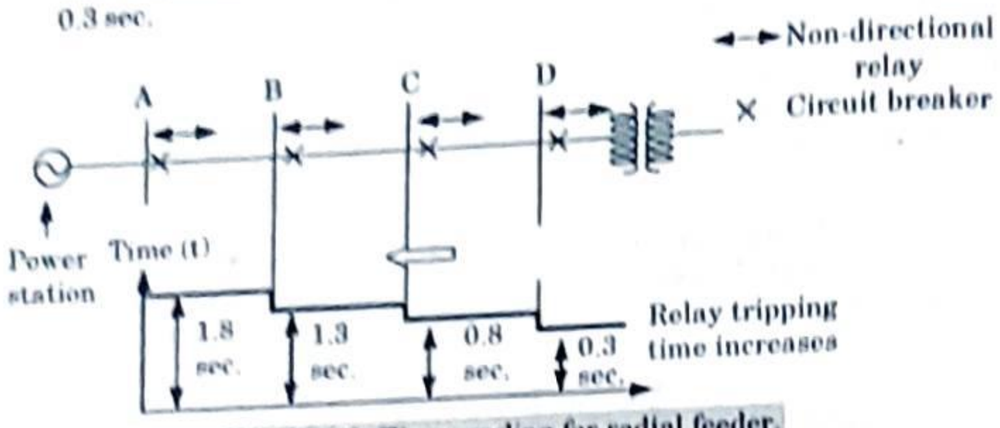


Fig. 3.14.1. Time grading for radial feeder.

4. The protections at *A*, *B* and *C* operate as backup protection for faults between *C* and *D*, relay at *C* trips with a time delay step of 0.5 sec.
5. The relay time at *C* is 0.8 sec. Thus for the section *BC* and *AB*, the time delay is successively increased. Time delay step lies between 0.3 and 0.5 sec.
6. The main disadvantage is that the time of relay at power station may increase to very high value.
7. If this time is more than 2 sec, then the protection is not recommended. Hence the tripping time for the faults near supply must be limited to 2 sec.

B. Directional time and current graded protection :

1. In many case, it is necessary to obtain the information about direction of flow of power where power can flow to the fault from both the directions.
2. In such cases, it is necessary that the circuit breakers on both sides must trip. Thus the directional relays are necessary for such systems.
3. The examples of such systems are :

i. Parallel feeder protection : Fig. 3.14.2 shows the parallel connection of three feeders which are connected between a power station and remote supply point.

Let the fault occurs on the second feeder. This fault is supplied from three paths :

a. From power station directly.

b. From feeder 1 through receiving end busbar indirectly.

c. From feeder 3 through receiving end busbar indirectly.

It is necessary to open circuit breakers 3 and 4 to clear this fault and disconnect the feeder. Thus the non-directional relays are employed on supply side while the directional relays are employed on receiving end.

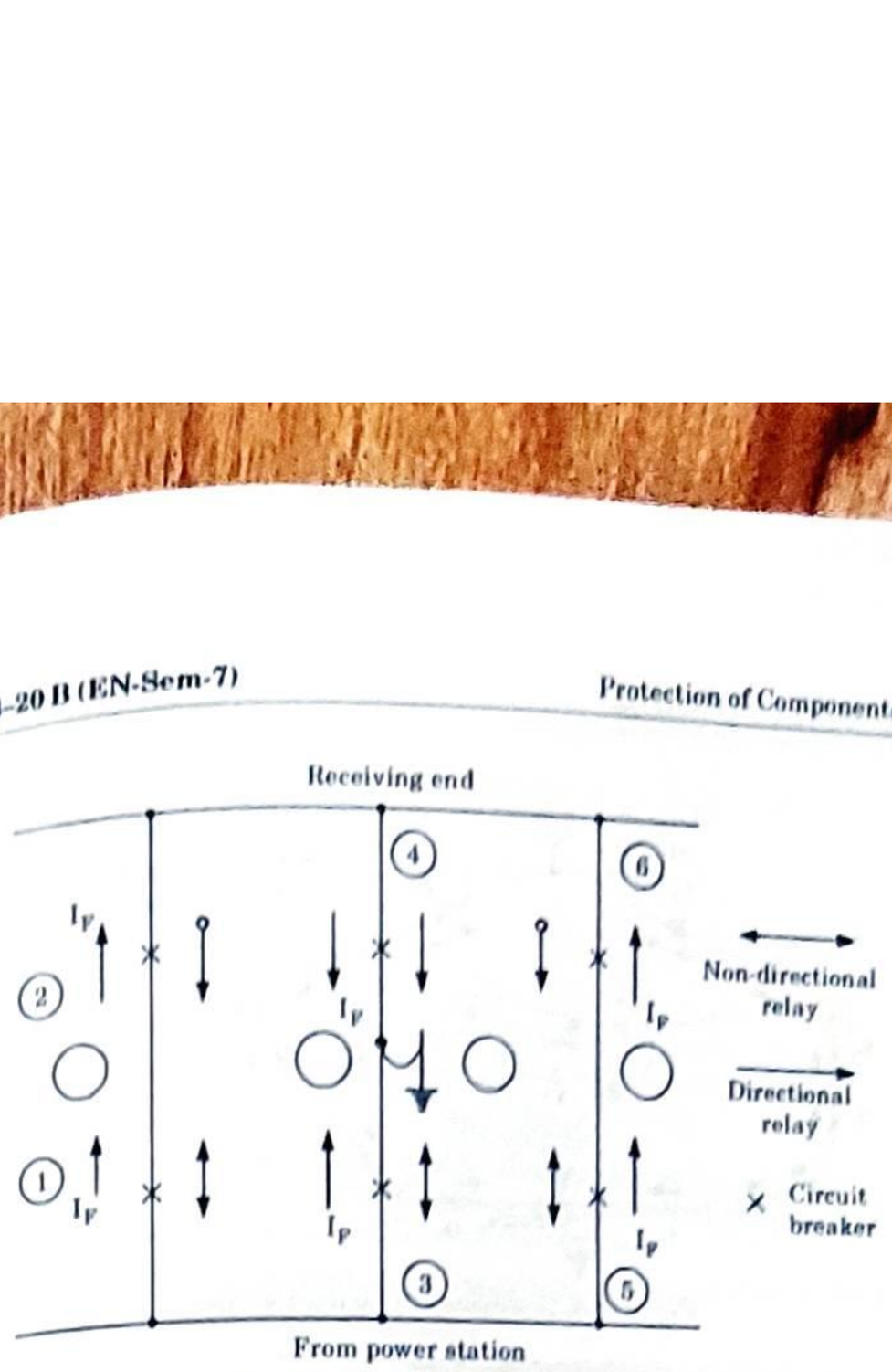


Fig. 3.14.2. Parallel feeder protection.

ii. Tee feeder protection :

a. The method of protection used for the parallel feeders is also used in the protection of Tee feeders. The arrangement is shown in the Fig. 3.14.3.

b. In this method also, the arrangement is such that the relay elements near the generating station are non-directional while those near the receiving ends are directional.

c. The directional relays are set for the lower time setting as well as current setting than the non-directional relays. Thus the directional relays operate before the non-directional.

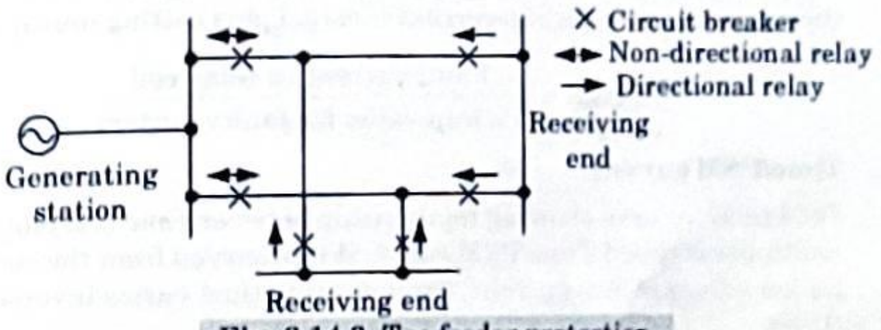


Fig. 3.14.3. Tee feeder protection.

iii. Ring main and interconnected system :

a. In ring main system, the various substations are interconnected by the alternate routes and hence the overall system forms a closed path.

b. This ensures the continuity of the supply to the healthy part if any section of the ring is damaged and separated for the repairs.

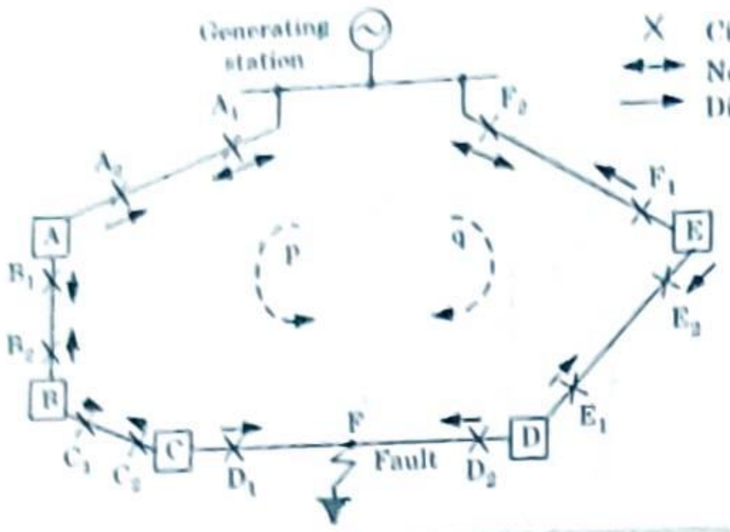


Fig. 3.14.4. Protection of ring main system.

c. If the fault develops in a particular section CD, then it will be fed from the source through path p and path q as shown in the Fig. 3.14.4.

d. In such case, the settings are such that the relays at D_1 and D_2 only will trip and disconnect the faulty section. The remaining relays are inoperative.

Que 3.15. Define the terms : Plug Setting Multiplier, Time/PSM curve, Time Multiplier Setting.

Answer

A. Plug setting multiplier (PSM) : The ratio of actual fault current in the relay coil to the pickup current is called plug setting multiplier.

$$\text{PSM} = \frac{\text{Fault current in relay coil}}{\text{Pickup value for faulty system}}$$

B. Time/PSM curve :

1. For a relay, a curve showing relationship between time and plug setting multiplier is called Time/PSM curve. It is observed from the curve that for low values of overcurrent, the operating time varies inversely with current.
2. But as the current becomes 20 times of its rated value, the time becomes almost constant. By using this curve (Fig. 3.15.1) and time multiplier setting, the actual time of operation of a relay can be obtained.

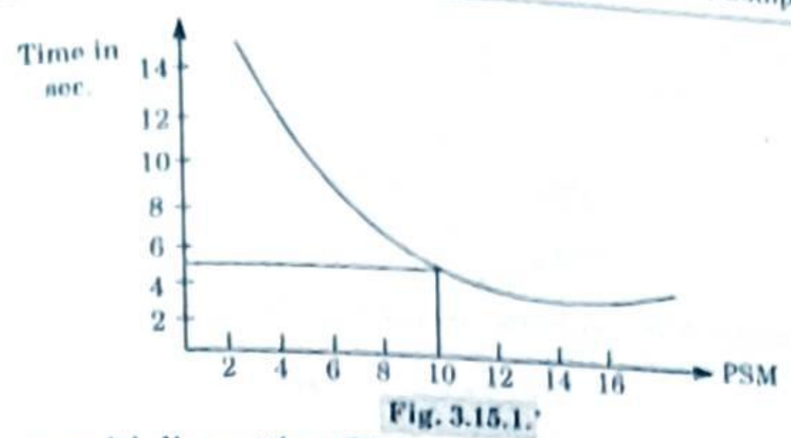


Fig. 3.15.1.

C. Time multiplier setting (TMS) : Similar to current setting, a relay is provided with a feature with which its time of operation can be controlled. This feature is known as time multiplier setting.

$$\text{Actual time} = \text{Time in second} \times \text{Time Multiplier Setting}$$

$$\text{TMS} = \frac{\text{Actual time of operation}}{\text{Time for PSM obtained}}$$

Que 3.16. An IDMT overcurrent relay has a current setting of 150 % and a time multiplier setting of 0.6. The primary of relay is connected to secondary of CT having ratio 400/5. Calculate the time of operation if the circuit carries a fault current of 5000 A. The time-current characteristic of the relay is given in Fig. 3.16.1.

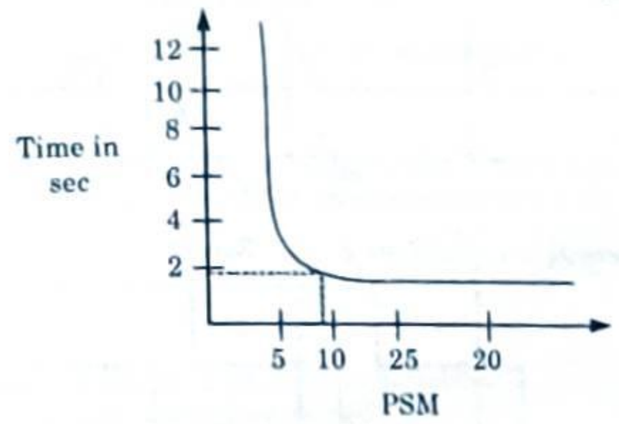


Fig. 3.16.1.

AKTU 2016-17, Marks 10

Answer

Given : Current setting = 150 % = 1.5, Time multiplier setting = 0.6, CT ratio = 5/400, Fault current = 5000 A.

To Find : Time of operation.

1. For PSM,
   FCR (Fault Current in Relay Coil) = Actual fault current × CT ratio
   $$= 5000 \times \frac{5}{400} = 62.5 \text{ A}$$
2. CT = 5 A (Rated Secondary)
   $$\text{PSM} = \frac{62.5}{5 \times 1.5} = 8.333$$
   From Fig. 3.16.1, approximate time for PSM of 8.333 is 1.8 sec.
3. Actual Operating Time = 1.8 × Time Multiplier Setting
   $= 1.8 \times 0.6 = 1.08$ sec

Que 3.17. **What is unit protection and distance protection ?**

OR

Explain stepped time-distance characteristics of three impedance relaying units used for I, II and III zone of protection.

AKTU 2017-18, Marks 10

Answer

A. Unit protection : Unit protection means protecting a specific area of the system *i.e.*, a transformer, transmission line, generator or bus bar.

B. Distance protection :

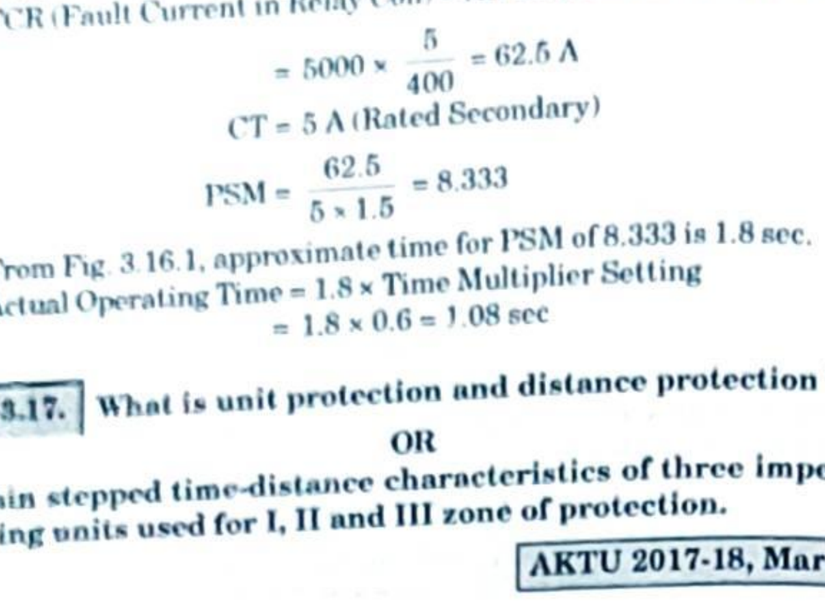


Fig. 3.17.1. Distance or impedance protection.

1. Fig. 3.17.1 shows the simplest system consisting of feeders in series such that the power can flow only from left to right. The relay at A, B, C and D are set to operate with impedances less than Z_A, Z_B, Z_C and Z_D respectively.

2. For a short-circuit fault at point F between substations C and D, the fault loop impedances at power station A and substations B and C are $(Z_A + Z_B + Z)$, $(Z_B + Z)$, and Z respectively. Now only relay at substation C will operate.
3. Similarly for short-circuit faults between substations B and C, and between power station and substation B only relays at substation B and power station A respectively will operate.
4. A system with instantaneous impedance relays, set to act on impedances less than or equal to the impedance of a section, as shown in Fig. 3.17.1(a), would be difficult to adjust; a fault near the junction of two sections is likely to cause the operation of two relays.
5. Furthermore, if a fault of finite resistance occurs near the end of a section, it is possible that total impedance is greater than that for relay operation. For these reasons it is advantageous to use impedance time relays.
6. A number of distance relays are used in association with timing relays so that the power system is divided into a number of zones with varying tripping times associated with each zone.
7. The first zone tripping which is instantaneous is normally set to 80 % of the protected section.
8. The zone 2 protection with a time delay sufficient for circuit breaker operating time and discriminating time margins covers the remaining 20 % portion of the protected section plus 25 to 50 per cent of the next section. Zone 2 also provides backup protection for the relay in the next section for fault close to the bus.
9. Zone 3 with still more time delay provides complete backup protection for all faults at all locations.

Que 3.18. **Draw and explain the characteristic of Mho relay on R-X diagram. Discuss the effect of power surge on its performance.**

AKTU 2017-18, Marks 10

Answer

A. Mho relay : Refer Q. 2.20, Page 2–29B, Unit-2.

B. Effect of power swing or surge :

1. During disturbances, the rotor of generator swings around the final steady state value.
2. When rotor swings, the rotor angle changes and the current flowing through line also changes. Such currents are heavy and are known as power surges or swing.
3. So, when the phase angle changes, the current flowing through line also changes. Therefore, the impedance measured by relay also changes during power swings.

4. Fig. 3.18.1 shows the characteristic of distance relays and power surges on R-X diagram. It is evident from the Fig. 3.18.1, that the relay characteristic occupying greater area on the R-X diagram is least affected.
5. The impedance relay characteristic has more area than Mho relay, it is affected less than the reactance relay.

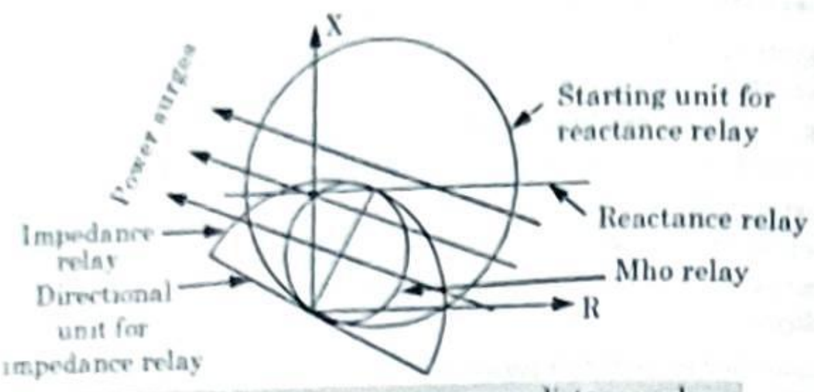


Fig. 3.18.1. Effect of power surges on distance relays.

PART-7

Pilot Relaying Schemes.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.19. **Describe pilot wire protection.**

OR

Explain in detail about longitudinal percentage biased differential protection.

OR

Explain circulating current scheme used in wire pilot protection.

AKTU 2019-20, Marks 07

OR

What is important operating principle which are used in pilot wire scheme ? Discuss the transley scheme of wire pilot protection.

AKTU 2020-21, Marks 07

Answer

Pilot wire protection :

1. In differential protection scheme, the current entering at one end of line and leaving for other end of line is compared. The pilot wires are used to connect the relays.
2. Under normal operation, the two currents at both ends are equal and pilot wires do not carry any current, keeping relays inoperative.
3. When fault occurs, both the currents are different, this causes circulating current to flow and relays trip which operate the circuit breakers to isolate the faulty section.
4. **The various schemes are :**

A. **Merz-Price voltage balance system :**

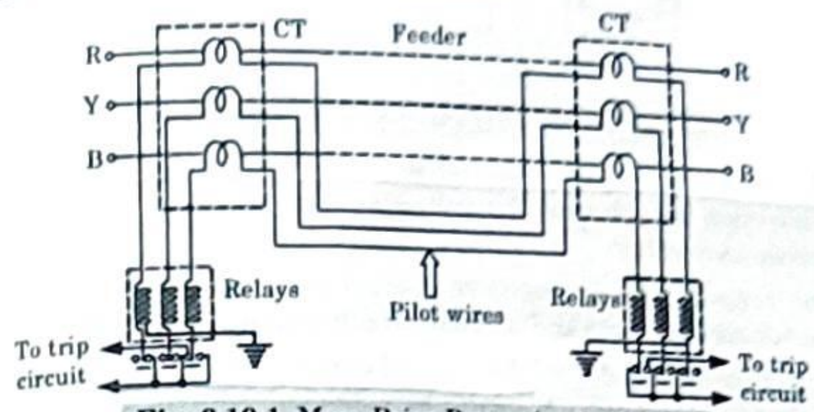


Fig. 3.19.1. Merz-Price Protection for feeder.

