Module 3

Pilot Relaying Schemes:
3.0 Introduction,
3.1 Wire Pilot Protection,
3.2 Carrier Current Protection
Differential Protection
3.3 Differential Relays,
3.4 Differential Protection of 3 Phase Circuits
3.5 Percentage or Biased Differential Relay,
3.6 Balanced (Opposed) Voltage Differential Protection.
3.8 Transformer Protection,
3.9 Protection of Generators
4.0 Protection of Motor
4.1 Buszone Protection
4.2 Frame Leakage Protection

Module 3 Pilot Relaying Schemes, Differential Protection, Rotating Machines Protection, Transformer and Buszone Protection

- To discuss pilot protection; wire pilot relaying and carrier pilot relaying.
- To discuss construction, operating principles and performance of various differential relays for Differential protection.
- To discuss protection of generators, motors, Transformer and Bus Zone Protection

3.0 Introduction- Pilot Relaying Scheme

A protection scheme which employs communications to send a signal from one station to another to allow high speed tripping (permission) or to prevent high speed tripping (blocking). Pilot protection allows over-reaching zones of protection to ensure full protection of the line as well as high speed tripping

Pilot Relaying Scheme Directional Comparison Blocking (DCB) A communications based protection scheme where high speed over-reaching tripping is allowed unless a block signal is received.

Permissive over-reaching transfer trip (POTT) A communications based protection scheme where high speed over-reaching tripping is allowed only if a permissive signal is received

3.1 Wire Pilot Protection

Pilot relaying is an adaptation of the principles of differential relaying for the protection of transmission-line sections

The term “pilot” means that between the ends of a transmission line there is an interconnecting channel of some sort over which information can be conveyed. Three different types of such a channel are presently in use, and they are called “wire pilot”, “carrier-current pilot” and “microwave pilot”. A wire pilot consists generally of a two-wire circuit of the telephone-line type, either open wire or cable. A wire pilot is generally economical for distances up to 8 or 15 km, beyond which a carrier-current pilot usually becomes more economical. Microwave pilots are employed when the number of services requiring pilot channels exceeds the technical or economic capabilities of carrier current.

The differential pilot-wire protection is most satisfactory and is widely employed on account of the advantages such as simplicity, flexibility, a high stability ratio, rapid fault clearance (a time varying between 0.1 and 0.5 second according to the “break time” of the circuit breaker).

The differential pilot-wire protection is based upon the principle that the currents compared at each end of the line or feeder by the use of pilot wires should be same under normal operating conditions and the equality is lost only when there is a fault in between the two ends. The system is quite similar to that employed for the protection of alternators and transformers and the difference lies only in the length of pilot wires.

3.2 Carrier-Current Protection:

In modern high-power electrical systems it is necessary to have quick-acting protections on long transmission lines. The requirements to be met by such protections are fully satisfied by the circulating current differential protection with its high sensitivity, quick action and independence upon the settings of the adjoining-section protections. Notwithstanding this, owing to the need for installing interconnecting conductors (cables), circulating current differential protections are confined to lines up to 8 or 15 km long.

It is, however, possible to make use of the main line conductors as the interconnecting conductors of a circulating current differential protection. The need for special interconnecting conductors (cables) then disappears and it hence becomes possible to set up a circulating current differential protection on transmission lines of any length. This is the basis of what are called carrier-current protections. The essential difference between carrier current protection and the voltage balance (Translay) pilot-wire protection is that, in the former, only the phase angles of the currents at the two ends of a line are compare instead of actual currents as in the latter case and this phase angle decides whether the fault is internal or external.

To make possible the transmission of commercial-frequency (50 Hz) load current, and at the same time use the main line conductors as the interconnecting conductors of the differential protection, it is necessary to use a current of higher frequency in order to be able to transmit current impulses from one end of the line to the other. High frequency signals in the range of 50 kHz to 400 kHz, commonly known as the carrier, are transmitted over the conductors of the protected line.

To inject the carrier signal and to restrict it within the protected section of the line suitable coupling apparatus and line traps are used at both ends of the protected section. This obviously makes this protection scheme quite expensive and justifies its application only in transmission lines of 110kV and above.

The main elements of the carrier channel are:

(i) Transmitter
(ii) Receiver
(iii) Coupling equipment and
(iv) Line trap.

