

Module-3

- **Pilot Relaying Schemes:** Introduction

 - Wire Pilot Protection

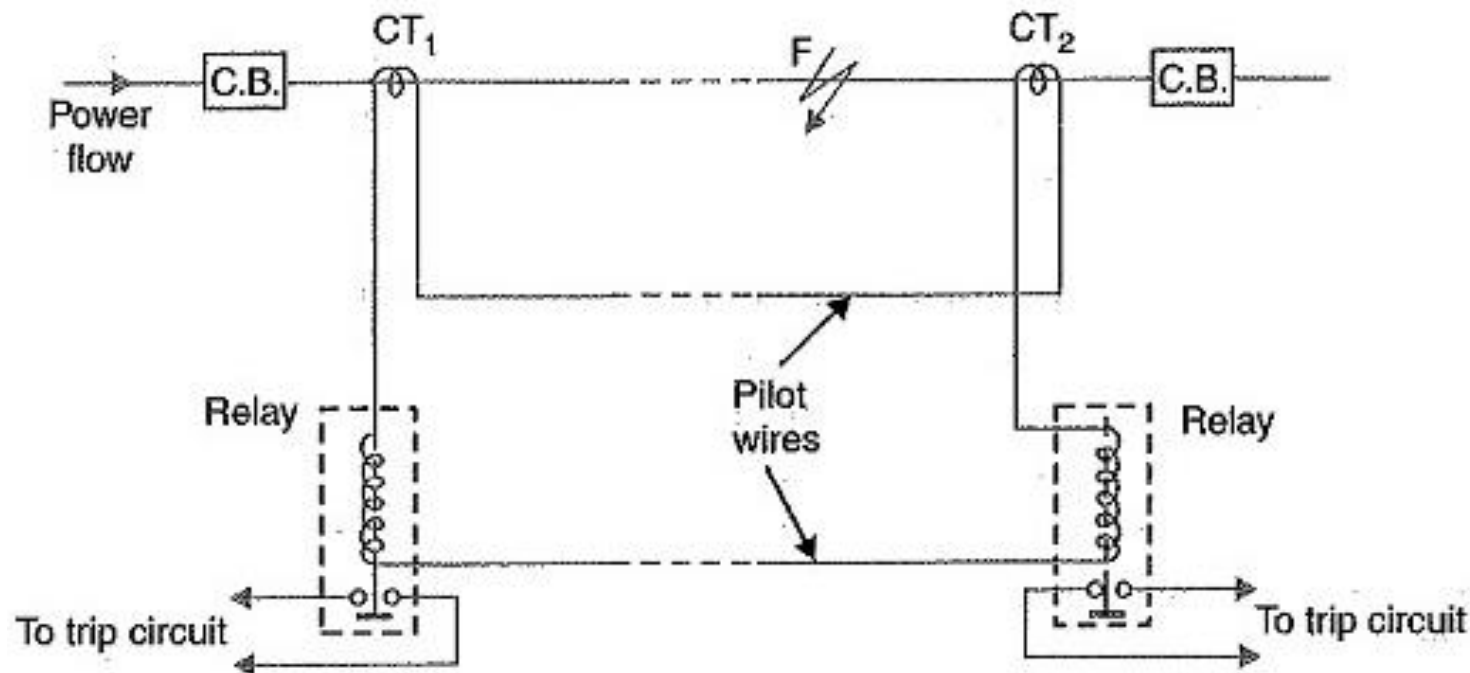
 - Carrier Current Protection

- **Differential Protection**
- **Generator Protection**
- **Transformer Protection**
- **Buchholz Relay**
- **Bus-Bar Protection**
- **Frame leakage protection**

- Pilot relaying schemes are used for the protection of transmission line sections.
- They fall into the category of unit protection.
- Electrical quantities at the two ends of the transmission, line are compared and hence they require some sort of interconnecting channel over which information can be transmitted from one end to the other. Such an interconnecting channel is called a Pilot.

A Pilot wire is a communication cable between the two relays located at different ends. Whenever a transmission line or equipment is to be protected by using a **differential relay**, a wire is connected between the **CTs (current transformer)** which are located in different ends of the protection zone to provide the path for the circulating current produced in an abnormal condition(fault) which is sensed by the relay and therefore breaker trips.

This protection is also called as **Differential Pilot Wire Protection**.



Three different types of such channels are presently in use, namely

1. Wire Pilot.
2. Carrier-current Pilot
3. Microwave Pilot.

- A wire pilot may be buried private cables or private telephone lines, Wire pilot schemes are usually economical for distances up to 30 km. For short important lines, wire-pilot relaying is recommended
- Carrier-current pilot is one in which a low-voltage, high frequency signal (50 kHz–700 kHz) is used to transmit information from one end of the line to the other. In this scheme, the pilot signal is coupled directly to the same high voltage line which is to be protected. This type of pilot is also called a power line carrier
- Carrier-current schemes are more economical for longer distances. For long lines, carrier-current schemes are cheaper and more reliable than wire-pilot schemes.

- When the number of services requiring pilot channels exceeds the technical or economical capabilities of carrier-current pilot, the microwave pilot is employed.
- Microwave pilot is a radio channel of very high frequency, 450 to 10,000 MHz
- Microwave pilot distance range up to 150 km is possible in a flat country, otherwise it is limited by hills and building. The link may operate up to 40 to 60 km without repeater station. The system is applicable only where there is a clear line of sight between stations. The power requirement for signal transmission is less than a watt because highly directive antennas are employed.

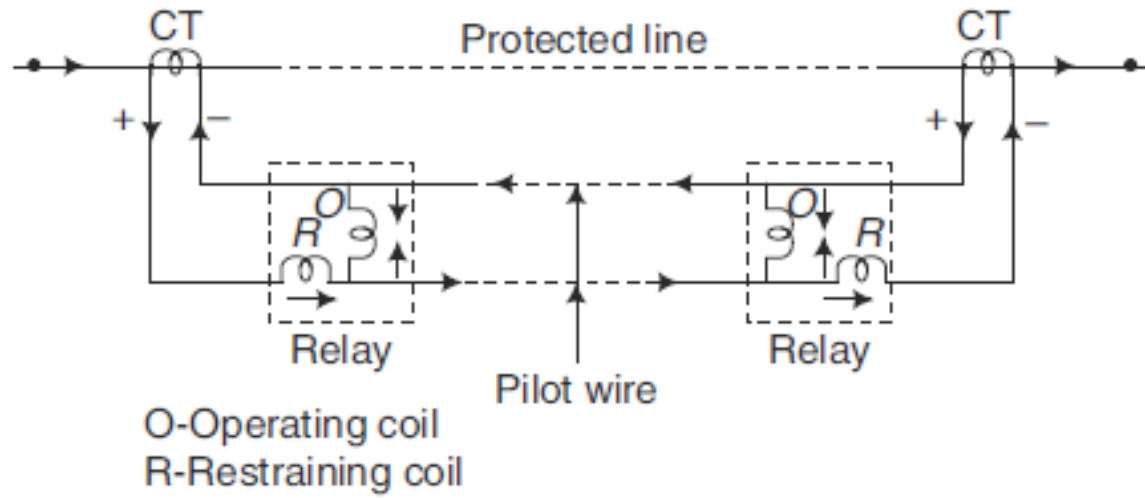
➤ WIRE PILOT PROTECTION

- In a wire pilot relaying scheme, two wires are used to carry information signals from one end of the protected line to the other.
- A wire pilot may be buried cable or a pair of overhead auxiliary wires other than the power line conductors.
- The scheme is a unit protection and operates on the principle of differential protection.
- The comparison is made between the CT secondary currents at the two ends of the line.
- As the pilot channels are very expensive, a single phase current is derived from three-phase currents at each end of the line, thereby using only a pair of pilot wires to carry information signal

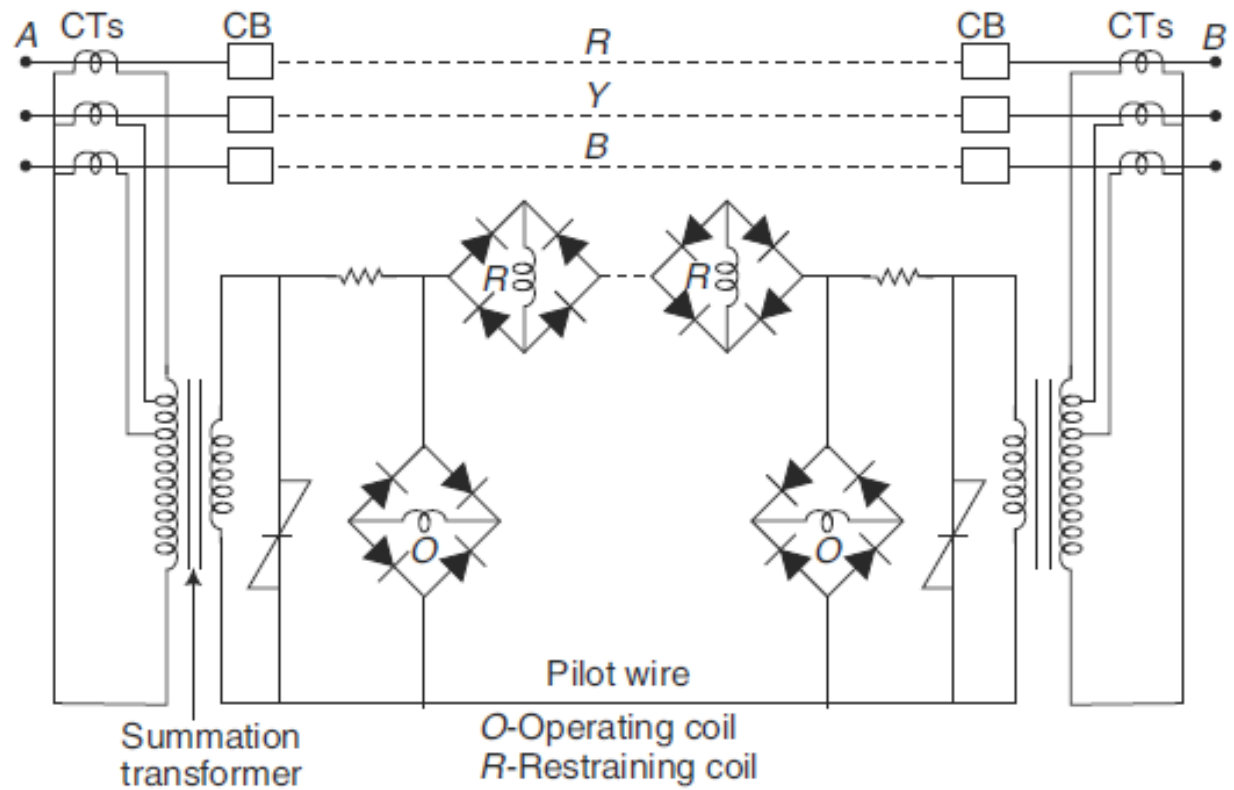
The two alternative operating principles which are used for most of the practical schemes are circulating current principle and balanced voltage principle.

Most wire pilot schemes use amplitude comparison in circulating current scheme since they are easier to apply to multi-ended lines and are less affected by pilot capacitance.