1. Under normal condition, both the currents are equal. Thus equal and opposite voltage are induced in the secondary CT at the two ends.

   Hence no current flows through relays.
2. Under fault condition, currents are different and secondary voltage of the two CTs also differs. Thus circulating current flows and trips the relay.

B. **Longitudinal differential protection system :**

a. **Translay Scheme :**

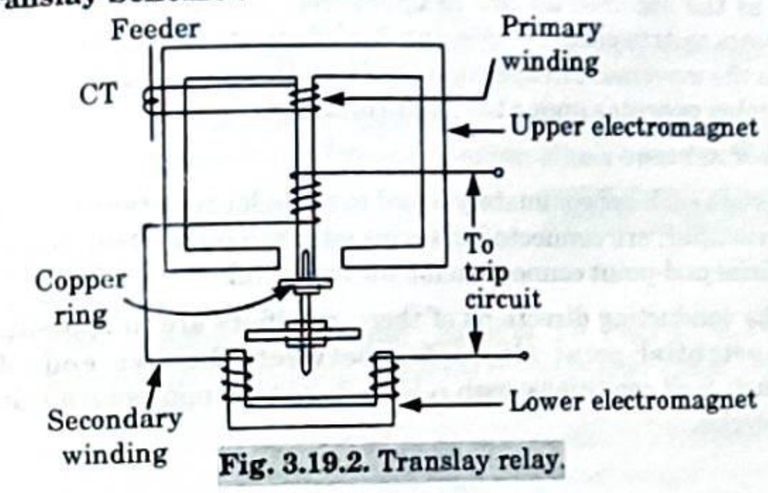


Fig. 3.19.2. Translay relay.

1. These relays are used in feeder protection and in this two such relays are employed at the two ends of feeder as shown in Fig. 3.19.3.

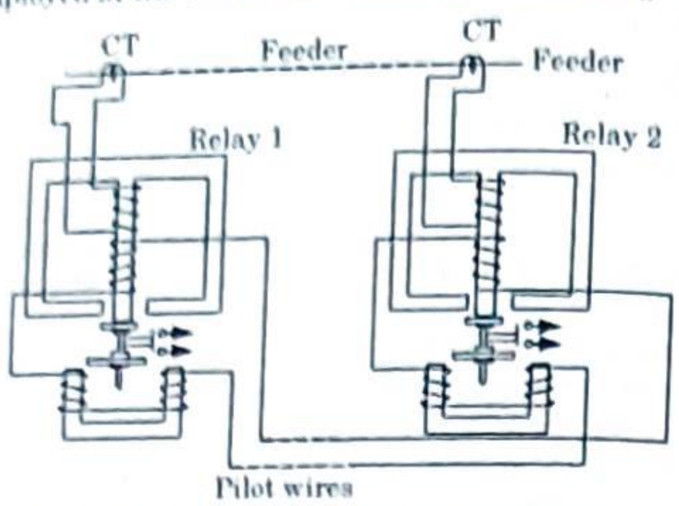


Fig. 3.19.3. Translay scheme of feeder protection.

2. The secondaries are connected to each other using pilot wires. The connection is such that the voltages induced in the two secondaries oppose each other.
3. The copper coils are used to compensate the effect of pilot wire capacitance currents and unbalance between two current transformers.
4. Under normal condition, the two end currents are same. The primaries of the two relays carry the same currents inducing the same voltage in the secondaries.
5. As these two voltages are in opposition, no current flows through the two secondary circuits and no torque is exerted on the discs of both the relays.
6. When fault occurs, the two currents are different. Hence unequal voltages are induced in the secondaries due to which circulating current flows causing torque to be exerted on the disc of each relay.
7. 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 just holds the movement in operated position. The case is taken that at least one relay operates under the fault condition.

b. Solkor scheme :

1. Resistors each approximately equal to the pilot resistance and bridged by a rectifier, are connected in series with the pilot circuit to obtain an artificial mid-point connection for the relay coil.
2. As the conducting directions of these rectifiers are in opposition, the equipotential point alternates between the two ends during through-fault conditions, each relay being at the mid-point on alternate half-cycles.

3. The series rectifier in the relay coil circuit prevents current from flowing in the relay circuit when it is not operating at the electrical mid-point.

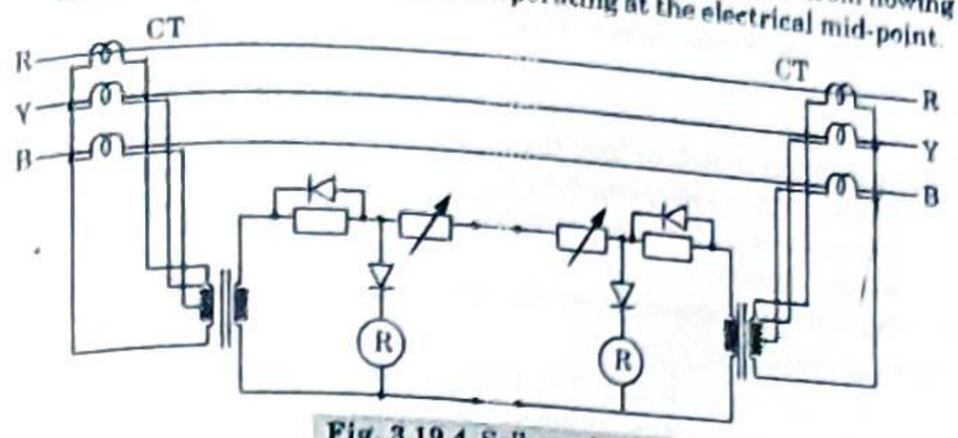


Fig. 3.19.4. Solkor scheme.

4. Under internal fault conditions current flows in the relay coil causing operation. Padding resistors are induced to enable the resistance of the complete pilot circuit between the relays to be adjusted to 1000 Ω.

PART-8

Power Line Carrier Protection.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 3.20. **What is carrier current protection ? What are its merits and demerits ?** **AKTU 2017-18, Marks 10**

OR

Describe the different components of carrier current protection.

OR

What is carrier current protection ? For what voltage range is it used for the protection of transmission lines ? **AKTU 2020-21, Marks 07**

Answer

A. Carrier current protection : Refer Q. 1.8, Page 1–9B, Unit-1.

B. Components : The main elements of the carrier channel are :

i. Transmitter :

1. When a voltage of positive polarity is impressed on the control circuit of the transmitter, it generates a high frequency output voltage.

2. This output voltage is impressed between one phase conductor of the transmission line and the earth. The carrier frequency range is from 30 kHz to 500 kHz on powers of about 100 W.

ii. Receiver :

1. Each carrier current receiver receives carrier current from its local transmitter as well as from the transmitter at other end of the line.
2. In effect the receiver converts the received carrier current into a DC voltage that can be used in a relay or other circuit to perform any desired function.
3. This voltage is zero when carrier current is not being received.

iii. Line traps :

1. Line traps shown in Fig. 3.20.1 are parallel resonant circuits having negligible impedance to power frequency current, but very high impedance to carrier frequency currents.
2. Traps are used to confine the carrier currents to the protected section so as to avoid interference with or from other adjacent carrier-current channels.
3. Consequently the carrier-current can flow only along the line section between the traps.

iv. Coupling capacitor :

1. Coupling capacitor is used for injection into and receipt of carrier signals from the line.
2. The capacitor gives an impedance of few million ohms to the 50 Hz power current but only a few thousand ohms to the carrier frequency.

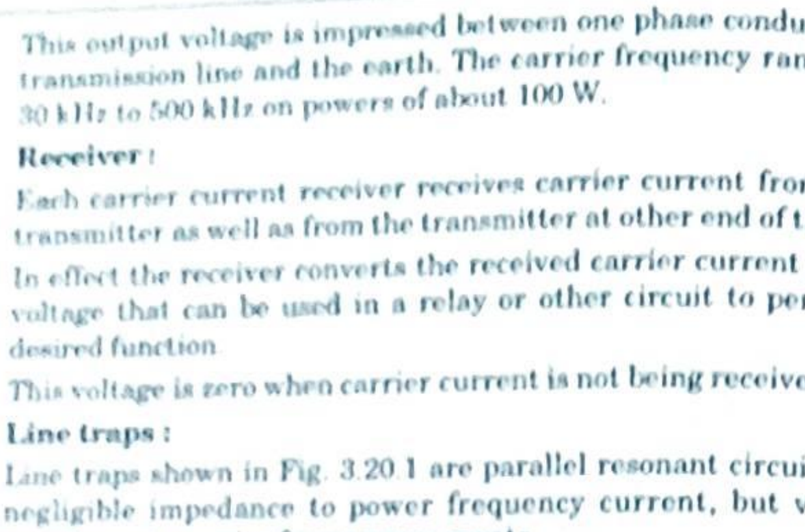


Fig. 3.20.1. Schematic of carrier current protection.

B. Advantages :

1. It has a fast and simultaneous operation of circuit breakers at both the ends.
2. It has a fast, clearing process and prevents shock to the system.

C. Disadvantages :

1. In order to avoid operation due to spurious signals, the carrier and receiver signals should be set at a higher power level.
2. Amplifier and oscillator are continuously energized and the stability and response time of these units are constraints.

Que 3.21. Describe the different components of carrier protection scheme and explain phase comparison carrier protection.

OR

Explain phase comparison method of carrier current protection.

AKTU 2016-17, Marks 10

OR

What is unit protection ? Discuss the phase comparison scheme of carrier current protection.

AKTU 2017-18, Marks 10

OR

What do you understand by carrier current protection scheme ? Explain phase comparison carrier current protection in detail.

AKTU 2019-20, Marks 07

Answer

A. **Unit protection :** Refer Q. 3.17, Page 3–23B, Unit-3.

B. **Carrier current protection :** Refer Q. 1.8, Page 1–9B, Unit-1.

Carrier current protection components : Refer Q. 3.20, Page 3–28B, Unit-3.

C. **Types of carrier current protection :**

a. Carrier aided distance protection.

b. **Phase comparison carrier current protection :**

1. Fig. 3.21.1 shows schematically the principal elements of equipment at both ends of a two-terminal transmission line using a carrier pilot.
2. The transmission line CTs feed a network that transforms the CT output currents into a single phase sinusoidal output voltage.
3. This voltage is applied to a carrier-current transmitter and to a comparer.
4. The output of a carrier current receiver is also applied to the comparer.
5. The comparer controls the operation of an auxiliary relay for tripping the transmission line-breaker.
6. These elements provide means for transmitting and receiving carrier-current signals for comparing at each end the relative phase relations of the transmission line current at both ends of the line.
7. For an external fault at *D* in Fig. 3.21.1 the network output voltages at stations *A* and *B* are 180° out of phase as shown in Fig. 3.21.2; this is because the CT connections at the two stations are reversed.

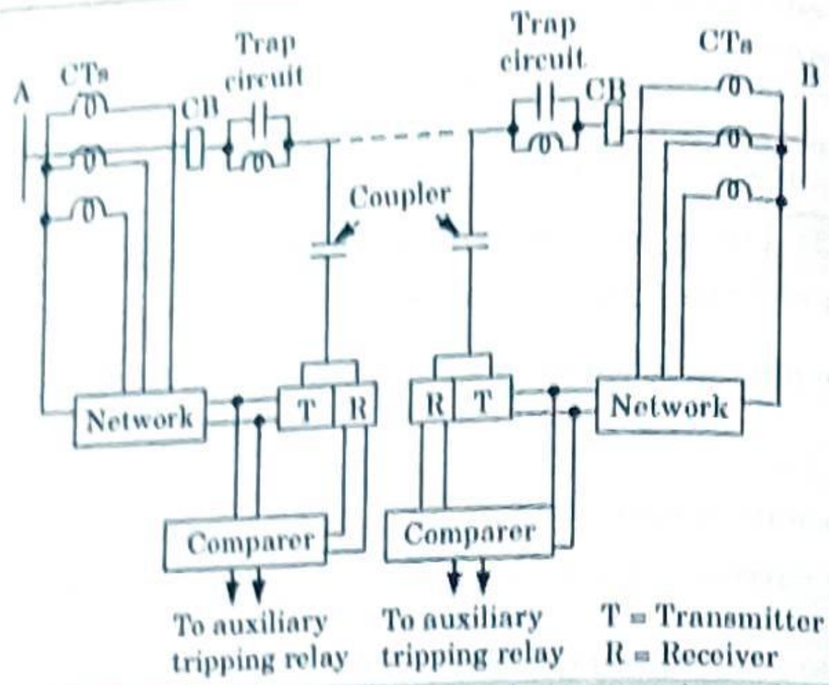


Fig. 3.21.1. Schematic of carrier phase comparison relay.

8. Since an AC voltage is used to control the transmitter, carrier current is transmitted only during the half cycles of voltage when the polarity is positive.
9. The carrier current signals transmitted from A and B are displaced in time, so that there is always carrier current signal from one end or the other.

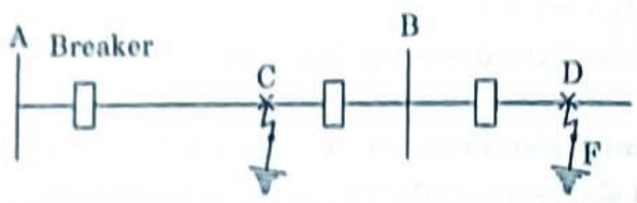


Fig. 3.21.2. Operation of carrier protection.

10. For internal fault at C, the network output voltage at station B reverses because of the reversal of power line currents at station B.
11. The carrier current signals are concurrent and there is no signal from either station.
12. Phase comparison relaying acts to block tripping at both terminals whenever the carrier current signals are displaced in time so that there is little or no time interval when a signal is not being transmitted from one end or the other.
13. When the carrier current signals are approximately concurrent tripping will occur wherever there is sufficient short circuit current flowing.

Que 3.22. What is a carrier blocking scheme? Discuss its merits and demerits over other types of carrier aided distance protection.

AKTU 2019-20, Marks 07

Answer

A. Carrier blocking scheme :

1. In this scheme, the carrier signal is used to block the operation of the relay in case of external faults.
2. When a fault occurs on the protected line section, there is no transmission of the carrier signal.
3. The blocking schemes are particularly suited to the protection of multi-ended lines.
4. In this scheme the zone 3 unit looks in the reverse direction and it sends a blocking signal to prevent the operation of zone 2 unit at the other end for an external fault.
5. When a fault occurs at F_1 as shown in Fig. 3.22.1, it is seen by zone 1 relays at both ends A and B.
6. Consequently, the fault is cleared instantaneously at both ends of the protected line.
7. The carrier signal is not transmitted by the reverse looking zone 3 unit because it does not see the fault at F_1.

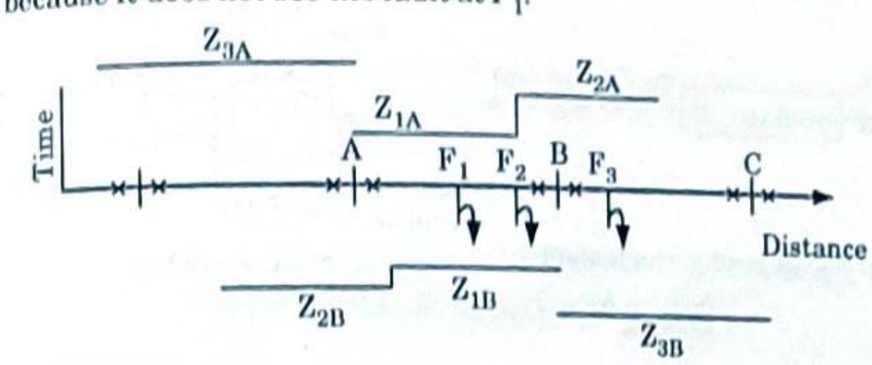


Fig. 3.22.1. Stepped time-distance characteristics of relays for carrier blocking scheme.

8. When a fault occurs on F_2, which is an end-zone fault, it is seen by zone 2 units at both ends A and B and also by zone 1 unit at B.
9. The fault is cleared by zone 1 unit at B and instantaneously by the zone 2 unit at A.
10. The zone 2 unit has two operating times one instantaneous and other delayed.
11. The instantaneous operation is through Z_2, and RR, as shown in Fig. 3.22.2(a).

12. The delayed operation is through T_2. As the fault is an internal one, there is no transmission of the carrier signal.
13. When a fault occurs at F_3, it is seen by the forward looking zone 2 unit A and the reverse looking zone 3 unit at B.
14. It is an external fault. Normally, it has to be cleared by the zone 1 unit associated with line BC.
15. So to prevent the operation of zone 2 unit at A, a carrier signal is transmitted by the reverse looking zone 3 unit at B.
16. If this fault is not cleared instantaneously by the relays of line BC, the zone 2 relay at A will trip after the zone 2 time lapse, as back-up protections.

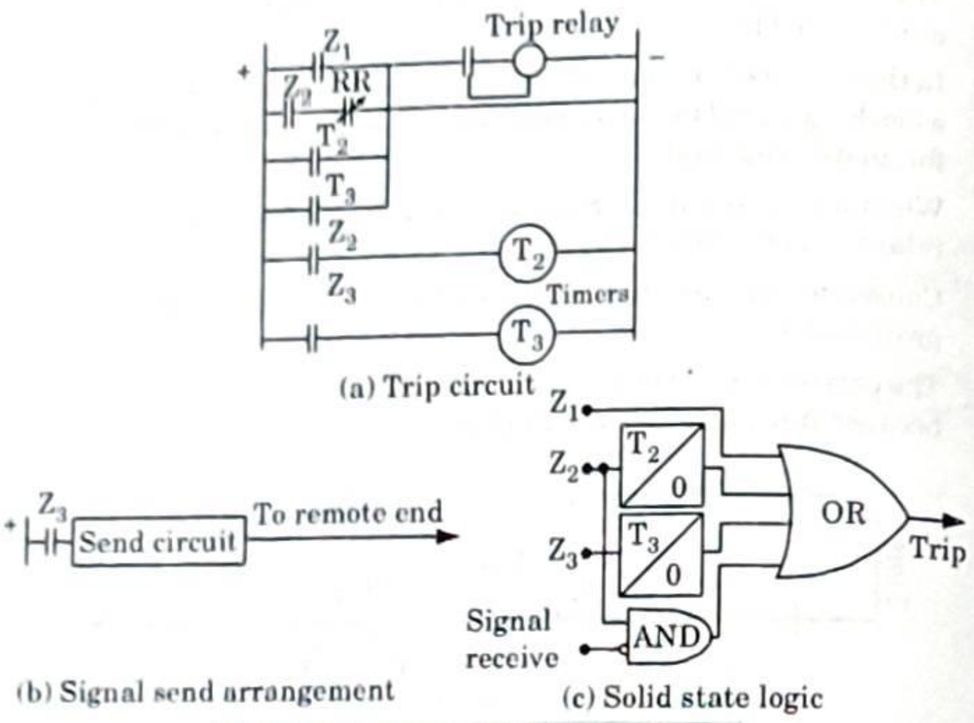


Fig. 3.22.2. Carrier blocking scheme.

B. Merit : The relay will operate for end-zone faults in the blocking scheme even in the event of the failure of carrier signal. But in the case of transfer trip schemes, the relay does not operate instantaneously for end-zone faults in the event of the failure of carrier signal.

C. Demerit : This scheme is not economical as compare to other scheme.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. Give the complete protection scheme for alternator.
Ans. Refer Q. 3.4.

Q. 2. Discuss the protection employed for the field winding of the alternator against ground faults.
Ans. Refer Q. 3.6.

Q. 3. With a neat schematic diagram, explain the protection of transformer with differential protection scheme.
Ans. Refer Q. 3.9.

Q. 4. What are the problems related to differential protection ?
Ans. Refer Q. 3.11.

Q. 5. With a neat sketch, discuss the differential scheme for bus-zone protection.
Ans. Refer Q. 3.13.

Q. 6. Explain stepped time-distance characteristics of three impedance relaying units used for I, II and III zone of protection.
Ans. Refer Q. 3.17.

Q. 7. Explain in detail about longitudinal percentage biased differential protection.
Ans. Refer Q. 3.19.

Q. 8. Explain phase comparison method of carrier current protection.
Ans. Refer Q. 3.21.

☺☺☺

4 UNIT

Circuit Breaking

CONTENTS

PART-1

Properties of Arc.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.1. Give the properties of arc.

Answer

i.

