



R. C. Patel College of Engineering & Polytechnic, Shirpur



Department of Electrical Engineering

Name of Subject: - **SWITCHGEAR AND PROTECTION (SGP)**

Course Code: - **315334**

Scheme:- **EE-5K**

Semester:- **Fifth**

Unit No. 04- Protection of Alternators, Motors, Transformers, Bus bars and Transmission lines

CO4 - Use suitable protection schemes for alternators, motors, transformers, bus bars and transmission lines.

Unit	Title	COs	Learning hours	R Level	U Level	A Level	Total Marks
IV	Protection of Alternators , Motors, Transformers, Bus bars and Transmission lines	CO4	20	2	8	14	24

THEORY SYLLABUS CONTENT

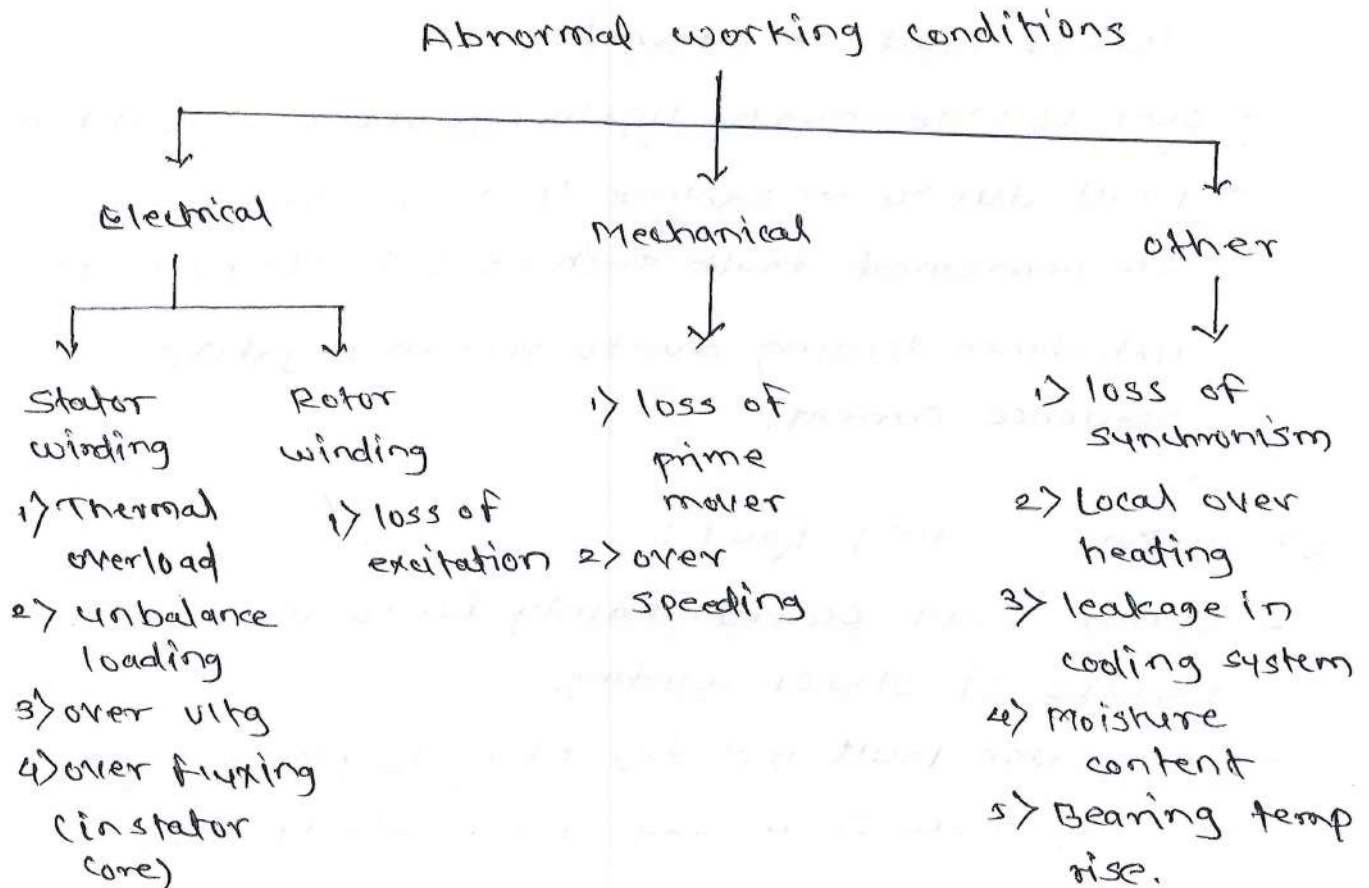
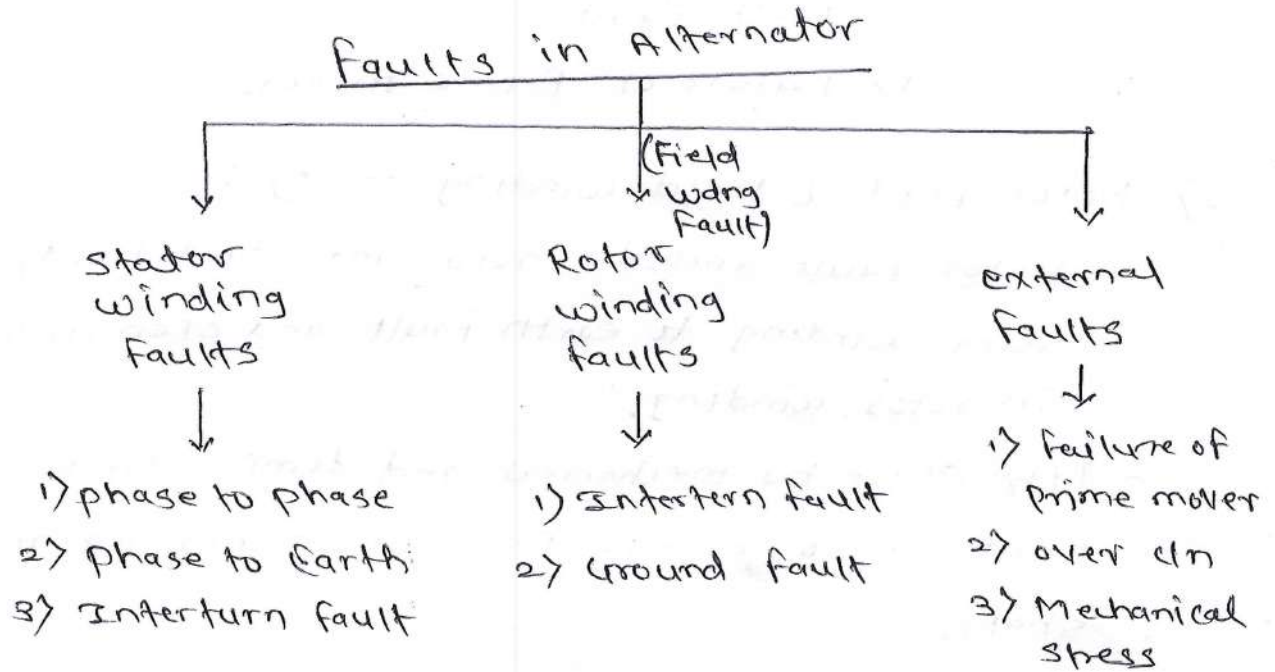
- 4.1 Abnormalities and Faults occurring in alternator
- 4.2 Differential, over current, Earth fault Protection: Schemes
- 4.3 Reverse power protection: Scheme
- 4.4 Abnormalities and Faults occurring in transformer
- 4.5 Differential, over current, earth fault, over heating protection.
- 4.6 Limitations of differential protection.
- 4.7 Buchholz relay: Construction, operation.
- 4.8 Motor: Abnormalities and Faults, Short circuit protection, Overload protection, Single phase preventer.
- 4.9 Busbar: Faults, busbar protection, differential and fault bus protection.
- 4.10 Transmission Line: Faults, over current, Distance and Pilot wire protection.

Subject Incharge
Mr. N. S. Borse

Protection of Alternators, Motors, Transformers, Busbars and Transmission lines.

I] Alternator:

* Abnormalities and faults in alternator.



Faults in Alternator:

1) External fault: This fault consist of

- a) Large short circuit current
- b) Mechanical stress on stator winding
- c) Temperature rise
- d) over current
- e) Earth fault
- f) Failure of prime mover.

2) Rotor fault [field winding fault]:

- Rotor fault include rotor inter turn fault, rotor winding to earth fault and open circuit in rotor winding.
- May cause by mechanical and temp stresses
- Fault due to excess pressure on bearing and shaft.
- Fault due to increase in a speed or sudden loss of load on alternator.
- over voltage due to lightning stroke or switching
- Fault due to unbalance loading causes unsymmetrical fault such as L-G, L-L-G, L-L etc.
- Unbalance loading due to rise in negative sequence current.

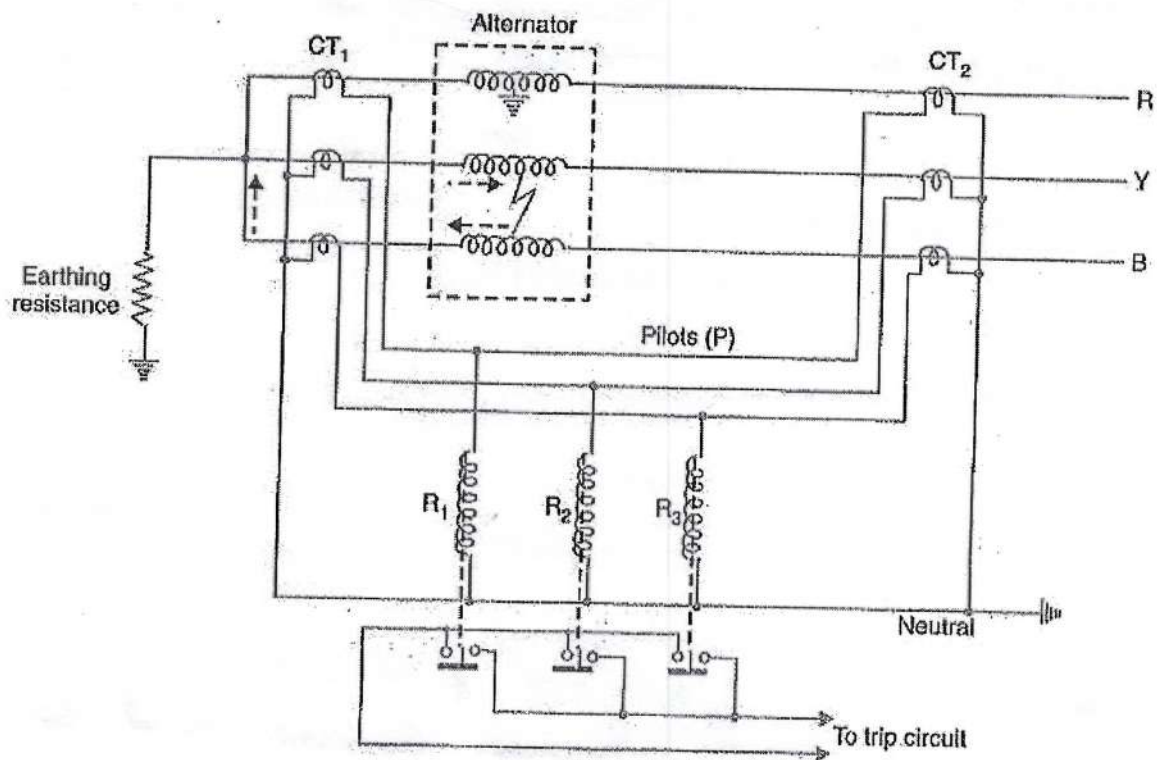
3) stator winding fault:

- stator fault occurs mainly due to insulation failure of stator winding.
- The stator fault includes phase to phase fault, phase to earth fault and stator interturn fault.