Circulating Current Scheme

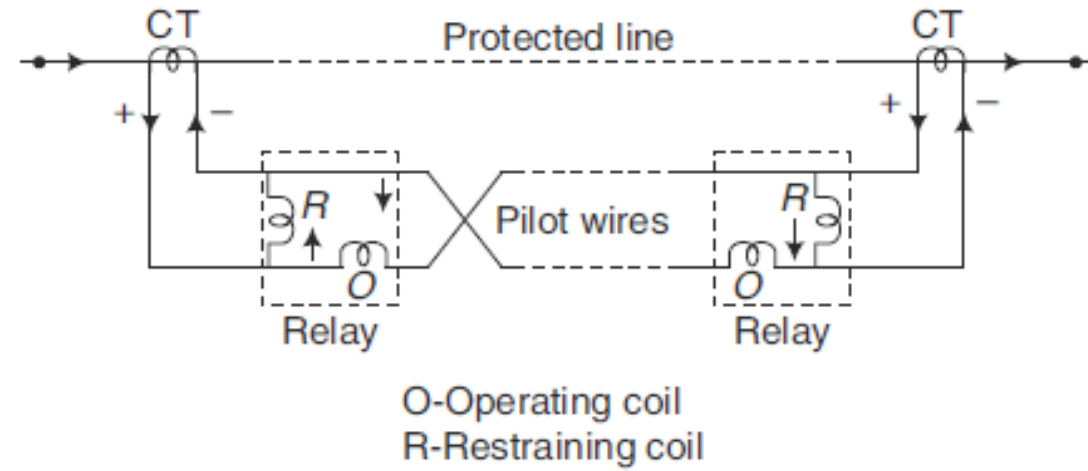


Schematic diagram of circulating current principle

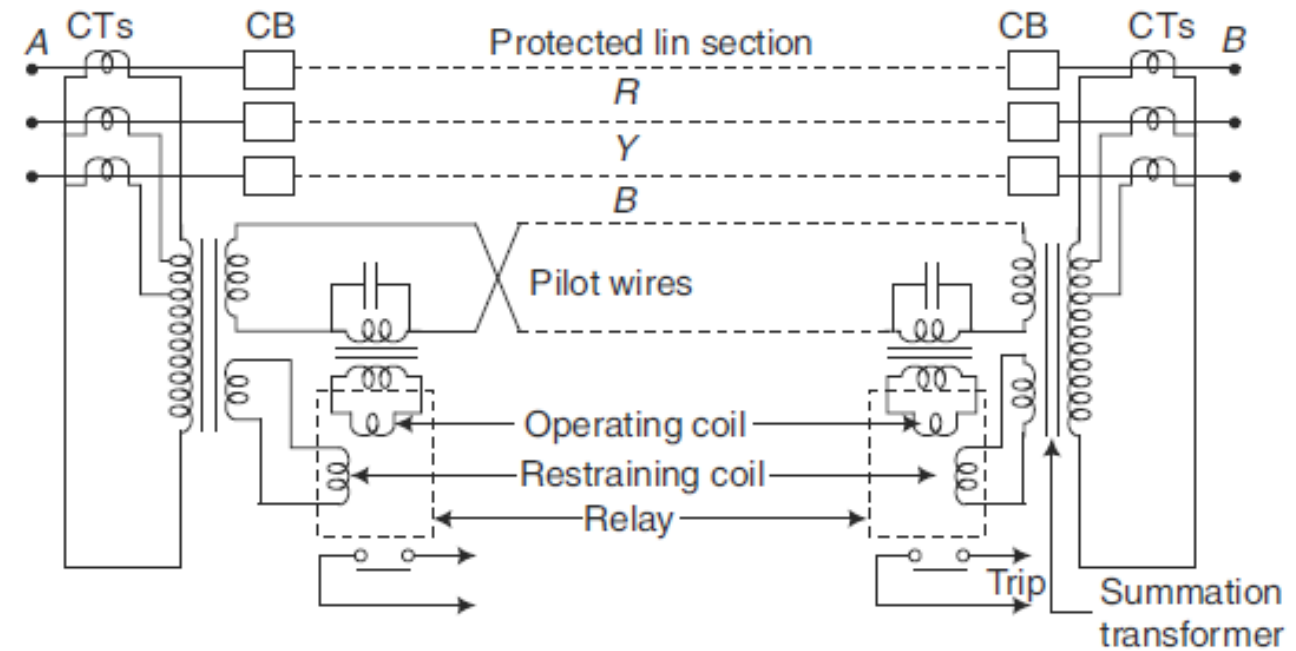


Practical scheme based on circulating current principle

Balanced Voltage Principle

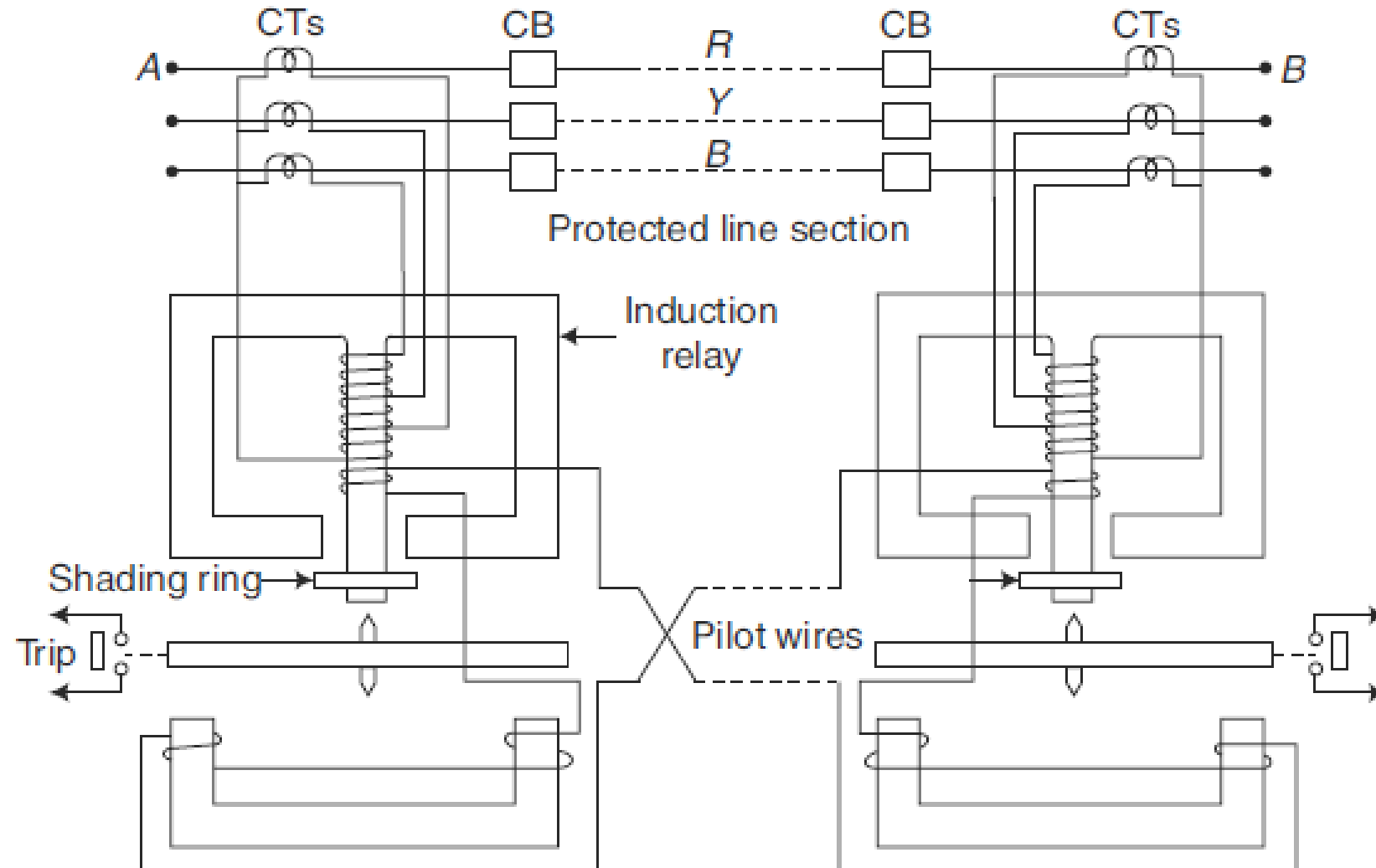


Schematic diagram of balanced voltage principle



Practical scheme employing balanced voltage principle

Transley S Protection

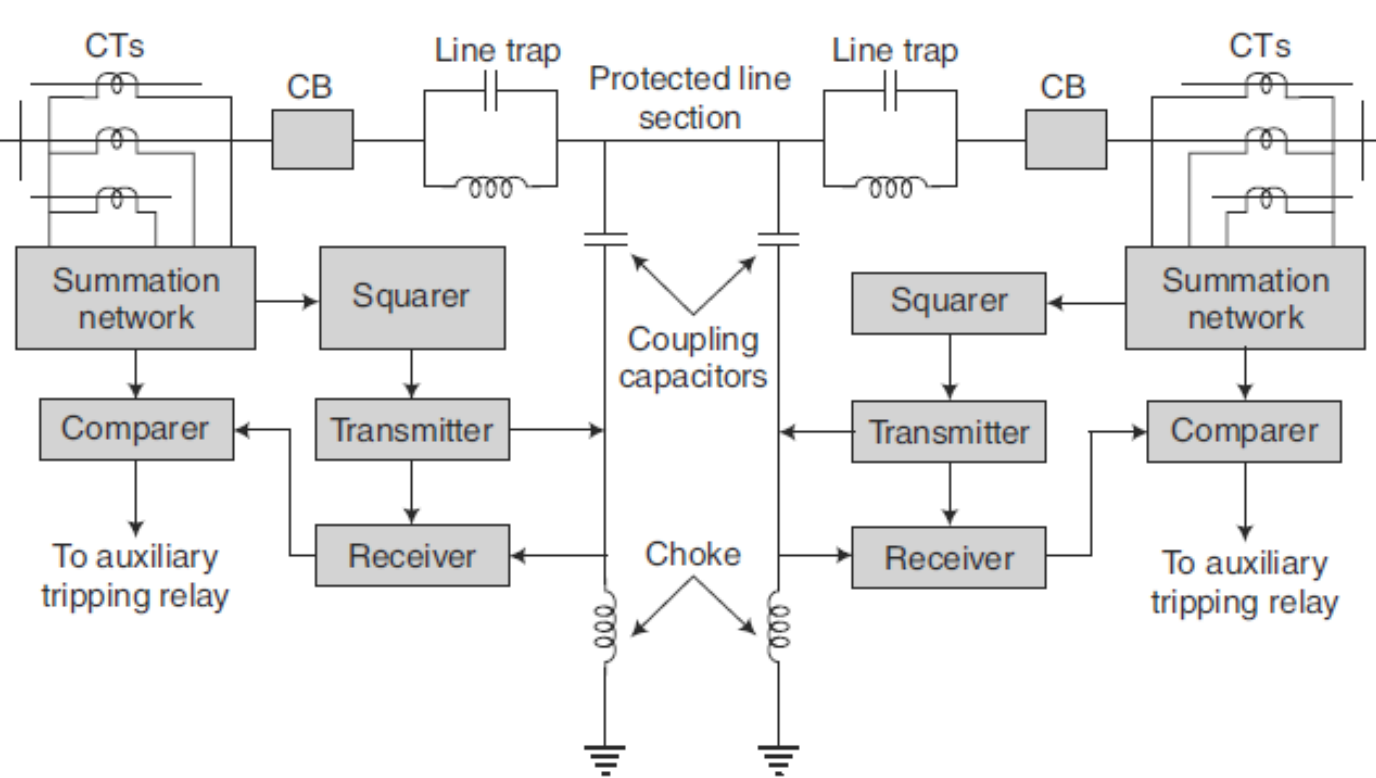


Transley Scheme

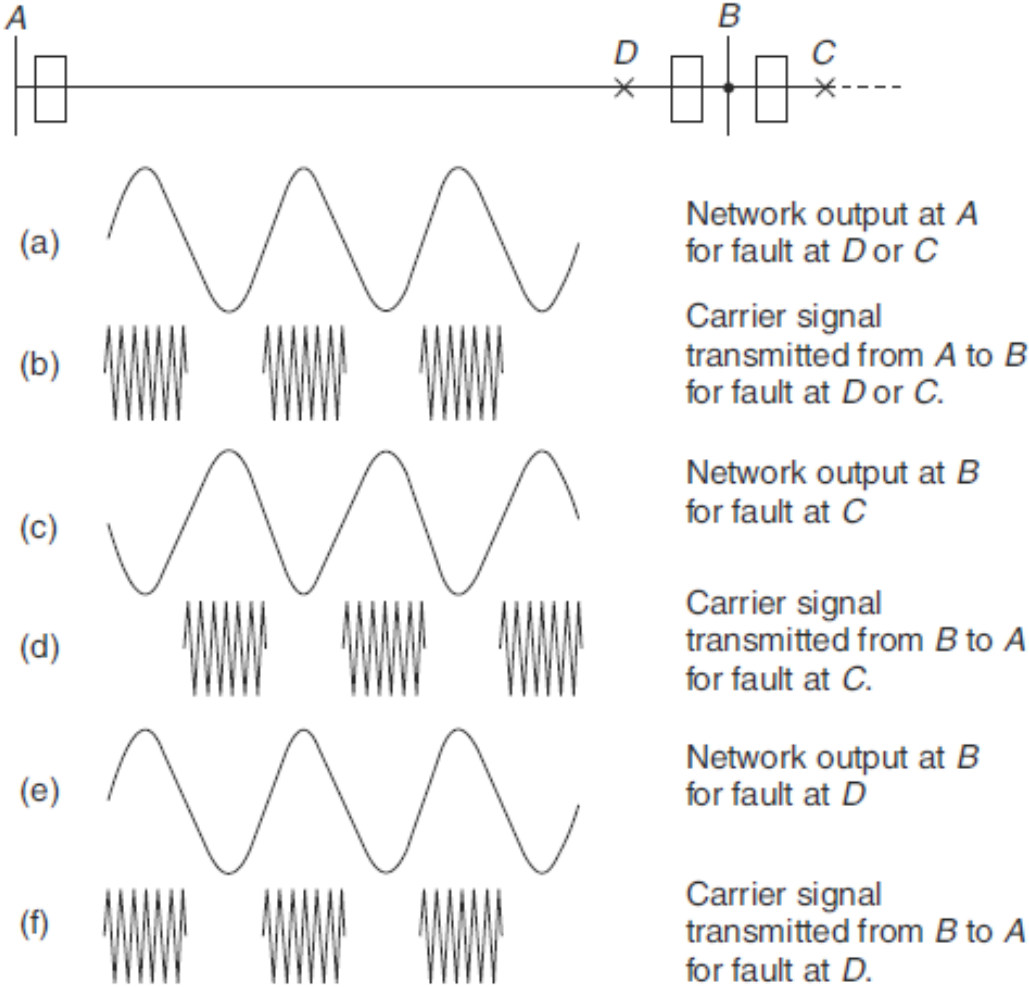
CARRIER CURRENT PROTECTION

The most widely used scheme for the protection of EHV and UHV power lines. In this scheme a carrier channel at high frequency is employed. The carrier signal is directly coupled to the same high voltage line that is to be protected. The frequency of the carrier signal is 50Hz to 700kHz

Phase Comparison Carrier Current Protection



Schematic diagram of phase comparison carrier current protection



Transmission of carrier signals during internal and external fault conditions

Differential Protection

“A differential relay responds to vector difference between two or more similar electrical quantities”.

From this definition the following aspects are known:

- The differential relay has at least two actuating quantities say i_1, i_2 .
- The two or more actuating quantities should be similar *i.e.* current/current.
- The relay responds to the vector difference between the two *i.e.* to $i_1 - i_2$, which includes magnitude and/or phase angle difference.

Differential Protection

Differential protection is generally unit protection. The protected zone is exactly determined by location of CT's or VTs. The vector difference is achieved by suitable connections of current transformer or voltage transformer secondaries

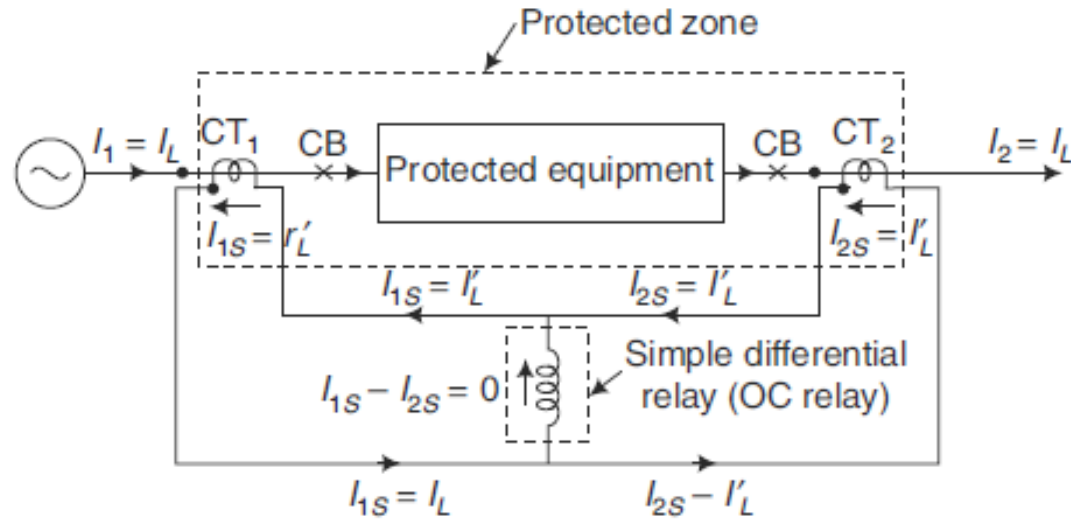
A differential relay is a suitably connected overcurrent relay which operates when the phasor difference of currents at the two ends of a protected element exceeds a predetermined value. Most of the differential relays are of current differential type.

The following are the various types of differential relays.

- (i) Simple (basic) differential relay
- (ii) Percentage (biased) differential relay
- (ii) Balanced (opposed) voltage differential relay

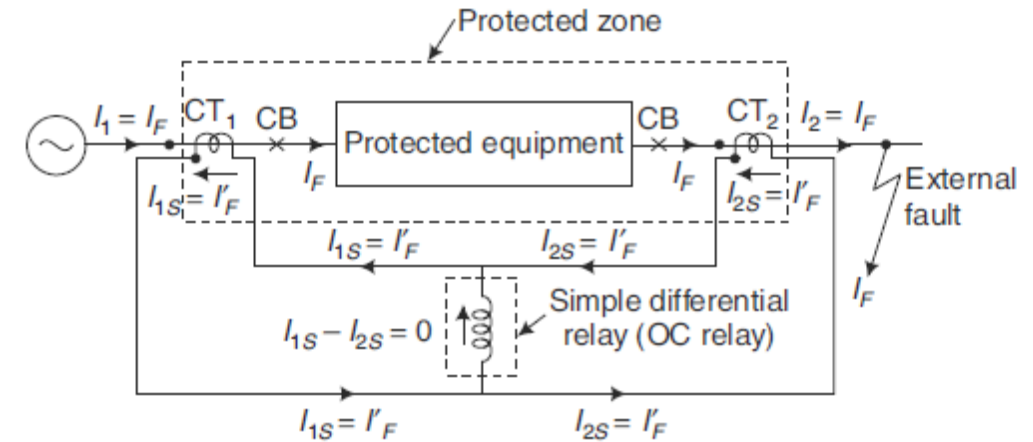
Simple (basic) differential relay

Behaviour of Simple Differential Protection during Normal condition



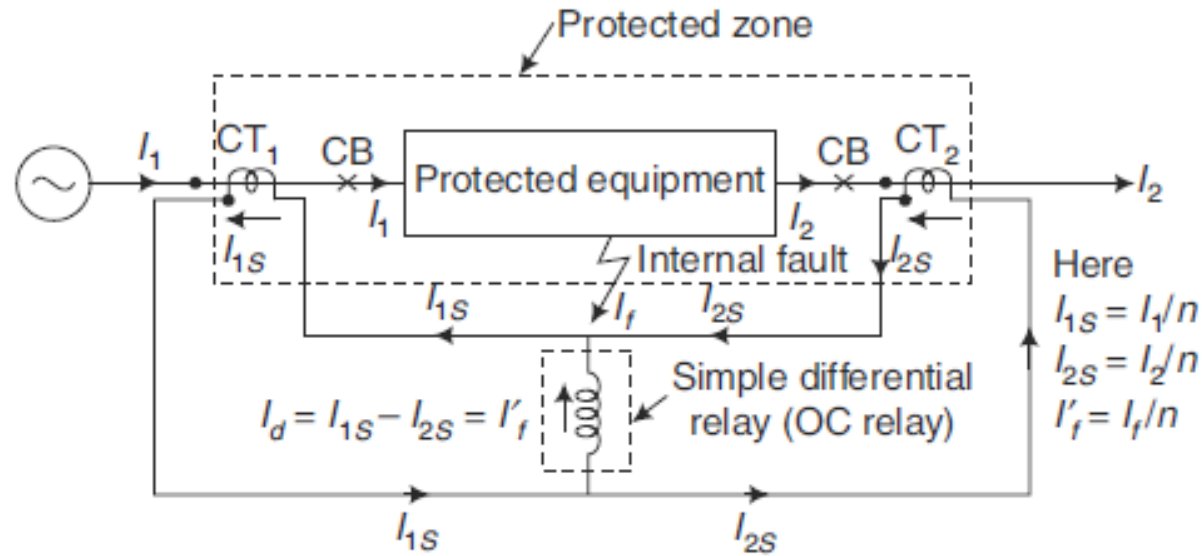
Simple differential protection scheme behaviour under normal condition.
($I_1 = I_2 = I_L$ and $I_{1S} = I_{2S} = I'_L$ hence $I_{1S} - I_{2S} = 0$)

Behaviour of Simple Differential Protection during External Fault



Behaviour of simple differential protection scheme on external (through) fault.
($I_{1S} - I_{2S} = 0$) (No current in OC relay)

Behaviour of Simple Differential Protection during Internal Fault



$$I_1 = I_2 + I_f, \text{ Differential current } (I_d) = I_{1s} - I_{2s} = I'_f$$

If both CTs (CT₁ and CT₂) have same CT ratio (n), $I_{s1} = I_1/n$, $I_{s2} = I_2/n$ and $I'_f = I_f/n$

If both CTs have different CT ratios (n_1 and n_2) as in the case of transformer,

$$I_{s1} = I_1/n_1 \text{ and } I_{s2} = I_2/n_2$$

DIFFICULTIES IN DIFFERENTIAL PROTECTION

- **Difference in pilot wire lengths**. The current transformers and machine to be protected are located at different sites and normally it is not possible to connect the relay coil to the equipotential points. The difficulty is overcome by connecting adjustable resistors in series with the pilot wires. These are adjusted on site to obtain the equipotential points.
- **CT Ratio errors during short-circuits**. The current transformer may have almost equal ratio at normal currents. But during short-circuit conditions, the primary currents are unduly large. The ratio errors of CT's on either sides differ during these conditions due
 - 1) Inherent difference in CT characteristic arising out of difference in magnetic circuit, saturation conditions etc.
 - 2) Unequal D.C. components in the short circuit-currents.

DIFFICULTIES IN DIFFERENTIAL PROTECTION

Tap-changing. The tap-changing causes change in transformation ratio of a transformer. Thereby the CT ratios do not match with the new-tap settings, resulting in current in pilot wires even during healthy condition. This aspect is taken care of by biased differential relay