1. Arc characteristics are given by the plot of instantaneous values of voltage between the electrodes of burning arc against the corresponding values of current.
2. With the increase of arc current, the temperature rises and process of ionization becomes more active and the arc voltage decreases.
3. The increase of arc current increases the conductivity but has less effect on the voltage.
4. If the current changes rapidly with time, the characteristics are known as dynamic and if the rate of change of current is small, it is called static characteristics.

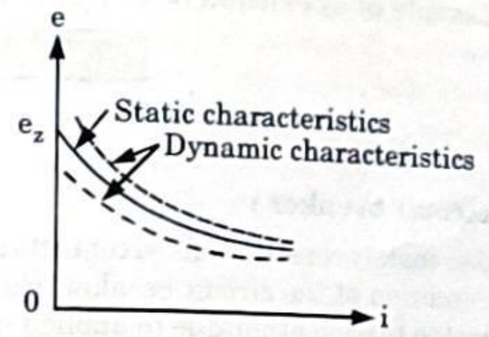


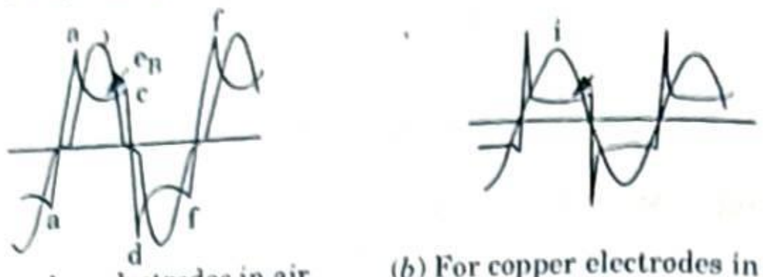
Fig. 4.1.1. Static and dynamic characteristics.

5. If the current is suddenly increased, the instantaneous voltage across it is found to be higher than that given by the static characteristics. It is because of the heat content of arc and its surroundings.

ii. There is thermal hysteresis in changing the arc, *i.e.*, total heat content in steady state as well as heat loss depends on the current but any change in heat content is affected slowly.

iii. The temperature of metallic arc spots is about 2000 °C to 3000 °C, whereas with carbon electrodes the temperature rises up to 3000 °C to 4000 °C.

While the gas temperature in the arc range from 5000 °C to 8000 °C depending upon the quantity of current flowing.



(*a*) For carbon electrodes in air (*b*) For copper electrodes in air

Fig. 4.1.2. Voltage and current waves of an AC arc.

iv. During interruption of loaded circuit, arc discharge takes place that results in large quantity of energy (W_e) being released in arc space (in form of heat majorly).

$$W_e = \int_0^{t_{arc}} i e_B dt$$

where, i = Instantaneous value of current.
e_B = Voltage drop across the arc.
t_{arc} = Time during which arc exists.

Que 4.2. Describe phenomena of arc, properties of arc, initiation and maintenance of arc. **AKTU 2016-17, Marks 10**

OR

Describe basic principle of operation of a circuit breaker. **AKTU 2016-17, Marks 10**

Answer

A. Operation of circuit breaker :

1. The circuit breaker mainly consists of fixed contacts and moving contacts. In normal ON condition of the circuit breaker, these two contacts are physically connected to each other due to applied mechanical pressure on the moving contacts.
2. There is an arrangement stored potential energy in the operating mechanism of circuit breaker which is released if the switching signal is given to the breaker.
3. The potential energy can be stored in the circuit breaker by different ways like by deforming metal spring, by compressed air, or by hydraulic pressure.
4. All circuit breaker have operating coils (tripping coils and close coil), whenever these coils are energized by switching pulse, and the plunger inside them displaced.

5. This operating coil plunger is typically attached to the operating mechanism of circuit breaker; as a result the mechanically stored potential energy in the breaker mechanism is released in forms of kinetic energy, which makes the moving contact to move.
6. And the contacts of circuit breaker separated.

B. Phenomena and initiation of arc :

1. Under faulty conditions heavy current flows through the contacts of the circuit breaker before they are opened.
2. As soon as the contacts start separating, the area of contact decreases which will increase the current density and consequently rise in the temperature. The medium between the contacts of circuit breaker may be air or oil.
3. The heat which is produced in the medium is sufficient enough to ionize air or oil which will act as conductor. Thus an arc is struck between the contacts. The potential difference between the contacts is sufficient to maintain the arc.
4. Then the relay excites the circuit breaker to open its contacts. And arc is quenched.

C. Properties of arc : Refer Q. 4.1, Page 4–2B, Unit-4.

D. Maintenance of arc :

1. The initiation of the arc is done by field emission and thermionic emission. The electrons which are travelling towards anode collide with other electrons to dislodge them and thus the arc is maintained.
2. The ionizing is facilitated by :

i. High temperature of the medium around the contacts due to high current densities. Thus the kinetic energy gained by moving electrons is increased.

ii. The increase in kinetic energy of moving electrons due to the voltage gradient which dislodge more electrons from neutral molecules.

iii. The separation of contacts of circuit breaker increases the length of path which will increase number of neutral molecules. This will decrease the density of gas which will increase free path movement of the electrons.

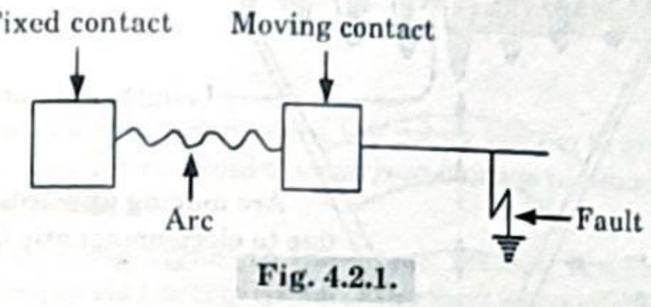


Fig. 4.2.1.

Que 4.3. What do you understand by high arc resistance and low arc resistance methods of arc quenching ?

OR

How do you quench an arc in a circuit breaker ?

Answer

Arc interruption (quenching) : There are two methods of extinguishing the arc in circuit breakers which are :

A. High resistance method :

a. In this the arc resistance is increased with time. This will reduce the current to such a value which will be sufficient to maintain the arc.

b. Thus the arc is interrupted and extinguished. It is employed in only DC circuit breakers.

c. The various methods of high resistance arc interruption are :

i. Lengthening the arc :

1. 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 shape of letter '*V*'.
2. The arc is initiated at the bottom and blows upwards due to electromagnetic force. Due to this arc length increases and arc is extinguished.

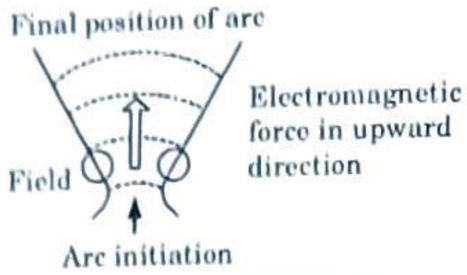


Fig. 4.3.1. Arc lengthening.

ii. Splitting of arc :

1. In this method elongation of arc is done and the arc is split using arc splitters which are specially made plates of resin bonded fibre glass.

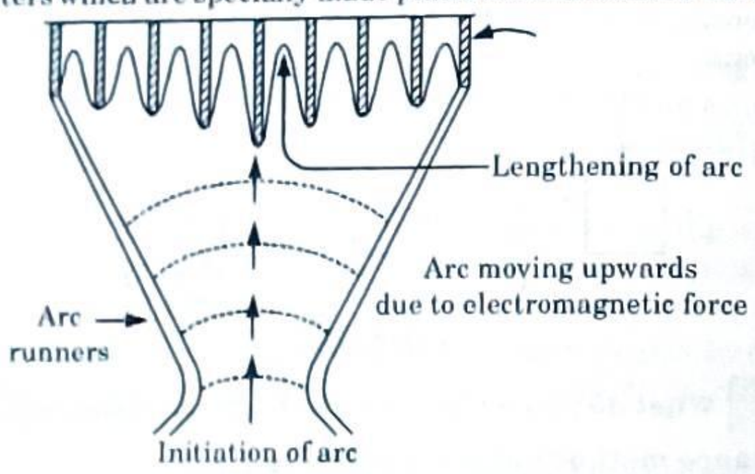


Fig. 4.3.2. Arc splitting.

2. These plates are placed in perpendicular path to arc so that it will be pulled towards it by electromagnetic force.
3. When the arc is pulled upwards it gets elongated, then split and cooled due to which it gets extinguished.

iii. Cooling of arc :

1. The recombination of ionized particles can be done by cooling the arc which removes heat from the arc. This is done by bringing the arc in contact with cooled air.
2. Hence the arc diameter reduces which will increase its resistance. Hence arc extinguishes.

B. Low resistance method :

a. It is employed for arc extinction in AC circuits. In this method arc resistance is kept low until current zero where extinction of arc takes place naturally and is prevented from restriking.

b. The process is divided in three parts :

i. Arcing phase :

1. In this, the temperature of the contact space is increased due to the arc. The heat produced must be removed quickly by providing radial and axial flow to gases.
2. The arc cannot be broken abruptly but its diameter can be reduced by the passage of gas over the arc.

ii. Current zero phase : In this, when AC current wave is near its zero, the diameter of the arc is very less and consequently arc is extinguished.

iii. Post arc phase :

1. In this, to avoid the re-establishment of arc, the contact space must be filled with dielectric medium having high dielectric strength.
2. Hot gases are removed and fresh dielectric medium is introduced.

Que 4.4. Describe in detail the fault clearing time of a circuit breaker. **AKTU 2020-21, Marks 07**

Answer

1. A circuit breaker is required in the power system to give rapid fault clearance, in order to avoid overcurrent damage to equipment and loss of system stability.
2. The fault tripping signal to the circuit breaker is derived from the protective relay via the trip circuit. After fault inception, the relay senses the fault and closes its contacts to complete the trip circuit.
3. The relay takes some time to close its contacts. After closing of the contacts of the trip circuit, the trip coil of the circuit breaker is energized and the operating mechanism of breaker comes into operation.

4 The contacts of the circuit breaker start separating to clear the fault. On the separating of the contacts, an arc is formed between them and the current continues to flow through the arc. The fault is cleared when the arc is finally extinguished.

5 The various components of fault clearing time of a circuit breaker as shown in Fig. 4.4.1.

6 The fault clearing time is the sum of relaying time and breaker interrupting time.

Fault clearing time = Relaying time + Breaker interrupting time

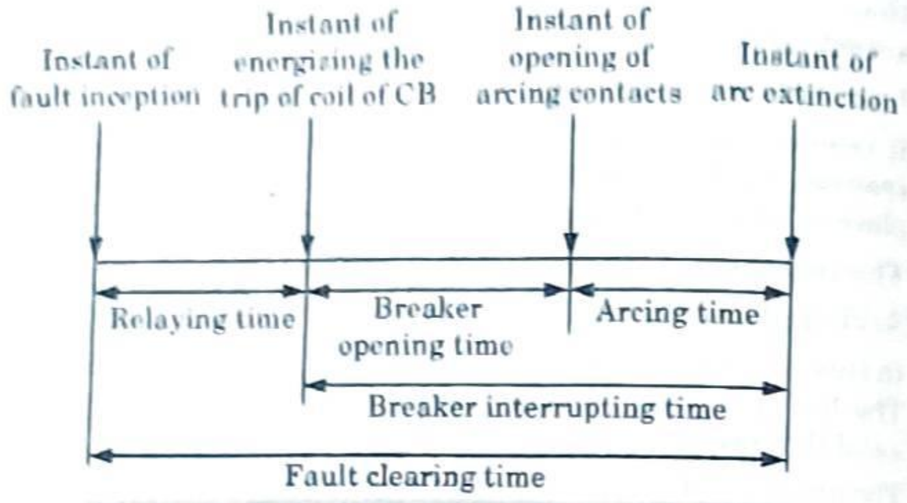


Fig. 4.4.1. Fault clearing time of a circuit breaker.

PART-2

Arc Extinction Theories.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.5. Describe the two theories related to arc extinction.

Answer

A. Slepian's theory :

1. Slepian described the process as a race between the dielectric strength and restriking voltage. After every current zero, there is a column of residual ionized gas.
2. This may cause arc to strike again by developing necessary restriking voltage and this voltage stress is sufficient to detach electrons out of their atomic orbits which releases great heat.

3. So in this theory rate at which positive ions and electrons recombine to form neutral molecules is compared with rate of rise of restriking voltage.
4. Due to recombination, the dielectric strength of gap gets recovered. So rate of recovery of dielectric strength is compared with rate of rise of restriking voltage.
5. If the restriking voltage rises more rapidly than the dielectric strength, gap space breaks down and arc strikes again and persists.

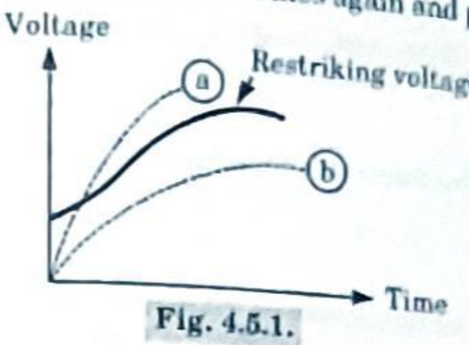


Fig. 4.5.1.

B. Cassie's theory :

1. Cassie suggested that the re-establishment of arc or interruption of an arc both are energy balance process. If the energy input to an arc continues to increase, the arc restrikes and if not, arc gets interrupted.
2. **The theory makes the following assumptions :**

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

ii. The temperature remains constant.

iii. The cross-section of the arc adjusts itself to accommodate the arc current.

iv. Power dissipation is proportional to cross sectional area of arc column.

The energy equation as expressed by Cassie is given by,

$$\frac{dQ}{dt} = EI - N$$

where, Q = Energy content / length of arc in cm
E = Volts / cm
I = Total current
N = Total power loss / cm

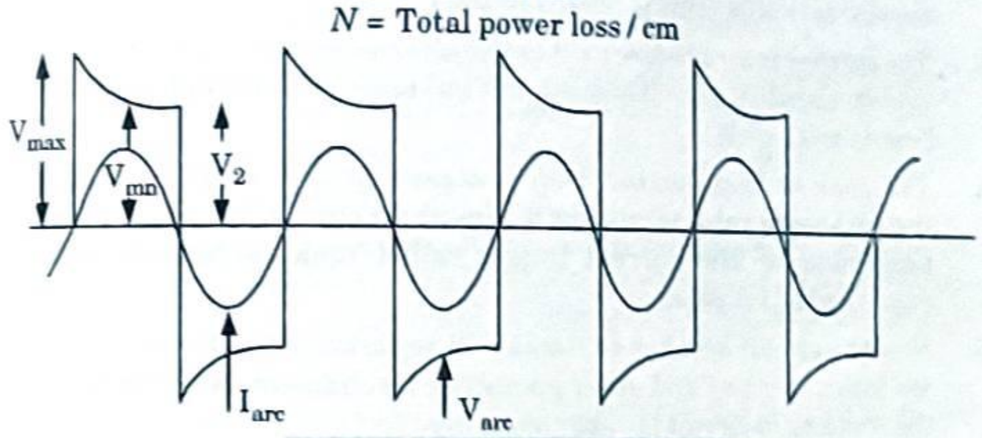


Fig. 4.5.2. Waveform of AC arc.

PART-3

Restriking Voltage Transient.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.6. Describe current interruption in AC circuit breakers.

Answer

1. Let us consider an alternator on no load to which a circuit breaker is connected which is shown in the Fig. 4.6.1. The circuit breaker is in open position with its other side short circuited.

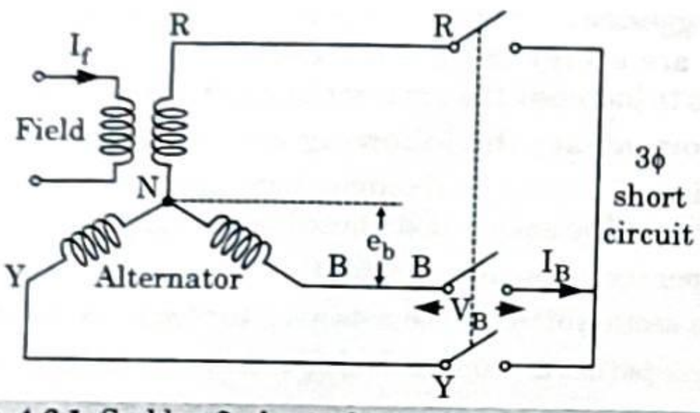


Fig. 4.6.1. Sudden 3-phase short circuit of an alternator.

2. When the voltage of phase *B* with respect to neutral is zero, the circuit breaker is closed.
3. Under this condition the *B* phase current will have maximum DC component and its current waveform will be unsymmetrical about normal zero axis. This is shown in the Fig. 4.6.2.
4. The current is zero before $t = 0$ as the alternator is on no load. The short circuit is applied at $t = 0$ and current increases to very high value during first quarter cycle.
5. The peak of first current loop is shown by *OA* which is maximum instantaneous value of current during short circuit. This instantaneous peak value of first current loop is called 'making current' which is expressed as kA peak.
6. Now the circuit breaker contacts will separate after few cycles which are taken by relay and other operating mechanism. At time say $t = T_1$ the contacts of circuit breaker separate.

7. The rms value of short circuit current at that instant of contact separation is called 'breaking current'.
8. At $t = T_2$ the arc is interrupted as the dielectric strength of arc space builds sufficiently. This will avoid the continuation of arc. Thus the arc will be extinguished.
9. Before the instant $t = 0$, the contacts are closed so the voltage between them is zero.

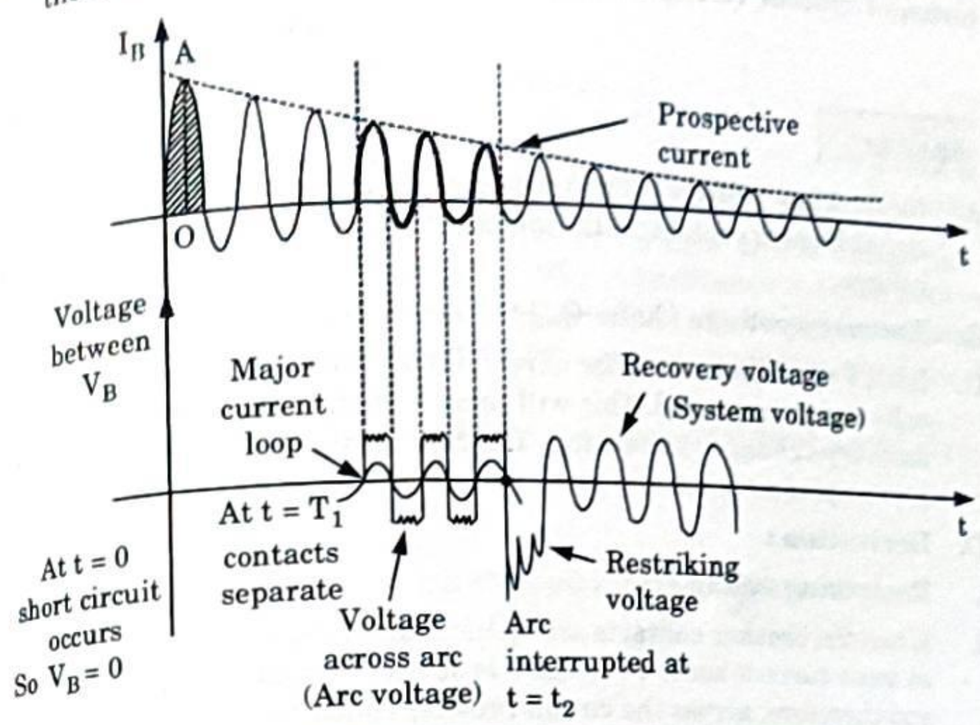


Fig. 4.6.2. Current and voltage during fault clearing.

10. At the instant $t = T_1$, the contacts begin to separate and voltage across them starts increasing. This voltage is nothing but the drop across the arc.
11. The current and the voltage across arc are in phase as the arc is resistive. Due to increased arc resistance the voltage across contacts increases in the next cycles. Finally at $t = T_2$ the arc is extinguished.
12. A high frequency transient voltage appears across the contacts which are superimposed on power frequency voltage. This high frequency voltage tries to restrike the arc. Hence it is called 'restriking voltage or transient recovery voltage (TRV)'.
13. This is the voltage which appears across circuit breaker contact which is responsible for restriking of arc. The power frequency system voltage between the circuit breaker contacts after arc extinction is called 'recovery voltage'.
14. **Active recovery voltage :** Instantaneous recovery voltage at the instant of arc extinction is known as active recovery voltage.

Active recovery voltage, $V_{ar} = kV_m \sin\phi$

where, $k = 1$, if the 3ϕ fault is grounded

and $k = 1.5$, if 3ϕ fault is isolated.

Que 4.7. Explain the terms : restriking voltage, recovery voltage and RRRV. Derive expression for restriking voltage and RRRV in terms of system voltage, inductance and capacitance.