- Fault due to thermal over loading, may increase winding temperature which causes insulation damage.
- Temperature rise also cause due to failure of cooling system.

Sr. No.	Types of fault	Causes	Protection Provided
1>	Thermal overload	continuous over load	Thermocouple, RTD
2>	Unbalance loading	unequal load	Negative phase seq. protection
3>	Loss of excitation	opening of field slw, break in field wdg	field failure protection
4>	loss of prime mover	loss of mechanical system.	Reverse Power protection directional relay
5>	over speeding	fault in governor system	over & under frequency protection
6>	Interturn fault	Failure of insulation	differential protection
7>	L-G, L-L-G fault	mechanical stress	Earth fault protection
8>	local overheating	insulation failure, cooling system fail	Gas operated relay

* Differential protection of Alternator /
Merz price protection of alternator:-

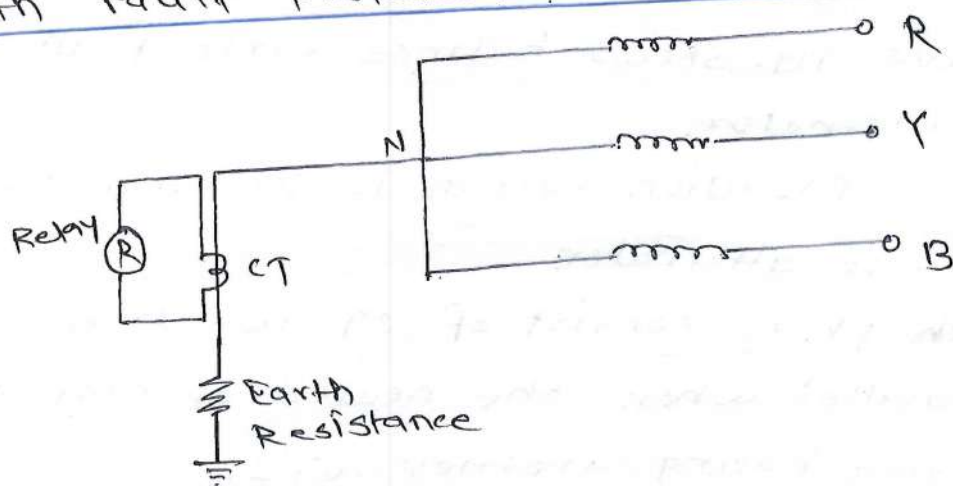


- Above fig. shows schematic arrangement of CT for star connected alternator.
- If alternator is delta connected, then CT₁ are connected in delta manner. CT₂ are always connected in star manner.
- Two sets of identical CTs are placed on both side of alternator winding, it consist of Restraining coil and operating coil.
- It protect from short circuit fault and earth fault.

- separate set of coil are use for each phase.
- restraining coil are connected in series with the pilot wire.
- operating coil is connected between midpoint of R.C. and neutral.
- In normal operating condition, current through CT_1 and CT_2 are same and hence no current will flow through R.C. hence the relay does not operate.
- In short circuit or earth fault condition, secondary current of CTs are different, hence differential current flows through R.C. and operate the trip circuit.

* ~~Connections of differential protection:~~

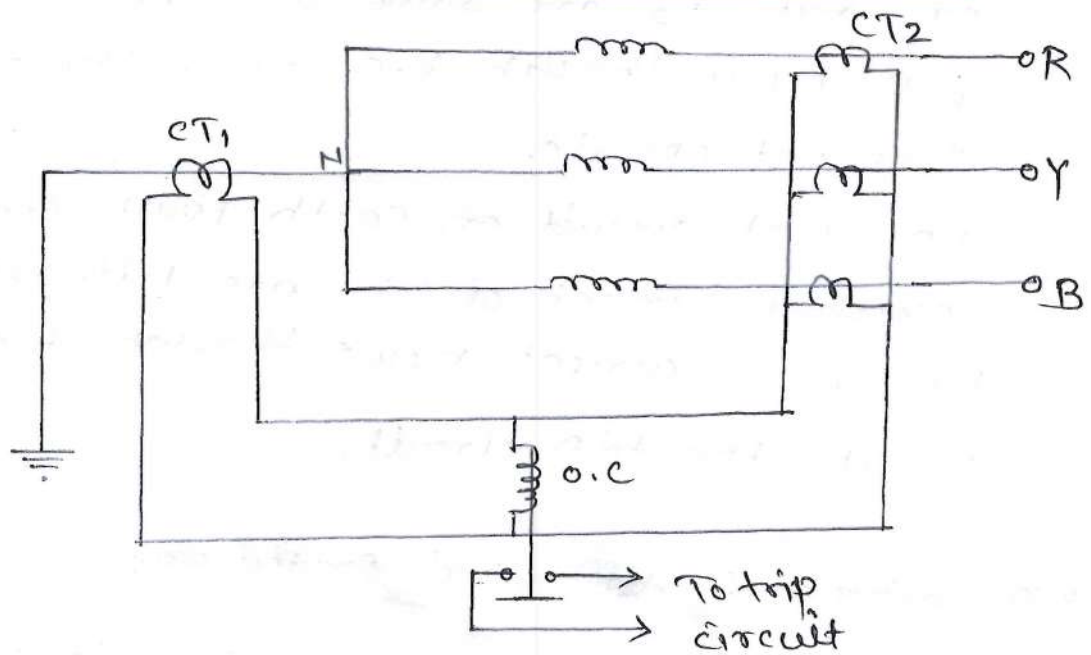
* Earth Fault Protection of Alternator;



- Above Fig. shows arrangement of alternator for protection from earth fault.
- In fault condition, c/n will flow through neutral point to earth, if the magnitude of flowing c/n will increases then this higher magnitude

- current pass through earth connected C.T.
- This CT induces secondary current which can sense by relay coil.
- The relay coil operates the trip circuit.

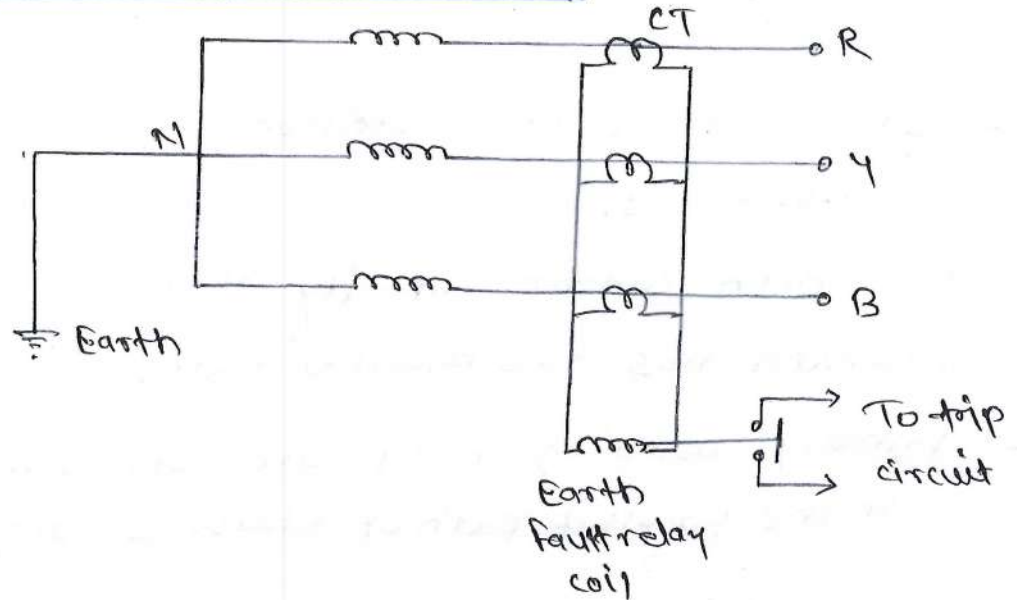
* Balance Earth fault Protection of Alternator;



- Above fig. shows balance earth fault protection of alternator.
- This protection system is provided for small size of alternator.
- Each phase consist of CT which are connected in parallel where the neutral of star connected winding having another CT's.
- CT₁ & CT₂ are connected in series in such a way that the current flowing through it is in same direction.
- The relay coil are connected across secondary of CT's.

- This protection system provides protection in protected zone therefore it is also known as restricted earth fault protection.

* Residual Earth Fault Protection;



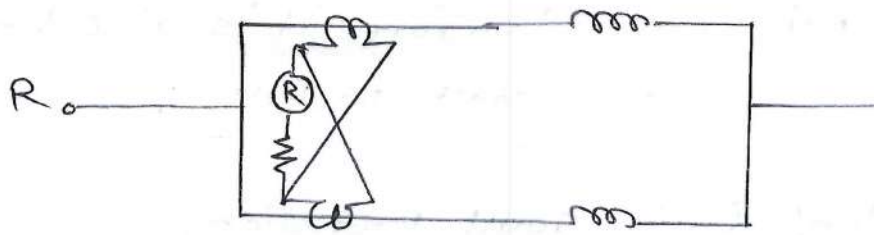
- It uses 3 CTs, connected in alternator shown in fig.
- Earth fault relay is connected across CT secondary.
- At normal working condition, the algebraic sum of CT secondary current is zero, i.e.

$$I_R + I_Y + I_B = 0$$

There is no residual current in relay coil.