Here we need not to go through the details of carrier current transmitters or receivers, all we need to know is that when a voltage of positive polarity is impressed on the control circuit of transmitter, it generates a high frequency output voltage. This output voltage is impressed between one phase conductor of the transmission line and the earth.

Each carrier-current receiver receives carrier current from its local transmitter as well as from the transmitter at the distant end of the line. 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. The voltage is zero when carrier current is not being received.

Line trap unit is inserted between the bus-bar and connection of coupling capacitor to the line. It is a parallel LC network tuned to resonance at the high frequency. It hence presents high impedance to the high-frequency carrier current, but relatively low impedance (less than 0.1 Ω) to the power-frequency (50 Hz) current. Traps are employed to confine the carrier currents to the protected section so as to avoid interference with or from other adjacent carrier current channels, and also to avoid loss of the carrier current signal in adjoining power circuits for any reason whatsoever, external short circuit being a principal reason. Consequently, carrier current can flow only along the line section between the traps.

The coupling capacitor (CC) connects the high frequency (carrier) equipment to one of the line conductors and simultaneously serves to isolate the carrier equipment from the high power-line voltage. It presents a relatively low reactance to the high frequency currents (about 150 Ω at 500 kHz) and a high reactance to the power frequency (about 1.5 M Ω at 50 Hz). To reduce impedance further a low inductance is connected in series with the coupling capacitors to provide a resonance at carrier frequency.

It is thus evident that the commercial-frequency current will be able to flow only through the line conductors, while the high-frequency carrier current will circulate, when the receiver-transmitter operate, over the line conductor fitted with the high-frequency traps, through the coupling capacitors and through ground (the return conductor).

Methods of Carrier-Current Protection:

There are different methods of carrier current protection and basic forms of carrier protection are:

(i) Directional Comparison Protection and

(ii) Phase-Comparison Carrier Protection.

(i) Directional Comparison Protection:

The protection operates on the basis of comparison of the fault-power flow directions at the two ends of the protected line. Operation takes place only when the flow of power at both ends of the line is in the bus-to-line direction, a condition which will evidently only arise in event of a fault on the protected section of the line. With directional- comparison relaying, the carrier pilot informs the equipment at one end of the line how a directional relay at the other end responds to a short circuit.

The conditions for internal and external faults are illustrated in Fig. 5.17. The relays at both ends of the protected section respond to fault power flowing away from the bus (tripping direction). For faults in the protected section, power flows in the tripping direction at both ends. For external faults power flow will be in opposite directions. A simple signal through carrier pilot is transmitted from one end to the other during faults.

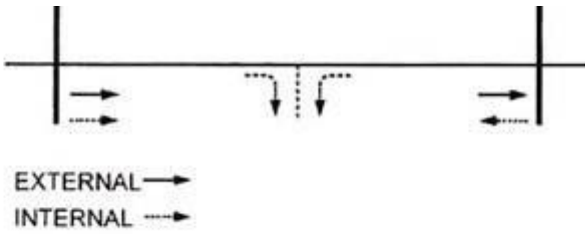


Fig. 5.17. ***Direction of Current Flow For External and Internal Faults***

The pilot scheme can be employed for transmitting either blocking, or permitting signals. Thus possible carrier protections are of two types viz., carrier-blocking scheme and carrier-permitting scheme.

In a carrier-blocking protection scheme, the presence of carrier prevents or blocks operation of the protection. Carrier is, therefore, transmitted only upon the occurrence of a fault and is employed to prevent tripping in the event of an external fault. In carrier-permitting scheme the presence of carrier permits operation of the protection. The carrier blocking scheme is more reliable than carrier- permitting scheme. This is because a failure in the carrier-permitting signal equipment will mean a failure in isolating the fault, whereas a failure in carrier-blocking signal equipment isolates the section on which no fault exists. However, such false operation is preferable to the failure to clear a faulted section.

In a carrier-permitting protection scheme, normally no pilot signal is transmitted from any terminal. Should a short circuit occur in an immediately adjacent line section, a pilot signal is transmitted from any terminal where short-circuit current flows out of the line (i.e., in the non-tripping direction). While any station is transmitting a pilot signal, tripping is blocked at all other stations. But should a short circuit occur on the protected section of the line, no pilot signal is transmitted and tripping occurs at any terminal where short-circuit current flows. Therefore, the pilot is blocking pilot, since the reception of a pilot signal is not required of permit tripping.