AKTU 2017-18, Marks 10

Answer

A. **Restriking voltage :** The transient voltage that appears across the circuit breaker contacts at the instant of arc extinction is called restriking voltage.

B. **Recovery voltage :** Refer Q. 4.6, Page 4–9B, Unit-4.

C. **RRRV :** It is the rate of rise of restriking voltage which is expressed in volts per microsecond. This will represent the rate at which transient recovery voltage is increasing. The rate of rise of TRV is dependent on system parameters.

D. **Derivation :**

i. **Restriking voltage :**

1. When the breaker contacts are opened and the arc finally extinguishe at some current zero, a voltage v is suddenly applied across capacitor and therefore, across the circuit breaker contacts.
2. The current i which would flow to the fault is not injected in the capacitor and inductor. Thus

$$i = i_L + i_c$$

or $$i = \frac{1}{L}\int v\,dt + C\frac{dv}{dt}$$

$$\therefore \quad \frac{di}{dt} = \frac{v}{L} + C\frac{d^2v}{dt^2} \qquad ...(4.7.1)$$

3. Assuming zero currents when $t = 0$, and further

$$v = V_{max}\cos\omega t$$

$$i = \frac{V_{max}}{\omega L}\sin\omega t \text{ before opening of circuit breaker}$$

$$\frac{di}{dt} = \frac{V_{max}}{\omega L} \times \omega\cos\omega t$$

At $$t = 0; \left|\frac{di}{dt}\right| = \frac{V_{max}}{L}$$

4. Substituting in eq. (4.7.1), we get

$$\frac{V_{max}}{L} = \frac{v}{L} + C\frac{d^2v}{dt^2} \qquad ...(4.7.2)$$

5. The solution of this standard equation is

$$v = V_{max}\left[1 - \cos\frac{t}{\sqrt{LC}}\right]$$

ii. **RRRV :**

$$\text{RRRV} = \frac{dv}{dt} = \frac{V_{max}}{\sqrt{LC}}\sin\frac{t}{\sqrt{LC}}$$

Que 4.8. A 50 Hz, 400 kV, three phase alternator with earthed neutral has a reactance of 10 ohm per phase and is connected to busbar through a circuit breaker. The capacitance to earth between the alternator and the circuit breaker is 0.05 μF per phase. Assuming the resistance of the generator to be negligible, calculate the following :

i. **Maximum restriking voltage across the contact of circuit breaker.**
ii. **Frequency of oscillations.**
iii. **Maximum value of RRRV.**
iv. **The average value of RRRV up to the first peak.**

Answer

$$E_{rms} = 400 \text{ kV},$$

$$\therefore \quad E_{peak} = \sqrt{2}\,E_{rms} = \sqrt{2} \times \frac{400}{\sqrt{3}} = 326.59 \text{ kV}$$

$$R/\text{phase} = 10\ \Omega,\ C/\text{phase} = 0.05\ \mu\text{F}$$

i. Maximum restriking voltage across the contact of circuit breaker :

$$= 2\,E_{peak} = 2 \times 326.59 \text{ kV} = 653.18 \text{ kV}$$

ii. $$L = \frac{R}{2\pi \times 50} = \frac{10}{2\pi \times 50} = 0.032 \text{ H}$$

$\therefore$ Frequency of oscillation,

$$f_n = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.032 \times 0.05 \times 10^{-6}}} = 3.98 \text{ kHz}$$

iii. Maximum value of RRRV $= \omega_m E_{peak} = 2\pi \times 50 \times 326.59 = 102.6$ kV

iv. Average value of RRRV up to first peak =

$$= \frac{\text{Maximum restriking voltage}}{\text{Time upto first peak}} = \frac{653.18\ \text{kV}}{t}$$

$$= 653.18 \times 2f_n$$

$$= 653.18 \times 2 \times 3.98 \times 10^3\ \text{kV/sec}$$

$$= 5.19 \times 10^6\ \text{kV/sec}$$

Que 4.9. **For a 132 kV system, the reactance and capacitance up to the location of the circuit breaker is 3 Ω and 0.015 μF, respectively. Calculate :**

i. **Frequency of transient oscillations.**

ii. **Maximum value of restriking voltage across the contacts of circuit breaker.**

iii. **Maximum value of RRRV.** **AKTU 2019-20, Marks 07**

Answer

The procedure is same as Refer Q. 4.8, Page 4–12B, Unit-4.

[Ans.

i. The frequency of transient oscillations is given by,

$$f_n = 13.298\ \text{kHz}$$

ii. Maximum value of restriking voltage across the contacts of circuit breaker is given by,

$$e_m = 215.55\ \text{kV}$$

iii. Maximum value of RRRV = 9.0045 kV/μsec]

Que 4.10. **Calculate the RRRV of 132 kV circuit breaker with neutral earthed. Given data as follows : Broken current is symmetrical; restriking voltage has frequency 20 kHz, pf = 0.15. Assume fault is also earthed.** **AKTU 2016-17, Marks 10**

Answer

Given : System voltage = 132 kV, $\cos\phi = 0.15$, $f_n = 20$ kHz
To Find : RRRV.

1. $K_1 = \sin\phi = \sin(\cos^{-1} 0.15) = 0.9886$

$K_2 = 1$ and $K_3 = 1$ both grounded

$$E_m = \frac{\sqrt{2} \times 132}{\sqrt{3}} = 107.77\ \text{kV}$$

2. $$V_{ar} = K_1 K_2 K_3 E_m = 106.54\ \text{kV}$$

3. $\therefore$ Maximum voltage, $e_m = 2\ V_{ar} = 213.09$ kV

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

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

$\therefore$ $$\pi\sqrt{LC} = t_m = \frac{1}{2f_n}\ \text{sec}$$

5. Maximum time, $$t_m = \frac{1}{2 \times 20 \times 10^3}\ \text{sec}$$

$\therefore$ $$\text{RRRV} = \frac{e_m}{t_m} = \frac{213.09}{[1/(20 \times 10^3 \times 2)]} = 8.52\ \text{kV/μsec}$$

PART-4

Current Chopping.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.11. **Explain the phenomenon of current chopping in a circuit breaker.** **AKTU 2016-17, Marks 10**

OR

Explain the phenomenon of current chopping in a circuit breaker. What measures are taken to reduce it ? **AKTU 2020-21, Marks 07**

Answer

A. **Current chopping :**

1. There are certain circumstances like disconnecting transformers on no load in which it is necessary to interrupt small inductive currents. The no load current of a transformer is almost at zero power factor lagging.

2. This current is normally smaller than the normal current rating of the breaker. Interrupting such current causes severe duty on the circuit breaker. This phenomenon is called current chopping.

3. Consider the circuit shown in the Fig. 4.11.1. Let the arc current be i when it is chopped down to zero value.

4. The stored energy in the inductor which $(1/2)\,Li^2$ will be discharged into the capacitance so that the capacitor is charged to a prospective voltage V such that,

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

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

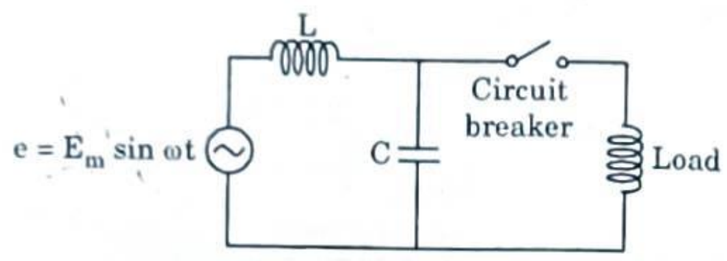


Fig. 4.11.1.

5. This prospective voltage is extremely high as compared to the normal system voltage. The frequency of natural oscillations is given by,

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

6. After first chopping the deionizing force which is still in action acts and second chop of current takes place.

7. But the arc current is now smaller than the previous one and arc current collapses and restriking voltage is again build.

8. Thus a sequence of chops will occur and arc will continuously decrease until a final chop brings arc current to zero. There will not be any further restriking as the gap is almost deionized. This is shown in Fig. 4.11.2.

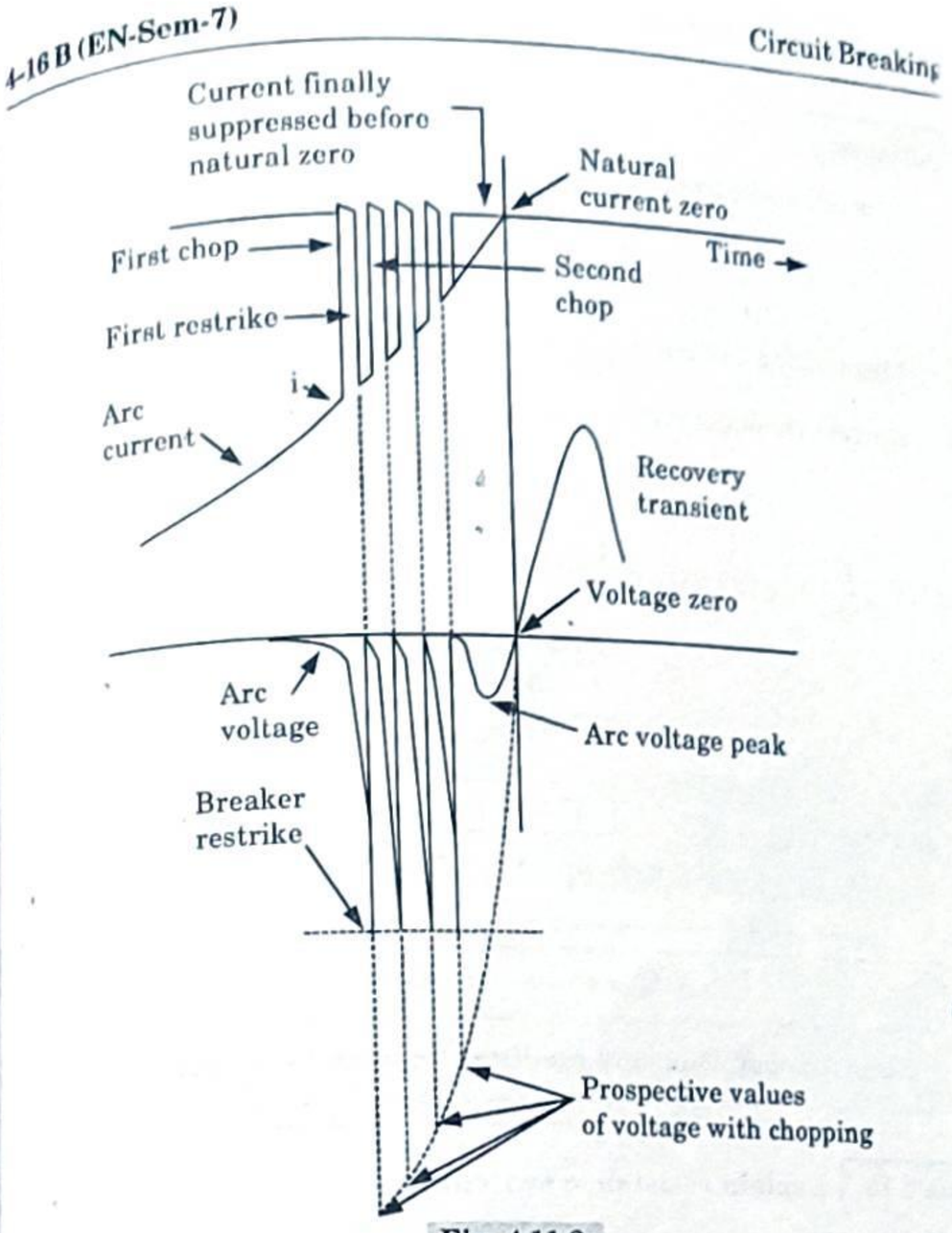


Fig. 4.11.2.

B. **Reduction of current chopping :** It is reduced by connecting non-linear resistors across the circuit breaker contacts during arc interruption.

Que 4.12. **A circuit breaker interrupts the magnetizing current of a 100 MVA transformer at 220 kV. The magnetizing current of the transformer is 5 % of the full load current. Find out the maximum voltage which may appear across the gap of the breaker when magnetizing current is interrupted at 53 % of its peak value. The stray capacitance is 2500 μF. The inductance is 30 H.**

AKTU 2020-21, Marks 07

Answer

1. The full load current of the transformer

$$= \frac{100 \times 10^6}{\sqrt{3} \times 220 \times 10^3} = 262.44 \text{ A}$$

2. Magnetizing current $= \frac{5}{100} \times 262.44 = 34.44$ A

3. Current chopping occurs at $0.53 \times 34.44\sqrt{2} = 25.83$ A

$$\frac{1}{2}Li^2 = \frac{1}{2}Cv^2$$

$$\therefore \quad \frac{1}{2} \times 30 \times (25.83)^2 = \frac{1}{2} \times 2500 \times 10^{-6} \times v^2$$

$$= \frac{2 \times 30 \times (25.83)^2}{2 \times 2500 \times 10^{-6}}$$

$$\therefore \quad v = 2829 \text{ V}$$

PART-5

Resistance Switching.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.13. Explain resistance switching.

Answer

1. The interruption of low inductive currents, interruption of capacitive currents gives rise to severe voltage oscillations.
2. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts. This process is known as resistance switching.
3. When the resistance is connected across the arc, a part of the arc current flows through the resistance. This will lead to decrease in arc current and increase in rate of deionization of the arc path and resistance of arc.
4. This will increase current through shunt resistance. This process continues until the current through the arc is diverted through the resistance either completely or in major part.

5. If the small value of the current remains in the arc then the path becomes so unstable that it is easily extinguished.
6. The resistance may be automatically switched in and arc current can be transferred.
7. The time required for this action is very small. As shown in the Fig. 4.13.1, the arc first appears across points A and B which is then transferred across A and C.

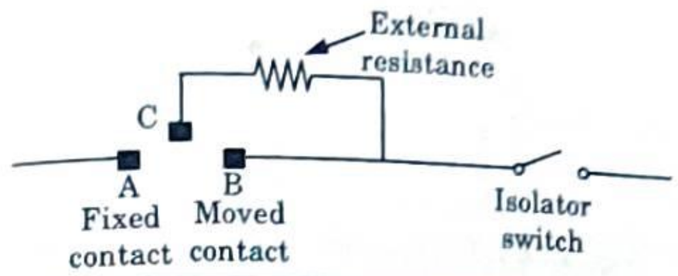


Fig. 4.13.1. Typical resistor connection.

8. The shunt resistance also ensures the effective damping of the high frequency restriking voltage transients. This is shown in the Fig. 4.13.2.

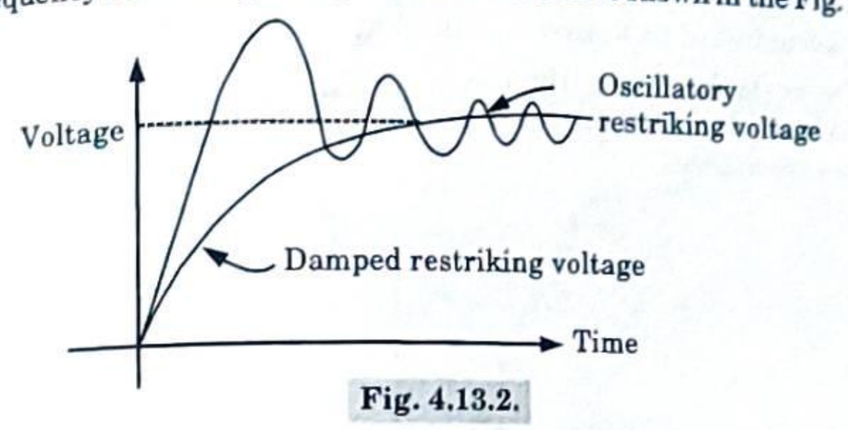


Fig. 4.13.2.

PART-6

Capacitive Current Interruption.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.14. Discuss about the interruption of capacitive current.

Answer

1. In power systems capacitor banks are used in the network which supplies reactive power at leading power factor.

2. There are various conditions such as opening a long transmission line on no load or disconnecting a capacitor bank etc., in which it is required to interrupt the capacitive current which is a difficult task for the circuit breakers.
3. Let us consider a simple circuit shown in the Fig. 4.14.1.

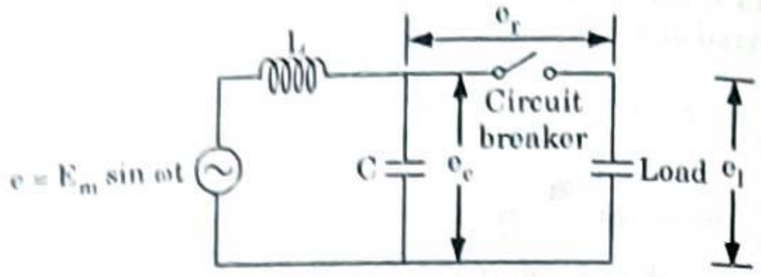


Fig. 4.14.1. Interruption of capacitive currents.

4. The value of lead capacitance C_L is greater than C. The voltage across a capacitor cannot change instantaneously.
5. The currents supplied to the capacitor are generally small and interruption of such currents take place at first current zero.
6. Also at the beginning, the rate of rise of recovery voltage is low and increases slowly. Whenever such circuit is opened a charge is trapped in the capacitance C_L.

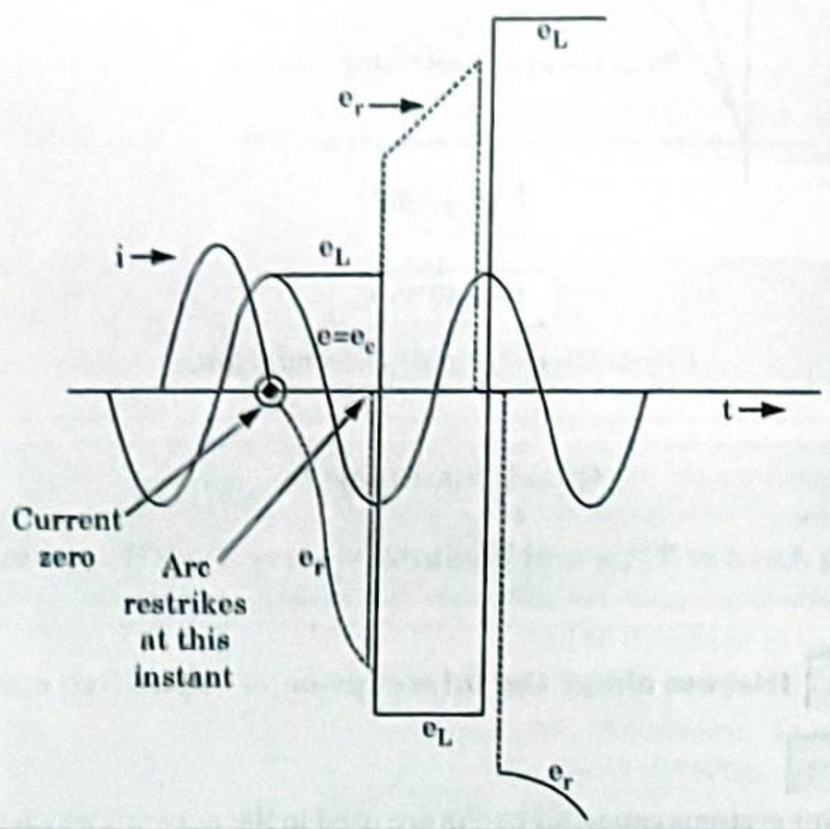


Fig. 4.14.2. Waveform showing interruption of capacitive current.

7. The voltage e_L across the load capacitance will hold the same value when circuit was opened. This voltage is nothing but peak of supply voltage as power factor angle is nearly 90° leading.
8. After opening the circuit, voltage V_C across the capacitance C oscillates and approaches a new steady value. But due to small value of capacitance C, the value attained is close to the supply voltage.
9. The recovery voltage e_r is nothing but difference between e_C and e_L. Its initial value is zero as the circuit breaker will be closed and increases slowly in the beginning.
10. When V_C reverses after half cycle, the recovery voltage is about twice the normal peak value.
11. Therefore it is possible that at this instant arc may restrike as the electrical strength between the circuit breaker contacts is not sufficient. The circuit will be reclosed and e_L oscillates at a high frequency.
12. The supply voltage at this instant will be at its negative peak; therefore a high frequency oscillation takes place.

PART-7

Short Line Interruption.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.15. What is short line interruption ?

Answer

1. The fault occurring between a distance of a few kilometres to a few tens kilometres from the circuit breaker are called short line faults or short line interruption.
2. Such faults are characterised by high frequency of restriking voltage of the order of 10 to 100 kHz depending upon length of line and location of the fault.
3. Fig. 4.15.1 represents a condition of a short line fault and simplified TRV form.
4. Fig. 4.15.1 supply voltage cause short circuit current I to flow through the circuit comprising the following impedances :

ωL = Impedance of source = $2\pi fL$
λ_1 = Impedance of 1 km length of line
L = Length of line between breaker and the fault in km

λ = Impedance per km length of line

5. The voltage appearing across breaker pole after final current interruption has two components v_1 and v_2

i. v_1 is the voltage at the terminal from supply side.

ii. v_2 is the voltage at the terminals from line side.