Percentage (biased) differential relay

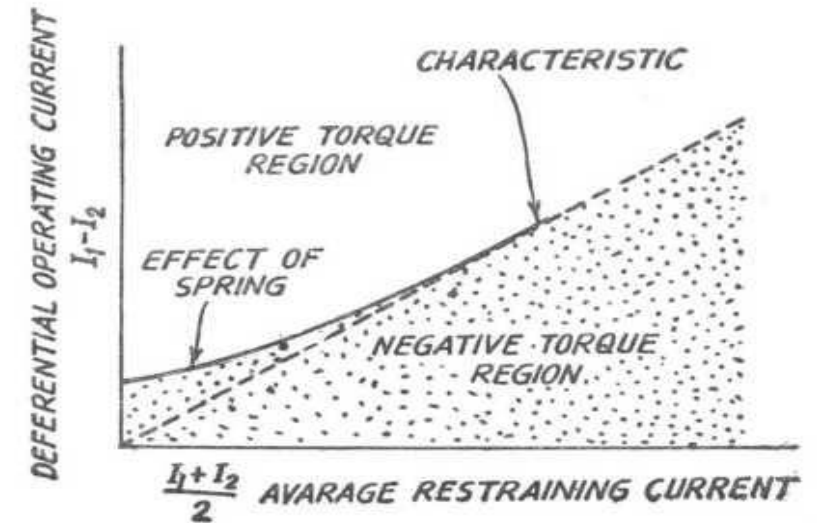
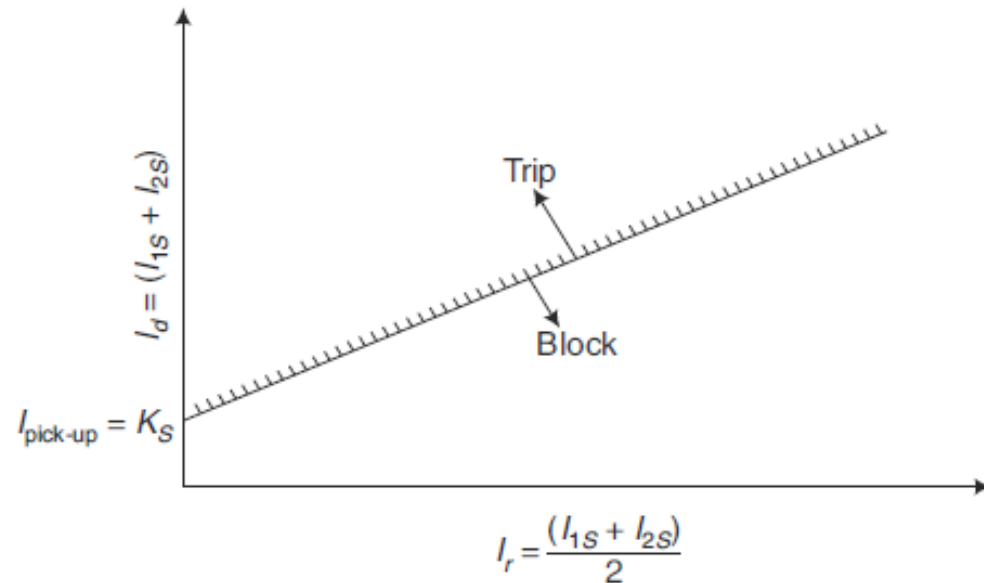
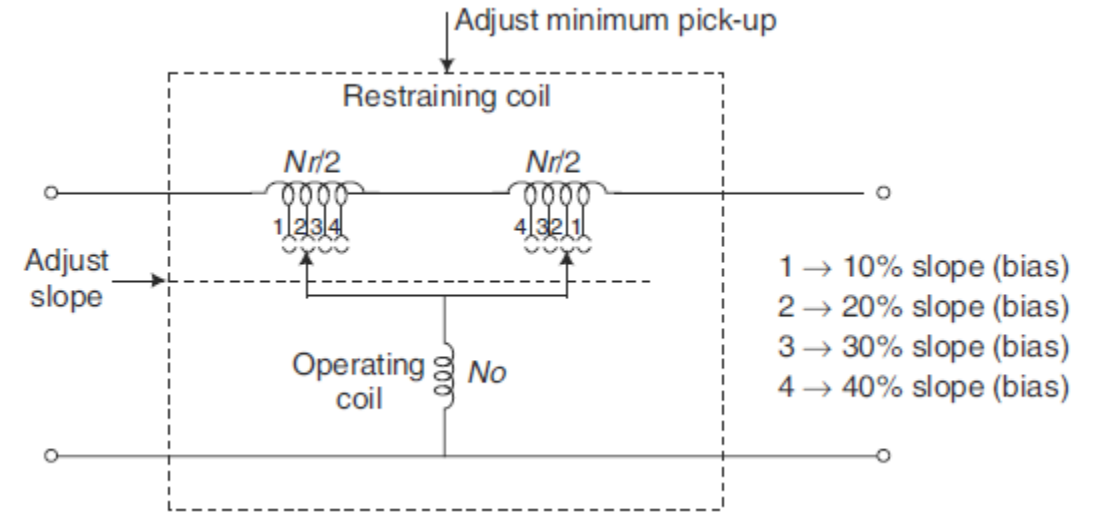
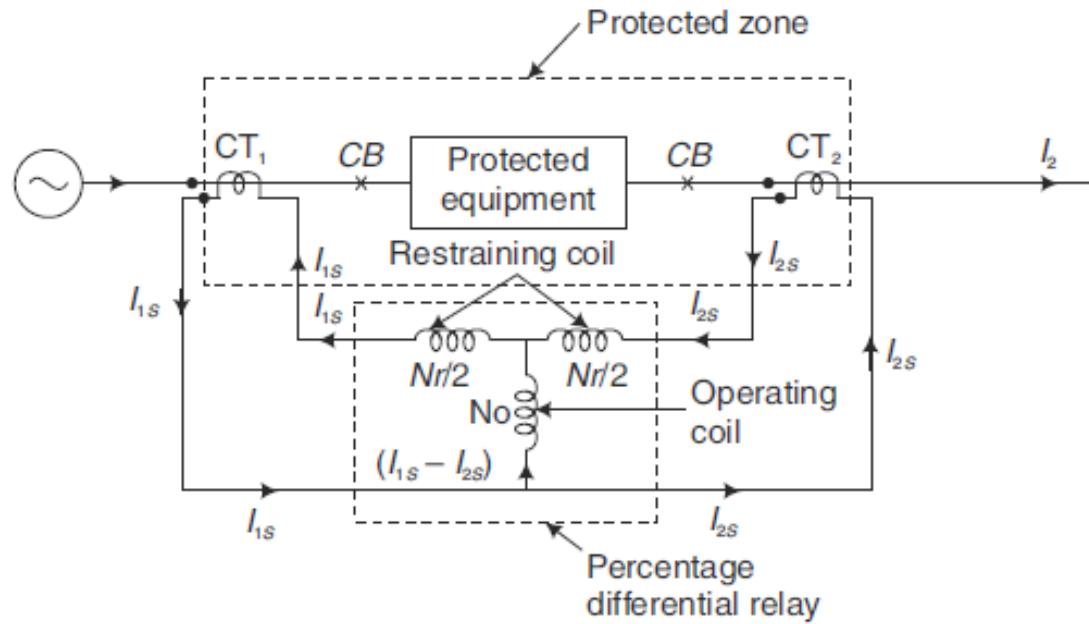
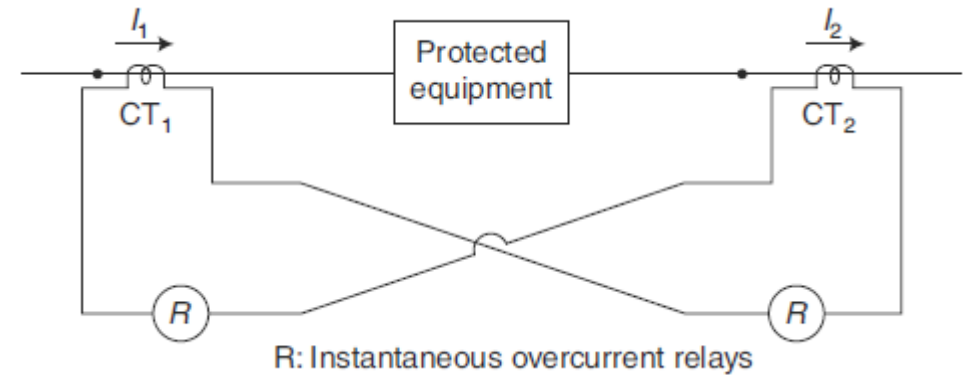
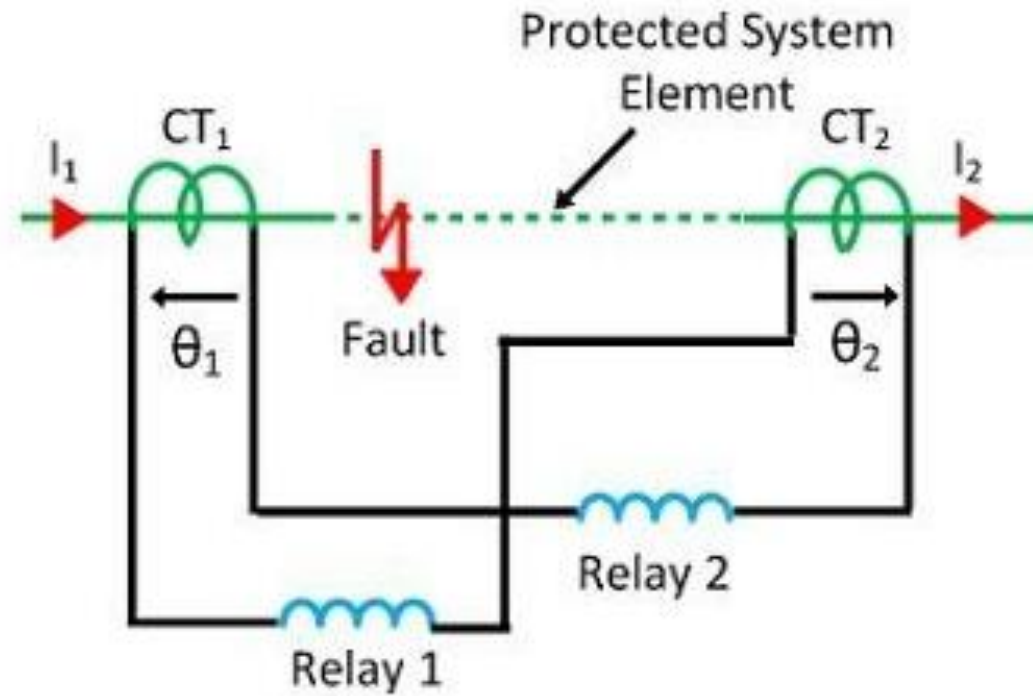


Fig. Operating characteristic of differential relay.

Balanced (Opposed) Voltage Differential Relay

- The current differential relay is not suitable for the protection of the feeders. For the protection of the feeders, the voltage balance differential relays are used.
- The voltage differential relay uses two similar current transformer places across the protective zone with the help of pilot wire.
- The relays are connected in series with the secondary of the current transformer. The relays are connected in such a way that no current flows through it in the normal operating condition.
- The voltage balance differential relay uses the air core CTs in which the voltages induces regarding current.





When the fault occurs in the protection zone, the current in the CTs become unbalance because of which the voltage in the secondary of the CTs disturbs.

The current starts flowing through the operating coil. Thus, the relay starts operating and gives the command to the circuit breaker to operates.

MODULE 3: GENERATOR PROTECTION

A modern generating set is generally provided with the following protective schemes.

(i) Stator protection

(a) Percentage differential protection

(b) Protection against stator inter-turn 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) Overvoltage protection
- (b) Overspeed protection
- (c) Protection against motoring
- (d) Protection against vibration
- (e) Bearing-overheating protection
- (f) Protection against auxiliary failure
- (g) Protection against voltage regulator failure

Introduction

- A generator is the heart of an electrical power system, as it converts mechanical energy into its electrical equivalent, which is further distributed at various voltages.
- The capacity of generators has increased in recent times from 50 MW to 500 MW, with the result that the loss of any single unit may cause system instability.
- Power-generating plants contribute to approximately 50% of the capital cost in an electrical power system, and the generator is the most expensive electrical equipment in a power plant. The protection of generators requires more consideration, to reduce the outage period by rapid clearance of faults.

- A modern generating unit is a complex system comprising the generator stator winding, associated transformer, rotor with its field winding and excitation system, and prime mover with its associated auxiliaries.
- Faults of many kinds can occur within this system, for which different forms of electrical and mechanical protection are required.
- The generator outage caused by faults, abnormal operating conditions, or maloperation of the generator protection scheme is very costly in terms of repair or replacement of any part and amounts to loss of revenue because of the loss of generation.
- Abnormal operating conditions, other than short circuits, do not necessarily require the immediate removal of a machine from service, and that might be left to the control of an assistant.

- As generators are exposed to more harmful operating conditions than any other power system element, more sophisticated and innovative protection schemes are required.
- Protection relay technology, over the last two decades, has evolved from single-function electromechanical relays to static relays and finally to multifunction digital/numerical relays.
- Multifunction numerical relays are capable of providing complete protection, including differential protection, stator ground fault protection, generator field winding fault protection, stator winding turn-to-turn fault protection, out-of-step protection, and loss-of-excitation protection, to generators of all sizes at low cost.

Differential Protection

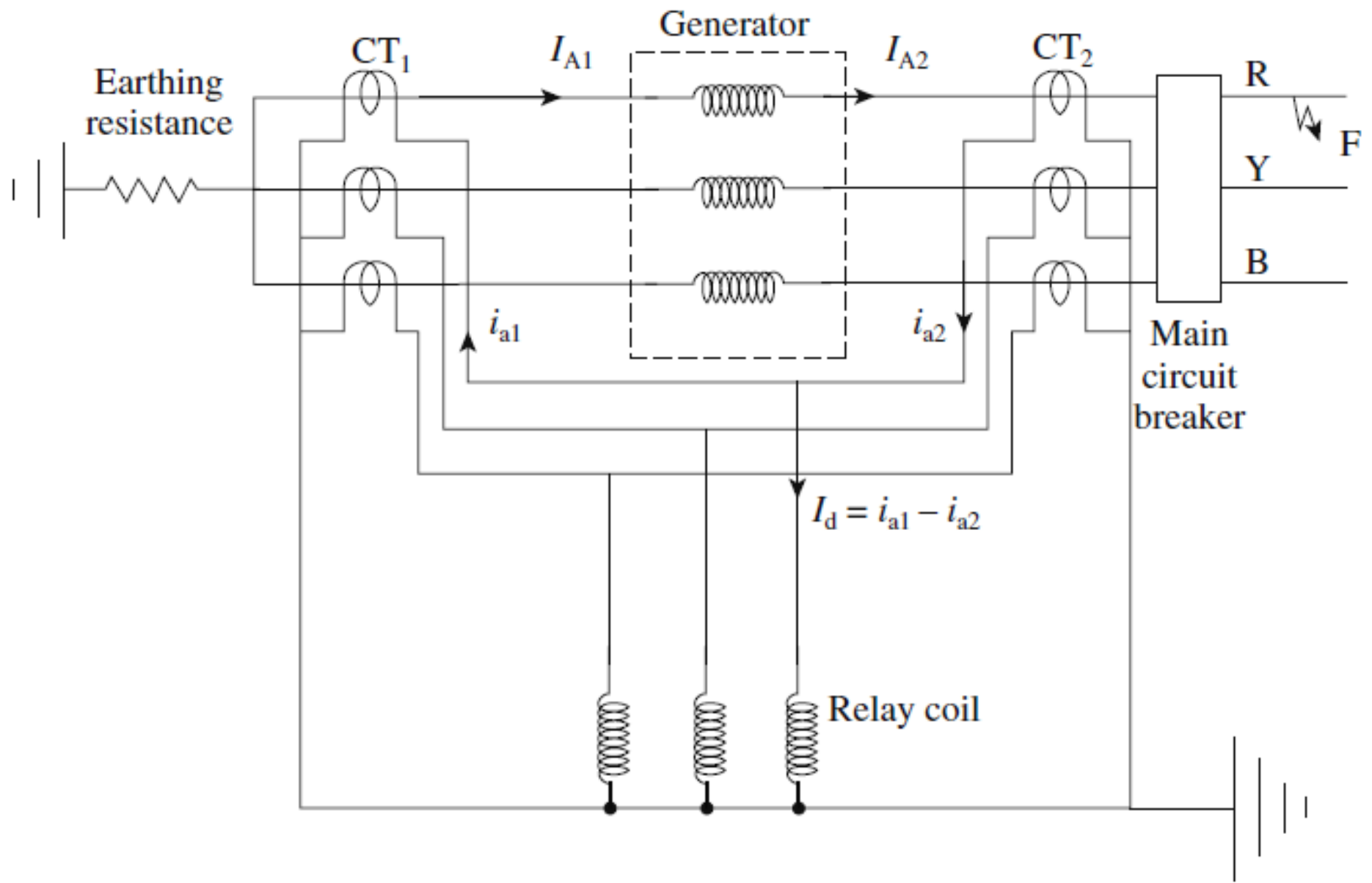
- Differential protection is the protection of selected equipment based on the current measuring principle at the input and output side of the equipment being protected.
- Depending on the earthing method used, the neutral can also be incorporated in measurement and balancing.
- The area between the input and output connections of current transformers (CTs) for the protection of the equipment is classified as the protection zone supervised by the relay unit.
- Protection against the stator phase faults is normally covered by a high-speed differential relay covering the three phases separately.
- All types of phase faults (phase–phase) and phase-to-ground faults are covered by this type of protection scheme.

- Differential protection is generally applied to generators with ratings more than 1 MVA.
- It provides protection to the stator windings of a generator against various types of phase faults.
- If a generator is solidly grounded, then the magnitude of ground fault current is very high which can be easily detected by the differential relaying scheme.
- However, if the generator is grounded through high impedance, then the ground fault currents may not have sufficient magnitude to operate the differential relay, particularly when the fault occurs closer to the neutral point of the generator stator winding.

Circulating Current/Mertz-Price Differential Protection

- In this scheme, the primaries of the CTs are connected in series on both sides of each phase winding of the generator.
- The secondaries of the CTs are connected in an additive manner to pass the circulating currents through a closed path.
- The differential relay checks constantly on the secondary sides of CTs as to whether the incoming current of a phase winding is equal to the respective outgoing current of the same winding.
- If currents on the primary sides, that is, I_{A1} and I_{A2} , have the same magnitude, then the secondary side currents, that is, i_{a1} and i_{a2} , will also have the same magnitude, considering that the CTs on both sides have the same transformation ratio and have identical characteristics.

Circulating Current/Mertz-Price Differential Protection



Circulating Current/Merz-Price Differential Protection

- If there is a significant difference between the CT secondary currents (I_d) on both sides of the windings, then this indicates a fault within the protection zone of the stator winding of the generator.
- Hence, the differential relay trips if the value of I_d exceeds a predetermined threshold value (relay setting).
- On the other hand, during external faults, the differential relay remains stable and does not initiate a trip signal.
- If the CTs are identical in nature, then the functioning of the differential relay is straightforward.
- However, in practice, it is impossible to achieve CTs with identical saturation characteristic

Circulating Current/Mertz-Price Differential Protection

- Hence, the secondary currents of CTs are unequal even though the primary currents are the same.
- This current is widely known as spill current. This spill current passes through the relay and may maloperate the relay if its value exceeds the setting of the relay.
- This is possible particularly in case of heavy through-fault conditions.
- Moreover, if the length of the connecting wires (also known as pilot wires) is unequal, then the value of the spill current increases.
- In order to avoid maloperation of the differential relay in these situations, a stabilizing resistance is connected in series with the relay.
- However, incorporation of stabilizing resistance reduces the sensitivity of the relay during an internal fault.

Circulating Current/Mertz-Price Differential Protection

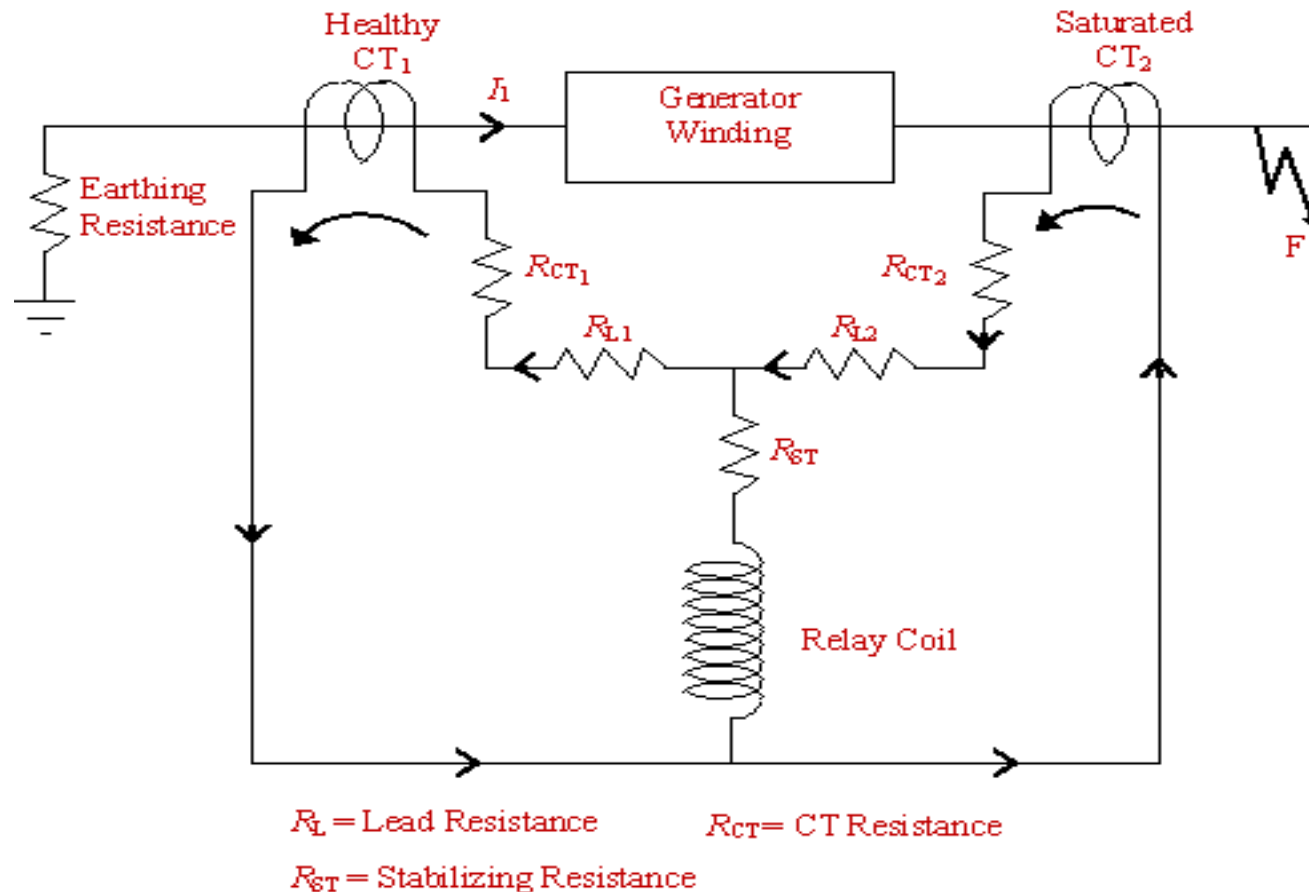
- However, in practice, it is impossible to achieve CTs with identical saturation characteristic.
- Hence, the secondary currents of CTs are unequal even though the primary currents are the same.
- This current is widely known as *spill current*. This spill current passes through the relay and may maloperate the relay if its value exceeds the setting of the relay.