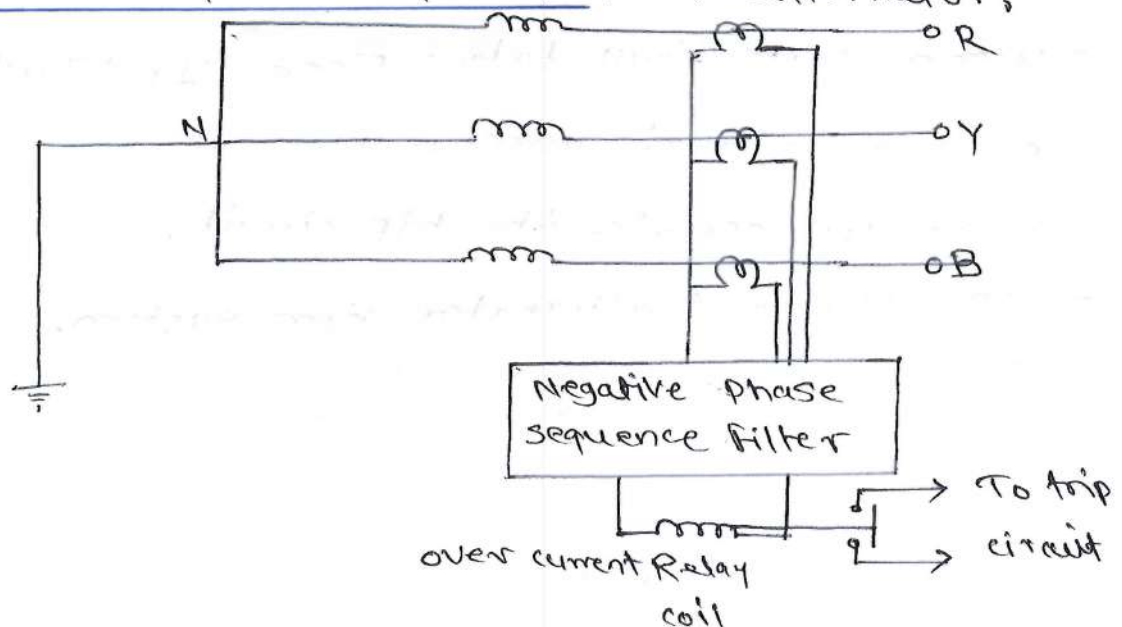
- When earth fault takes place, $I_R + I_Y + I_B \neq 0$, hence a residual current is flow through relay coil, relay coil operates the trip circuit.
- CB disconnect alternator from system.

* Interturn fault protection of Alternator:



- Interturn fault protection scheme is shown in above fig.
- For high current capacity stator winding of alternator has two parallel path.
- Primary winding of CT are connected in series with the parallel path of stator winding.
- Relay coil is connected across the secondary of CT's.
- When inter turn fault occurs, the current flowing through the secondary of CT are not equal and differential current start to flow through relay coil and ~~which~~ it operate the trip circuit.

* Negative Sequence protection of alternator:



- Fig. shows negative phase sequence protection of alternator against unbalance load.
- Unbalance 3- ϕ load have negative phase sequence component produce negative phase sequence current
- Therefore negative phase sequence filter with over c/n relay is use to provide protection against unbalance load.
- Three CT's connected in three phases.
- The secondary current of CT are given to the relay coil through the negative phase sequence filter.
- Under balance load condition, there is no negative phase sequence current and relay remains open.
- When unbalance load condition occurs then negative phase sequence current is produced across filter which operates the relay and trip the circuit breaker.

* Reverse power protection:

- During normal operating condition, the power flow from alternator to grid and to load. But if the prime mover fails, alternator act as motor and takes power from the grid. Thus the power flow reverse.
- It uses directional relay to protect from reverse power flow.
- Directional relay explain in chapter - 3.

II] Transformer:

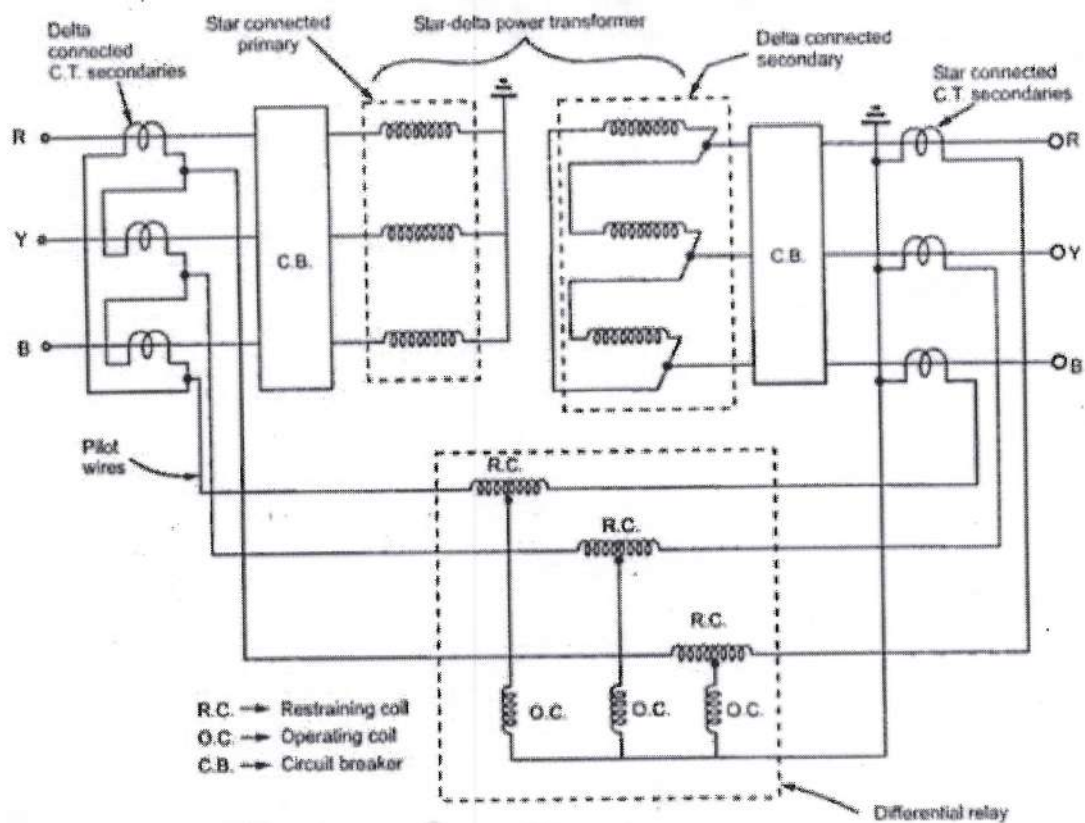
* Abnormalities and faults in transformer.

Fault	Remedies / protection used
1) over load	1) Temp relay 2) Thermal over load relay
2) Earth fault	1) Differential relay 2) Earth fault relay
3) over voltage	1) Lightning Arrester 2) Horn gap arrester
4) Incipient fault (slow developing)	1) Buchholz relay
5) Interturn fault	1) Buchholz relay
6) Saturation of core	1) over voltage protection 2) over fluxing protection
7) Fault in tap changer	1) percentage differential protection 2) over current relay 3) Buchholz relay

- The protection provided depends on capacity of transformer.

Rating of transformer	protection provided
1) small distribution x'mer	fuses on HV side
2) x'mer upto 500 KVA	Buchholz relay, earth fault relay, over c/n relay, restricted earth fault relay
3) 5 MVA and above	Buchholz relay, over c/n relay, differential relay, earth fault relay.

* Differential protection of transformer / Merz price protection of transformer:



- Fig. shows differential protection of star-delta transformer.
- In this system CT on delta connected side are connected in star manner and CT on star connected side are connected in delta manner.
- Secondary of CT's are connected by using pilot wire.
- operating coil of relay is connected in CT Secondary as shown.
- under normal operating condition, there are equal current will flow in CT secondary.

- No current will flow in the operating coil of relay and relay will not operate.
- In abnormal or fault condition, CT secondary current are no longer equal. A differential current flow in the operating coil of relay.
- The relay operates and sends trip signal to CB.
- The CB disconnects transformer from system.

* Limitations of differential protection:

1] Difference in a pilot wire length: Impedance of pilot wire affected to the secondary circuit.
 - which causes unequal current flowing through secondary of CT.

2] Different CT characteristics:
 - Due to difference in CT ratio, voltage across secondary also different.

3] Tap changing:

- During tap changing, voltage ratio are different from original, which affect on the operation of differential protection.

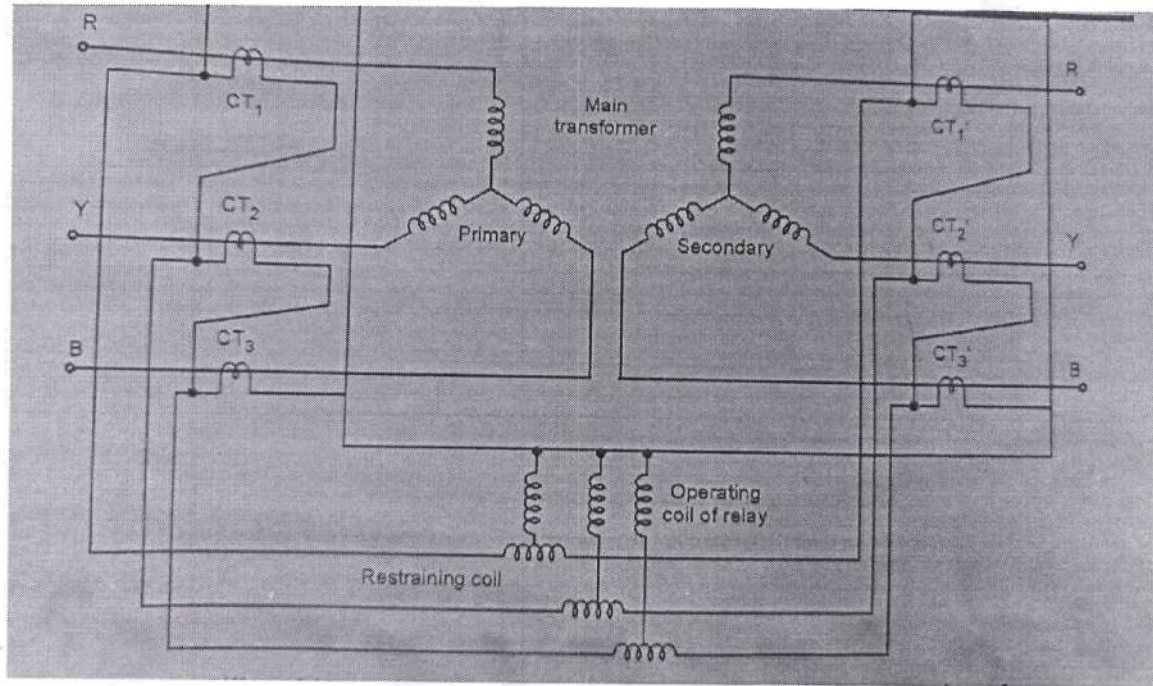


- All the limitations can be overcome by using biased differential protection or percentage differential protection.