6. The voltage v_1 has power frequency component and high frequency component and reaches a peak value $\sqrt{2}\,V_s$ as illustrated in the Fig. 4.15.1, whereas v_2 has sawtooth waveform and drops to zero after a few microseconds.

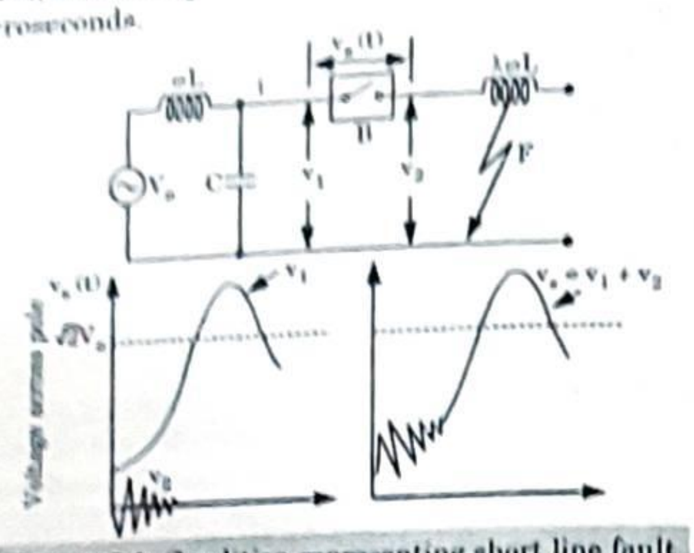


Fig. 4.15.1. Condition representing short line fault (kilometric fault) and (t in microsec).

PART-8

Circuit Breaker Ratings.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.16. **Explain duties of circuit breaker under short circuit condition and give the important ratings of a typical high voltage AC circuit breaker.**

OR

Describe the breaking and making capacity rating of the circuit breaker. **AKTU 2020-21, Marks 07**

Answer

A. Major duties of a circuit breaker under short circuit conditions are :

1. It opens the contacts to clear the faults.
2. To carry faults current for short duration while another circuit breaker is clearing the fault.
3. To close the contacts on a fault.

B. The ratings of the circuit breaker are as follows :

a. Rated current, frequency and voltage :

1. The rated current is the rms value of the current that circuit breaker can carry continuously without any temperature rise.
2. Rated frequency is the frequency at which the circuit has been designed to operate.
3. Rated voltage is the maximum voltage at which the operation of the circuit breaker is generated.

b. Breaking capacity : Breaking capacity of circuit breaker is of two types :

i. **Symmetrical breaking capacity :** Symmetrical breaking capacity is the rms value of the AC component of the fault current that the circuit breaker can break under specified conditions of recovery voltage.

ii. **Asymmetrical breaking capacity :** Asymmetrical breaking capacity is the rms value of the total current comprising of both AC and DC currents that the circuit breaker can break under specified conditions of recovery voltage.

2. The breaking capacity of circuit breaker is generally in MVA.
3. For a three phase circuit breaker :

$$\text{Breaking capacity} = \sqrt{3} \times \text{Rated voltage in kV} \times \text{Rated current in kA}$$

$$\text{Rated } I_{asym.} = 1.6 \times (\text{Rated } I_{sym.})$$

c. Making capacity : The rated making capacity is defined as the peak value of current at which the circuit breaker can be closed into a short circuit.

$$\text{Making current} = \sqrt{2} \times 1.8 \times \text{Symmetrical breaking current.}$$

$$\text{Making capacity} = 2.55 \times \text{Symmetrical breaking capacity.}$$

d. Short time current rating :

1. The short time current rating is based on thermal and mechanical limitations. The circuit breaker must be capable of carrying short circuit current for a short period while another circuit breaker is clearing the fault.
2. The rated short time current is the rms value of the total current that the circuit breaker can carry safely for specified short period.

PART-9

Testing of Circuit Breaker : Classification.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.17. Give classification of various tests of circuit breaker.

Answer

Classification of the test :

A. The tests on high-voltage AC circuit breakers can be classified as follows :

i. Development tests :

1. These are carried out on components, sub-assemblies and complete circuit breaker during and after the development of the circuit breaker.
2. The designers and research scientist verify the effect of various parameters on the behaviour of circuit breakers, by conducting development tests. Development tests are not specified in the standards.

ii. Type tests :

1. These are conducted on first few prototype circuit breakers of each type to prove the capabilities and to confirm the rated characteristics of the circuit breaker of that design.
2. Type tests are not conducted on every circuit breaker. The tests are conducted in specially built testing laboratories. Type tests are performed as per recommendations of standards (IEC) or (IS).

3. Type test can be broadly classified in the following groups :

a. Mechanical tests
b. Tests of temperature rise, millivolt drop test.
c. High voltage test (Dielectric tests).
d. Basic short circuit test duties.
e. Critical current tests.
f. Single phase short-circuit test.
g. Short time current test.

iii. Routine tests :

1. Routine tests are also performed as per the recommendations of the standards (IEC/IS). Routine tests are conducted on each circuit breaker.

2. These are performed in the manufacturer's premises. Routine tests confirm the proper functioning of the circuit breaker.
3. **The routine tests include the following tests :**

a. Mechanical operation tests.
b. Millivolt drop test, measurement of resistance.
c. Power frequency voltage tests at manufacturers premises.
d. Voltage tests on auxiliary circuits, control circuits.

iv. Reliability tests :

1. Reliability tests are conducted to verify the reliability of the circuit breakers under various stresses occurring in actual applications.
2. Reliability tests can be conducted in specially built laboratories and also at site.

v. Commissioning tests : These are conducted on the circuit breaker after installation at site to verify the operational readiness and proper functioning.

B. Test on low-voltage circuit-breakers :

i. Type tests :

a. Verification of temperature rise limits.
b. Dielectric tests.
c. Short-circuit making and breaking tests.
d. Mechanical endurance test.
e. Electrical endurance test.
f. Verification of overload performance.

ii. Routine tests :

a. Mechanical operation tests.
b. Calibration of releases.
c. Dielectric tests.

PART-10

Testing Station and Equipment, Testing Procedure.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.18. Describe the equipments used in testing station of circuit breaker and draw the layout of testing station.

Answer

1. Three phase induction motor is used to drive the generator and impulse excitation is also provided. Variable resistors and reactors are provided to adjust magnitude of short circuit current.
2. Master circuit breaker is provided which operates when circuit under test fails to operate. Making switch can close at desired moment and carries the making current.
3. Transformer gives the test voltages, these units can be connected in various ways to get different test voltages. Some equipment is provided for measurement record and control.

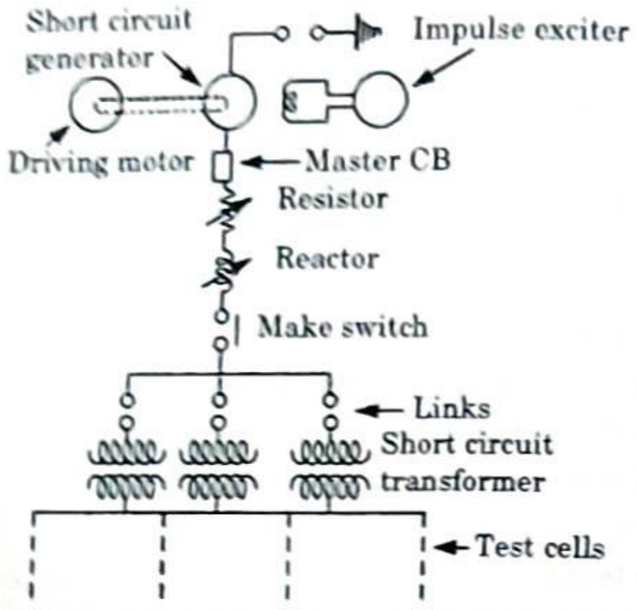


Fig. 4.18.1. Basic circuit of short circuit test plant.

4. **Equipments :**

i. **Short circuit generator :**

a. Power to the circuit breaker under test is provided by the short circuit generator. This generator should be capable of withstanding the reactive power surges for short duration.

b. Generator is driven by 3ϕ induction motor mounted on same shaft. Impulse excitation is provided by separate DC converter.

ii. **Short circuit transformer :** Transformers test the circuit breaker at the voltage other than generator voltage. 3ϕ transformer steps down the voltage whereas 1ϕ transformer steps up the voltage.

iii. **Reactors :** Reactors are connected to control the short circuit current. They can be single phase or 3-phase and they should be capable of withstanding stresses applied on them.

iv. **Master circuit breaker :**

a. It is air blast circuit breaker and its capacity is more than the circuit breaker on test, it will operate when the breaker under test fails.

b. It also isolates the specimen under test from supply after every test. It should have the capability to carry full short circuit current.

v. **Make switch :** This is a switch which is used to provide short circuit voltage surge at desired moment.

vi. **Capacitors :** It is a capacitor bank which provides leading currents to varying performance.

vii. **Resistors :** The resistors are connected in series with reactors. Using them power factor is varied.

viii. **Sequence switch :**

a. During testing many operations are performed in sequence and in less time under such condition switch is used.

b. It is a drum switch with several contacts. Due to the rotation of drum, control circuits are opened or closed in specified sequence.

ix. **Different measurements :** Test events take very short time so all the measurements must be recorded by oscillographs.

Que 4.19. Discuss how making capacity and breaking capacity of a circuit breaker are tested in a laboratory type testing station.

AKTU 2019-20, Marks 07

Answer

A. Test for making capacity :

1. The master circuit breaker and the making switch are closed first, then the short-circuit is initiated by closing the circuit breaker under test.
2. The rated making current, *i.e.*, the peak value of the first major loop of the short-circuit current wave is measured.

B. Test for breaking capacity :

1. First of all, the master circuit breaker and the circuit breaker under test are closed.
2. Then the short-circuit current is passed by closing the making switch. The short-circuit current is interrupted by opening the breaker under test at the desired moment.
3. The following measurements are taken :

i. Symmetrical breaking current

ii. Asymmetrical breaking current

iii. Recovery voltage

iv. Frequency of oscillation and RRRV.

4. The circuit breaker must be capable of breaking all currents up to its rated capacity.
5. As it is not possible to test at all values of current, tests are performed at 10 %, 30 %, 60 % and 100 % of its rated breaking current.

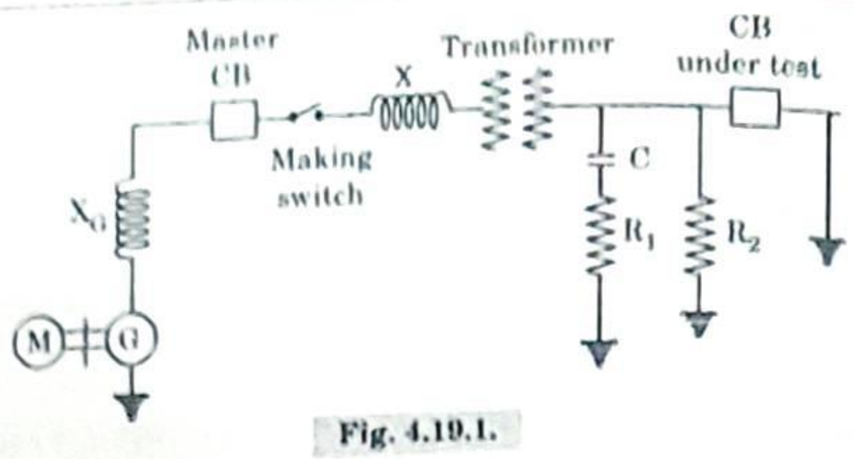


Fig. 4.19.1.

PART-11

Direct and Indirect Testing.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.20. Write a short note on direct testing of circuit breaker.

Answer

A. Direct testing of circuit breaker :

1. In direct testing, a circuit breaker is subjected to full power or stress. The circuit of direct testing of single phase circuit breaker is shown in the Fig. 4.20.1.

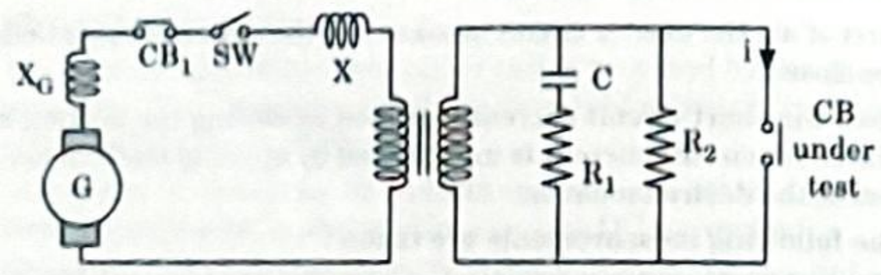


Fig. 4.20.1.

2. G is a generator generating voltage V_G with reactance X_G. CB_1 is back up or master circuit breaker.
3. X is the current controlling reactance. SW is the making switch while T is the transformer. C, R_1 and R_2 are capacitance and resistances for adjusting the transient recovery voltage.

4. The transformer is used to obtain proper test voltage. During actual testing, many of the operations are performed in sequence and total time for these operations is too small to have manual operation.
5. The sequential switching circuitry is useful here. A sequence switch is a drum type switch with several pairs of contacts and is rotated by a motor.
6. When the drum is rotated, there is opening and closing of various control circuits as per the sequence.
7. The sequential operations include switching ON impulse excitation, closing of master circuit breaker, oscillograph circuit connected, closing of make switch, opening of circuit breaker under test, opening of master circuit breaker, switching OFF the exciter etc.
8. The operations involved in the above test are performed by means of a sequence switch.

B. Advantages :

1. The circuit breaker is tested same as of actual conditions.
2. Special occasions like breaking of charging currents of long lines, very short line faults, interruption of small inductive currents, etc. can be tested by direct testing only.

C. Disadvantages :

1. The circuit breaker can be tested at only a given rated voltage and network capacity.
2. The necessity to interrupt the normal services and to test only at light load conditions.

Que 4.21. What are the different methods of testing of circuit breakers ? Discuss their merits and demerits.

AKTU 2017-18, Marks 10

OR

What are the different methods of testing circuit breakers ? Discuss their merits and demerits. Which method is more suitable for testing the circuit breakers of large capacity ? **AKTU 2019-20, Marks 07**

OR

Discuss in detail the testing of the circuit breaker.

AKTU 2020-21, Marks 07

Answer

A. **Methods of testing :**

a. **Direct testing :** Refer Q. 4.20, Page 4–27B, Unit-4.

b. **Indirect testing :**

High capacity circuit breakers cannot be tested directly. So indirect testing has to be done.

Types of indirect testing are :

i. **Unit testing :**

1. The modern EHV circuit breakers contain two or more similar interrupters per pole. These interrupters operate simultaneously and share the voltage across the pole equally.
2. The breaking capacity is also equally shared. The results obtained on one unit can be extended further for total capacity of breaker. This is known as unit testing or element testing.
3. During the application of unit test, the voltage must be reduced by a factor b so the corresponding impedances are also reduced by b to get test voltage across the unit by following expression :

$a = \frac{1}{m}$, where m = Number of units per pole and one unit is tested.

$a = \frac{n}{m}$, where n unit are tested.

4. $\therefore$ Voltage required for testing one unit = $a \times$ Voltage per pole

$= 127 \times \frac{1}{3} = 42.33$ kV

ii. **Synthetic testing :**

1. It consists of current source and voltage source with relatively low voltage and low current respectively. The principle of synthetic testing can be explained from the Fig. 4.21.1.
2. The current source provides short circuit current. The voltage source provides restriking voltage and recovery voltage.
3. The test conditions are given by L, R, C. The short circuit current I_G is supplied by closing switch S_1. At final current zero, switch S_2 is closed and voltage contains transient as it contains L and C.

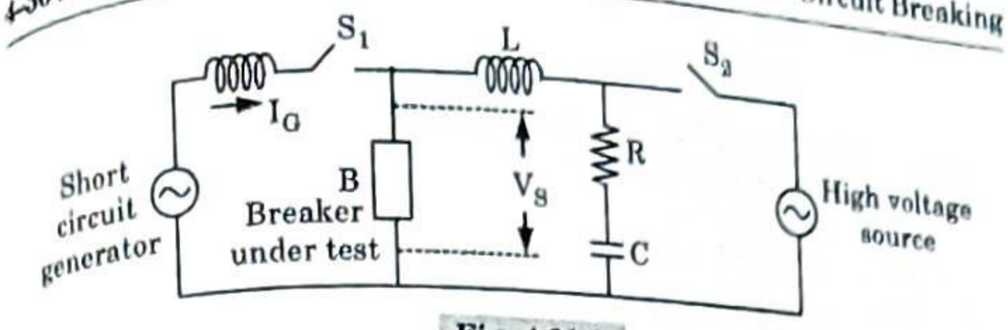


Fig. 4.21.1.

B. Indirect testing is used for testing the circuit breaker of large capacity.

C. **Advantages of indirect testing :**

1. The breaker can be tested for desired TRV and RRRV.
2. The short-circuit generator has to supply current at a relatively less voltage as compared to direct testing.
3. Both test current and test voltage can be independently varied. This gives flexibility to test

D. **Disadvantages of indirect testing :**

1. These tests are primarily a single loop test where it is still very difficult to do a fast reclosing with extended arcing times.
2. This method is not suitable for testing interrupters which have impedance connected in parallel with the interrupter contacts.

PART-12

Selection of Circuit Breakers.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.22. **How are the circuit breakers classified ? Give details of the same.**

OR

Discuss the selection of circuit breakers for different ranges of the system voltages. **AKTU 2019-20, Marks 07**

Answer

1. The selection of circuit breaker for different ranges of system voltages is given in the form of table as :

Table 4.22.1 : Types of circuit breakers.

Type	Arc Quenching Medium	Voltage range and Breaking capacity
Miniature circuit breaker	Air at atmospheric pressure	400-600 V; for small current rating
Air-break circuit breaker	Air at atmospheric pressure	400 V-11 kV; 5-750 MVA
Minimum oil breaker	Transformer oil circuit	3.3 kV-220 kV; 150-25000 MVA
Vacuum circuit breaker	Vacuum	3.3 kV-33 kV; 250-2000 MVA
SF_6 circuit breaker	SF_6 at 5 kg/cm^2 pressure	3.3-765 kV; 1000-50,000 MVA
Air blast circuit breaker	Compressed air at high pressure	66 kV-1100 kV; 2500-60,000 MVA

Table 4.22.2 : Selection of circuit breakers.

Rated Voltage	Choice of circuit breaker	Remark
Below 1 kV	Air-break CB	—
3.3 kV-33 kV	Vacuum CB, SF_6 CB, minimum oil CB	Vacuum preferred
132 kV-220 kV	SF_6 CB, air blast CB, minimum oil CB	SF_6 preferred
400 kV-760 kV	SF_6 CB, air blast CB	SF_6 preferred

2. Earlier oil circuit breakers were preferred in the voltage range of 3.3 kV-66 kV. Between 132 kV and 220 kV, either oil circuit breakers or air blast circuit breakers were recommended.
3. For voltages 400 kV and above, air blast circuit breakers were preferred. The present trend is to recommend vacuum or SF_6 circuit breakers in the voltage range 3.3 kV-33 kV.
4. For 132 kV and above, SF_6 circuit breakers are preferred. Up to 1 kV, air-break circuit breakers are used. Air blast circuit breakers are becoming obsolete and oil circuit breakers are being superseded by SF_6 and vacuum circuit breakers.

PART-13

Constructional Features and Operation of Bulk Oil Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.23. Discuss bulk oil circuit breaker.

Answer

1. In this circuit breaker, the contact separation takes place in steel tanks filled with oil. The gases formed due to the heat of the arc expand and set the turbulent flow in the oil.
2. To assist of arc extinction process, arc control devices are fitted to the contact assembly.
3. These are semi-enclosed chamber of dielectric materials. The performance of oil circuit breaker depends on the effectiveness of arc control devices.
4. Fig. 4.23.1 illustrates the tank type bulk oil circuit breaker, in open positions with the arc not yet extinguished.
5. The tension rod is raised by operating mechanism while closing the circuit-breaker.
6. The opening and closing is obtained by lowering and raising the tension rod.