High Impedance Differential Protection

- The high impedance differential protection scheme differs from the biased differential protection scheme in the manner in which the relay stability is accomplished in case of external faults and by the fact that the differential current must be managed through the electrical connections of the CT secondary circuits.
- In the event of a heavy through-fault, it is quite possible that the CT may saturate, and hence, current flows through the saturated CT rather than through the relay. The remedy for this is to use a tuned relay element that provides the required stability. The necessary high impedance is gained by adding an external resistance in the relay circuit.

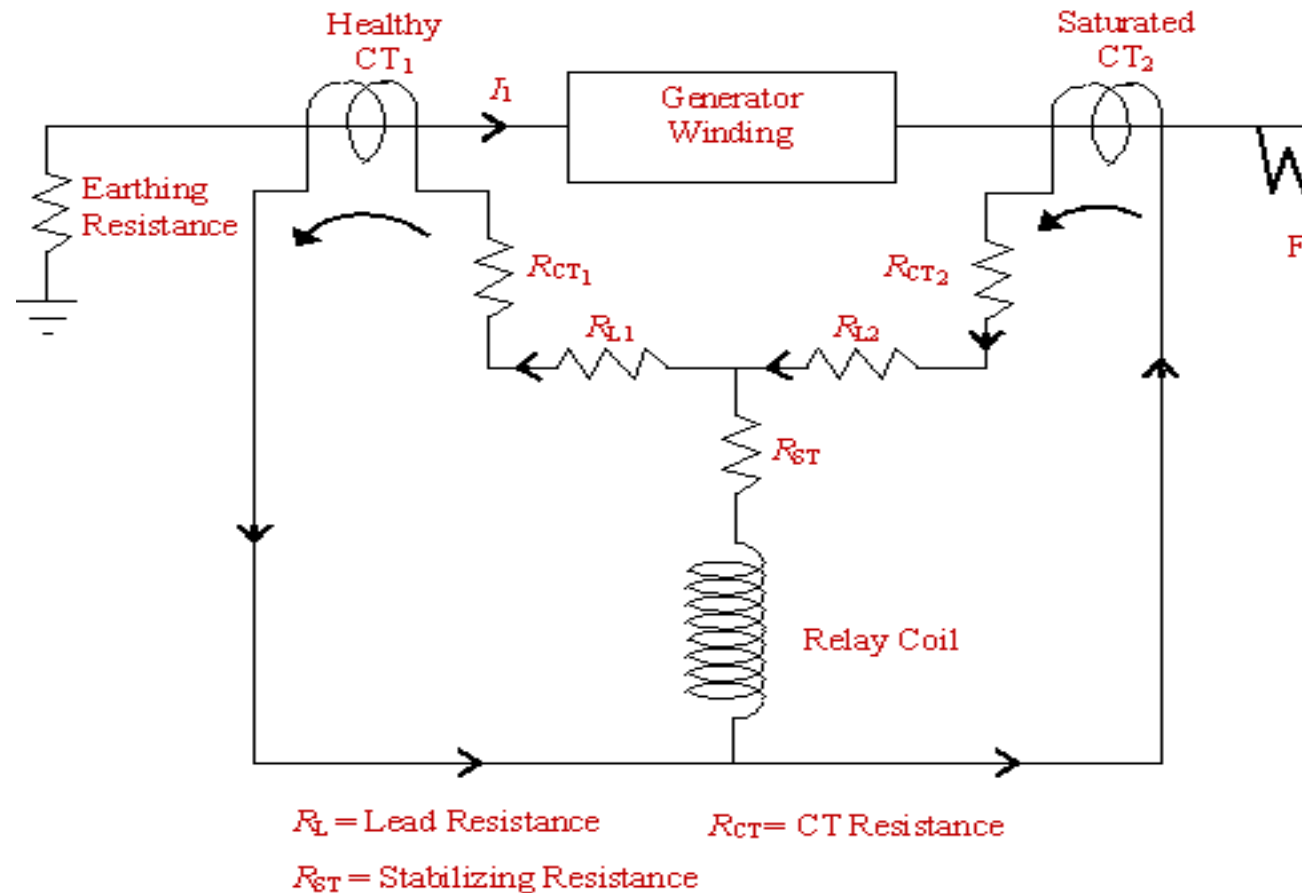
High Impedance Differential Protection

- The application of the principle of high impedance protection is illustrated in Fig. In some applications, protection may be required to limit voltages across the CT secondary circuits when the differential secondary current for an internal phase fault flows through the high impedance relay circuit(s).



High Impedance Differential Protection

- However, this is not commonly a requirement for generator differential applications unless very high impedance relays are applied. Shunt-connected, non-linear resistors should be deployed to fulfil the necessary requirement of the high impedance relaying scheme, as shown in Fig.



High Impedance Differential Protection

The primary operating current is given by

$$I_R = \text{CTR} \times (I_s + n \times I_e) \text{ where,}$$

I_R = primary operating current

CTR = CT ratio

n = number of CTs in parallel with the relay element

I_e = CT magnetizing current

I_s = relay setting

Voltage across the relay circuit is given by

$$V_r = I_f \times (R_{CT} + 2 \times R_L)$$

where R_{CT} and R_L are CT secondary winding resistance and CT lead resistance, respectively.

High Impedance Differential Protection

➤ The knee-point voltage (KPV) of a CT decides the working range of the CT, and it should be high for higher saturation flux density.

➤ The KPV of the CT is given by $V_K \geq 2V_r$

The stabilizing resistor, R_{ST} , limits the spill current below the relay setting. $R_{ST} = (V_r/I_s) - RR$

where RR is the relay burden resistance given by $RR = \text{Relay burden}/(\text{Relay setting})$

High Impedance Differential Protection

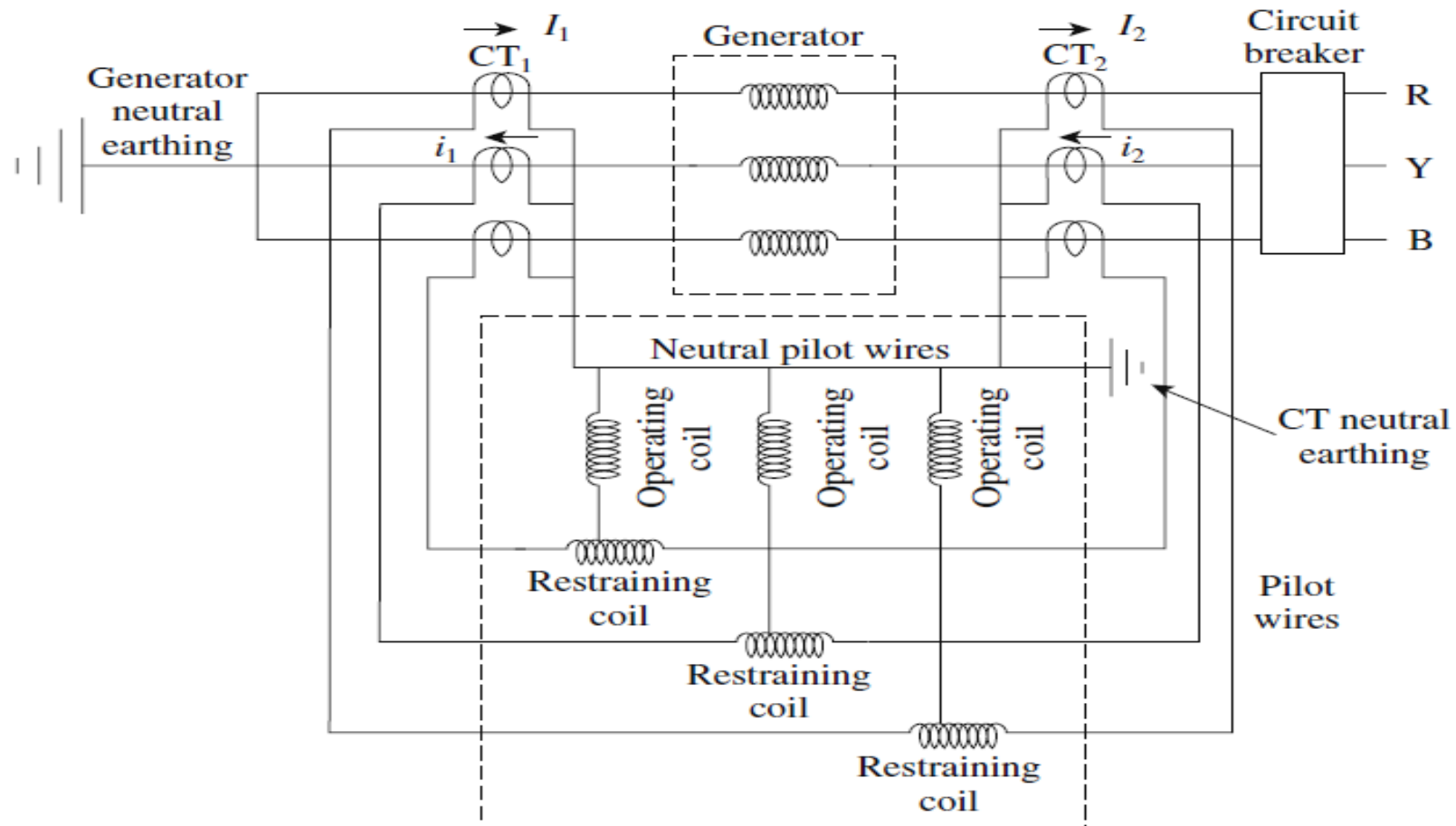
- If the value of the stabilizing resistance (R_{ST}) as calculated using Eq. (5.4) is added to the circuit, the sensitivity of the relay to internal faults is reduced.
- Further, it produces a high voltage across the CT during heavy external faults. Hence, to avoid this problem, the value of R_{ST} can be considered as nearly about one-third of the calculated value, in practice.
- Relay setting is typically set to 5–10% of the generator-rated secondary current.
- It follows from these calculations that the application of the high impedance differential protection scheme is much more complex than that of the biased differential protection scheme.
- However, it is still used because of its simplicity and stability during heavy through-faults and external switching events.

Biased Differential Protection

- The main drawback of Mertz-Price differential protection is the reduction in sensitivity of the relay due to the incorporation of the stabilizing resistance.
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- Hence, to minimize this effect and also to increase the sensitivity of the differential relay, biased differential protection scheme is used.
- In biased percentage differential protection scheme where no additional Stabilizing resistance is connected in series with the relay.

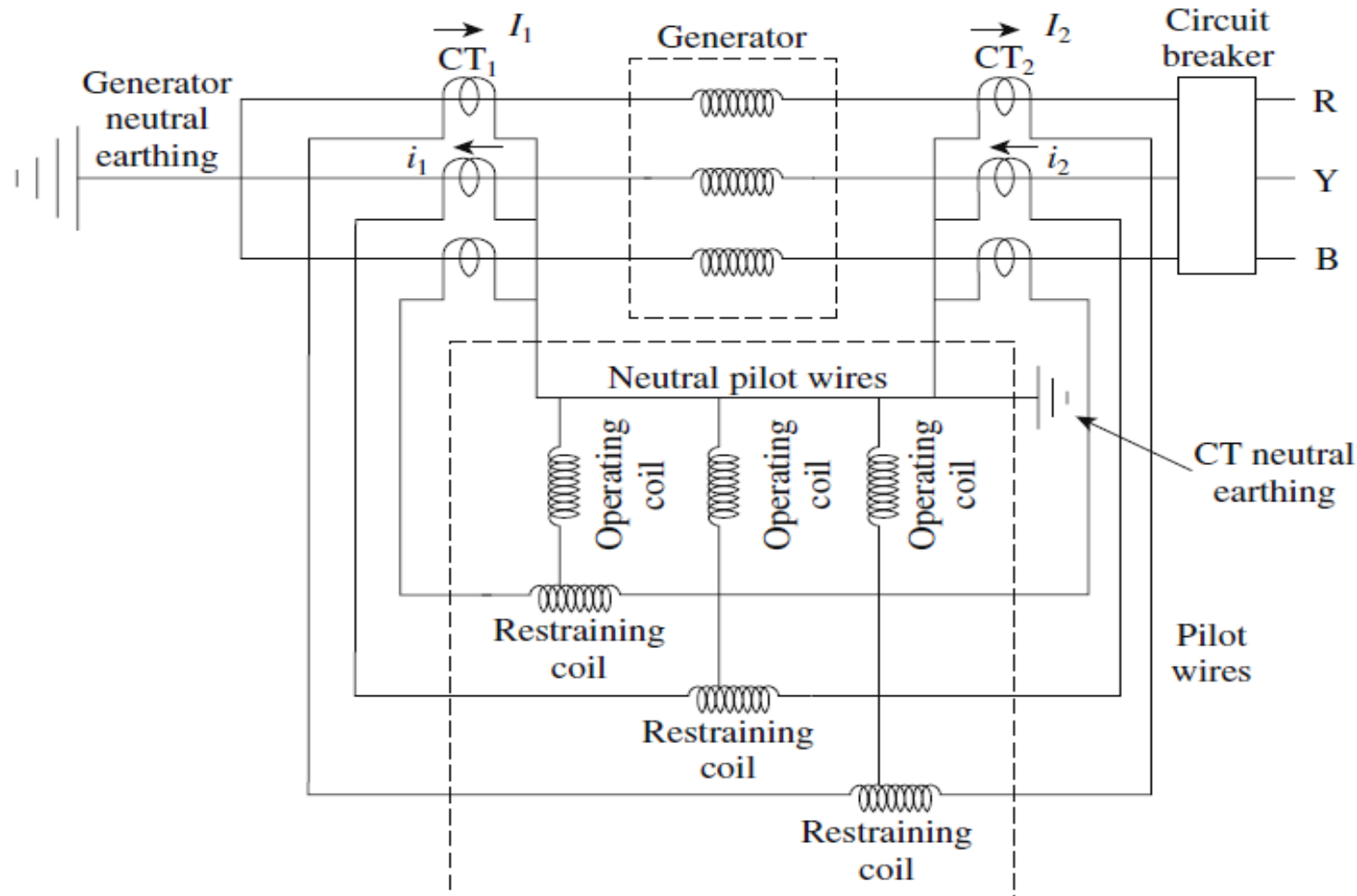
Biased Differential Protection

- The biased percentage differential relay has two settings, namely, **basic setting** and **bias setting**.
- Basic setting is the difference between two CT secondary currents.



Biased Differential Protection

- Bias setting is the ratio of the difference between two secondary currents to the average values of those two currents, that is, $\frac{(i_1 - i_2)}{\left(\frac{i_1 + i_2}{2}\right)}$



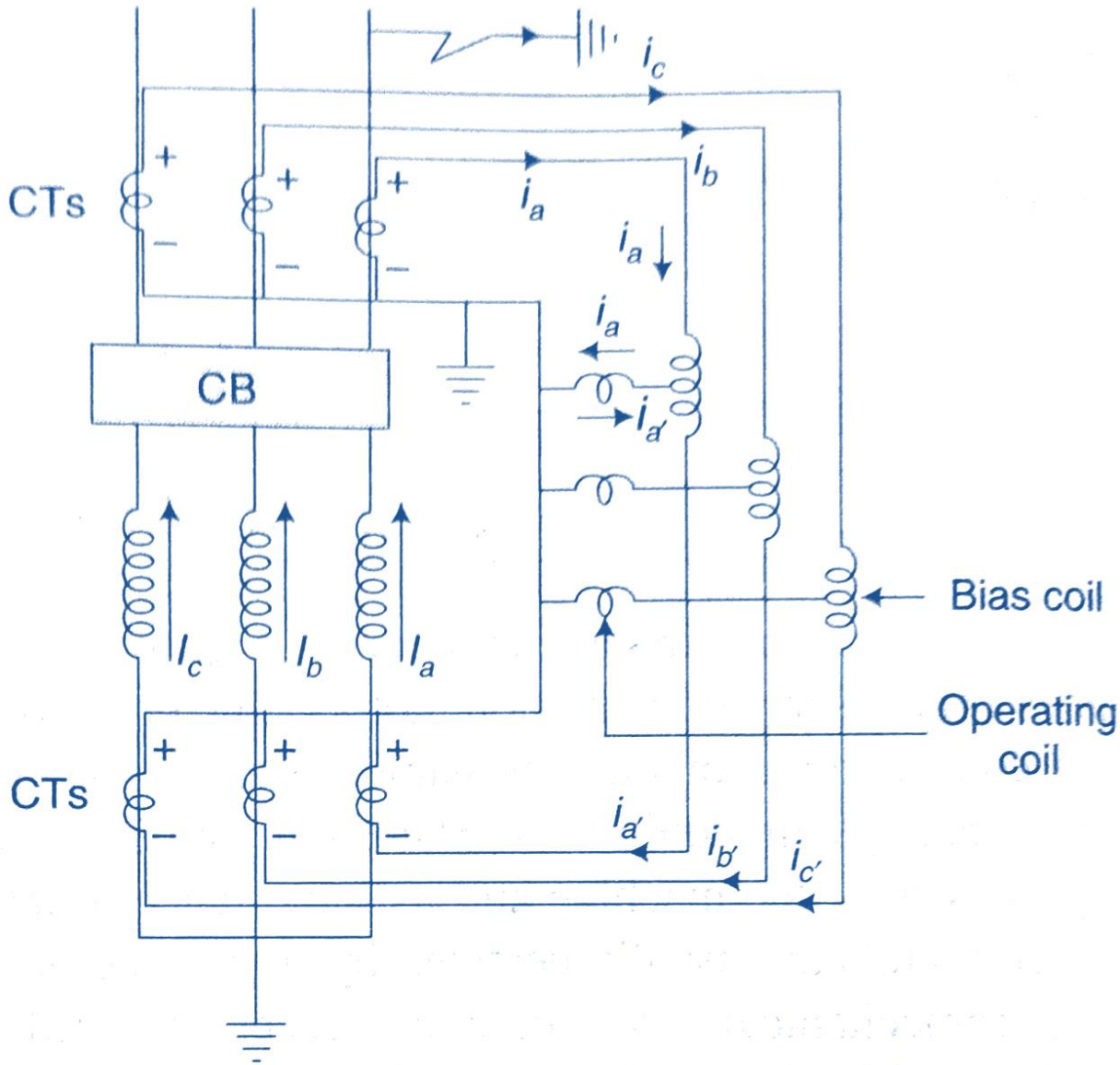
Biased Differential Protection

- In the case of normal condition/external fault condition, some amount of spill current $(i_1 - i_2)$ is already available because of the non-identical CTs and unequal lead length.
- However, at the same time, the average values of the two currents $\left(\frac{i_1 + i_2}{2}\right)$ also increases.
- Hence, the fault current will not cross the bias setting of the relay even though the basic setting is exceeded. Therefore, maloperation of the relay can be avoided.
- On the other hand, during an internal fault, two currents on the primary sides of the CTs become unequal. Hence, high spill current $(i_1 - i_2)$ is produced on the secondary side of the two CTs.