* CT connection for differential protection of x'mer:

x'mer connection	CT connection
star - Delta	Delta - star
Delta - Delta	star - star
star - star	Delta - Delta
Delta - star	star - Delta

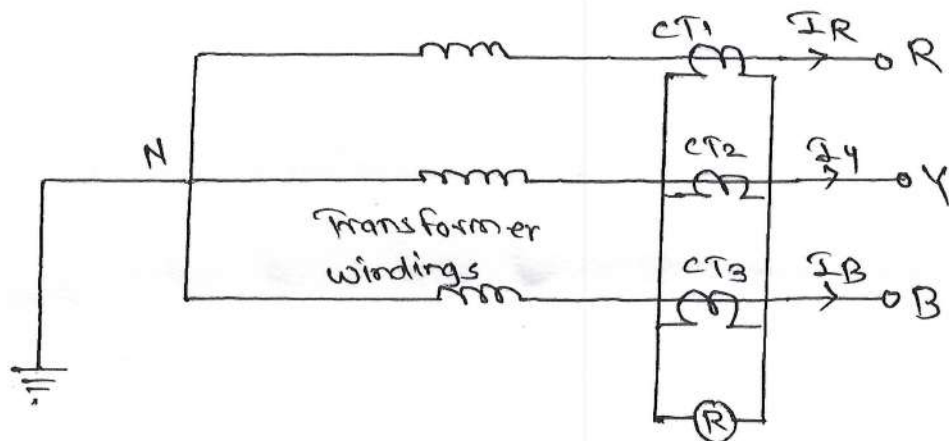
* Percentage differential protection: or
Biased differential protection:



- Figure shows arrangement of percentage differential protection for star-star transformer.
- The working is exactly similar as differential protection scheme. The restraining coil avoids drawbacks in differential protection scheme.

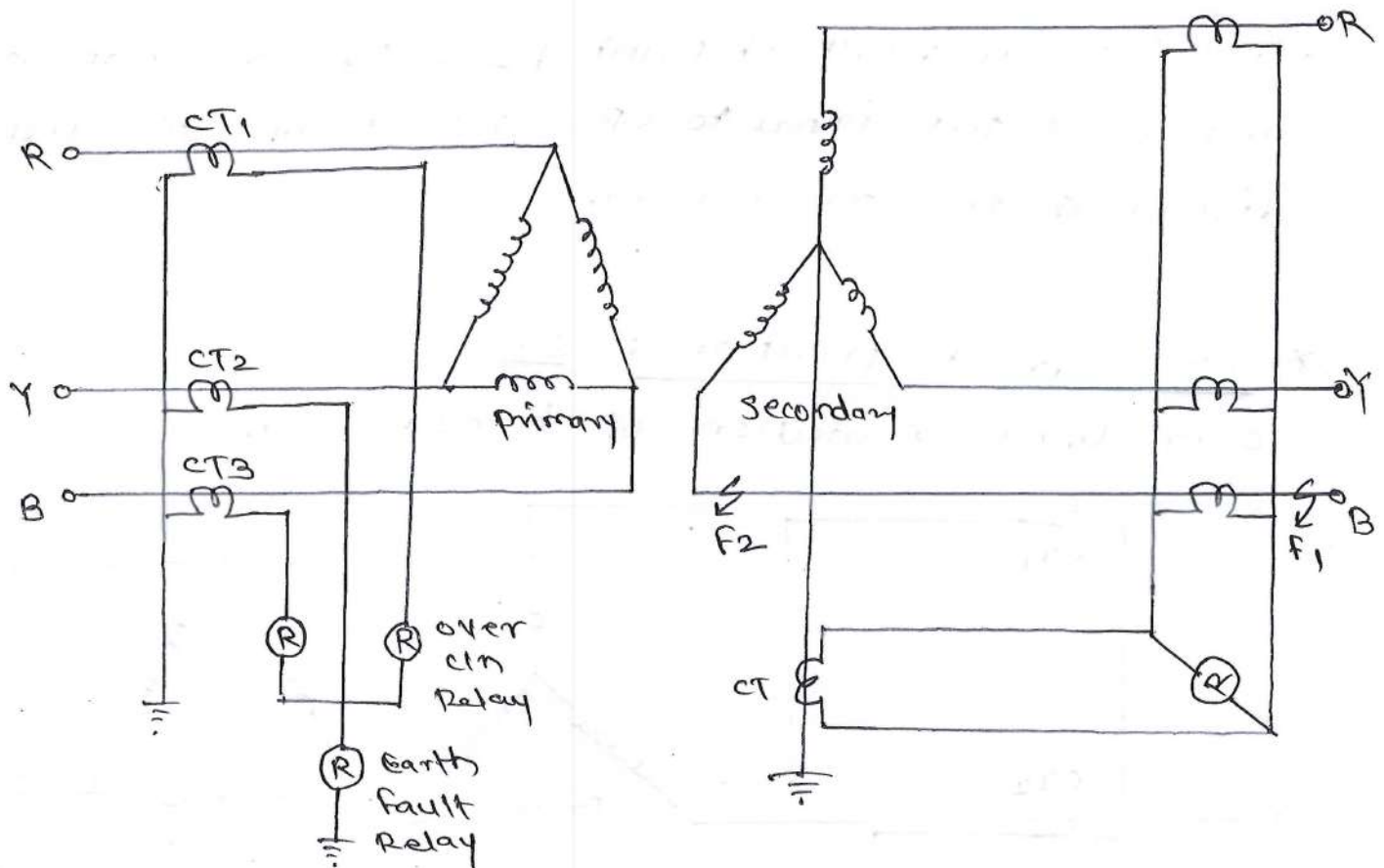
* Earth Fault Protection:

1) Residual Earth Fault protection:



- Above fig. shows arrangement of earth fault protection for transformer.
- The three CT's are connected in lines and an earth fault relay is connected across these CT's
- At normal condition, the sum of three secondary current of CT is zero i.e.
$$I_R + I_Y + I_B = 0$$
- The sum of these current is called residual current.
- at normal condition, no current will flow through relay coil.
- At earth fault condition, the sum of three current is not zero, i.e.
$$I_R + I_Y + I_B \neq 0$$
- the residual current flow through earth fault relay,
- which operates a trip circuit and CB disconnect the transformer.
- This protection is also called unrestricted earth fault protection. (operate on fault beyond X_{mer} winding)

2] Restricted Earth Fault protection:



- Fig. shows arrangement of CT's in restricted earth fault protection.

- on primary side over current and ground fault protection is provided.

- on secondary side four CT's are connected, three in the line and one connected in earth circuit. A relay (R) connected in CT secondary circuit.

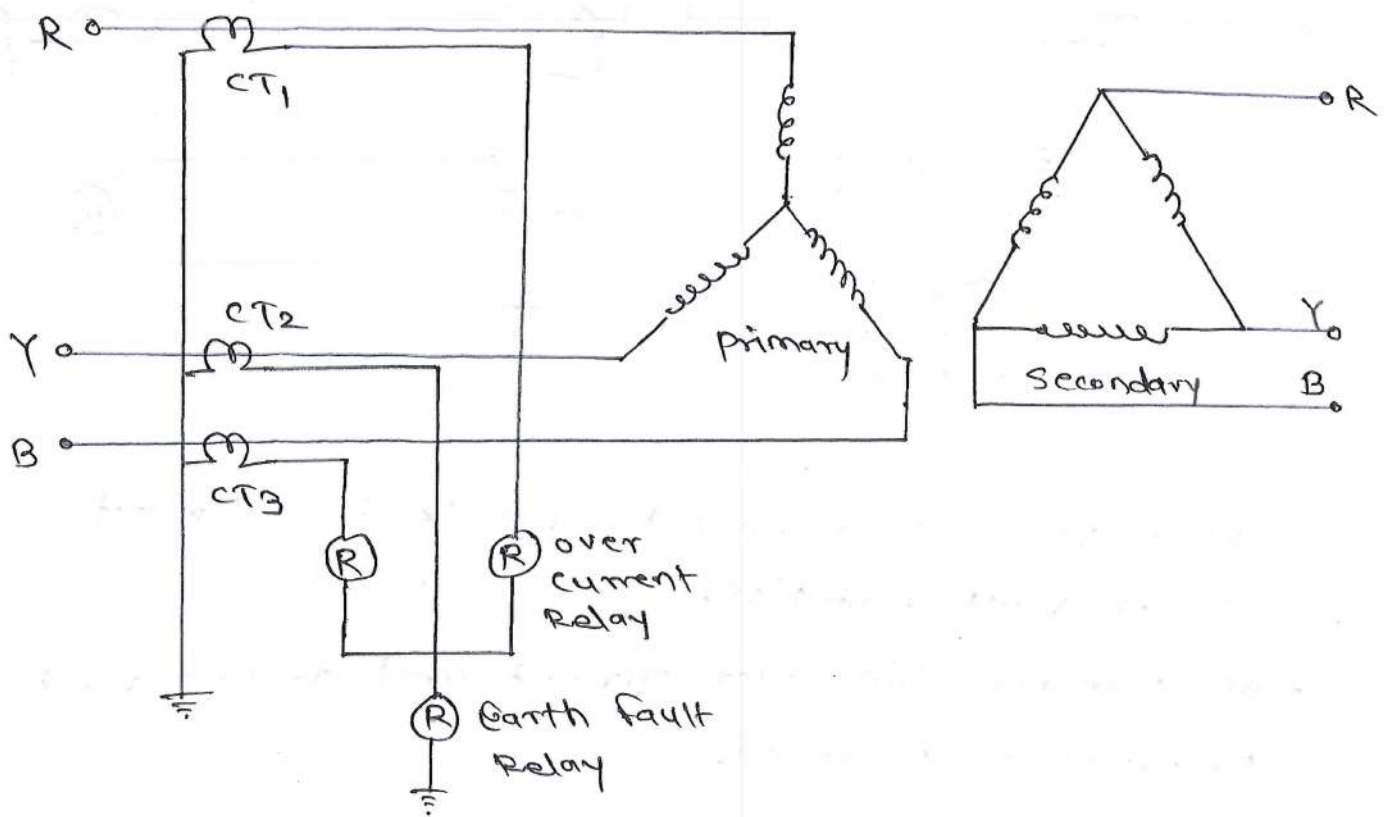
- If Fault occurs in primary side, the secondary current of CT₁ & CT₃ increases, it operate the trip circuit of over current relay.