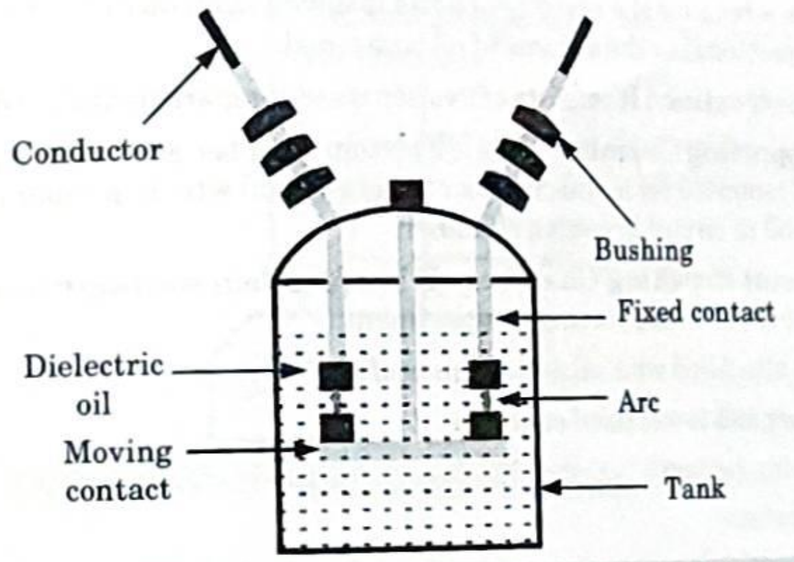


Fig. 4.23.1. Bulk oil circuit breaker with arc control device.

7. As the contacts separate, the arc is drawn. This arc is extinguished by the oil and by the gases formed by the decomposition of oil.
8. The arc control devices are normally connected to the fixed contact assembly, such that contact separation takes place inside this semi-enclosed device.
9. The gas produced in the device produces high pressures in it. Thereby the arc extinction is quick.
10. As the moving contacts leave the arc control devices, the trapped gas gets released from the arc control device, while doing so the arc is extinguished by blast effect.

PART- 14

Minimum Oil Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.24. Describe the construction and operation of a minimum oil circuit breaker.

Answer

A. Minimum oil circuit breaker :

1. The design requirement of a minimum oil circuit breaker is to reduce the amount of oil required.
2. This is because the severity of a fire involved in oil switch is to an extent proportional to the volume of oil contained.

B. Construction : It consists of two separate compartments filled with oil.

1. **Supporting Chamber :** This is a bottom chamber and made of porcelain and mounted on metal chamber filled with oil which is separated from the oil in circuit breaking chamber.
2. **Circuit Breaking Chamber :** It is a porcelain enclosure mounted on the top of the supporting compartment.

It is also filled with oil and consists of :

i. Upper and lower fixed contacts.
ii. Moving contact.
iii. Turbulator.

3. **Top chamber :** It is a metal chamber mounted on the top of circuit breaking chamber. It provides expansion space for the oil present in circuit breaking chamber. It contains a separator which avoids loss of oil by centrifugal action caused by circuit breaker operation during fault conditions.

C. Operation :

1. The moving and fixed contacts are in engaged position during normal operations. When fault occurs, the moving contact is pulled down by the tripping springs.
2. Due to separation of contacts, an arc is struck between them. It vapourises oil which produces gases at high pressure.
3. This action prevents the oil to pass through central hole in the moving contact and results in forcing series of oil through the passages of the turbulator, which quenches the arc successively by the effect of separate streams of oil moving across each section.

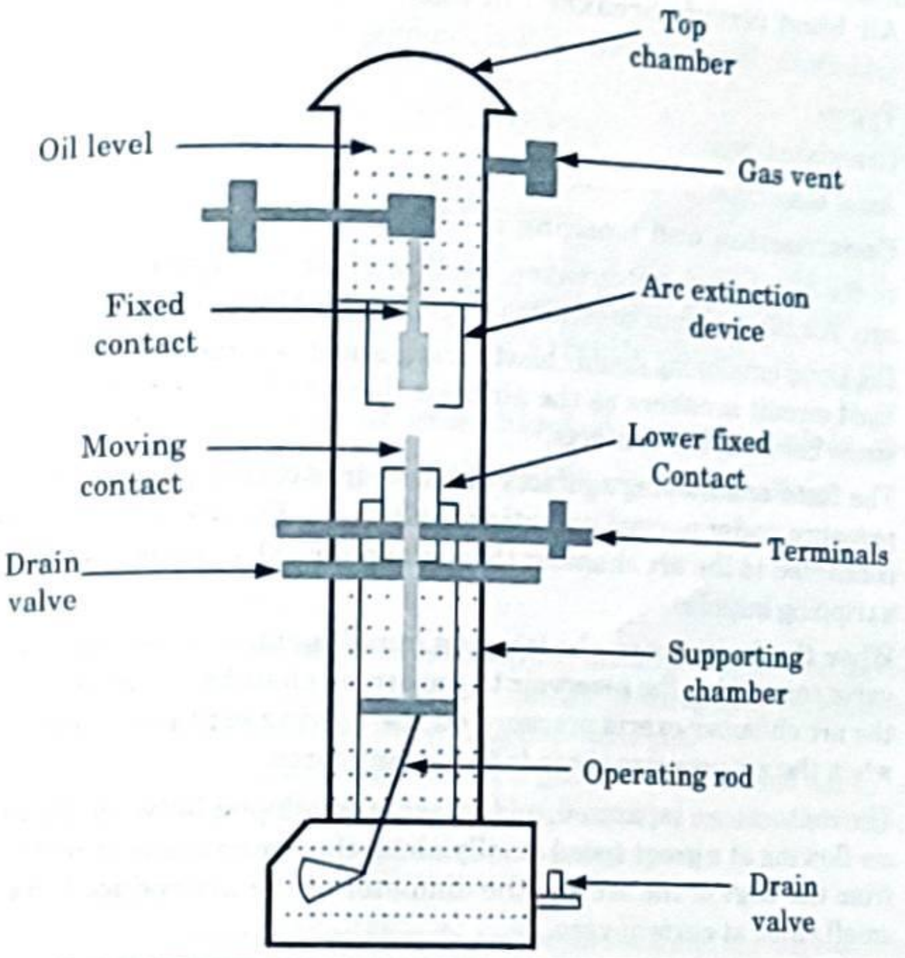


Fig. 4.24.1. Construction of minimum oil circuit breaker.

PART- 15

Air Blast Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.25. Explain construction and working of air blast circuit breaker.

AKTU 2016-17, Marks 15

Answer

A. Air blast circuit breaker : In this, compressed air is used for arc extinction. Hence it is also called compressed air circuit breaker.

B. Types :

1. Cross blast type
2. Axial blast type

C. Construction and working :

1. In the air blast circuit breaker, the flow of air is longitudinal along the arc. Air blast circuit breaker may be a single blast or double blast.
2. Breaking employing double blast arrangement is sometimes called radial blast circuit breakers as the air blast flows radially into the nozzle or space between the contacts.
3. The fixed and moving contacts are kept in a 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.
4. When the fault occurs, 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 air pressure exceeds the spring force.
5. The contacts are separated, and an arc is developed between them. The air flowing at a great speed axially along the arc cause removal of heat from the edge of the arc and the diameter of the arc reduced to a very small value at current zero.
6. Thus, the arc is interrupted, and the space between the contacts is flushed with fresh air flowing through the nozzle. The flow of fresh air removes the hot gasses between the contact space and rapidly build up the dielectric strength between them.

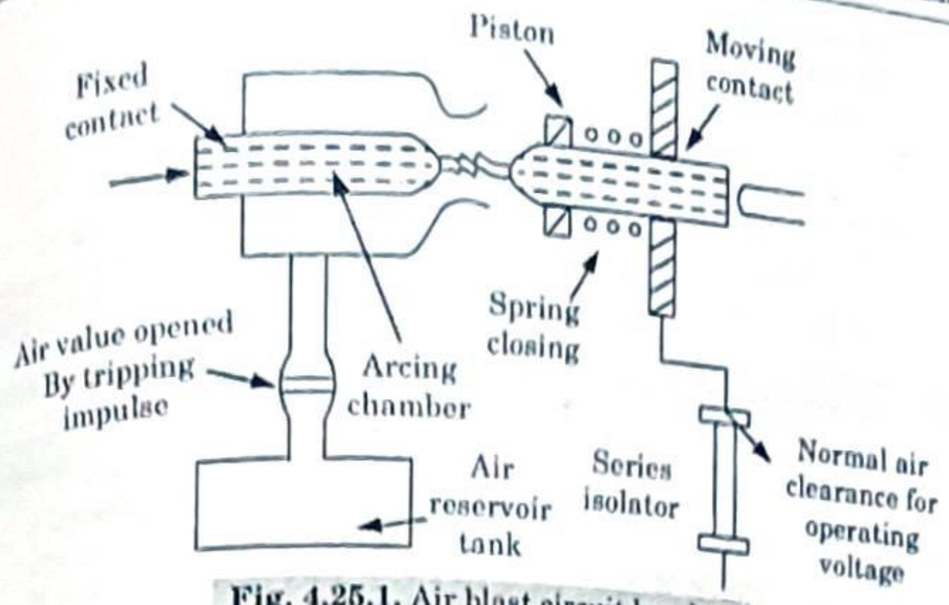


Fig. 4.25.1. Air blast circuit breaker.

PART- 16

SF_6 Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.26. With the help of neat block diagram, explain the construction and operating principle of SF_6 circuit breaker.

Answer

A. SF_6 circuit breaker :

1. In SF_6 circuit breaker, a gas called sulphur hexafluoride is used as the medium of insulation and arc interruption. SF_6 is chemically very stable, odourless, inert, non-inflammable and non-toxic gas.
2. The properties of SF_6 are such that the gas blast speed need not to be high. The gas is sealed inside the breaker body at a pressure of 3 atm. Puffer mechanism is used to obtain the needed speed.

B. Construction :

1. It consists of arc interruption chamber wherein fixed and moving contacts are enclosed. The chamber is filled with SF_6 gas and connected to a reservoir containing SF_6 gas.
2. When the contacts are opened, the value mechanism allows high pressure SF_6 gas from the reservoir to flow towards the arc interruption chamber.

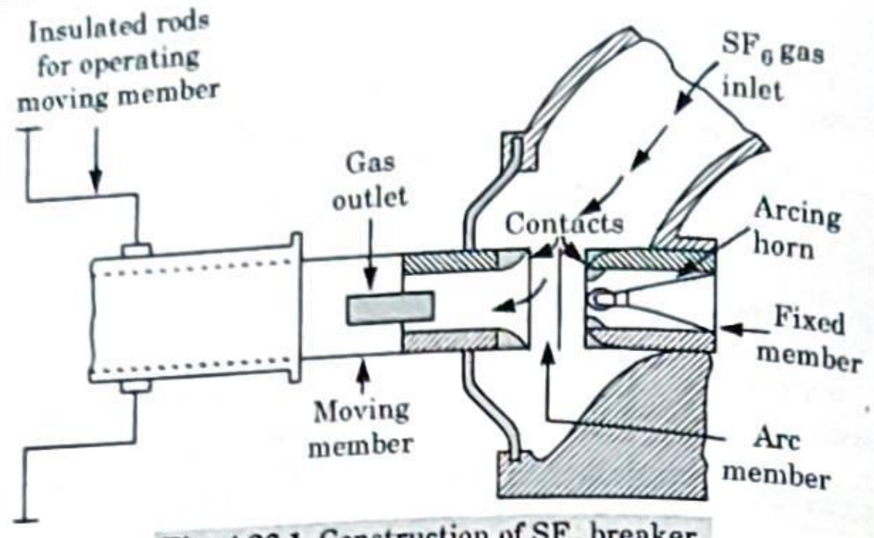


Fig. 4.26.1. Construction of SF_6 breaker.

3. The fixed contact is a hollow, cylindrical current carrying contact fitted with arc horn.
4. The moving contact is also hollow cylinder containing holes in the side to permit SF_6 gas to pass through these holes after flowing across the arc.
5. The tips of fixed and moving contacts are coated with copper tungsten arc resistant material. The gas is reconditioned and reused by suitable auxiliary system after each operation of the breaker.

C. Working :

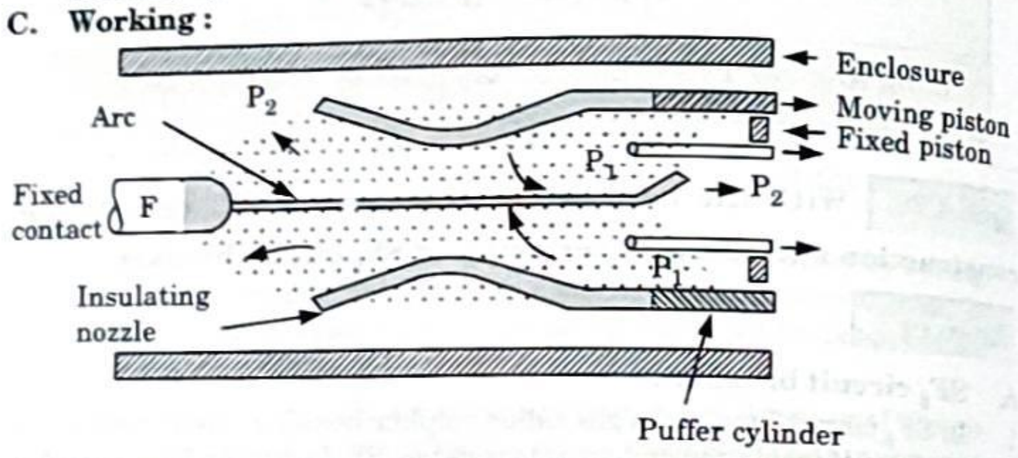


Fig. 4.26.2. Arc extinction in single pressure puffer type circuit breaker.

1. Puffer mechanism is nothing but a piston cylinder arrangement. The gas moves out through a convergent-divergent nozzle at high speed and quenches the arc.
2. During normal working condition, the contacts are closed. When the contacts are separated, then arc is struck between them.
3. The high pressure SF_6 gas enters the arc interruption chamber. It absorbs free electrons in the arc path to form immobile negative ions.
4. The gas also removes the heat from the arc. Due to this, arc diameter reduces and it becomes small during current zero with the turbulent flow around current zero, the arc is extinguished.

5. Consider the flow pattern shown in Fig. 4.26.1. When breaker is fully closed, the pressure in puffer cylinder P_1 is equal to that of outside the cylinder.
6. But during opening, puffer cylinder and moving contact start moving. Gas gets compressed within puffer cylinder ($P_1 > P_2$).
7. When contacts move further, arc is drawn. The compressed gas flows from higher pressure P_1 to lower pressure P_2 through the nozzle.

Que 4.27. Discuss the properties of SF_6 which makes it most suitable for circuit breakers. **AKTU 2019-20, Marks 07**

Answer

A. Physical properties of SF_6 gas : The physical properties of SF_6 gas are as follows :

1. It is a colourless, odourless, non-toxic and non-inflammable gas.
2. It is in gas state at normal temperature and pressure.
3. It is heavy gas having density 5 times that of air at 20°C and atmospheric pressure.
4. It has an excellent heat transfer property. The heat transfer capability of SF_6 is 2 to 2.5 times that of air at same pressure.
5. The heat content property is much higher than air. This property of SF_6 assists cooling of arc space after current zero.

B. Chemical properties of SF_6 gas :

1. It is chemically stable at atmospheric pressure and at temperatures up to 500 °C.
2. It is a chemically inert gas.

PART-17

Vacuum Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.28. Explain the construction and working of a vacuum circuit breaker.

Answer

A. Construction :

1. Fig. 4.28.1 shows the diagram of vacuum circuit breaker. Its enclosure is made up of glass.

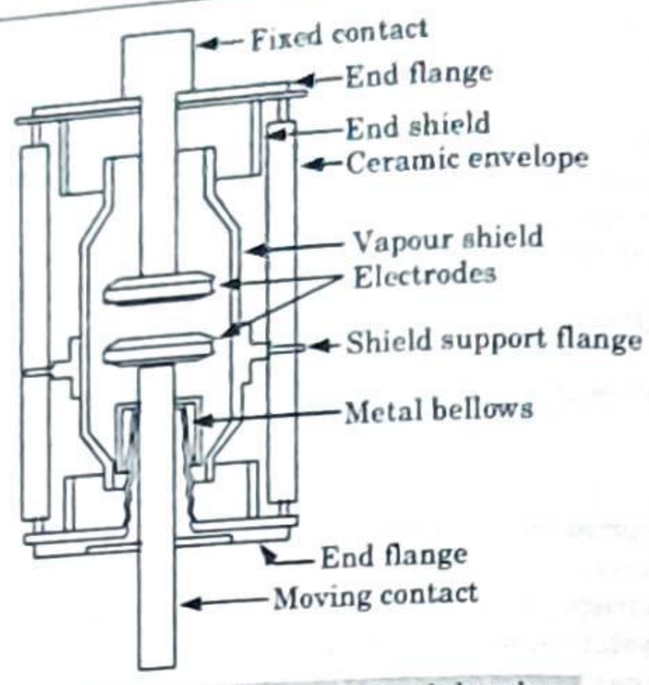


Fig. 4.28.1. Vacuum circuit breaker.

2. Vapour shield is made up of resin. This shield prevents the metal vapour from reaching the insulating envelope.
3. One of its ends is welded to the moving contact. And other end is welded to lower end flange.
4. Its contacts have large disc space faces and these faces contain spiral segments because of which the arc current produces axial magnetic field.
5. This helps the arc to move over the contact surface. Two metal flanges are provided which support the fixed contact and outer insulating enclosure.

B. Working :

1. Separation of current carrying contacts causes the vapour to be released from the contacts giving rise to plasma.
2. Thus on separation of current carrying contacts, the contact space is filled with vapour of positive ions liberated from the contact material; the vapour density depending on the current in the arcing.
3. During the decreasing mode of current wave the rate of release of the vapour falls and after the current zero, the medium regains its dielectric strength provided vapour density around the contacts has substantially reduced.
4. The arc usually has several parallel paths and each arc path originates and sinks in a hot spot of current.
5. Thus the total current is divided in several parallel arcs.
6. The interruption of arc is possible when vapour density varies in phase with the current and the arc remains in the diffused state.

7. The arc does not restrike again if the metal vapour is quickly removed from the contact zone.

Que 4.29. **Discuss the operating principle of vacuum circuit breaker. What are its advantages over other circuit breakers ?**

AKTU 2017-18, Marks 10

OR

Describe the construction, operating principle and application of vacuum circuit breaker. What are its advantages over other circuit breakers ?

AKTU 2019-20, Marks 07

Answer

A. Vacuum circuit breaker : Refer Q. 4.28, Page 4–38B, Unit-4.

B. Applications :

1. The vacuum circuit breakers are effectively used for capacitor bank switching.
2. Vacuum circuit breakers can also be used for on-load tap changing applications.

C. Advantages :

1. Vacuum circuit breaker is a self contained and does not require filling of oil or gas.
2. Rapid recovery of very high dielectric strength on current interruption so that only half cycle or less arcing occurs after proper contact separation.
3. No emission of gases-pollution free.

D. Disadvantages of vacuum circuit breaker :

1. Requirement of high technology for production of vacuum interrupters.
3. Loss of vacuum, due to transit damage or failure, makes the entire interrupter useless and it cannot be repaired at site.
3. It needs additional surge suppressors in parallel with each phase for interruption of low magnetizing currents in a certain range.

PART-18

DC Circuit Breaker.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 4.30. **Discuss in detail about a DC circuit breaker with suitable diagram and waveforms.** **AKTU 2020-21, Marks 07**

Answer

1. The requirement of DC circuit breaking is to interrupt load currents in circuits at high potential with respect to ground because the short circuit current can be limited to normal load currents using the grid control.
2. If such switches are developed, lines are switched into or out of an unfaulted network without running the voltage down.
3. A schematic diagram of such a switch is shown in Fig. 4.30.1(*a*). *A* is normally open contact whereas *M* and *B* are normally closed contacts.

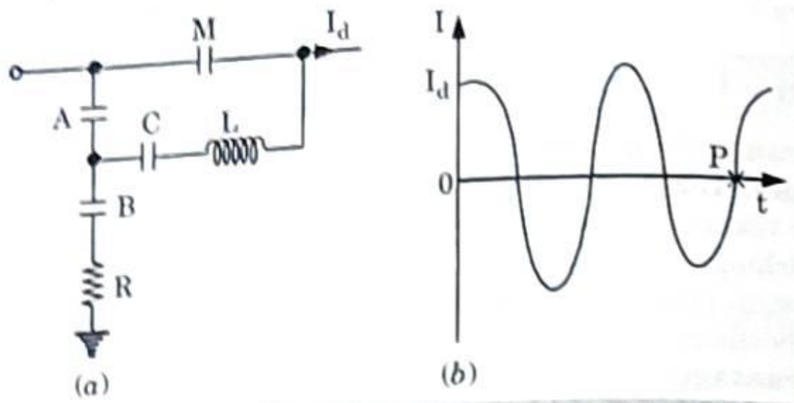


Fig. 4.30.1. (*a*) Schematic diagram of a DC switch (oscillatory discharge). (*b*) Current waveform through *M*.

4. As a result, the capacitor *C* is charged to line voltage through the high resistance *R*.
5. When it is desired to interrupt the current I_d, the operating mechanism opens contact *B* and closes *A*, thus initiating the oscillations in the circuit consisting of *M*, *A*, *C*, *L* and immediately afterwards the contact *M* opens which interrupt the current at a current zero such as *P* as shown in Fig. 4.30.1(*b*).
6. After this, contact *A* is opened and *B* is closed.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION

Q. 1. Describe phenomena of arc, properties of arc, initiation and maintenance of arc.

Ans. Refer Q. 4.2.