Directional comparison protection scheme (carrier blocking type) is illustrated in Fig. 5.18. The operation of the directional element provided on each breaker is indicated by the arrow arid the non- operation by the letter O. Occurrence of fault activates relays on each of the breakers near the fault. This relay unless blocked from operation, causes tripping of breakers. The blocking signal is controlled by the directional relays on each breaker, and is transmitted from one end of a protected section to the other by carrier.

If a directional element determines that the fault is external to the protected section, a signal is transmitted blocking the operation of breakers at both ends of the section. In case the directional elements at both ends determine that fault is in the protected section, no blocking signal is transmitted from either end, and both breakers trip. The sequence of event for a fault at F is made clear by illustration in Fig. 5.18.

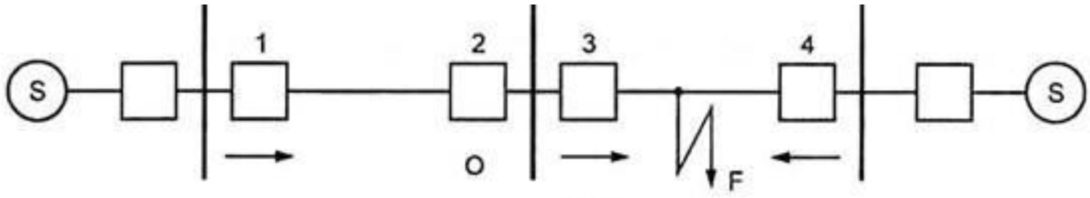


Fig. 5.18. ***Illustration of Directional Comparison Protection of a Power System***

At breaker 1 the directional element shows that the fault may be in the section 1-2. This breaker trips if no blocking signal is received. No blocking signal is transmitted to breaker 2. At breaker 2 the directional element shows that the fault is not in section 1-2. A carrier signal is transmitted that blocks tripping of both the breakers 1 and 2.

At breakers 3 and 4 the directional elements show that the fault may be in section 3-4. No blocking signal is transmitted and after a very short time delay (1 to 3 cycles), both the breakers 3 and 4 trip.

(ii) Phase-Comparison Carrier Protection:

Phase-comparison relaying equipment uses its pilot to compare the phase relation between current entering in the protected zone and the current leaving the protected zone. The current magnitudes are not compared. Phase comparison protection provides only main or primary protection, backup protection must be provided in addition.