- In case of ground fault or earth fault, the relay in ground circuit operates & trip the CB.

over load & phase fault

- If Fault occurs in Secondary winding at Point F_1 , the relay does not operate (i.e. restricted)
- For internal fault at point F_2 , the relay operates and send trip signal to CB. The CB operates and disconnect the transformer.

* over current protection : or
over load protection of transformer.

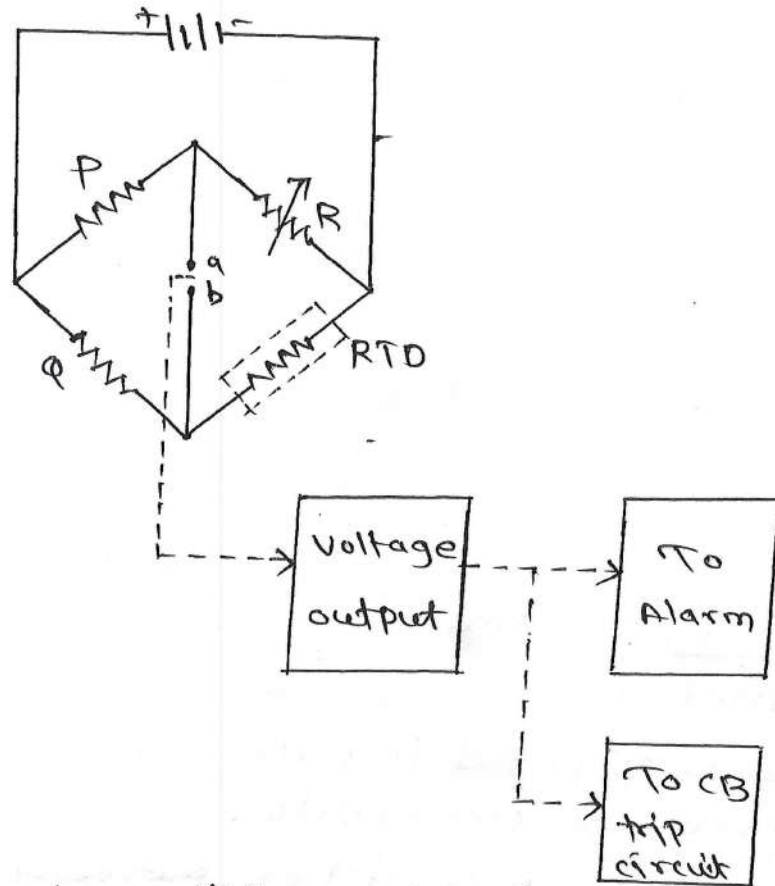


- The primary has 3 CT's connected in the line.
- Two over current relays are provided in CT secondary ckt of R & B phase. one earth fault relay is provided in CT secondary ckt of Y phase.
- construction & working is same as restricted earth fault protection provided to primary winding.

* over heating protection OR

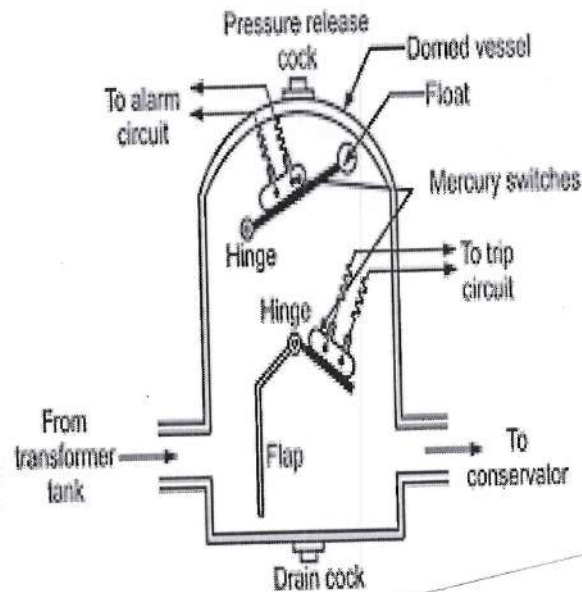
Thermal protection of transformer:

- Temperature sensors like resistance temperature detector (RTD), thermocouples are kept in x'mer winding to sense the temperature.



- Under normal condition, bridge is balanced.
- When temperature of transformer increases beyond limit, the bridge is imbalanced. A voltage appear across point a & b . This voltage output can be fed to alarm circuit or trip circuit of CB.
- In case of small fault alarm is sounded,
- In case of Severe Fault, CB operates.

* Buchholz Relay:



- Location: Buchholz relay is used only with oil filled transformer. It is gas actuated relay. It is connected in path between transformer tank and conservator.

- Construction: It consists of ~~mercury switches~~ two element i.e., upper element & lower element.

1) Upper element: It consists of mercury switch attached to the float and used to close the alarm circuit during incipient fault or slow developing fault.

2) Lower element: It consists of mercury switch mounted on flap.

The flap is located in the path of oil flow from transformer tank to conservator and it gives trip signal during major fault.

- Working: When the incipient fault occurs in transformer, heat is generated.
 - This heat causes vaporisation of oil in main tank. Vaporisation of oil produces hydrogen gas.
 - Due to light weight of hydrogen gas it tries to go into conservator.
 - During this gas flow through buchholz relay, due to gas pressure, float goes up and closed the mercury switch and closing the alarm ckt contacts.
 - When major or severe fault occurs, large amount of hydrogen gas is produce in main tank.
 - Due to high pressure hydrogen gas, the flap turns in anticlock wise direction, to close the mercury switch and operate the trip circuit.

* Advantages:

- 1) It detect the incipient fault
- 2) Simple in construction
- 3) Fault detection is faster
- 4) operation is reliable

- Disadvantages:

- 1) only used in oil immersed x'mer
- 2) It can ~~not~~ detect the fault below oil level.
- 3) operation time is slow.
- 4) Not suitable for transformers below 500 kVA due to economic reason.

III] Motor:

* Abnormalities and fault in motor:

- 1) Prolong overloading: If the load on machine is increased 1.5 to 2 times for long time.
 - It causes increases the temperature and damage the insulation.
- 2) Stalling: Due to the overloading, at the time of start or failure of bearing motor refuse to start in that case motor draws large current from supply.
- 3) Unbalance supply Voltage: due to unbalance voltage, it produces negative phase sequence current & produce heating of motor.
- 4) Single phasing: When one of the phase from three phase supply is disconnected, then motor continue to operate on single phase supply this condition is known as single phasing.
 - It causes magnetic unbalance, reduction in torque and overheating.
- 5) Undervoltage: If the motor current increases for the same load condition, voltage decreases which causes undervoltage.
- 6) Reverse phase: If the phase sequence is reverse, motor rotating in a reverse direction.
- 7) Stator earth fault: It cause due to failure of insulation and temperature rise.
- 8) Rotor fault: rotor fault occurs in slip ring type motor.

- 9) change in frequency: due to frequency change it affects speed, Torque, power factor & efficiency.
- 10) Noise production: due to electrical & mechanical causes noise produced.

* protective system for motor:

Sr. No.	Abnormality	protective provision
1)	over loading	1) overload relay 2) MCB 3) Thermal over load relay
2)	single phasing	1) single phasing preventer 2) Thermal over load relay
3)	un-balance supply	1) Negative phase sequence relay
4)	stator side fault	1) HRC fuse 2) instantaneous over c/n relay 3) differential protection
5)	Rotor side fault	1) Instantaneous over current relay
6)	Reverse phase	1) phase reversal protection
7)	Under voltage	1) Under voltage Relay

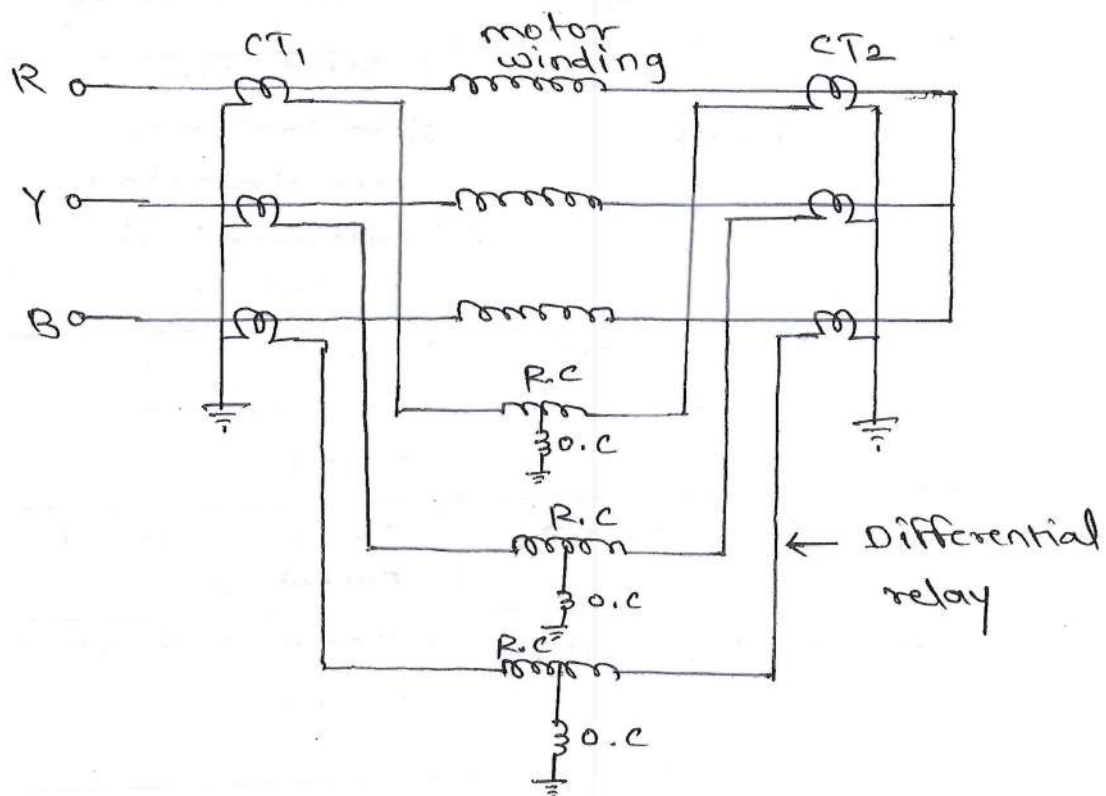
* Short circuit protection of motor:

- When the short circuit occurs, motor current increases beyond 1.5 to 2 times more than rated current.
- This current is considered as overload current.
- Types of protection used are
 - i) HRC fuse
 - ii) Differential protection
 - iii) over current relay.

i) HRC fuse:

- HRC fuses are connected in the lines.
- On occurrence of short circuit, HRC fuse melts and disconnects the motor from supply.
- The fusing current must be greater than the starting current of motor.

ii) Differential protection.