Q. 2. Describe in detail the fault clearing time of a circuit breaker.

Ans. Refer Q. 4.4.

Q. 3. Explain the terms : restriking voltage, recovery voltage and RRRV. Derive expression for restriking voltage and RRRV in terms of system voltage, inductance and capacitance.

Ans. Refer Q. 4.7.

Q. 4. Explain the phenomenon of current chopping in a circuit breaker.

Ans. Refer Q. 4.11.

Q. 5. Discuss about the interruption of capacitive current.

Ans. Refer Q. 4.14.

Q. 6. Explain duties of circuit breaker under short circuit condition and give the important ratings of a typical high voltage AC circuit breaker.

Ans. Refer Q. 4.16.

Q. 7. What are the different methods of testing of circuit breakers ? Discuss their merits and demerits.

Ans. Refer Q. 4.21.

Q. 8. How are the circuit breakers classified ? Give details of the same.

Ans. Refer Q. 4.22.

Q. 9. Describe the construction and operation of a minimum oil circuit breaker.

Ans. Refer Q. 4.24.

Q. 10. Explain construction and working of air blast circuit breaker.

Ans. Refer Q. 4.25.

Q.11. Discuss the operating principle of vacuum circuit breaker. What are its advantages over other circuit breakers ?

Ans. Refer Q. 4.29.

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UNIT 5

Modern Trends in Protection

CONTENTS

PART-1

Electronic Relays.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.1. Discuss electronic relay with the help of neat sketch.

Answer

1. The electronic relay is a type of an electronic switch that open or close the circuit contacts by using electronic component without any mechanical operation.
2. The two basic arrangements of electronic relays are :

a. Amplitude comparator electronic relay :

i. The amplitude comparator electronic relay is shown in Fig. 5.1.1.

ii. The relay has two input AC quantities which are compared and rectified by the help of rectifier bridge circuit. The AC quantity is applied to the control grid of the bridge circuit.

iii. The relay placed in series with the bridge circuit start operating when any one of the input quantities exceeds to the other.

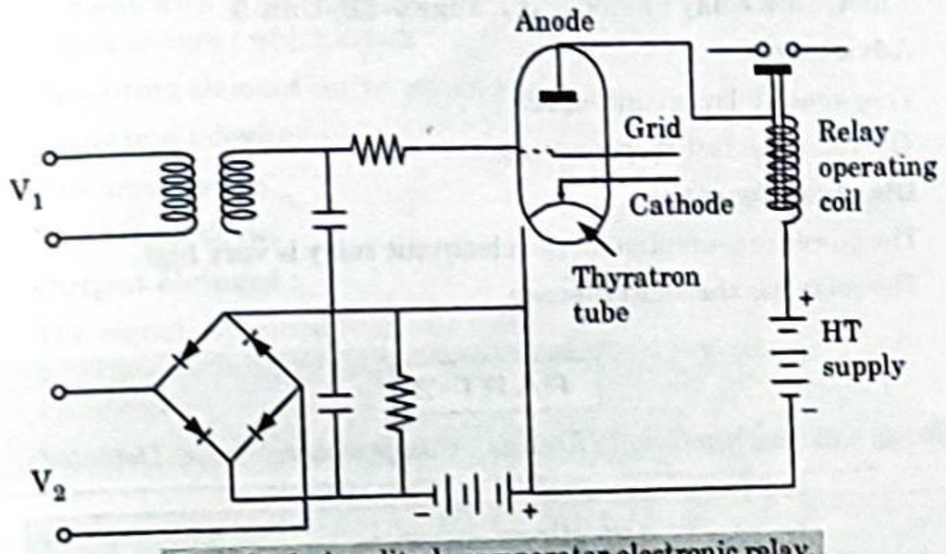


Fig. 5.1.1. Amplitude comparator electronic relay.

b. Phase comparator electronic relay :

i. In electronic phase comparator relay one of the AC quantities is given to the control grid of the electronic tube, and the other is directly connected to the screen of the tube.

ii. The relay starts operating when both the AC quantities are in phase with each other.

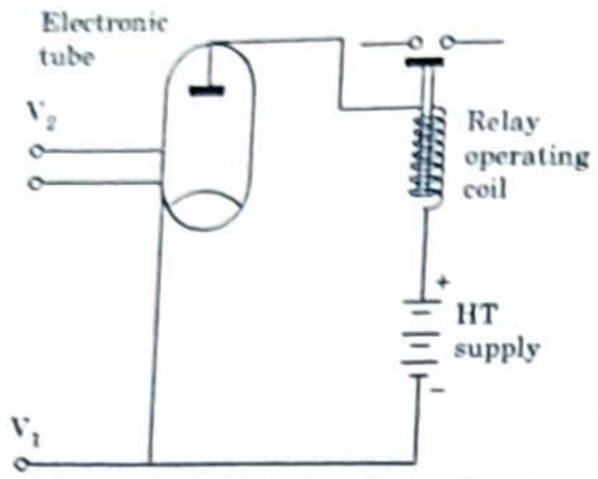


Fig. 5.1.2. Phase comparator electronic relay.

Que 5.2. **What is electronic relay ? Also write its advantages and disadvantages.**

Answer

A. Electronic relay : Refer Q. 5.1, Page 5–2B, Unit-5.

B. Advantages :

1. They require low maintenance.
2. The relay has fast response time.

C. Disadvantages :

1. The power consumption in the electronic relay is very high.
2. The relay has the short lifespan.

PART-2

Static Relays Functional Circuits : Comparators, Level Detectors.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.3. **What are the basic elements of a static relay ? Describe the function of each element.**

Answer

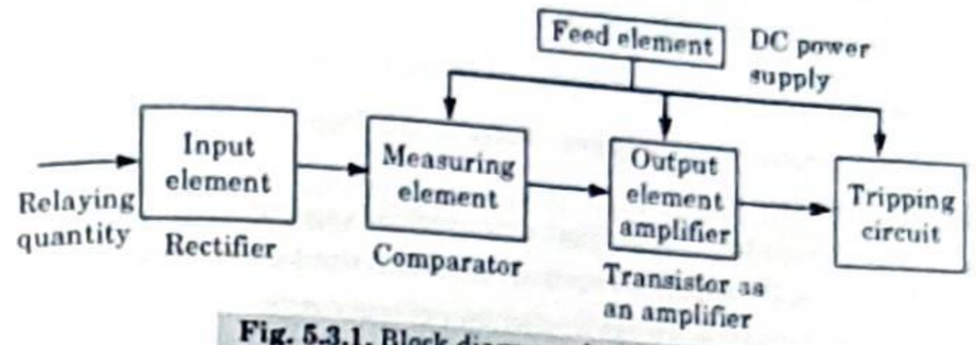


Fig. 5.3.1. Block diagram of a static relay.

The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc., are called static relays.

A. Input element :

1. The relaying quantity can be the output of CT or PT or it may be the output of a transducer or it may be combination of various signals.
2. 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.

B. Measuring element :

1. This is the head 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 drives the tripping circuit.
2. Measuring element can be classified as :

i. Single input device.

ii. Two input device.

iii. Multi-input device.

C. Output element :

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

D. Feed element :

1. The measuring element uses electronic circuits consisting transistors, diodes etc. The output element uses transistor as an amplifier.

2. All these components, circuits along with the tripping circuit require DC supply for the proper functioning. The feed element provides the DC voltage required by the various elements.

Que 5.4. What is comparator and explain its types ? Also write the limitations of static relay.

Answer

A. Comparator and its types : Refer Q. 2.9, Page 2–14B, Unit-2.

B. Limitations :

1. These relays have lower short time overload capacity.
2. Additional DC supply is required for various transistor circuits.
3. Susceptible to the voltage fluctuations of transients.
4. Less robust.

Que 5.5. Explain level detector in static relays.

Answer

1. Level detector circuits are used in static relays as a final stage before the trip coil circuit of the circuit breaker.
2. The level detector is derived from the fact that the circuit operates abruptly when the input level exceeds a predetermined value.
3. It is shown in Fig. 5.5.1, which shows the principle of a level detector. Here there is normally a positive bias on the base of the transistor to keep it non-conducting.
4. The transistor can be made to conduct or switch to operation, if the input voltage is made to exceed the input bias in the opposite direction *i.e.*, the base is made negative with respect to its emitter.

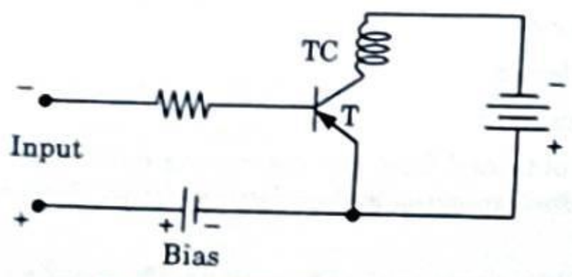


Fig. 5.5.1. Level detector.

PART-3

Logic and Training Circuits.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.6. Discuss logic circuits in static relays.

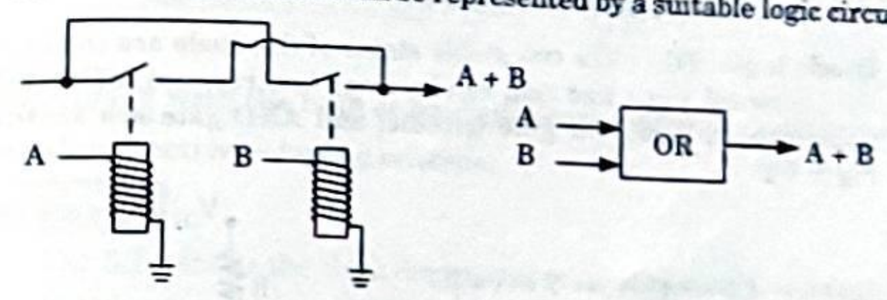
Answer

1. The concept of logic circuits in static relay can be understood by considering the logic operations performed by the devices. This makes complex static relay operation also simple.
2. Basically, all relays are bistable devices, *i.e.*, they have two stable states: either they operate or they do not operate.
3. Consequently Boolean algebra can be applied to study and analyze protection schemes consisting of a number of relays.
4. Logic circuits can be obtained using different types of devices :

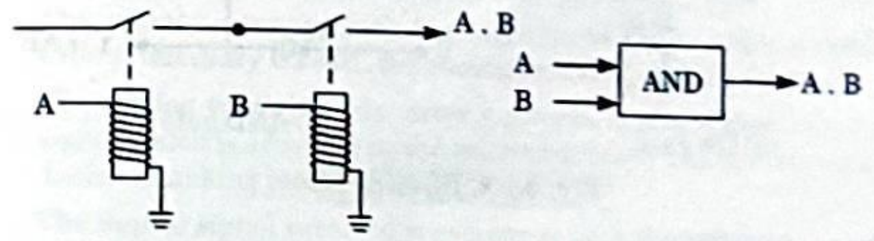
a. Relay logic :

i. To make a connection between relay circuits and their logic operations, the basic operations mechanized using relays are shown in Fig. 5.6.1.

ii. All contacts are shown in their normal position, *i.e.*, deenergized position. Thus each relay operation could be subdivided into basic switching functions which in turn can be represented by a suitable logic circuit.



(a)



(b)

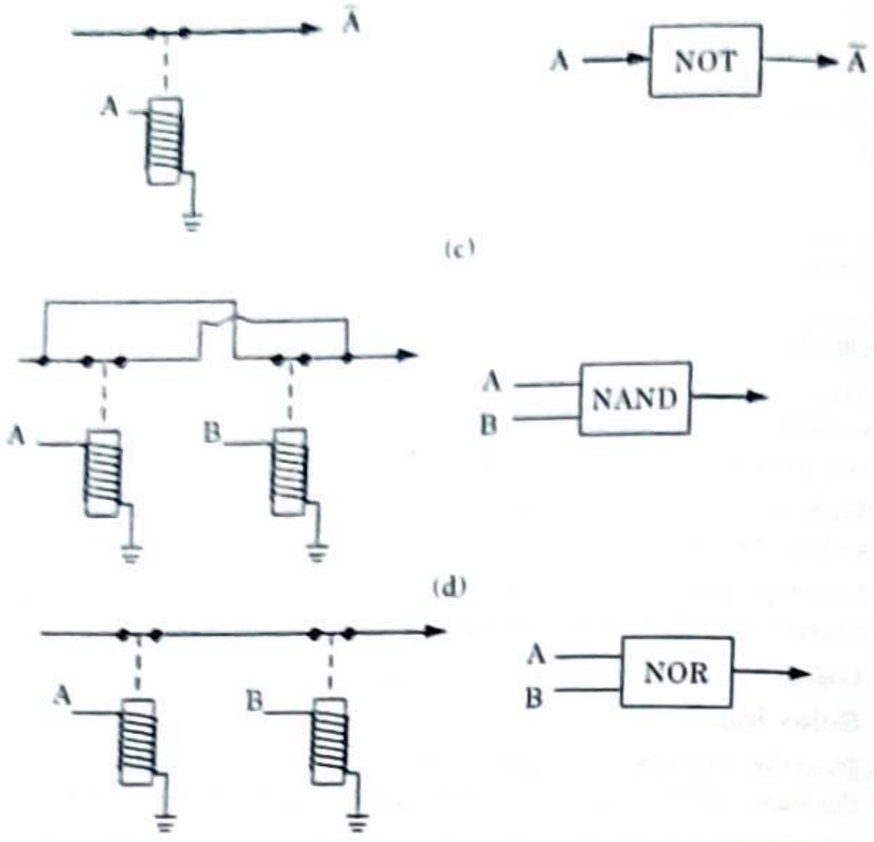


Fig. 5.6.1. Logic operations using relays.

b. **Diode logic (DL) :** The two stable states of the diode are conducting (*i.e.*, forward bias) and non-conducting (*i.e.*, reverse bias) states. Conventional diode OR gate (circuit) and AND gate are shown in Fig. 5.6.2.

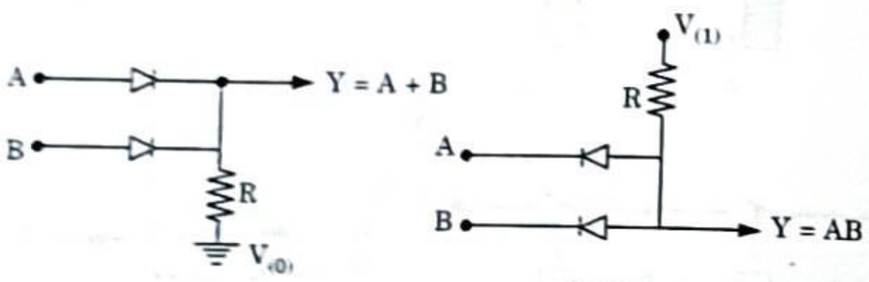


Fig. 5.6.2. DL circuits.

c. **Transistor logic :**

i. Logic circuits using transistors could be developed in two forms :
Resistor transistor logic (RTL)
Direct coupled transistor logic (DCTL).

ii. Basic NAND and NOR circuits based on DCTL are shown in Fig. 5.6.3.

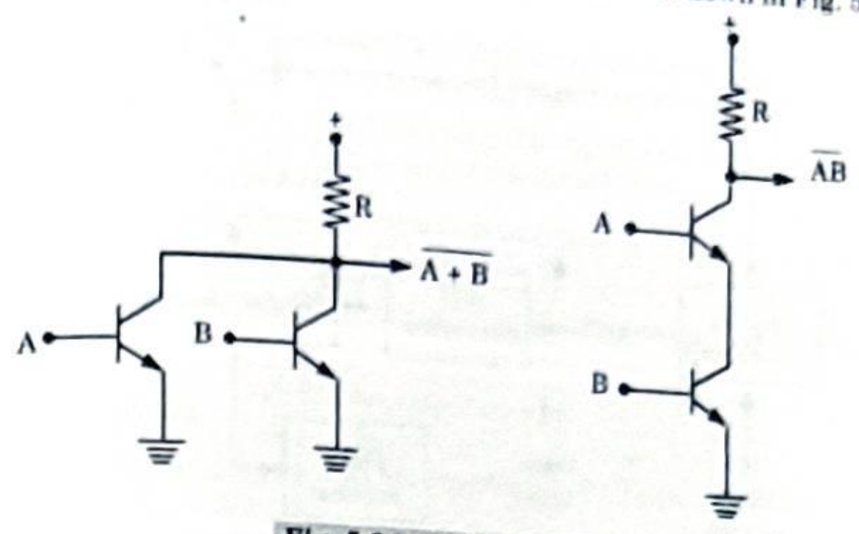


Fig. 5.6.3. DCTL circuits.

PART-4

Microprocessor and Computer Based Protection Schemes.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.7. With the help of block diagram, explain microprocessor based protective relaying scheme.

Answer

1. Fig. 5.7.1 shows the block diagram of microprocessor based relay.
2. In this relay, the output of line current transformer (CT) is given to the input receiver block where signal is processed.
3. The signal processing includes surge protector, rectifier, smoothening filters, auxiliary CT etc., depending upon the requirement.
4. The analog to digital converter converts analog signal into a digital signal which is accepted by the microprocessor. The microprocessor is a decision making block.
5. The digital signal received is compared with the reference to generate the proper tripping signal.

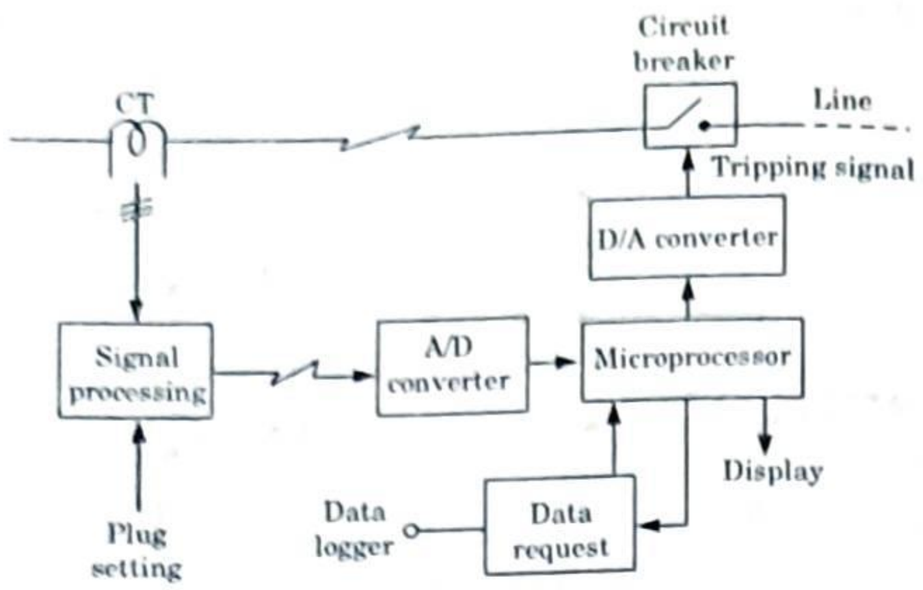


Fig. 5.7.1. Microprocessor based relay.

6. This is a digital signal which is converted to analog again to operate the tripping coil. This is achieved by the D/A converter.
7. The data logger captures the data and feeds it to the microprocessor when there is a request from the microprocessor. The information can be displayed with a proper display device by taking signal from the microprocessor.

Que 5.8. **Explain computer based protective relaying scheme.**

Answer

1. The computer based relays have been developed from a torque balancing device to a programmable information processor.
2. In this relay, after taking the fault signals through the CT and PT, the signals are passed through an analog type low pass filter.
3. During the conversion of the signal from the analog to digital form, the analog signal must be kept constant. For this purpose, the analog signal is put to the sample and hold circuit after filtering.
4. In next stage, the sample and hold value is passed on to the analog to digital converter.
5. The computer processor controls the action of the sample and hold circuit along with the analog to digital conversion with the help of end of conversion signal issued by the analog to digital converter.
6. The output signal of the analog to digital converter represents the digital form of the fault signal, which is suitable for computer processor.

7. The digital values of the signals are then stored in the RAM of the processor.
8. The relay software processes these digital signals representing the fault signals in accordance with the relaying algorithm.
9. The processor responsible for issuing the trip signal. This trip signal is kept compatible with the trip coil of the circuit breaker.

PART-5

Software Development for Protection, Security and Reliability.

Questions-Answers

Long Answer Type and Medium Answer Type Questions

Que 5.9. **Explain software for relay protection and security.**

Answer

1. The software for relay protection and security mainly includes test editing software, test execution software, Web server, and some relevant program importing software, etc.
2. The test editor is mainly used for editing test cases, which is divided into several modules by different relay protection functions.
3. Each functional module is used for testing an independent relay protection function, such as protection, monitoring, control, and has its own test parameter list, related configuration files, several input and output files, tolerance setting.
4. Every function module consists of dozens of or hundreds of test cases, defining all the related datum related to a test (e.g., settings, I/O mapping, configuration file, test procedure, expected result, criteria to evaluate the test result, curve for the test result, etc.).
5. The development of a test case is based on a specific test template (e.g. operate value, operate time, test sequence, etc.).
6. A test case could be modified or deleted and could be created based on an existing test case.
7. Database is source of test data and it stores test cases, files, test project data and test hardware information. And it also gives the link to run the test engine. It's like a bridge to connect the database to the testing hardware.
8. The test executive part includes : user interface, test sequencer, database processor, testing result evaluation program, and test project processor.