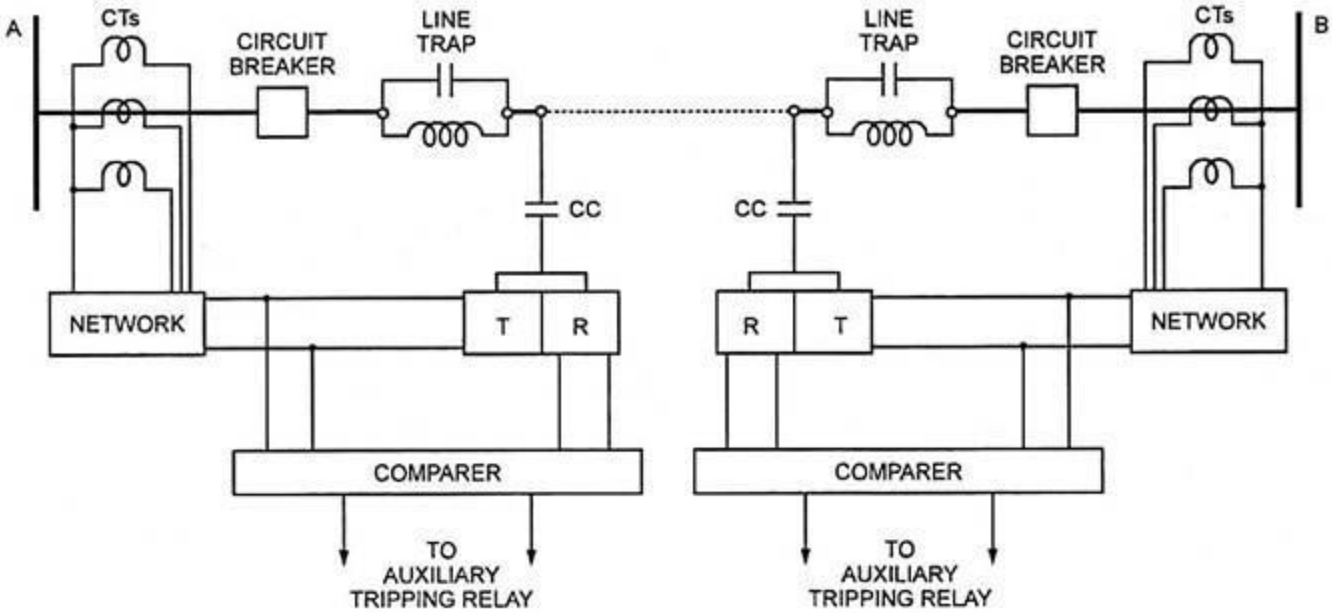


Fig. 5.19. ***Schematic Representation of Phase-Comparison Carrier Protection***

Figure 5.19 shows schematically the principal elements of the equipment provided at both ends of a two-terminal transmission line, employing a carrier-current pilot. As in ac wire-pilot protection, the transmission-line CTs feed a network that transforms the CT output currents into a single-phase sinusoidal output voltage. This voltage is applied to a carrier-current transmitter and to a ‘comparer’.

The output of a carrier-current receiver is also applied to the comparer. The comparer controls the operation of an auxiliary relay for tripping the transmission-line circuit breaker. These elements provide means for transmitting and receiving carrier-current signals for comparing at each end of the relative phase relations of the transmission-line current at both ends of the line.

For examining the relations between the network output voltages at both ends of the line and also the carrier-current signals that are transmitted during external and internal fault conditions refer to Fig. 5.20. For an external fault at point D in Fig. 5.20, the network output voltages at stations A and B (waves a and c) are 180° out of phase.

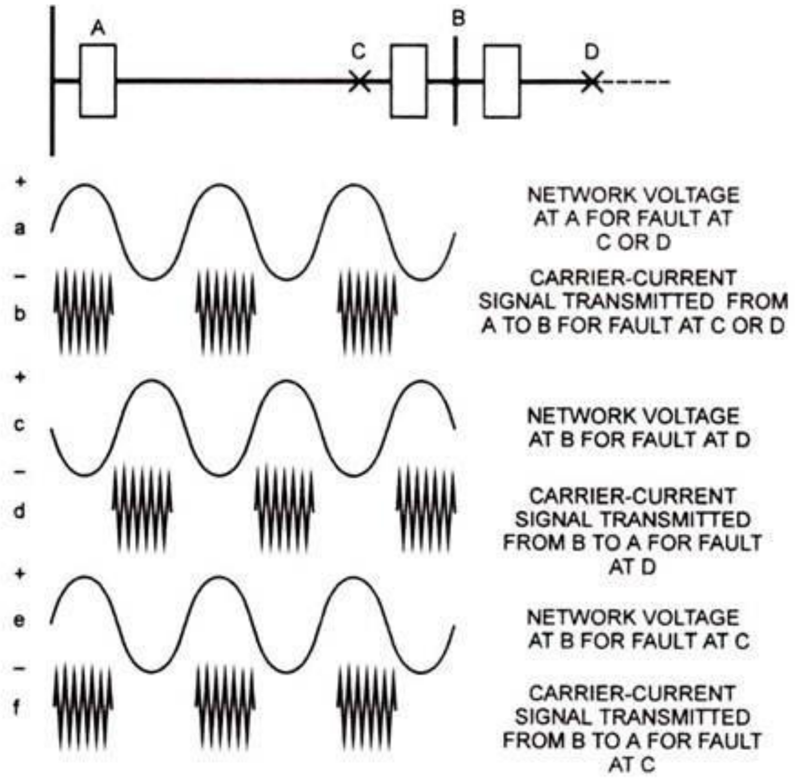


Fig. 5.20. ***Relations Between Network Output Voltages and Carrier-Current Signals***

This is because the connections of CTs at the two stations are reversed. Since an ac voltage is used to control the transmitter, carrier-current is transmitted only during the half cycles of the voltage wave when the polarity is positive. The carrier-current signals transmitted from stations A and B (waves b and d) are displaced in time, so that there is always a carrier-current signal being sent from one end or the other.

For internal fault at point C, the network output voltage at station B reverses because of reversal of power-line currents at station B, the carrier-current signals (waves b and d) are concurrent, and there is no signal from either station every other half cycle.

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. When the carrier-current signals are approximately concurrent, tripping will occur whenever there is sufficient short-circuit current flowing. This is shown in Fig. 5.21 where network output voltages are superimposed, and the related tripping and blocking tendencies are illustrated.