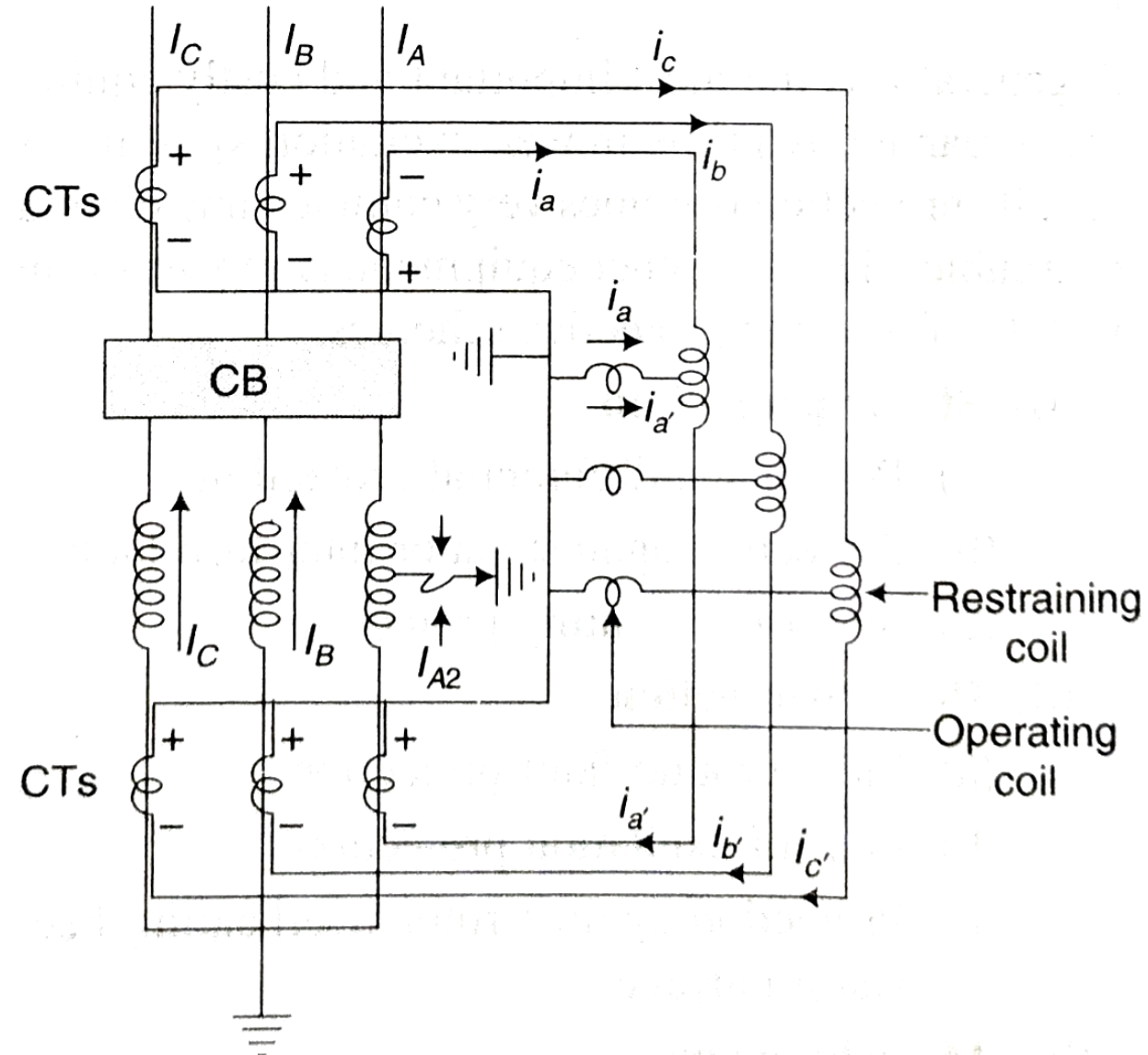
Biased Differential Protection

- This crosses not only the basic setting limit of the relay but also the bias setting limit because of the increase in spill current and decrease in the average of the two currents $\left(\frac{i_1 + i_2}{2} \right)$. Finally, the relay operates and trips the generator as per the requirements.

Biased Differential Protection



Percentage differential protection for external fault condition
(instantaneous current directions shown for external fault condition)



Percentage differential protection for external fault condition
(instantaneous current directions shown for internal fault condition)

Biased Differential Protection

- The fundamental advantage of this scheme is that it makes the scheme more permissive towards CT mismatch, thus reducing the relay's sensitivity to external faults.
- Moreover, it provides high sensitivity in case of internal faults.

Stator Earth Fault Protection

- The performance of the generator protection system during ground fault conditions depends on the various types of stator grounding methods used in the system.
- The three types of grounding methods are used.
 - (i) Low impedance (solid) grounding method
 - (ii) Medium impedance grounding method
 - (iii) High impedance grounding method

Stator Earth Fault Protection

- In case of low impedance grounding method, generator neutral is grounded through ideally zero and practically minimum impedance.
- Advantage:

The healthy phase voltages do not rise with reference to the neutral point during ground fault conditions.
- Disadvantage:

The magnitude of fault current during ground fault (may be equal to three-phase fault current)

Stator Earth Fault Protection

➤ In the medium impedance grounding method, substantial impedance is connected in the neutral circuit of the generator.

- Advantage:

The ground fault current is reduced at a reasonable level.

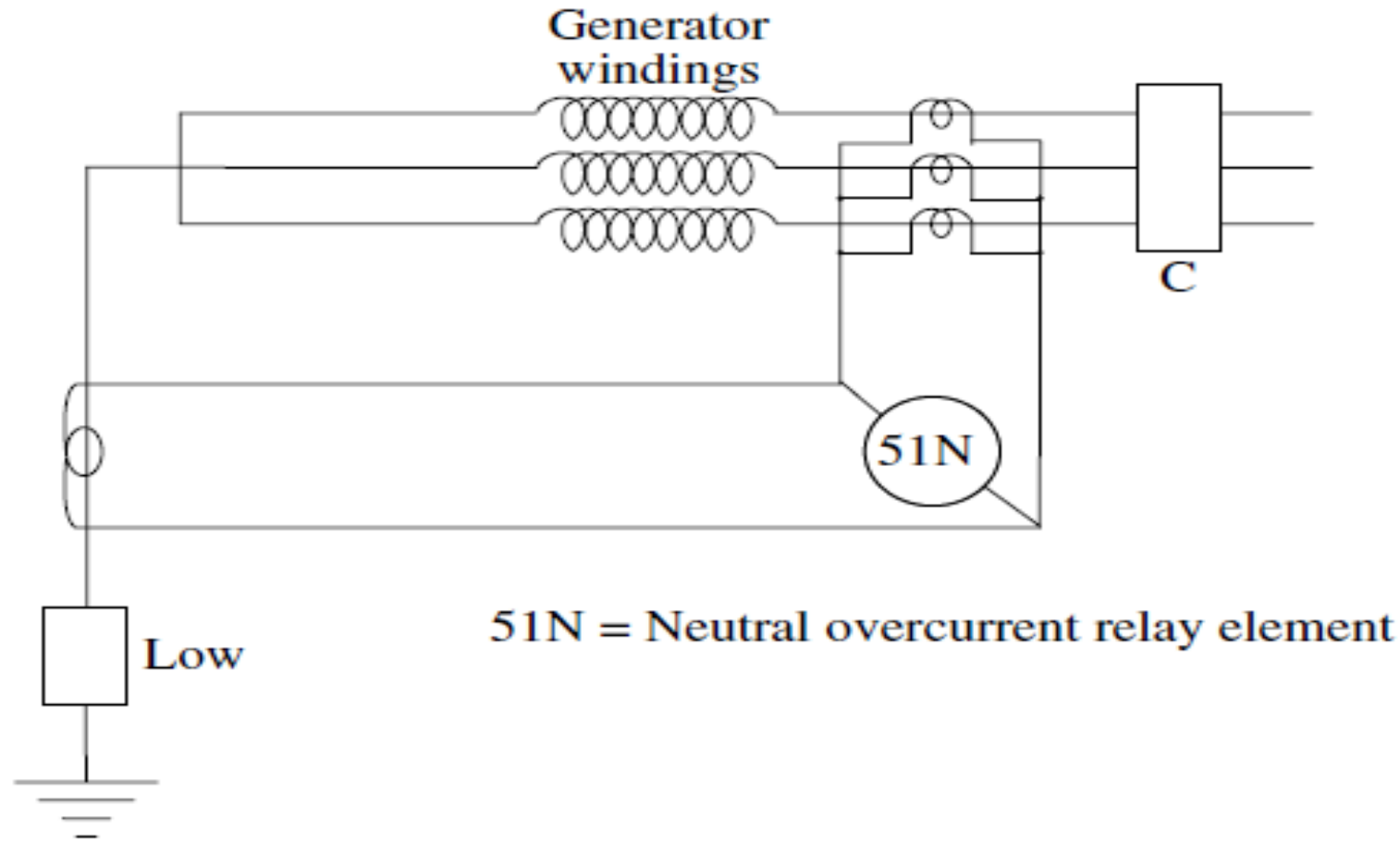
- Disadvantage:

Due to the presence of significant impedance in the neutral circuit of the generator, healthy phase voltages increase to some extent which further increases cost due to requirement of high grade of insulation

Stator Earth Fault Protection

- In case of the high impedance grounding method, a large value of impedance is connected in the neutral circuit of the generator to minimize the possibility of sufficient iron core damage.
- Hence, during ground fault conditions, a nearly undetectable value of fault current flows, which reduces sensitivity of the relay during internal fault conditions.

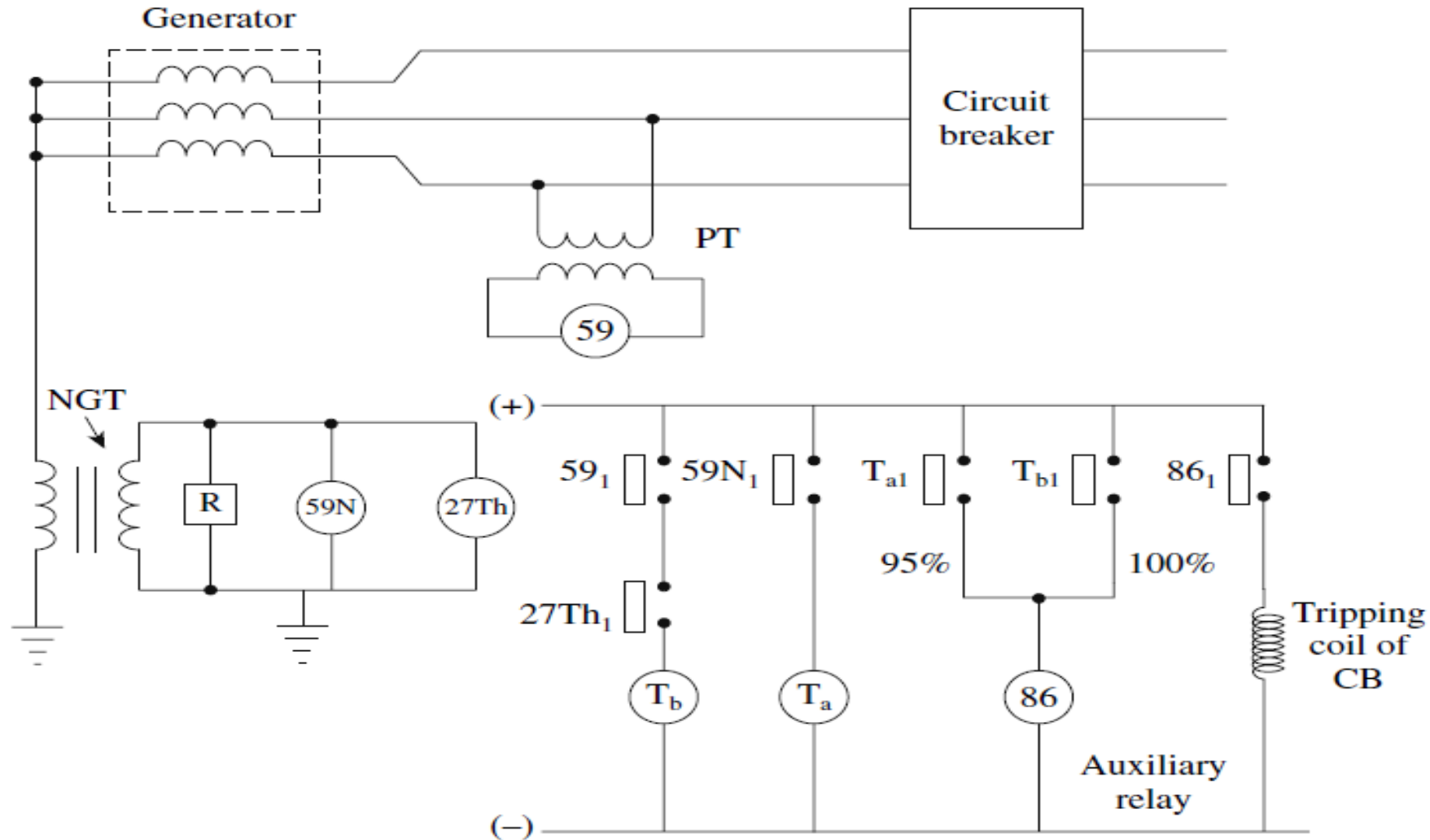
Stator Earth Fault Protection during low impedance grounding



Stator Earth Fault Protection during low impedance grounding

- In case of low/medium impedance grounding, one ground relay is used in the neutral of the generator winding to protect the generator against ground faults.
- This provides unrestricted earth-fault protection, and hence, it must be graded with the feeder protection scheme.
- Therefore, the relay has a time-delayed operating characteristic.

Stator Earth Fault Protection during High impedance grounding



59 = Overvoltage relay

59N = Overvoltage relay tuned to fundamental frequency

27Th = Undervoltage relay tuned to third harmonic frequency

T_a and T_b = Timers; T_{aI} and T_{bI} = Contacts of timers

86 = Auxiliary relay; 86_I = Contacts of auxiliary relay

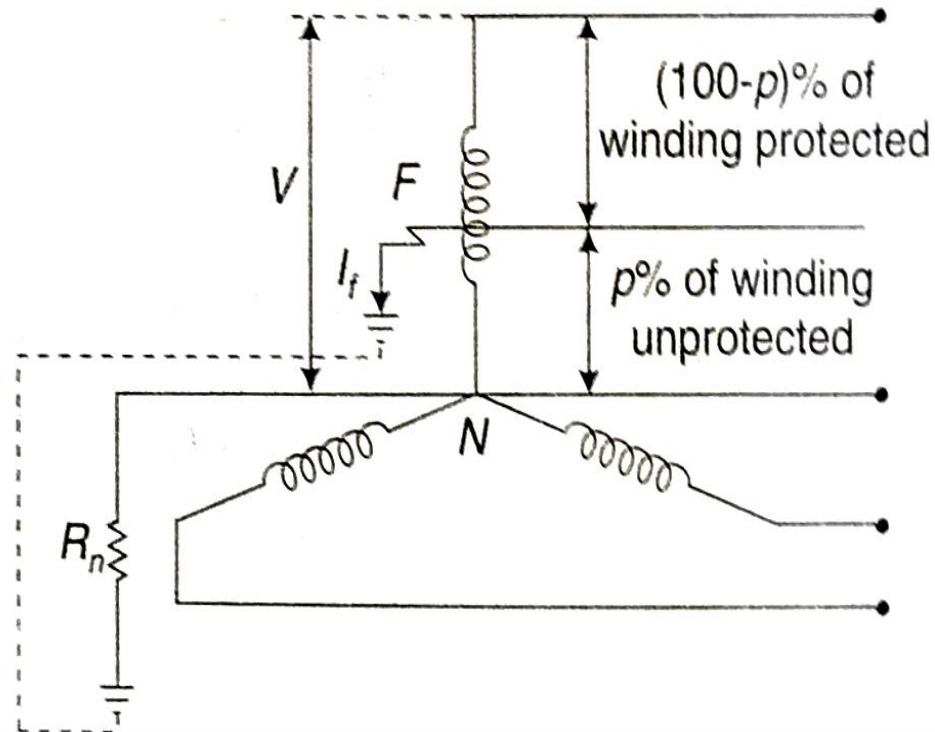
NGT = Neutral grounding transformer

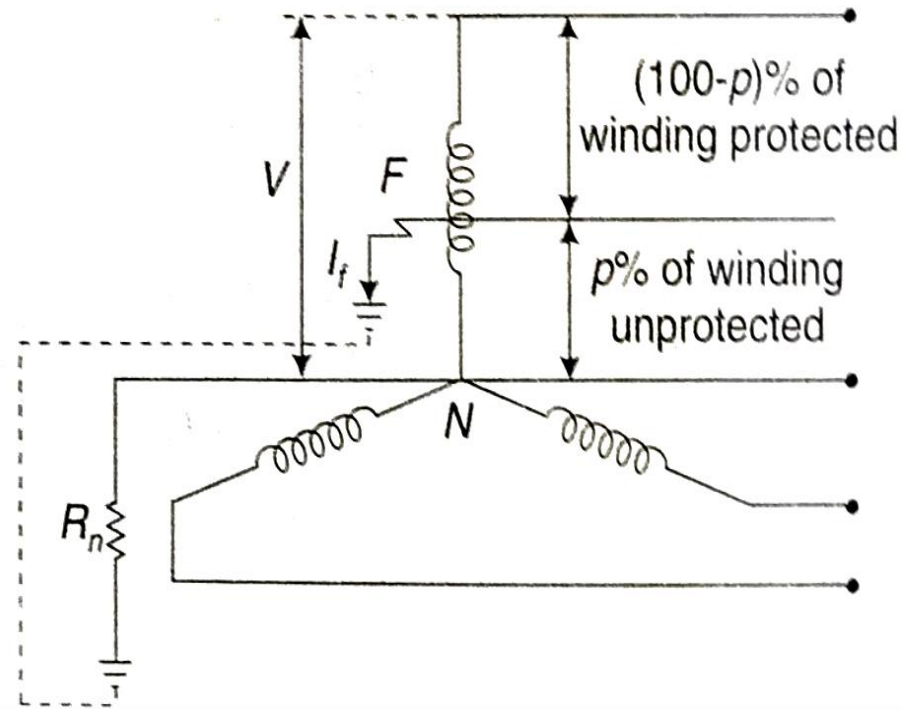
Abnormal frequency and Voltage Protection

- Over frequency Protection
- Under frequency Protection
- Overvoltage Protection
- Under voltage Protection
- Voltage dependent overcurrent protection
- Thermal protection using resistance temperature detector

➤ Restricted earth-fault protection by differential relay

- When the neutral is solidly grounded, it is possible to provide protection to complete winding of the generator against ground faults. However, the neutral is grounded through resistance to limit ground fault currents.
- With resistance grounding it is not possible to protect the complete winding against ground faults.
- The percentage of winding protected depends on the value of the neutral grounding resistor and the relay setting.
- The usual practice is to protect 80 to 85% of the generator winding against ground fault. The remaining 15-20% from neutral end is left unprotected





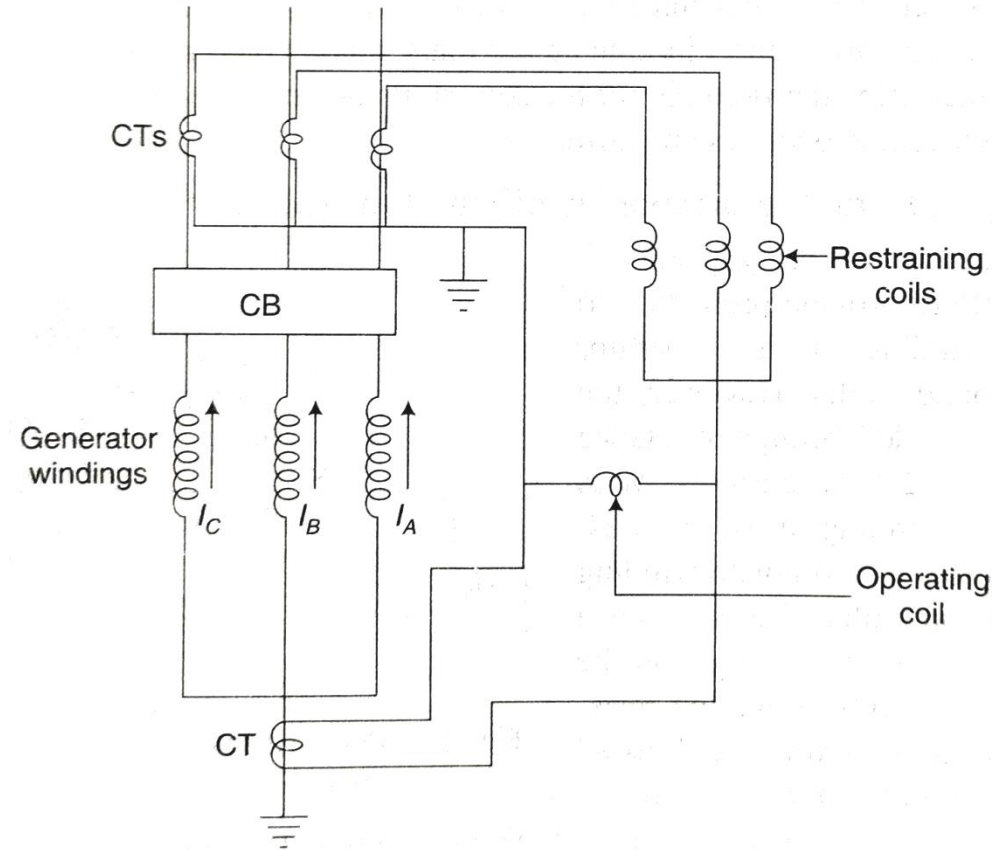
In above Fig. for phase to ground fault, it can be seen that the relay setting for the differential protection is determined by the value of the neutral grounding resistor and the percentage of winding to be protected

Let $p\%$ of the winding from the neutral remains unprotected. Then $(100 - p)\%$ of the winding is protected.