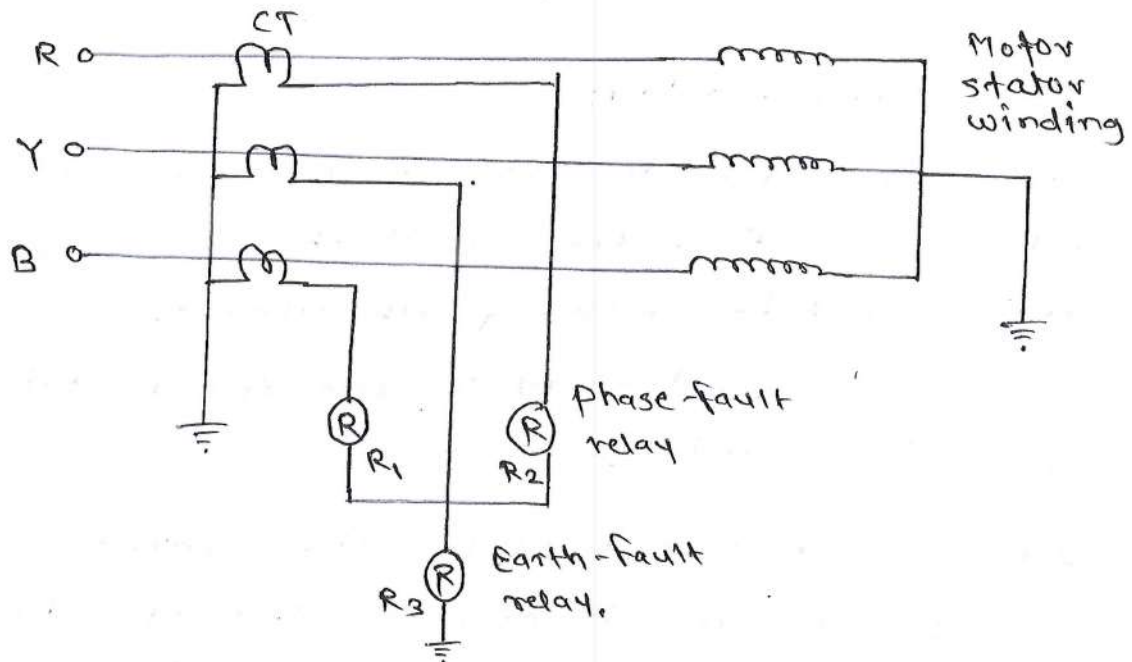
- For large capacity motors, percentage differential protection is used.
- It can be used for phase to phase or phase to ground fault.

iii) Over current relay:

- The main characteristics of the relay is to reduce operating time with the increase in the magnitude of the fault current.
- The fuses and relay is use for protection of stator winding.
- When short circuit occurs, the current sensing relay operates which operates the operating coil and trip circuit of circuit breaker.

* overload protection:

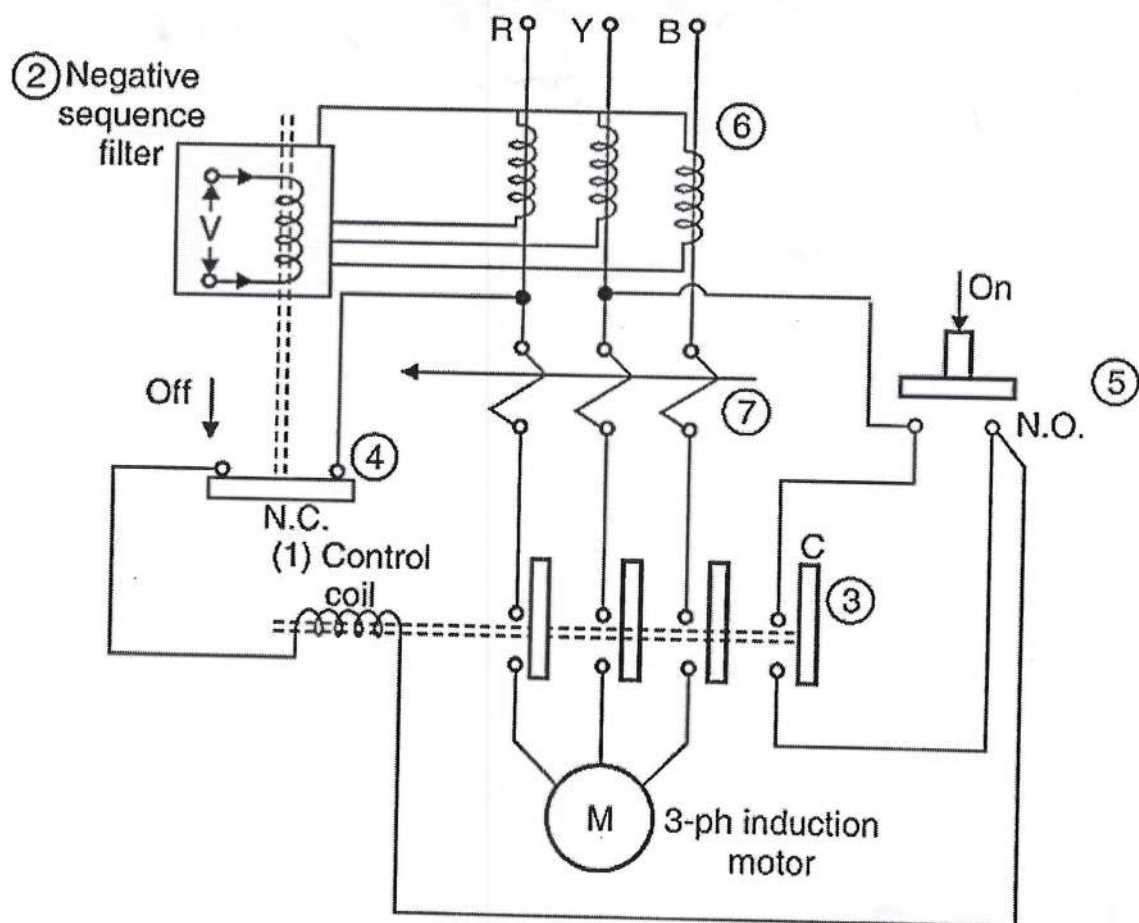
- This protection is provided by means of phase fault relay and ground fault relay.



- Relay R₁ & R₂ operates for phase fault and relay R₃ operates for ground fault.
- on occurrence of fault, trip circuit is operated by respective relay and then CB is operated.
- This protection scheme is usually employed for high voltage induction motors.
- Sometimes, core balanced CT is used,

* Single phasing Preventer:

- The single phasing means, one of the phase from three phase supply is disconnected from supply, so that motors runs on single phase only.
- Due to single phasing, load on the remaining phases increases which causes increase in a temperature.
- The following fig. shows single phasing preventer, it consist-
 - ① control coil
 - ② Negative seq. filter
 - ③ contactors
 - ④ NC contacts
 - ⑤ NO contacts
 - ⑥ CT.
 - ⑦ Thermal relay,



- The preventive circuit is connected in secondary of CT, and RYB lines act as primary of CT.
- The negative sequence filter is use to detect the fault condition.
- Under the normal condition, vector sum of line current is equal to zero and no current flows through the negative phase sequence filter.
- When the single phasing occurs, negative phase sequence current flow through control coil.
- It sends the tripping signal to the starter and NC contact gets open, which disconnect the motor from supply.
- This type of preventer is generally used for small/medium capacity motors.

IV] Bus bar:

Busbar is a thick copper strips, single conductor having number of input and output terminals.

* Abnormalities and faults in bus-bar

1. Earth fault or line to ground fault:

L-G, L-L-G, L-L-L-G fault

2. phase to phase fault:

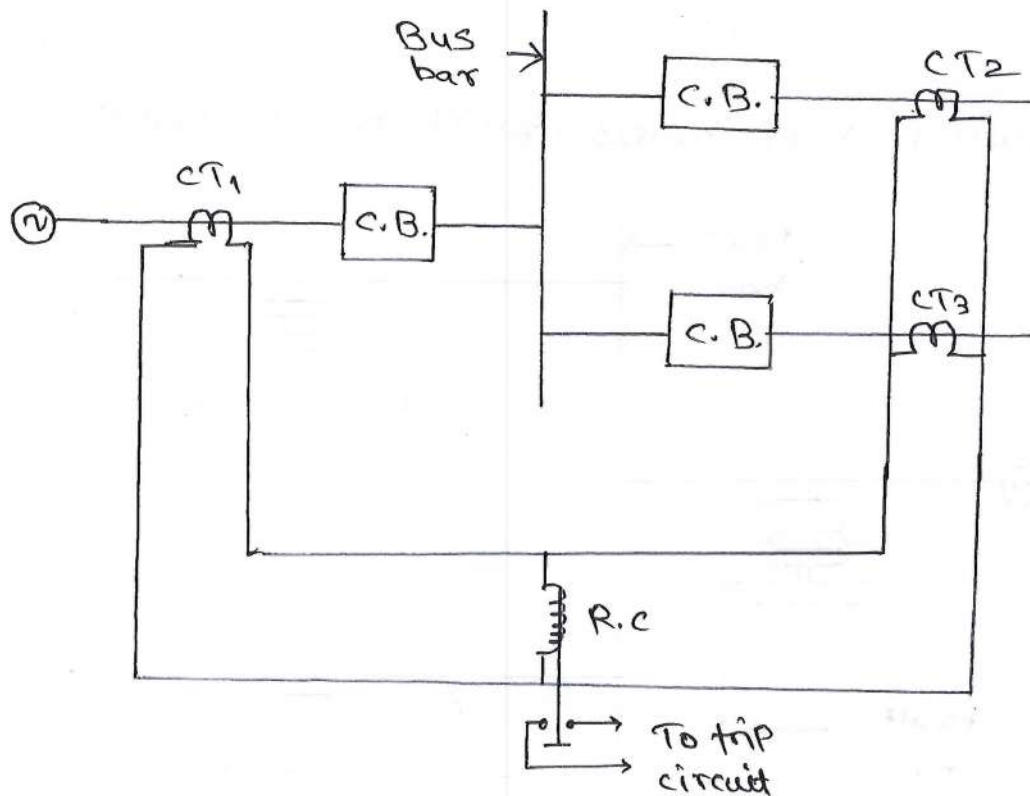
L-L, L-L-L fault

3. open circuit fault.