9. The test execution interface can display the test schedule and test results of the assessment.
10. Webpage server is an application which is used to browse the test project and report generated by the test system.
11. It allows users with permissions to modify the project or test state.

Que 5.10. What do you understand by relay security and reliability ?

Answer

A. **Relay security :** The relay must not operate incorrectly during normal system operation. This is known as security.

B. **Reliability :** Refer Q. 1.7, Page 1–8B, Unit-1.

VERY IMPORTANT QUESTIONS

Following questions are very important. These questions may be asked in your SESSIONALS as well as UNIVERSITY EXAMINATION.

Q. 1. What is electronic relay ? Also write its advantages and disadvantages.

Ans. Refer Q. 5.2.

Q. 2. What are the basic elements of a static relay ? Describe the function of each element.

Ans. Refer Q. 5.3.

Q. 3. Explain level detector in static relays.

Ans. Refer Q. 5.5.

Q. 4. With the help of block diagram, explain microprocessor based protective relaying scheme.

Ans. Refer Q. 5.7.

Q. 5. Explain software for relay protection and security.

Ans. Refer Q. 5.9.

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1 UNIT

Protection Scheme (2 Marks Questions)

1.1. Define switchgear. **AKTU 2016-17, Marks 02**

Ans. The apparatus used for controlling, regulating and switching ON or OFF the electrical circuit in the electrical power system is known as switchgear. The switches, fuses, circuit breaker, isolator, relays, current and potential transformer, indicating instrument, lightning arresters and control panels are examples of the switchgear devices.

1.2. Discuss what you understand by stability of a protective relay. **AKTU 2017-18, Marks 02**

Ans. Stability is the quality of protective relays due to which system remains inoperative and stable under certain specified conditions such as transient etc.

1.3. What do you understand by primary and backup protection ? **AKTU 2016-17, Marks 02**

OR

Explain the terms primary and backup protection. **AKTU 2019-20, Marks 02**

Ans.

1. **Primary protection :** It is used to protect any equipment by isolating it from the system or it is the protection provided by each zone to its elements. It is the first line of defense.
2. **Backup protection :** It is the one which came into play when primary protection fails. It operates after a time delay to give primary relay sufficient time to operate.

1.4. Explain what you understand by pickup value of actuating quantity. **AKTU 2017-18, Marks 02**

Ans. It is the value of actuating quantity at which the relay is on the verge of operation. These quantities can be current, voltage, frequency etc.

1.5. What are the desirable qualities of protective relaying ?

AKTU 2020-21, Marks 02

Ans.

1. Reliability
2. Speed and time
3. Sensitivity
4. Stability
5. Adequateness.

1.6. Explain the need of protective system.

Ans.

1. It is needed for the protection of short circuit condition arising in a power system.
2. To minimize damage to the system components involved in the failure.

1.7. Give the uses of summation transformer.

Ans.

1. Summation transformer is used for converting the three-phase quantities into a single phase quantity.
2. Summation transformer is used during unbalanced or faulty conditions in the system, in order to ensure the relay operates normally.

1.8. Write the different types of protection scheme.

Ans.

1. Overcurrent protection
2. Distance protection
3. Carrier-current protection
4. Differential protection

1.9. What is auto re-closing ?

Ans. About 90 % of faults in transmission lines are transient in nature, which disappears if the line circuit breakers are tripped for a moment to isolate the line. The line is re-energized again by re-closing the circuit breakers. Automatic reclosing of circuit breakers is known as auto re-closing.

1.10. Write the different types of potential transformer.

Ans.

1. Electromagnetic
2. Capacitor type
3. Opto electric type.

1.11. What is protection zone ? **AKTU 2020-21, Marks 02**

Ans.

1. A protective zone covers one or at the most two elements of a power system.
2. The protective zones are planned in such a way that the entire power system is collectively covered by them, and thus no part of the system is left unprotected.

1.12. Draw the circuit diagram of basic protection scheme.

AKTU 2019-20, Marks 02

Ans.

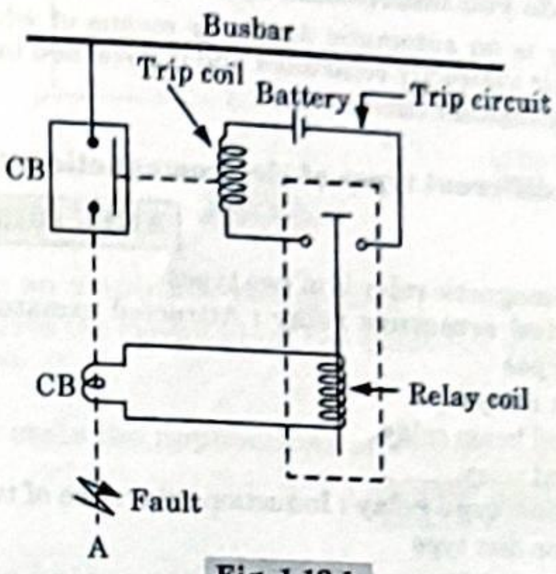

Fig. 1.12.1.

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2 UNIT

Relays (2 Marks Questions)

2.1. What do you understand by relay ?

Ans. A relay is an automatic device by means of which an electrical circuit is indirectly controlled and is governed by a change in the same or another circuit.

2.2. Name different types of electromagnetic attraction relays.

AKTU 2016-17, Marks 02

Ans. Electromagnetic relay is of two types :

1. **Attracted armature relay :** Attracted armature relays are of three types :
   i. Plunger relays
   ii. Balanced beam relay
   iii. Polarized relay.
2. **Induction type relay :** Induction relays are of two types :
   i. Induction disc type
   ii. Induction cup type.

2.3. Discuss problems related with the attracted armature type relays.

Ans.

1. The directional feature is absent.
2. The working can be affected by the transients.
3. Due to the presence of moving parts, the response is not very quick due to inertia of the parts, compared to modern static relays.
4. Due to moving parts, frequent maintenance is required. The bearing friction and contact troubles may exist.

2.4. Explain time setting of overcurrent relay.

AKTU 2017-18, Marks 02

Ans. Time setting decides operating time of relay. By increasing or decreasing the time setting, the relay operating time can be increased or decreased proportionally.

2.5. Compare the time-current characteristics of very inverse relay with that of IDMT relay.

AKTU 2017-18, Marks 02

Ans.

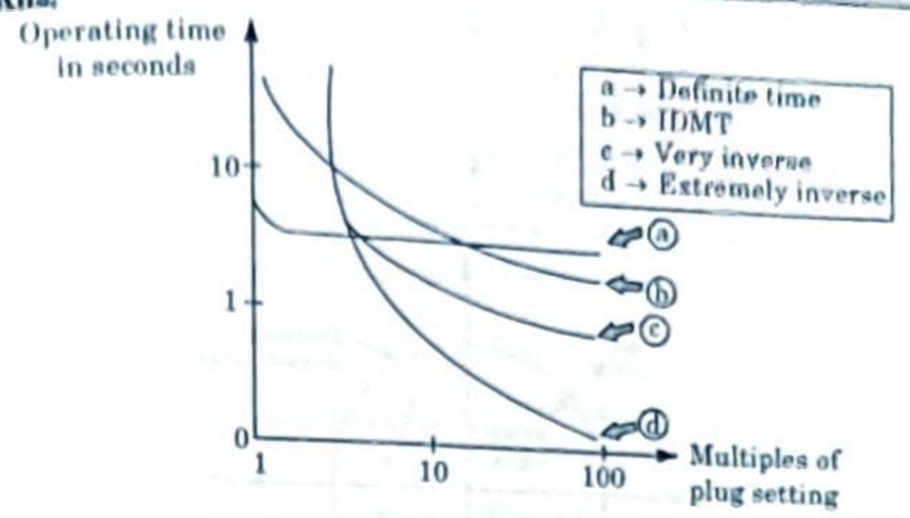

Fig. 2.5.1.

2.6. What is an amplitude comparator ?

Ans. It compares the magnitude of two quantities without considering its angles.

2.7. Briefly state the applications of over current relaying.

AKTU 2020-21, Marks 02

Ans.

1. It is used for the protection of distribution lines.
2. It is used for the protection of industrial motors.

2.8. Explain the operating principle of differential relay.

AKTU 2019-20, Marks 02

Ans. Differential relay is a suitably connected overcurrent relay which operates in a condition when the phasor difference of currents at the two ends of a protected element exceeds a particular value.

2.9. Write the different types of distance relay.

Ans.

1. Impedance relays
2. Reactance relays
3. MHO relays.

2.10. Explain briefly reactance relay characteristic of the R-X diagram.

AKTU 2017-18, Marks 02

Ans: The diagram in Fig. 2.10.1, is shown in a plane having X-axis as R (resistance) while Y-axis as X (reactance), this plane is called R-X plane.

$$\therefore \quad |Z| = \sqrt{R^2 + X^2}$$

and $$\tan \phi = \frac{X}{R}$$

$$\therefore \quad \phi = \tan^{-1} \frac{X}{R}$$

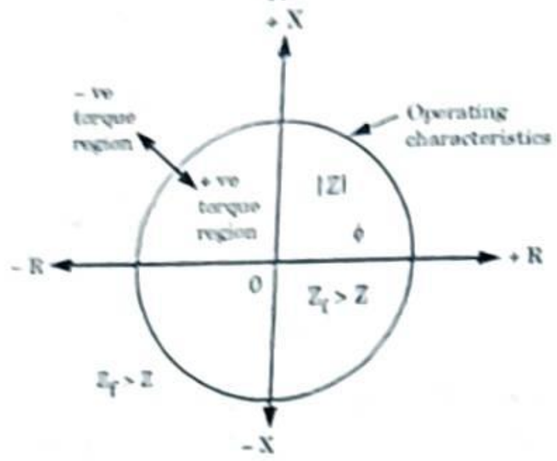

Fig. 2.10.1. Characteristics on R-X diagram.

2.11. What are the advantages of distance relays ?

Ans:

1. Simpler to co-ordinate.
2. Less effect of fault levels and fault current magnitude.
3. Permits high line loading.

2.12. Write advantages of static relay. **AKTU 2016-17, Marks 02**

Ans:

1. CT burden is less, so small CT can be employed.
2. Instantaneous reset can be achieved easily.
3. Accuracy in time-current characteristics.
4. Fast operation, absence of mechanical inertia and bouncing of contacts.

2.13. Write the limitations of static relays.

Ans:

1. These relays have lower short time overload capacity.
2. Additional DC supply is required for various transistor circuits.
3. Susceptible to the voltage fluctuations of transients.
4. Less robust.

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UNIT 3

Protection of Components (2 Marks Questions)

3.1. Write the different types of fault.

Ans: There are two types of fault

1. Symmetrical fault. 2. Unsymmetrical fault.

3.2. Classify the generator faults. **AKTU 2016-17, Marks 02**

Ans:

1. Stator fault 2. Rotor fault
3. Abnormal running conditions.

3.3. What type of protective device is used for the protection of an alternator against overheating of the rotor ?

AKTU 2017-18, Marks 02

Ans: Thermal relay or overcurrent relay.

3.4. What is magnetizing inrush current ?

AKTU 2017-18, Marks 02

Ans: When a power, transformer is switched ON then the primary of transformer may draw a very high peak current from the source. This is known as the transformer inrush current or magnetizing inrush current of the transformer.

3.5. What are the various faults possible in transformers ?

Ans:

1. Overheating
2. Winding faults
3. Open circuits
4. Through faults
5. Overfluxing.

3.6. What are the protective schemes provided in generator ?

Ans:

i. Stator protection :

1. Percentage differential protection
2. Protection against stator inter-turn faults
3. Stator-overheating protection.

ii. Rotor protection :

1. Field ground fault protection
2. Loss of excitation protection
3. Protection against rotor overheating because of unbalanced three phase stator currents.

3.7. What do you understand by the term 'under-reach' ?

AKTU 2017-18, Marks 02

Ans. Failure of distance relay and within set distance is called under-reach.

3.8. What is pilot wire ?

Ans. Pilot wire means a communication channel of wire through which exchange of information takes place between the two end terminals of transmission system.

3.9. What do you understand by pilot wire protection scheme ?

AKTU 2019-20, Marks 02

Ans.

1. Under normal working condition, the two currents at both ends are equal and pilot wires do not carry any current, keeping relays inoperative.
2. Under fault conditions the two current, at two ends are no longer same, this causes circulating current to flow through pilot wires. This causes relays to trip which operate the circuit breakers to isolate the faulty section.

3.10. What are the advantages and limitations of Merz-Price voltage balance system ?

Ans.

A. Advantages :

1. It can be used for parallel as well as ring main system.
2. It provides instantaneous protection to the ground faults.

B. Disadvantages :

1. The CTs used must match accurately.
2. The pilot wires must be healthy without discontinuity.

3.11. What are the advantages of the Translay scheme ?

Ans.

1. Only two pilot wires are required.
2. The cost is very low.

3.12. List the various possible busbar faults.

Ans.

1. Failure of insulation due to material deterioration.
2. Failure of circuit breaker.
3. Earth fault due to failure of support insulator.
4. Flashover due to sustained excessive overvoltage.
5. Errors in the operation and maintenance of switchgear.
6. Earthquake and mechanical damage.

3.13. What are the schemes of busbar protection ?

Ans.

1. Frame leakage protection of busbar.
2. Circulating current protection of busbar.
3. High impedance differential protection of busbar.

3.14. Why bus bar protection is important in power system ?

AKTU 2020-21, Marks 02

Ans. It is limit the damage on equipment and also remove bus bar faults before back up line protection.

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4 UNIT

Circuit Breaking (2 Marks Questions)

4.1. What is the purpose of circuit breakers (switchgear) ?

AKTU 2016-17, Marks 02

Ans. A circuit breaker is an automatically operated electrical switch designed to protect an electrical circuit from damage caused by excess current, typically resulting from an overload or short circuit. Its basic function is to interrupt current flow after a fault is detected.

4.2. Define arc extinction. **AKTU 2016-17, Marks 02**

OR

What is meant by the term arc quenching ?

Ans. Arc interruption (quenching) is a process in which path of arc is interrupted for the purpose to extinguish it. For arc interruption, different processes like air blast, high air pressure turbulence and arc splitting are used.

4.3. Discuss the energy balance theory of arc interruption in circuit breaker. **AKTU 2017-18, Marks 02**

Ans. The rate of generation of heat between the contacts of the circuit breaker is lower than the rate at which heat between the contacts is dissipated. Thus, if it is possible to remove the generated heat by cooling, lengthening and splitting the arc at a high rate then the arc can be extinguished.

4.4. What do you understand by recovery and restriking voltage ?

Ans.

A. **Recovery voltage :** Power frequency rms voltage which appears across the circuit breaker contacts after the transient oscillations die out and final extinction of arc has resulted is known as recovery voltage.

B. **Restriking voltage :** The transient voltage that appears across the circuit breaker contacts at the instant of arc extinction is called restriking voltage.

4.5. Define RRRV. **AKTU 2019-20, Marks 02**

Ans. It is the rate of rise of restriking voltage which is expressed in volts per microsecond. This will represent the rate at which transient recovery voltage is increasing.

4.6. What do you understand by the term "Current Chopping"?

AKTU 2019-20, Marks 02

Ans.

1. There are certain circumstances like disconnecting transformers on no load in which it is necessary to interrupt small inductive currents. The no load current of a transformer is almost at zero power factor lagging.
2. This current is normally smaller than the normal current rating of the breaker. Interrupting such current causes severe duty on the circuit breaker. This phenomenon is called current chopping.

4.7. Explain short time current rating of a circuit breaker.

AKTU 2020-21, Marks 02

Ans.

1. The short time current rating is based on thermal and mechanical limitations. The circuit breaker must be capable of carrying short circuit current for a short period while another circuit breaker is clearing the fault.
2. The rated short time current is the rms value of the total current that the circuit breaker can carry safely for specified short period.

4.8. What do you understand by short line interruption ?

Ans. The fault occurring between a distance of a few kilometer to a few ten kilometers from the circuit breaker is called short line interruption.

4.9. How the air break circuit breaker works ?

AKTU 2016-17, Marks 02

Ans. The principle of high resistance interruption is employed for air blast circuit breaker. The length of the arc is increased using arc runners which will increase its resistance in such a way that the voltage drop across the arc becomes more than the supply voltage and the arc will be extinguished.

4.10. Give the classification of circuit breakers based on medium used for arc quenching. **AKTU 2019-20, Marks 02**

Ans.

Type	Arc Quenching Medium	Voltage range and Breaking capacity
Miniature circuit breaker	Air at atmospheric pressure	400-600 V; for small current rating
Air-break circuit breaker	Air at atmospheric pressure	400 V-11 kV; 5-750 MVA
Minimum oil breaker	Transformer oil circuit	3.3 kV-220 kV; 150-25000 MVA
Vacuum circuit breaker	Vacuum	3.3 kV-33 kV; 250-2000 MVA
SF_6 circuit breaker	SF_6 at 5 kg/cm^2 pressure	3.3-765 kV; 1000-50,000 MVA
Air blast circuit breaker	Compressed air at high pressure	66 kV-1100 kV; 2500-60,000 MVA

4.11. Why current chopping is not common in oil circuit breaker ?

AKTU 2020-21, Marks 02

Ans. Current chopping is not common in oil circuit breakers because in most of the oil circuit breakers the arc extinguishing power is proportional to the magnitude of current to the interrupted.

4.12. Write the advantages and disadvantages of air blast circuit breaker.

Ans.

A. Advantages :

1. No power hazards are possible.
2. High speed operation is achieved.

B. Disadvantages :

1. The maintenance of compressor and other related equipments is required.
2. There is possibility of air leakages at the pipe fittings.

4.13. Give the advantages and disadvantages of SF_6 circuit breaker.

Ans.

A. Advantages :

1. Problems connected with current chopping are minimum.
2. Size is smaller than conventional breaker of same rating.

B. Disadvantages :

1. Sealing problem arises due to the type of construction.
2. Imperfect point leads to leakage of gas.

4.14. Write the advantages and disadvantages of minimum oil circuit breaker.

Ans.

A. Advantages :

1. Small tank size and weight.
2. Low maintenance problem.

B. Disadvantages :

1. Increased degree of carbonization due to smaller quantity of oil.
2. Difficulty in removal of gases from the contact space in time.

4.15. What is resistance switching ? **AKTU 2020-21, Marks 02**

Ans.

1. The interruption of low inductive currents, interruption of capacitive currents gives rise to severe voltage oscillations.
2. These excessive voltage surges during circuit interruption can be prevented by the use of shunt resistance R across the circuit breaker contacts. This process is known as resistance switching.

4.16. Define breaking capacity of a circuit breaker.

AKTU 2017-18, Marks 02

Ans. It is current (rms) that circuit breaker is capable of breaking at given recovery voltage and under specified conditions.

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5 UNIT

Modern Trends in Protection (2 Marks Questions)

5.1. What do you understand by electronic relay ?

Ans. The electronic relay is a type of an electronic switch that open or close the circuit contacts by using electronic component without any mechanical operation.

5.2. What are the advantages of electronic relay ?

Ans.
1. They require low maintenance.
2. The relay has fast response time.

5.3. Give the disadvantages of electronic relay.

Ans.
1. The power consumption in the electronic relay is very high.
2. The relay has the short lifespan.

5.4. Draw block diagram of static relay.

AKTU 2016-17, Marks 02

Fig. 5.4.1.

Fig. 1.

5.5. Write the basic elements of static relay.

Ans. The basic elements are :
1. Input element
2. Measuring element
3. Output element
4. Feed element.

5.6. What do you understand by phase comparator ?

Ans. A phase comparator compares the two quantities by comparing their phase angle irrespective of their magnitude.

5.7. Define level detector in static relay.

Ans.
1. Level detector circuits are used in static relays as a final stage before the trip coil circuit of the circuit breaker.
2. The level detector is derived from the fact that the circuit operates abruptly when the input level exceeds a predetermined value.

5.8. Write the advantages of microprocessor based protective relaying scheme.

Ans.
1. It is very efficient and reliable.
2. It is very fast in operation.
3. Programmable in nature.

5.9. What is static relay ?

Ans. The relays which do not use moving parts and use the solid state electronic components such as diodes, transistors etc., are called static relays.

5.10. What do you understand by reliability ?

Ans.
1. A protective relaying should be reliable in its basic quality. It indicates the ability of the relay system to operate under predetermined conditions.
2. Every component and circuit which is involved in the operation of relay plays an important role and reliability of a protection system depends on the reliability of various components like circuit breakers, PTs etc.

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