The ground fault current I_f is given by $I_f = \frac{p}{100} * (V/R_n)$

where V is the line to neutral voltage and R_n is the neutral grounding resistance. For the operation of the relay, the fault current must be greater than the relay pick-up current

Percentage differential protection for Y connected generator with only four leads brought out



When the neutral connection is made within the generator and only the neutral terminal is brought out, the percentage differential protection can be provided, as shown in Fig. This scheme protects the generator winding only against ground faults. It does not protect it against phase faults. This is also called restricted earth fault protection because the relays operate only for ground faults within the protected windings.

An 11 kV, 100 MVA alternator is grounded through a resistance of 5 ohm. The CTs have a ratio 1000/5. The relay is set to operate when there is an out of balance current of 1 A. What percentage of the generator winding will be protected by the percentage differential scheme of protection?

Primary earth-fault current at which the relay operates = $(1000/5) * 1 = 200\text{A}$

Suppose p% of the winding from the neutral remains unprotected. The fault current = $(p/100) * (11 * 10^3 / \sqrt{3} * 5)$

For the operation of the relay, the fault current must be greater than the relay pick-up current

$$(p/100) * (11 * 10^3 / \sqrt{3} * 5) > (1000/5) * 1 \quad \text{OR} \quad p > 15.75$$

This means that 15.75% of the winding from the neutral is not protected.

In other words, $100 - p = 100 - 15.75 = 84.25\%$ of the winding from the terminal is protected.

Note: Near the neutral point voltage stress is less and therefore, phase to earth faults are not likely to occur.

Assignment

An 11 kV, 100 MVA alternator is provided with differential protection. The percentage of winding to be protected against phase to ground fault is 85%. The relay is set to operate when there is 20% out of balance current. Determine the value of the resistance to be placed in the neutral to ground connection

Solution: (a) Primary earth-fault current at which the relay operates

$$= \frac{100 \times 10^3}{\sqrt{3} \times 11} \times \frac{20}{100} = 1049.759 \text{ A}$$

Suppose that the percentage of winding which remains unprotected is

$$p = 100 - 85 = 15\%.$$

$$\text{The fault current} = \frac{p}{100} \times \frac{11 \times 10^3}{\sqrt{3} R_n},$$

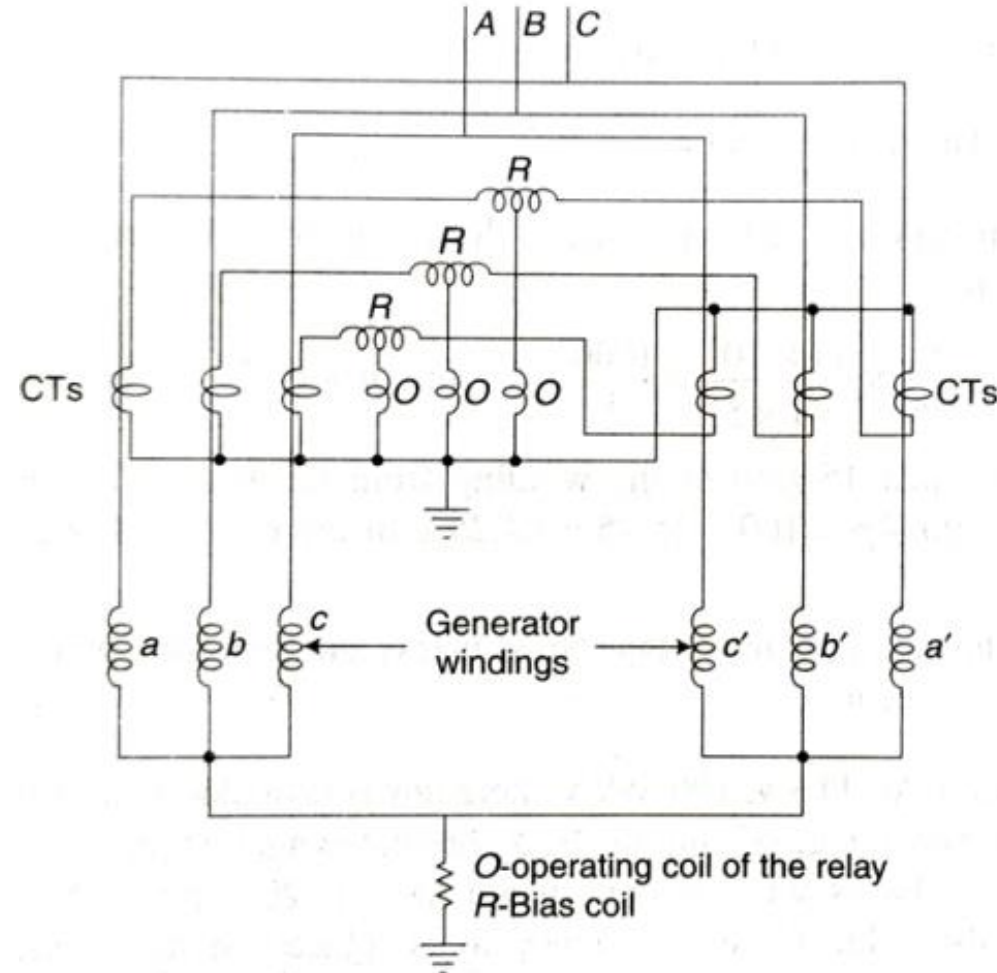
where R_n is the resistance in the neutral connection

$$\therefore \frac{15}{100} \times \frac{11 \times 10^3}{\sqrt{3} R_n} = 1049.759$$

$$\therefore R_n = \frac{15 \times 11 \times 10^3}{100 \times \sqrt{3} \times 1049.759} = 0.91 \, \Omega$$

Protection against Stator Interturn Faults

Longitudinal percentage differential protection does not detect stator interturn faults. A transverse percentage differential protection, as shown in Fig. is employed for the protection of the generator against stator interturn faults. This type of protection is used for generators having parallel windings separately brought out to the terminals.



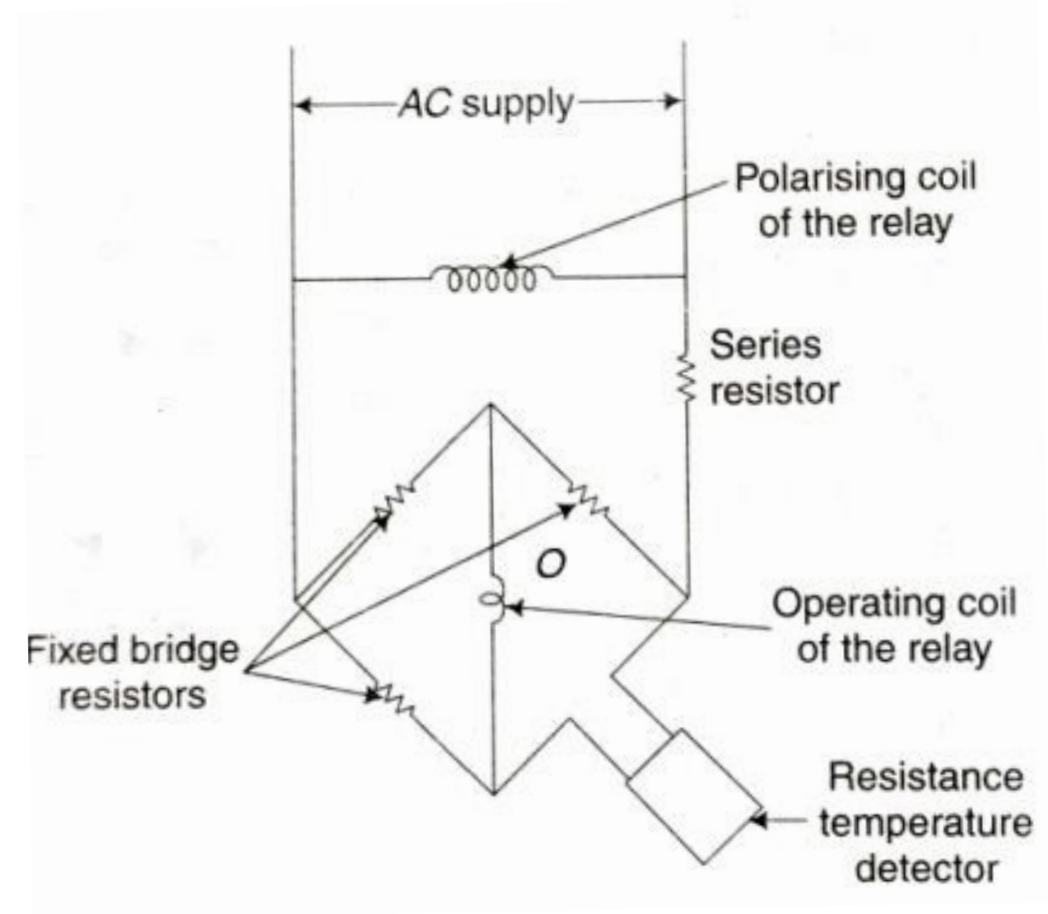
Transverse percentage differential protection for multi-winding generators

Stator-overheating Protection

Overheating of the stator may be caused by the failure of the cooling system, overloading or core faults like short-circuited laminations and failure of core bolt insulation, Modern generators employ two methods to detect overheating both being used in large generators (above 2 MW).

In one method, the inlet and outlet temperatures of the cooling medium which may be hydrogen/ water are compared for detecting overheating.

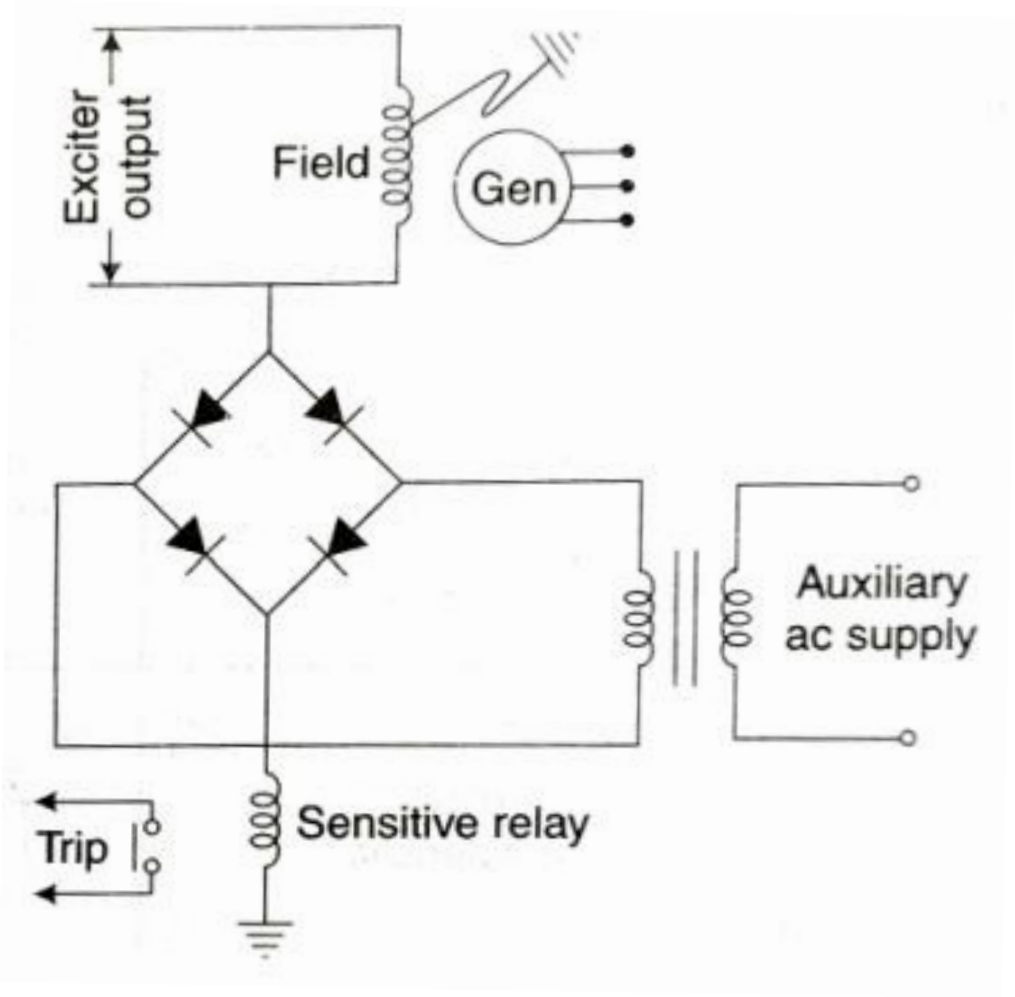
In the other method, the temperature sensing elements are embedded in the stator slots to sense the temperature