4. Short circuit fault.

* Differential Protection:

- The following fig. shows differential protection of bus bar.

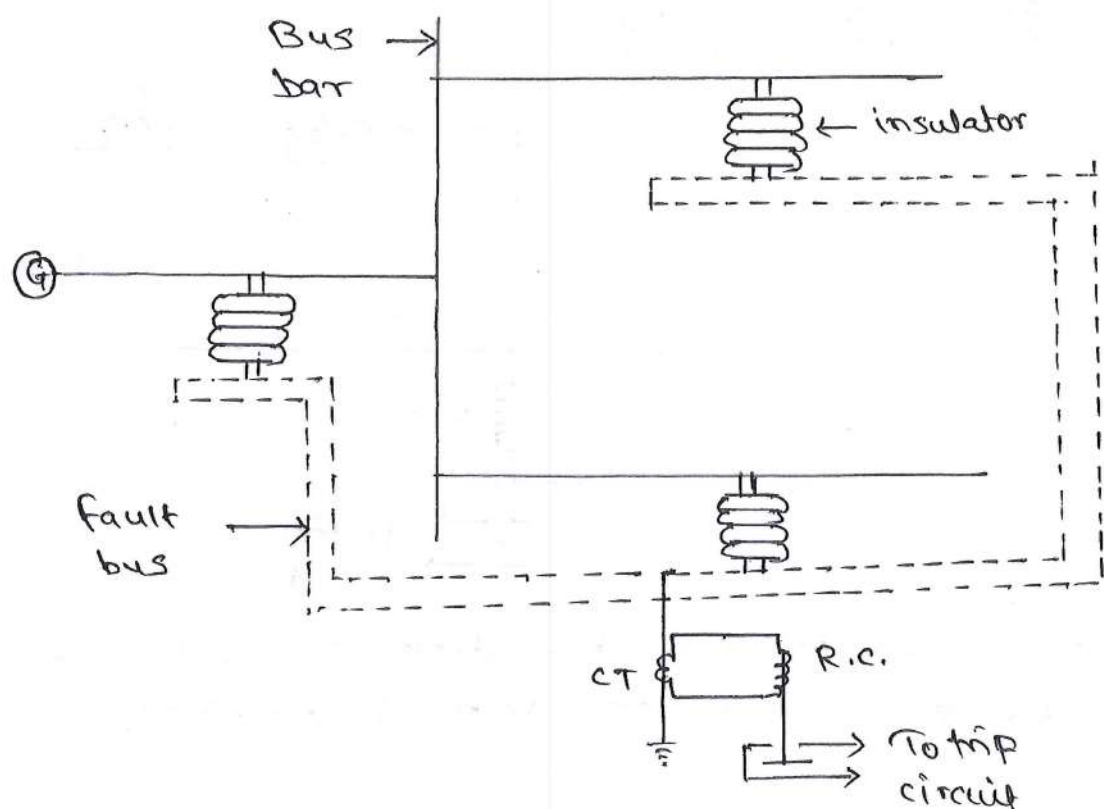


- It works on vector difference between two or more similar electrical quantity.

- Under the normal operating condition current entering into the busbar is equal to the current leaving from the busbar.
- Under the fault condition, vector summation of incoming and outgoing current is non zero. In that case differential current flows through relay coil.
- The relay gets operated the trip circuit and opens the circuit breaker in fault condition.

* Fault bus Protection:

- In fault bus protection, the substation is so designed that every fault is converted into earth fault.
- Following fig. shows fault bus protection scheme.



- In this system, fault bus run around the conductor throughout it's entire length.
- Fault bus earth properly and c.T. is connected in series with it.
- Under the normal condition, there is no current flowing through the Fault bus to ground and relay remains open.
- When the fault occurs there is a connection between conductor and earth fault bus.
- Therefore current flow through the fault bus which operates the relay coil and close the trip circuit.

V] Transmission Line:

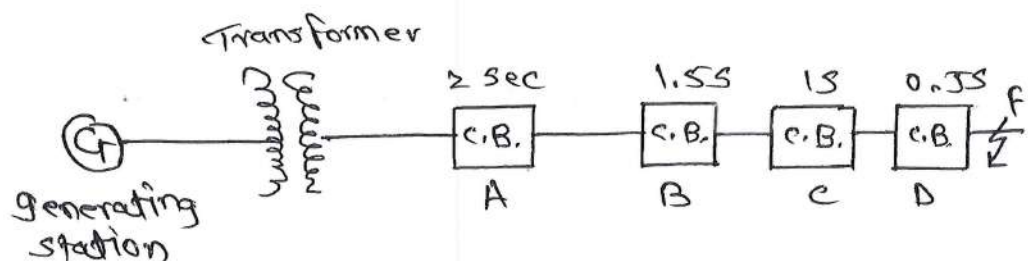
* Requirement of protection of transmission line:

- Fault on transmission line should be detected as fast as possible to maintain the continuity of supply.
- protective system should be capable to identify the location of fault.
- In the event of failure of fault nearest circuit breaker should open and all others remains close.
- Adjustment of C.B. should be provide backup protection on the event of failure of C.B. nearest to the fault.

* over current protection:

i) Time graded over current protection of transmission line [for-radial feeder line]

- In this type of protection, the operating time of relay is set. [definite relay]
- time setting of relay is so graded that, in the event of fault, smallest possible part of system is to be isolate by operating relay which is near to the fault location.



- Fig. shows the time graded protection provided for radial feeder by definite relay.
- In the time graded protection, operating time of relay is fixed.
- i.e. operating time of relay is independent on magnitude of fault current.
- operating time of relay is so graded that distance from the generating station is large then operating time is small.
- From Fig. if fault occurs at F point, then relay at location 'D' is operate after 0.5 sec from the fault occurrence.
- In case, if C.B. at D location is fail to operate then C.B. at location 'C' will provide backup protection and operates after 1 sec from fault occurrence.
- This system applicable for small length feeder line in which the impedance betⁿ substation is lower.

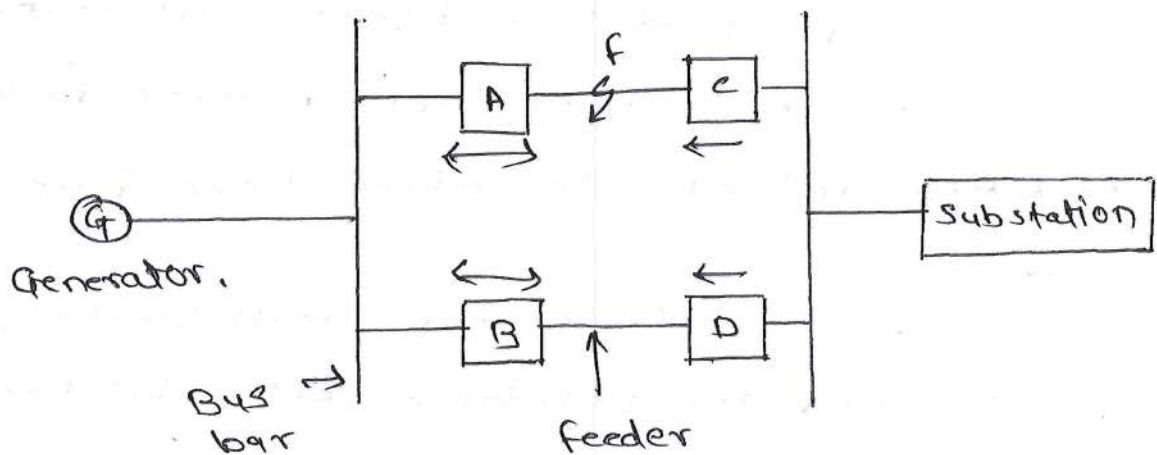
* Disadvantages:

1. If feeder having large length, the operating time near supply side point is more.
2. If L-G fault occurs near to source, in that case amount of fault current will be more because line impedance is less.
3. This system is not suitable for ring main system or interconnected lines.
4. Not suitable for long length lines.
5. Continuity of supply can not be maintained.

ii) Inverse time protection system for radial feeder:

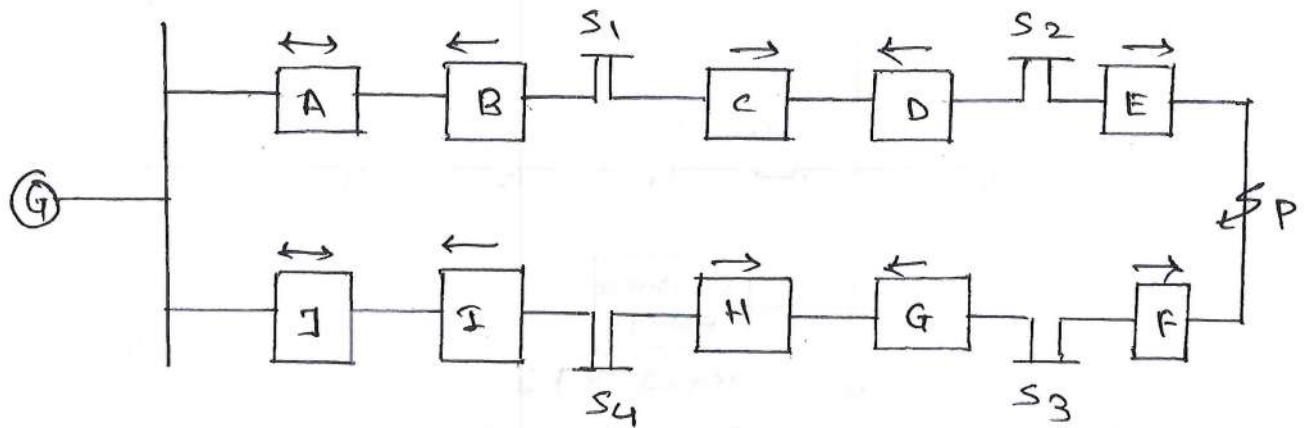
- In inverse time relay, time of operation of relay is depend on magnitude of fault current.
- The operating time of relay is inversly proportional to current magnitude.
- In case of dangerous fault, the nearer relay operate instantly.
- If nearer relay fail to operate then next relay will operate.

iii) Time graded protection of Parallel feeder:



- In the parallel feeder, two feeders are connected in parallel between generating station and substation.
- If the fault occurs on any one feeder then supply is continue and it is maintain by another feeder.
- In this protection system, non-directional relay are use at generating side and directional over current relay are use at substation side.