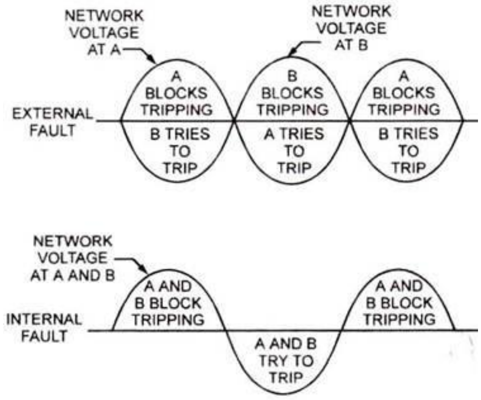


Fig. 5.21. ***Relation of Tripping and Blocking Tendencies To Network Output Voltages***

As shown in Figs. 5.20 and 5.21, the equipment at one station transmits a blocking carrier-current signal during one half cycle, and then stops transmitting and tries to trip during the next half cycle, if carrier current is not received from the other end of the line during this half cycle, the equipment operates to trip its breaker. But, if carrier current is received from the other end of the line during the interval when the local carrier-current transmitter is idle, tripping does not occur.

Advantages of Carrier-Current Protection:

Carrier current over the power line provides simultaneous tripping of circuit breakers at both ends of the line in one to three cycles. Thereby high speed fault clearing is obtained, which improves the power system stability. Besides, there are several other advantages of carrier-current protection.

These are:

1. Fast, simultaneous operation of circuit breakers at both ends.
2. Auto-reclosing simultaneous reclosing signal is sent thereby simultaneous (1 to 3 cycles) reclosing of circuit breaker is obtained.
3. Fast clearing prevents shocks to systems.
4. Tripping due to synchronising power surges does not occur, yet during internal fault clearing is obtained.
5. For simultaneous faults, carrier-current protection provides easy discrimination.
6. Carrier-current relaying is best suited for fast relaying in conjunction with modern fast circuit breakers.
7. No separate wires are required for signalling, as the power lines themselves carry power as well as communication signalling. Hence the capital and operating costs are smaller.

The main application of power line carrier has been for the purpose of supervisory control, telephone communication, telemetering and relaying.

3.3 Differential Protection

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

From this definition the following aspects are known:

1. The differential relay has at least two actuating quantities say i_1, i_2.
2. The two or more actuating quantities should be similar *i.e.* current/current.
3. 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 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.

APPLICATIONS OF DIFFERENTIAL PROTECTION

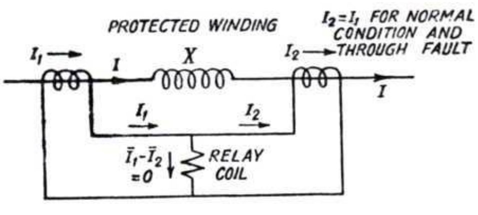
Most differential relays are current differential relays in which vector difference between the current entering the winding and current leaving the winding is used for sensing and relay operation.

Differential protection principle is used in the following applications

— Protection of Generator, Protection of Generator-Transformer Unit.
— Protection of Transformer.
— Protection of Feeder (Transmission Line) by Pilot wire differential protection.
— Protection of transmission Line by Phase Comparison Carrier Current Protection.
— Protection of large motors.
— Bus-zone protection.

PRINCIPLE OF CIRCULATING CURRENT DIFFERENTIAL (MERZ-PRIZE) PROTECTION.

Fig (a) illustrates the principle of differential protection of generator and transformer. X is the winding of the protected machine. When there is no internal fault, the current entering in X is equal in phase and magnitude to current leaving X, the CT's are of such a ratio that during the normal conditions or for external faults (Through Faults) the secondary currents of CT's are equal. These currents say and i2 circulate in the pilot wires. The polarity connections are such that the currents and i2 are in the same direction in pilot wires, during normal conditions or external faults



For Through Fault
Fig. a). Principle of circulating current relay of generators, transformers.

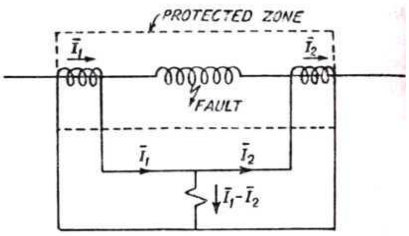


Fig. (b). Internal Fault : $I_1 - I_2 \neq 0$.