Stator-overheating Protection

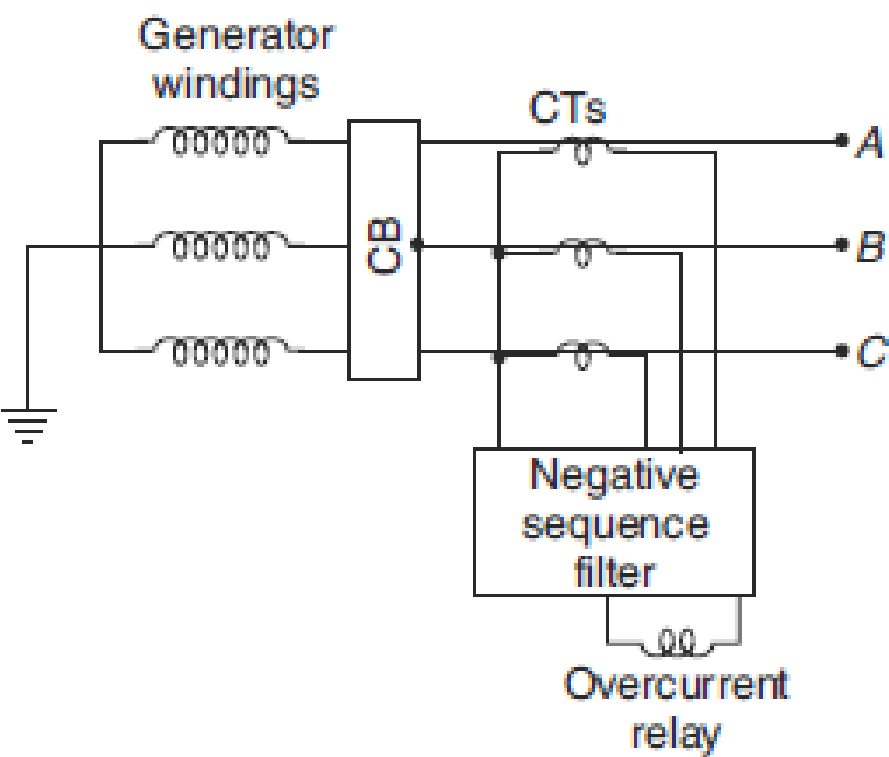
Rotor Protection

(a) Field Ground-fault Protection



Earth-Fault Protection

(b) Protection against unbalanced stator current



(iii) Miscellaneous

(a) Overvoltage protection

(b) Overspeed protection

(c) Protection against motoring

(d) Protection against vibration

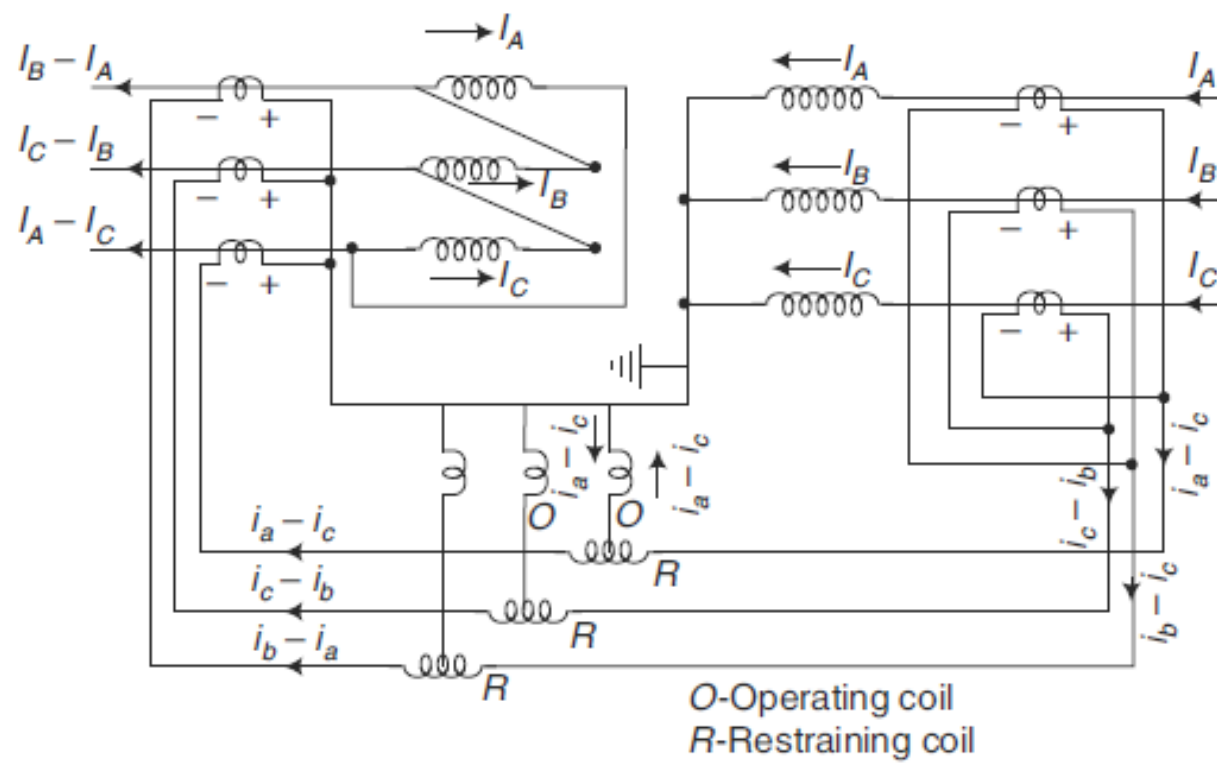
(e) Bearing-overheating protection

(f) Protection against auxiliary failure

(g) Protection against voltage regulator failure

Module 3: Transformer Protection

Percentage differential protection for Star-Delta connected transformer

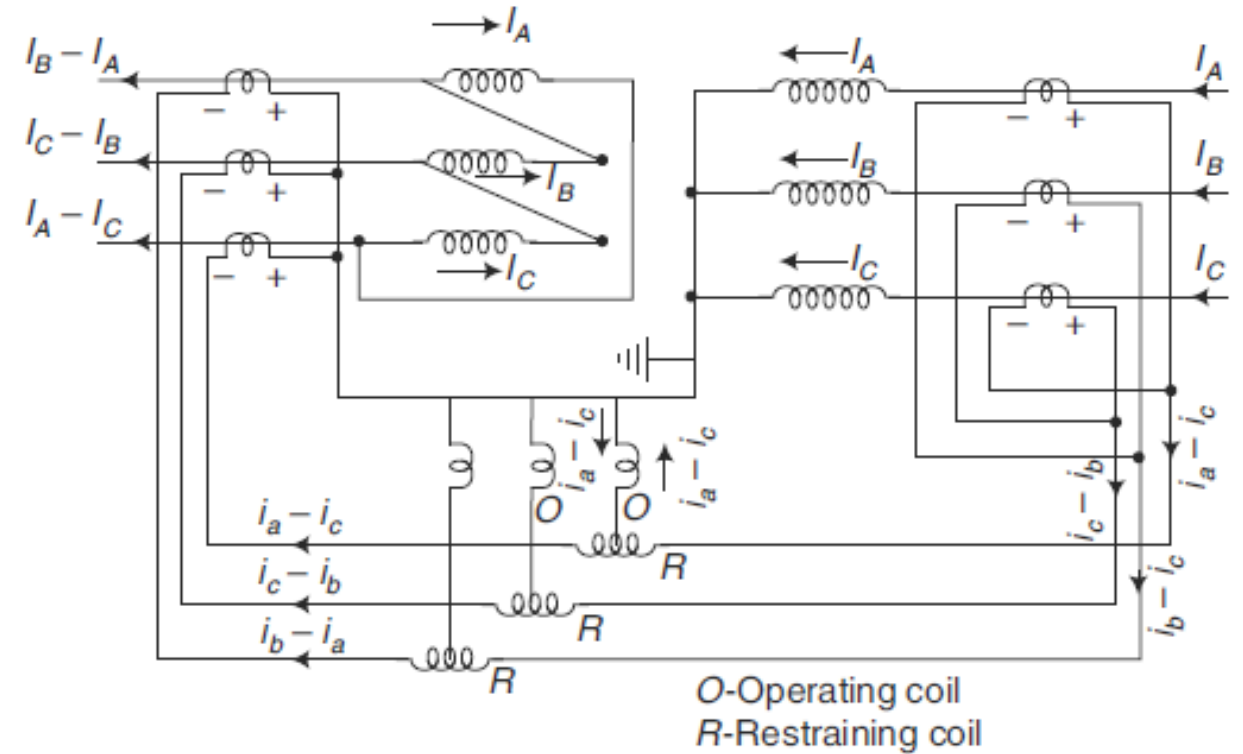


The power transformer is star connected on one side and delta connected on the other side. The CTs on the star connected side are delta-connected and those on delta-connected side are star-connected. The neutral of the current transformer star connection and power transformer star connections are grounded.

The restraining coil is connected between the secondary winding of the current transformers. Restraining coils controls the sensitive activity occurs on the system. The operating coil is placed between the tapping point of the restraining coil and the star point of the current transformer secondary windings.

Working of Differential Protection System

Normally, the operating coil carries no current as the current are balanced on both the side of the power transformers. When the internal fault occurs in the power transformer windings the balanced is disturbed and the operating coils of the differential relay carry current corresponding to the difference of the current among the two sides of the transformers. Thus, the relay trip the main circuit breakers on both sides of the power transformers.



Common transformer faults: As compared with generators, in which many abnormal conditions may arise, power transformers may suffer only from :

- open circuits
- overheating
- winding short-circuits g. earth-faults, phase-to-phase faults and inter-turn faults

- **Buchholz devices** providing protection against all kinds of incipient faults i.e. slow-developing faults such as insulation failure of windings, core heating, fall of oil level due to leaky joints etc.
- **Earth fault relays** providing protection against earth-faults only.
- **Overcurrent relays** providing protection mainly against phase-to-phase faults and overloading.
- **Differential system** (or circulating-current system) providing protection against both earth and phase faults.

The complete Protection of Transformers usually requires the combination of these systems. Choice of a particular combination of systems may depend upon several factors such as

- **Size of the transformer**
- **Type of cooling**
- **Location of transformer in the network**
- **Nature of load supplied and**
- **Importance of service for which transformer is required.**

Problems Encountered in Differential Protection of Transformer:

The differential scheme described suffers from the following drawbacks:

- **Unmatched characteristics of CTs.**
- **Ratio change as a result of tapping.**
- **Magnetizing inrush current.**

CT Characteristics:

Unless saturation is avoided, the difference in CT characteristics due to different ratios being required in circuits of different voltages may cause appreciable difference in the respective secondary currents whenever through-faults occur. This trouble is aggravated in the case of transformers due to unequal ratio CTs being employed on either side of the protected transformer. A source of ratio error which results in circulating currents under through-fault condition is the unequal burden imposed on the CTs due to unequal lead lengths.

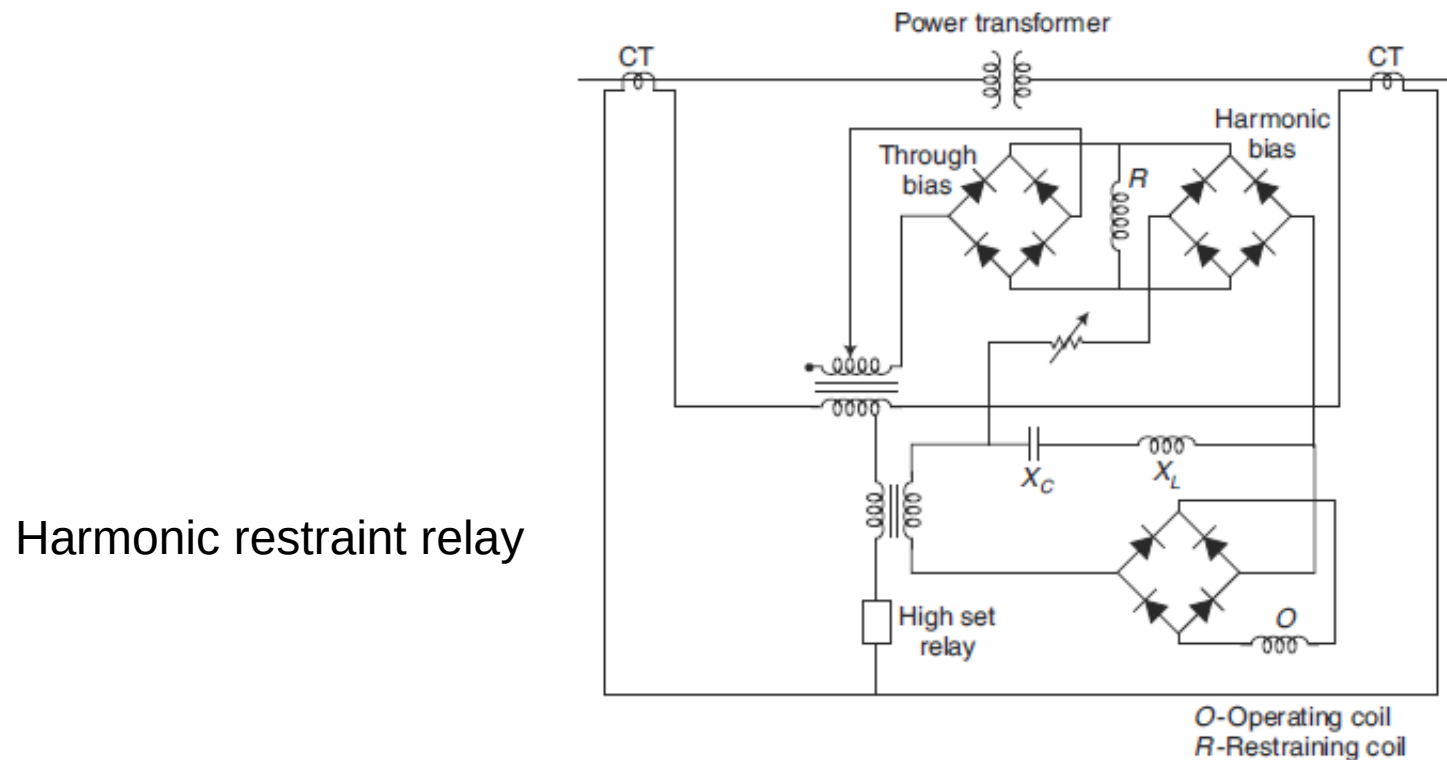
Ratio Change as a Result of Tapping:

Tap changing equipment is a common feature of a power transformer which effectively alters the turns ratio.

Compensating for this effect by varying the tappings on differential-protection CTs is impracticable. Biased or percentage differential relays ensure stability with the amount of unbalance occurring at the extremities of the tap-change range. Biased relays are better suited to the overall protection of variable-ratio transformers.

Protection against Magnetising Inrush Current :

When the transformer is energized, the transient inrush of magnetizing current flowing into the transformer may be as great as ten times full-load current and it decays relatively slowly. This is bound to operate the Differential Protection of Transformers falsely. The magnitude of the magnetizing inrush current is a function of the permanent flux trapped in the transformer core and the instant on the voltage cycle when it is switched on.

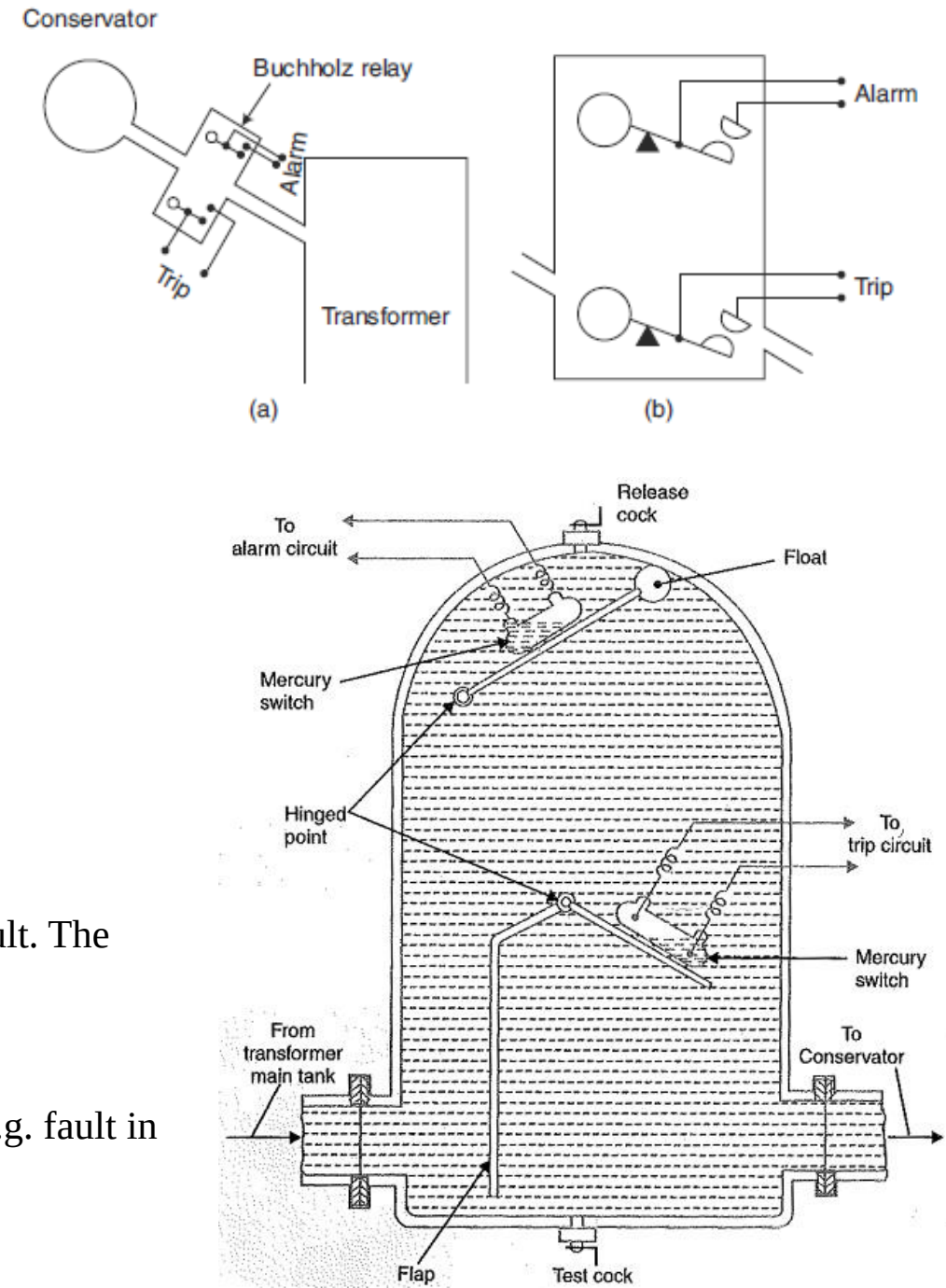


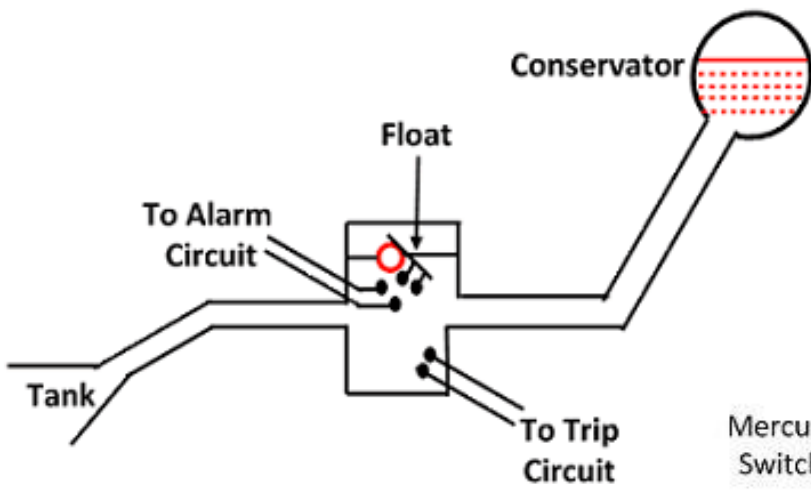
Buchholz Relay:

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

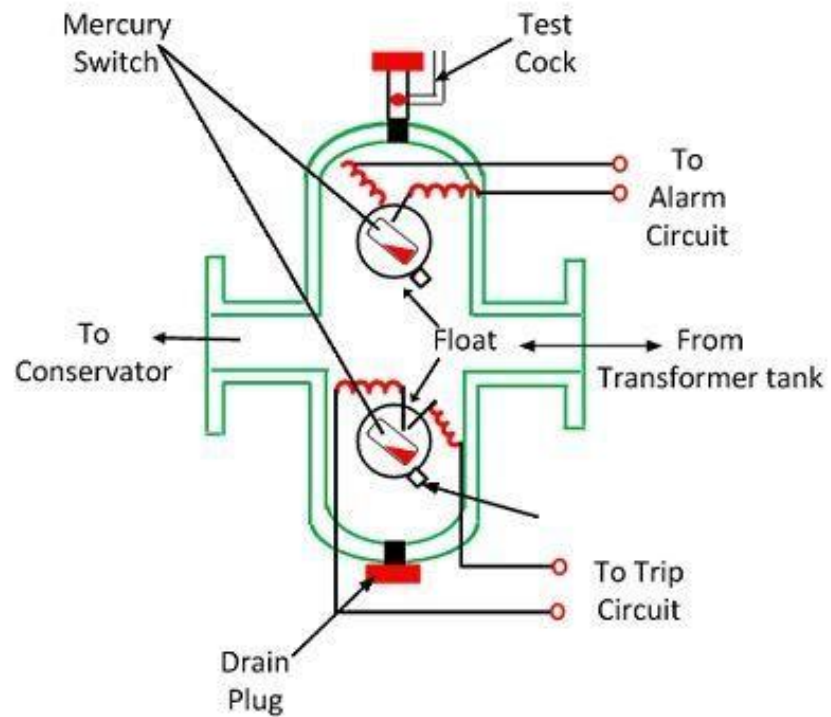
The analysis of gas collected in the relay chamber indicates the type of the incipient fault. The presence of;

- A. C_2H_2 and H_2 shows arcing in oil between constructional parts;
- B. C_2H_2 , CH_4 and H_2 shows arcing with some deterioration of phenolic insulation, e.g. fault in tap changer;
- C. CH_4 , C_2H_4 and H_2 indicates hot spot in core joints;
- D. C_2H_4 , C_3H_6 , H_2 and CO_2 shows a hot spot in the winding.