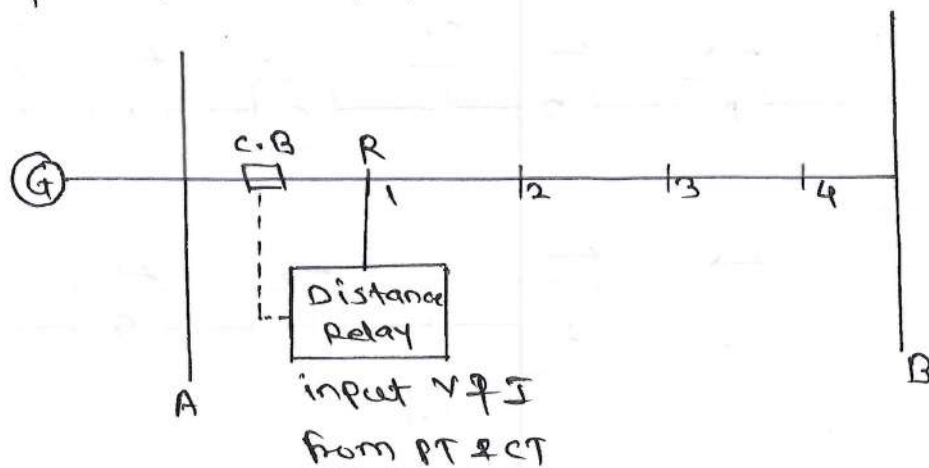
- iv) Ring Main system:



- Fig. shows ring main system, in which generator supply electrical energy to four substations i.e. S_1, S_2, S_3, S_4 .
- It consist of non-directional relay at generator side and directional relay at substation side.
- If fault occurs at point 'P', then only C.B E & F will operate to clear the fault where at other section of ring should be maintain the continuity.
- It is clear that relay at ABCD as well as JIHG will not trip.
- Therefore only relay at E & F will operate and clear the fault or isolate the faulty section.

* Distance protection:

- The impedance of transmission line is proportional to its length. If distance is to be measured, relay that can measure impedance can be used. This relay can measure impedance upto predetermined point.



- let the distⁿ betⁿ AB is 5 km, for simplicity assume total impedance is 5Ω which is equally distributed along the length. Thus impedance is 1Ω per km.
- The distance relay is connected at point R, which is 1 km from A.
- The ip quantities to this relay are voltage and current at point R. It is sensed by CT & PT.
- suppose sending end voltage is 100 Volt and maximum current is 5 Amp.
- If fault occurs at 1 km, the impedance up to the fault is
$$Z = 1 \text{ km} \times 1\Omega/\text{km} = 1\Omega$$
if voltage remains constant 100V,
$$\text{c/n } I = \frac{V}{Z} = \frac{100}{1} = 100 \text{ A.}$$

The relay measures, $V = 100 \text{ V}$, $I = 100 \text{ A}$

$$\text{Hence } Z = \frac{100 \text{ V}}{100 \text{ A}} = 1 \Omega$$

$\therefore$ Estimated distance $= 1 \text{ km}$

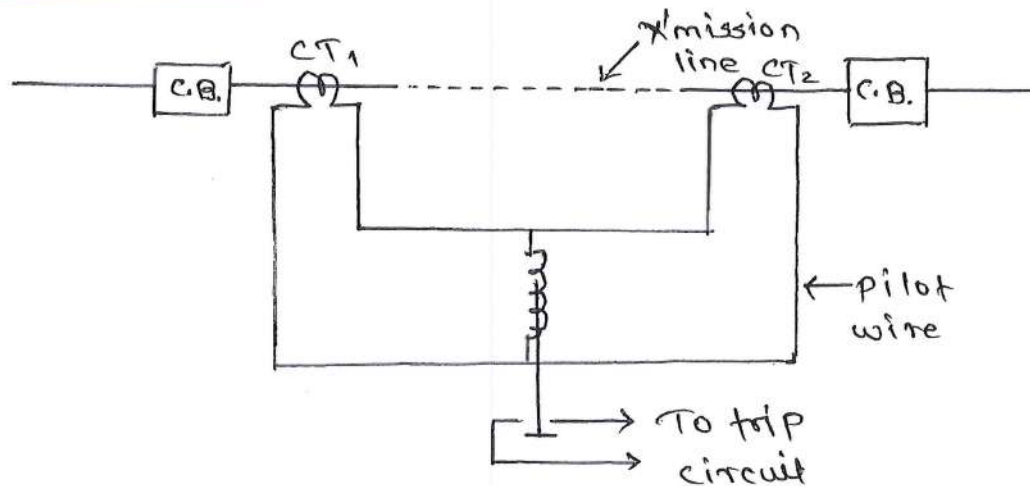
Since the relay trips the circuit breaker,

VI] pilot wire protection:

There are two types of pilot wire protection

- i) current balance differential protection or Translay scheme of protection
- ii) Merz price voltage balance protection

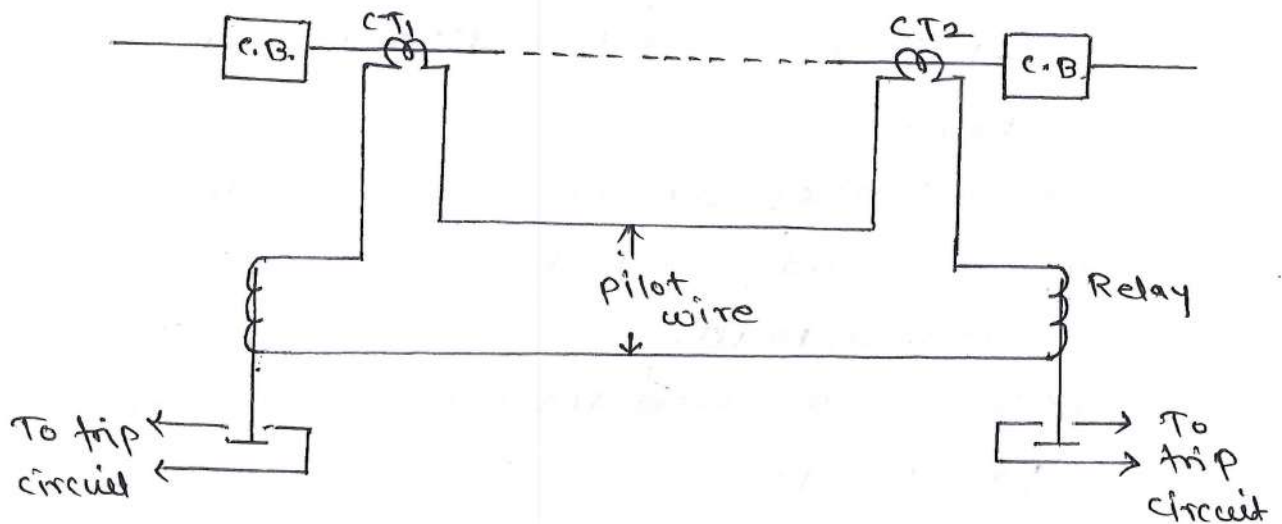
i) current balance differential protection:



- In the current differential protection system, two C.T. are placed at each end of transmission line.
- Under normal condition, current flowing through pilot wire are equal and no differential current flows through the relay coil and relay remains open.
- When fault occurs on pilot wire then current through the secondary of CT are not equal and differential current flows through relay and circuit breaker gets open.
- This system is based on current entering at one end is equal to current leaving at the other end.

* Advantages: 1) It is economical, because only two pilot wires used for 3- ϕ system also
2) Normal CT can be used,
at normal condition it does not affect the operation.

ii) Merz price voltage balance protection:



- Fig. shows arrangement for this scheme.
- Two identical CT's are placed at both end of the line.
- The CT secondaries are connected in phase opposition i.e. their secondary voltage oppose each other.
- Relay coils are connected in CT Secondaries as shown.
- Under normal condition, no current flows through relay coil and relay remains open.
- When the fault occurs, CT₁ secondary current increase compared to CT₂, so voltage of CT secondaries are no longer equal.
- current flows through pilot wire and relay coil
- Relay operates circuit breaker and isolate the faulty section.

* Advantages: 1) It provide fast operation

2) It provide the protection against earth fault.

3) Amount of damage to the system reduces.

4) It provide instantaneous protection for ground fault.

5) It can be used for ring system and parallel feeder system.

* Disadvantages: 1) CT should be identical

2) If pilot wire breaks, malfunctioning occurs.

3) Expensive in cost

4) Not suitable for very long lines.



Subject Incharge

Mr. N. S. Borse


HOD

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Unit - 4

Question Bank

- ⇒ ~~state the need of~~ ~~curr~~.
- 1) state any four abnormalities in case of transformer.
- 2) With the help of diagram, explain earth-fault protection of 3- ϕ alternator.
- 3) Explain single Phasing preventer to protect 3- ϕ induction motor.
- 4) With the help of diagram, explain fault bus protection to protect the bus-bar system.
- 5) With the help of neat diagram explain the construction & working of Buchholz relay.
- 6) With the help of neat diagram explain differential protection of alternator. State any two limitations. What do you mean by percentage differential protection.
- 7) With the help of neat diagram explain working of differential pilot wire protection of transmission lines. State any four limitations of this scheme.
- 8) List out any four faults that occurs in alternator.
- 9) State the application of Pilot wire protection scheme.
- 10) State the location where buchholz relay is installed in the protection of transformer.

- 11) state the working of differential protection scheme provided for bus-bar.
- 12) state the specification of CT & PT as protective transformer.
- 13) With neat sketch, state the importance of single phasing preventer.
- 14) A, 3- ϕ , 33/66 kV star delta transformer is protected by merv-Price circulating current system. If the CT on low voltage side has a ratio of 300/5, determine the ratio of CT on high voltage side.
- 15) List out different fault taking place in induction motor. suggest protection of small HP motor and high HP motor from short circuit.



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