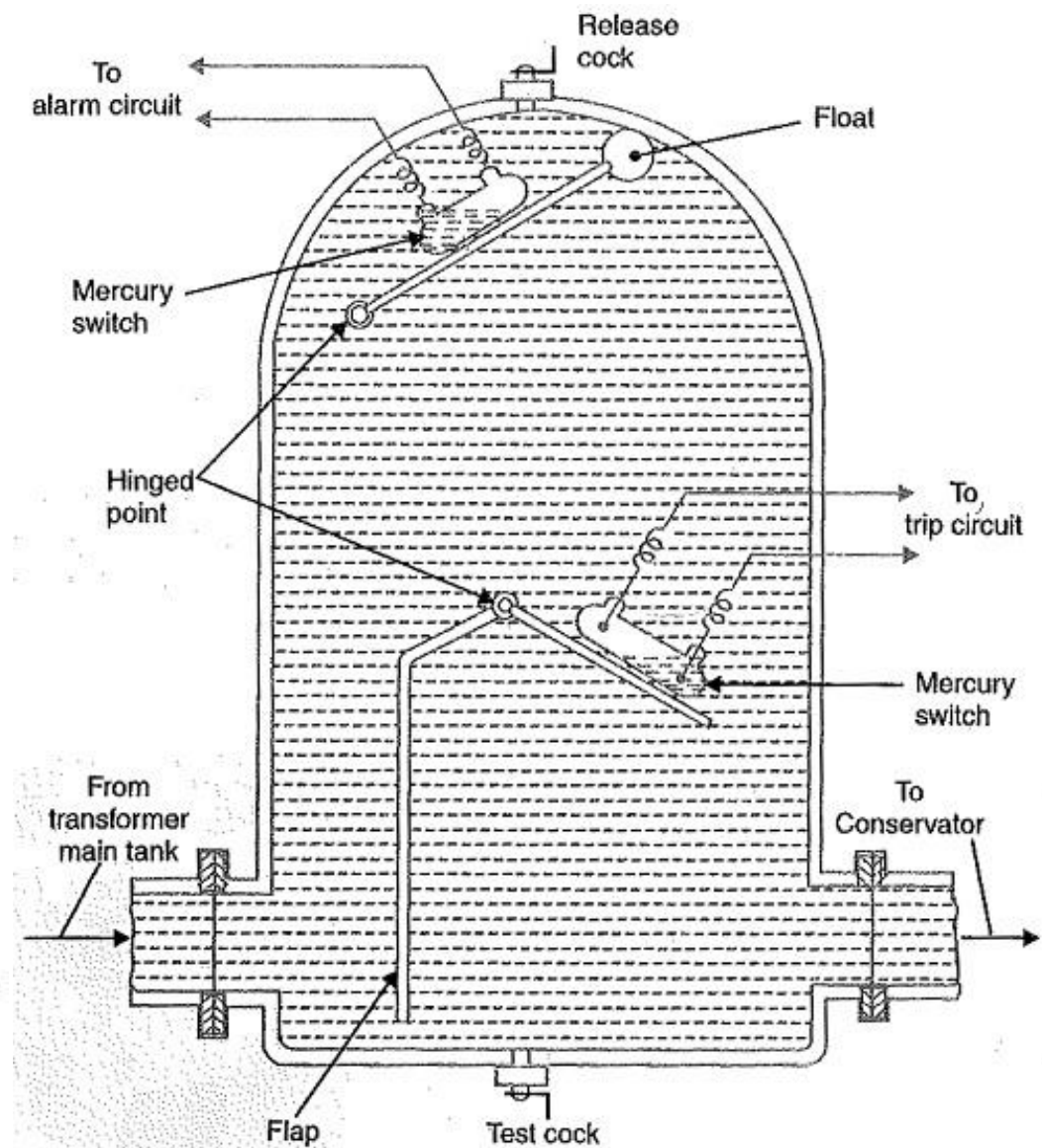




Arrangement of Buchholz Relay



Buchholz Relay



Circuit Globe

Operation: The operation of Buchholz relay is as follows :

- (i) In case of incipient faults within the transformer, the heat due to fault causes the decomposition of some transformer oil in the main tank. The products of decomposition contain more than 70% of hydrogen gas. The hydrogen gas being light tries to go into the conservator and in the process gets entrapped in the upper part of relay chamber. When a predetermined amount of gas gets accumulated, it exerts sufficient pressure on the float to cause it to tilt and close the contacts of mercury switch attached to it. This completes the alarm circuit to sound an alarm.
- (ii) If a serious fault occurs in the transformer, an enormous amount of gas is generated in the main tank. The oil in the main tank rushes towards the conservator via the Buchholz relay and in doing so tilts the flap to close the contacts of mercury switch. This completes the trip circuit to open the circuit breaker controlling the transformer.

Limitations of Buchholz Relay

The following are the disadvantages of Buchholz relay.

- The relay is used only in oil immersed transformer.
- It can only detect the fault below oil level.
- This relay does not protect the connecting cables. Hence separate protection is used for the cables.

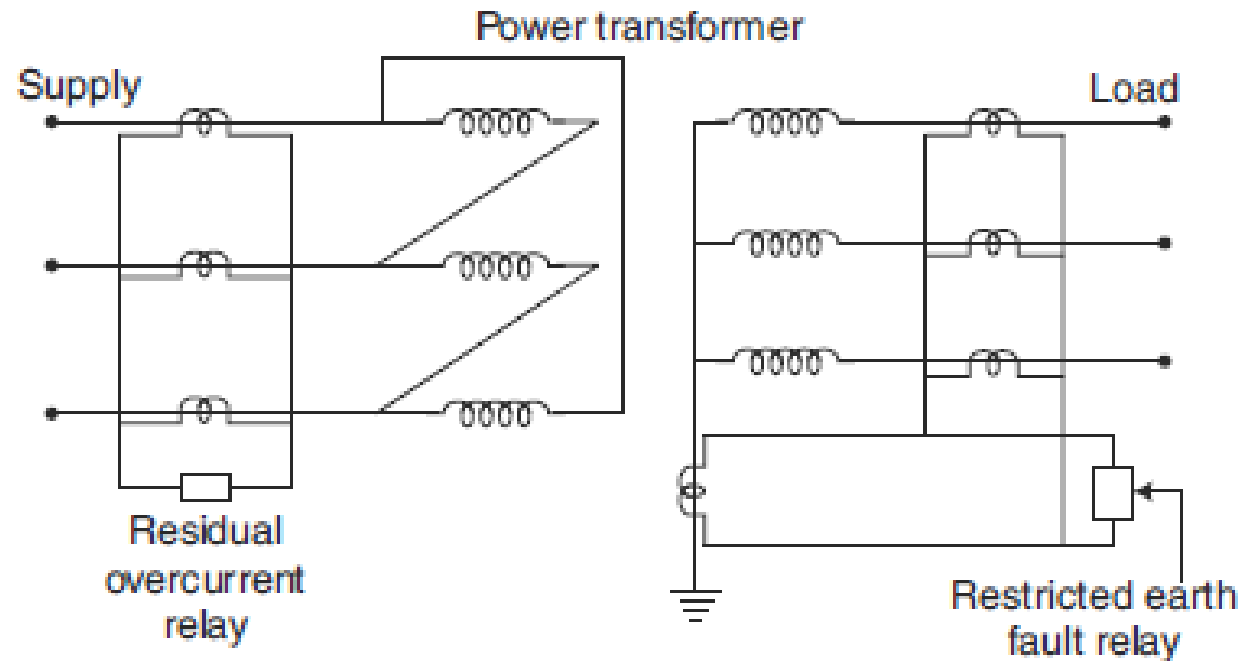
Advantages

The response time of the relay is high, The minimum operating time of the relay is 0.1 seconds.

Earth fault protection of a power transformer

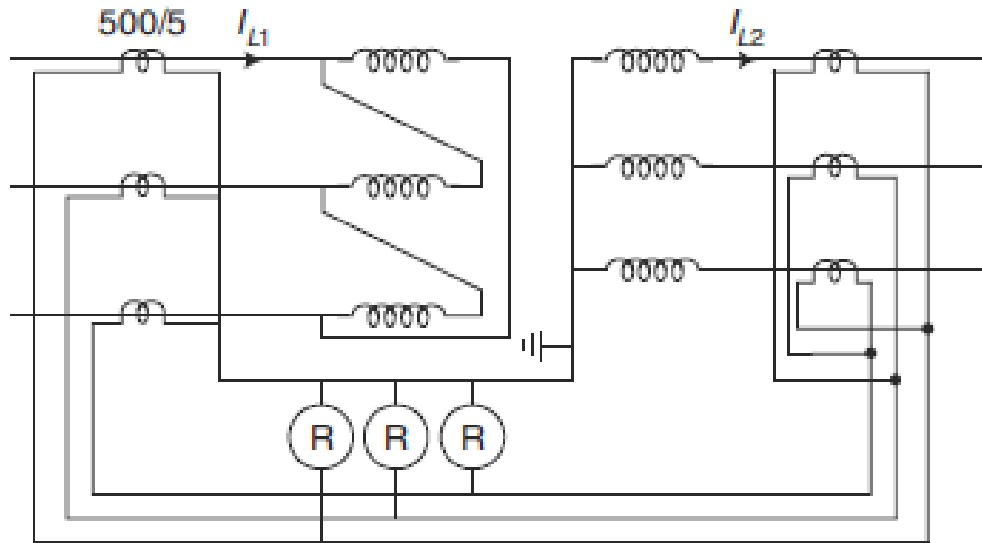
A simple overcurrent and earth fault relay does not provide good protection for a star connected winding, particularly when the neutral point is earthed through an impedance. Restricted earth fault protection, as shown in Fig. 10.5 provides better protection. This scheme is used for the winding of the transformer connected in star where the neutral point is either solidly earthed or earthed through an impedance.

The relay used is of high impedance type to make the scheme stable for external faults.



A three-phase, 11 kV/132 kV, D-Y connected power transformer is protected by differential protection. The CT_s on the LV side have a current ratio of 500/5. What must be the current ratio of the CT_s on the HV side and how should they be connected.

Solution: In order that circulating currents in the relay are in phase opposition, the CT_s on the delta connected LV side of the transformer should be connected in star and the CT_s on the star connected HV side of the transformer should be connected in delta. Connections of CT_s on LV and HV sides are shown in Fig. 10.11



Let the line currents on the primary and secondary sides of the transformer be I_{L1} and I_{L2} respectively. Then,

$$\sqrt{3} \times 11 \times I_{L1} = \sqrt{3} \times 132 \times I_{L2}$$

or
$$I_{L2} = \frac{11}{132} I_{L1}$$

For I_{L1} of 500 A, $I_{L2} = \frac{11}{132} \times 500 = 41.66$ A

Since the CT_s on the LV side are connected in star, the current through the secondary of the CT and the pilot wire will be 5 A. The CT_s on the HV side being delta connected will have a current of $5/\sqrt{3}$ A in the secondary.

Hence CT ratio on HV side

$$= 41.66 / (5/\sqrt{3})$$

$$= \sqrt{3} \times 41.66 / 5$$

$$= 72.15 / 5$$

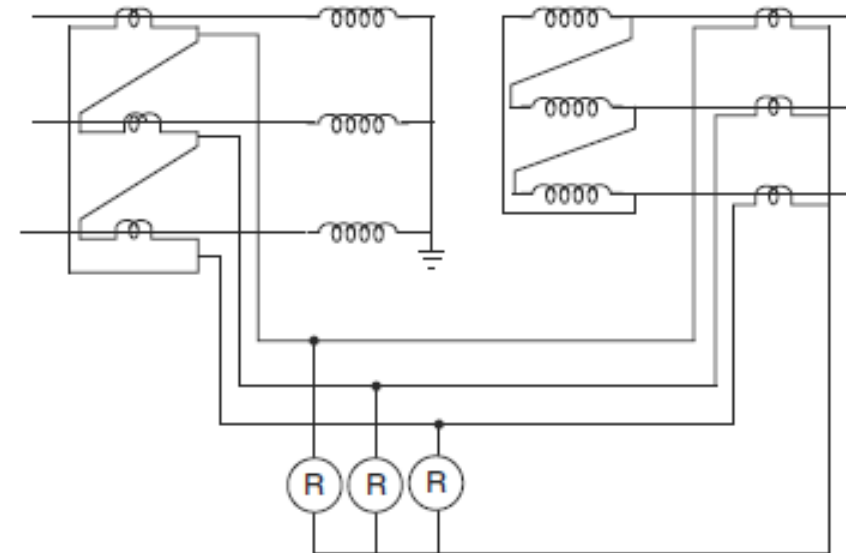
Three-phase, 11 kV/33 kV, Y-D connected power transformer is protected by differential protection. The CTs on the LV side have a current ratio of 400/5. What must be the ratio of CTs on the HV side. How the CTs on both the sides of the transformer are connected

Solution: The connections of the CTs on both the sides of the transformer are shown in Fig.
Let the line currents on the primary and secondary sides of the transformer be I_{L1} and I_{L2} respectively

Then, $\sqrt{3} \times 11 \times I_{L1} = \sqrt{3} \times 33 \times I_{L2}$

or $I_{L2} = \frac{11}{33} I_{L1}$

For I_{L1} of 400 A, $I_{L2} = \frac{11}{33} \times 400 = 133.3$ A



The current through secondary of the CT on the primary side of the transformer will be 5A. Since the CTs on the primary side are connected in delta, the current through its pilot wire will be $5\sqrt{3}$ A. The CTs on the secondary side being star connected will have a current of $5\sqrt{3}$ in the secondary

Hence CT ratio on HV side $= \frac{133.3}{5\sqrt{3}}$
 $= 76.7/5$

Module 3: Bus-Bar Protection

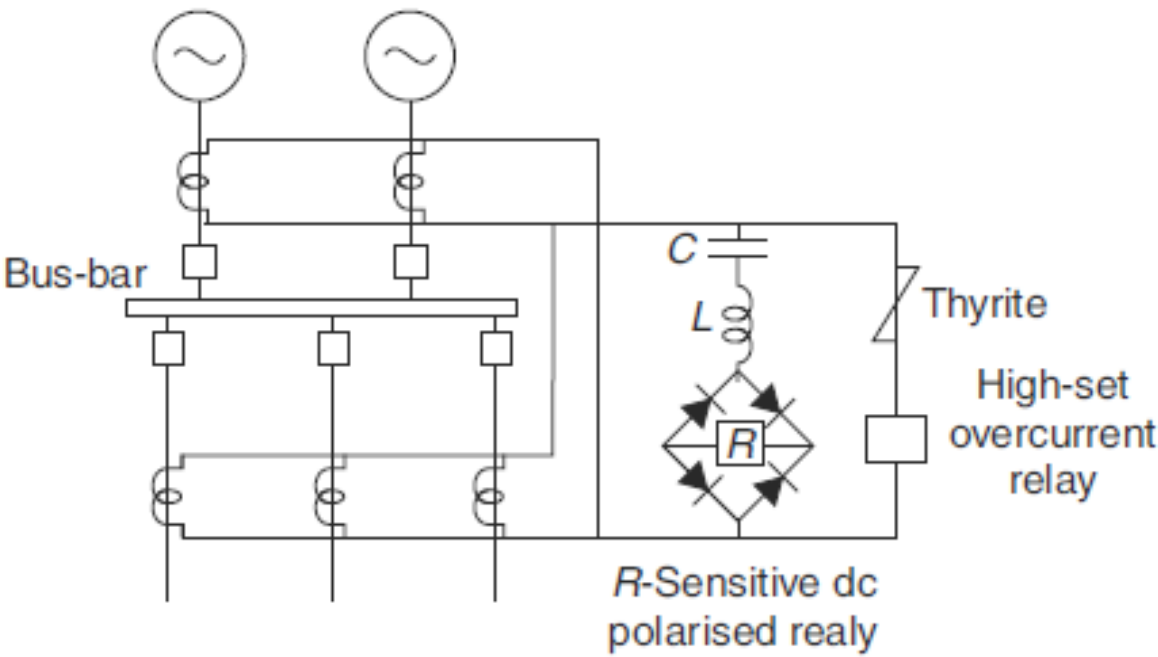
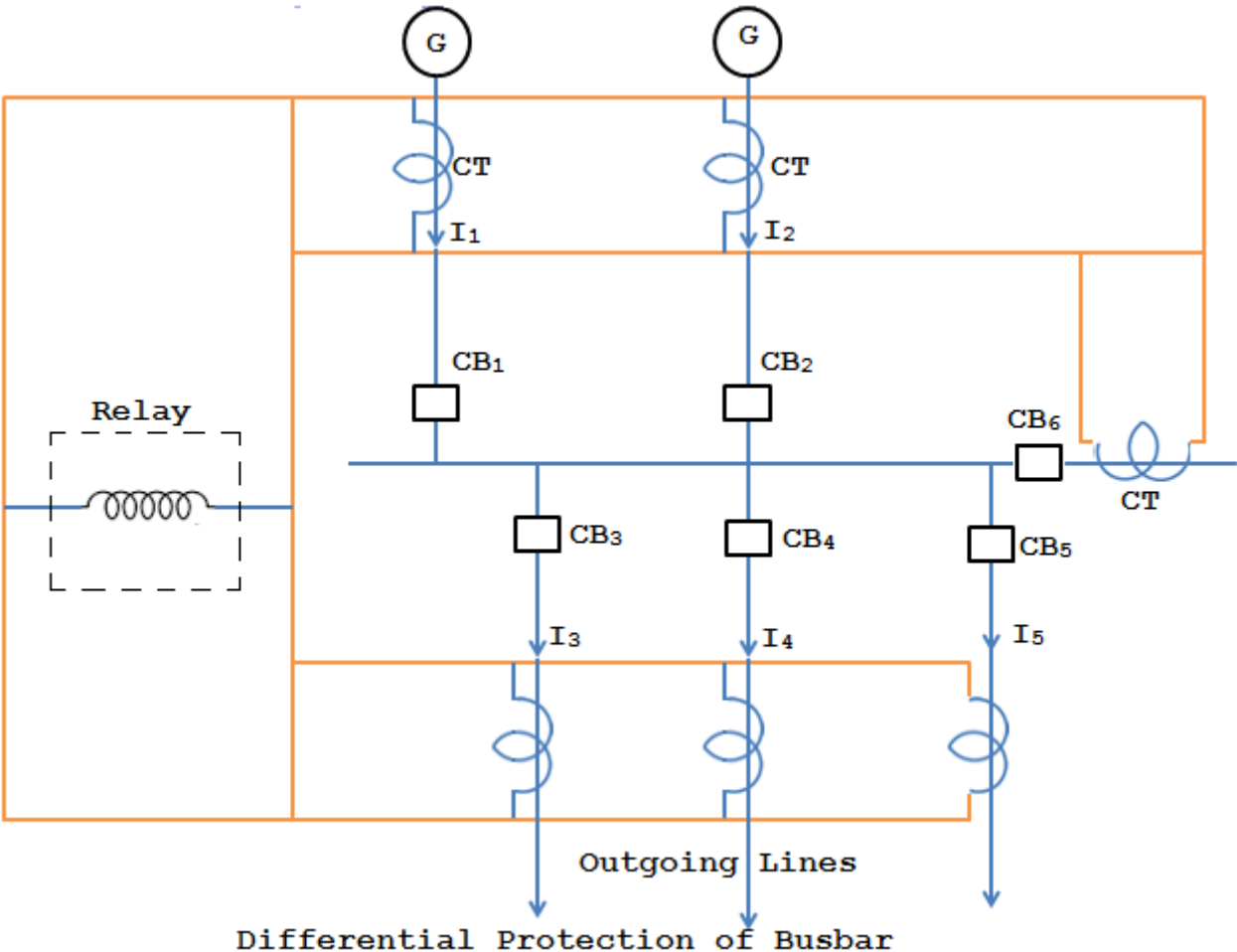
Bus-Bar Protection

When the fault occurs on the bus bars whole of the supply is interrupted, and all the healthy feeders are disconnected.

The majority of the faults is single phase in nature, and these faults are temporary. The bus zone fault occurs because of various reasons likes failure of support insulators, failure of circuit breakers, foreign object accidentally falling across the bus bar, etc., For removing the bus fault, all the circuits connecting to the faulty section needs to be open.

Bus Zone Protection by Differential Principle

A simple **differential protection scheme** is shown in the figure below. It is based in simple **circulating current principle** that during normal load conditions or external fault conditions, the sum of currents entering the bus equals the sum of the currents leaving the busbas, i.e., $I_1 + I_2 = I_3 + I_4 + I_5$.



Differential protection using high impedance relay

Frame leakage protection