Relay operating coil is connected at the middle of pilot wires. Relay unit is of over current type.

During normal condition and external fault the protection system is balanced and the CTs ratios are such that secondary currents are equal. These currents circulate in pilot wires. The vector

differential current i1 - i2 which flows through the relay coil is zero
i1 - i2 = 0 (normal condition or external faults)

This balance is disturbed for internal faults. When fault occurs in the protected zone, the current entering the protected winding is no more equal to the leaving the winding because some current flows to the fault. The differential i1 - i2 flows through the relay operating coil and the relay operates if the operating torque is more than restraining torque.

The currents i1 and i2 circulate in the secondary circuit. Hence CT’s does not get damaged. Polarities of CT’s are considered. CT’s are connected such that the circulating currents i1 and i2 are as shown in Fig. (a) For normal condition

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.

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

3.4 Differential Protection for 3-Phase Circuits:

The above principle can be extended to a system element having several connections. A three-phase circuit is only necessary, as before, that all the CTs have the same ratio, and that they be connected so that the differential relay carries no current when the total current entering the circuit is vectorially equal to that current leaving the circuit.

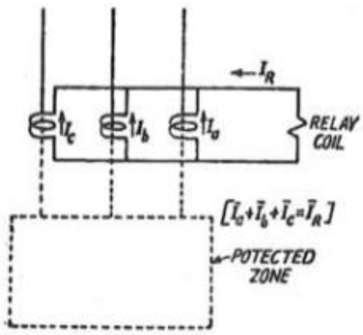


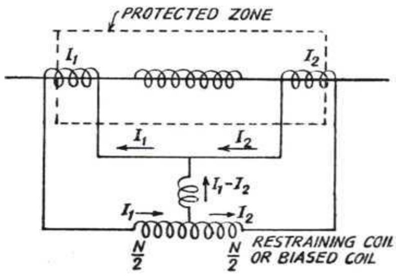
Fig. 2. Differential Protection of 3-phase circuit.

During normal operating conditions the three secondary currents of CTs are balanced and no current flows through the relay coil. But during fault in the protected zone, the balance is disturbed and differential current flows through the relay operating coil and when the differential current exceeds the relay’s pick-up value, the relay operates.

The principle can still be applied for the protection of a 3-phase power transformer, but in this case, the ratios and connections of the CTs on the opposite sides of the power transformer must be such as to compensate for the magnitude and phase-angle change between the power transformer currents on either side.

3.5 BAISED OR PERCENT DIFFERENTIAL RELAY

The reason for using this modification is circulating current differential relay is to overcome the trouble arising out of differences in CT ratios for high values of external short-circuit currents.



$$A.T. = \left(\frac{I_1 + I_2}{2}\right)N$$

Fig. Per cent Differential Relay. (Biased Differential Relay.)

The percentage differential relay has an additional restraining coil connected in the pilot wire as shown in Fig.

In this relay the operating coil is connected to the mid-point of the restraining coil.
The differential current in operation coil is ($i_1 - i_2$),

While current in restraining coil is $\frac{i1+i2}{2}$

If the Number of turns on the restraining coil is 'N', the total ampere turn are $\frac{I1N}{2} + \frac{I2N}{2}$, which is same as if $\frac{I1+I2}{2}$ were to flow through whole coil.
For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal-operation.

The operating characteristic of such a relay is given in Fig.

Except for the effect of the control spring at low current the ratio of differential operating current to average restraining current is Fixed Percentage. Hence the relay is called 'Percentage Differential Relay'.

The relay is also called 'Based Differential Relay' because the restraining coil is also called a biased coil as it provides additional flux.

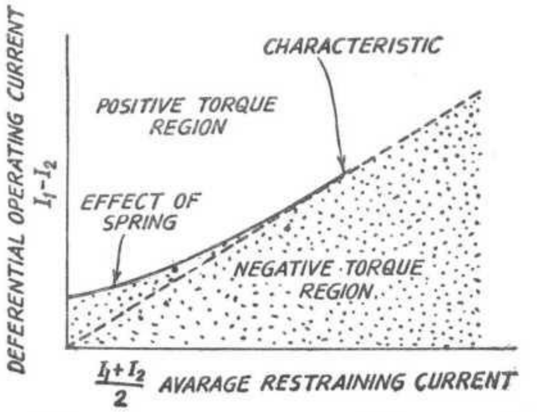
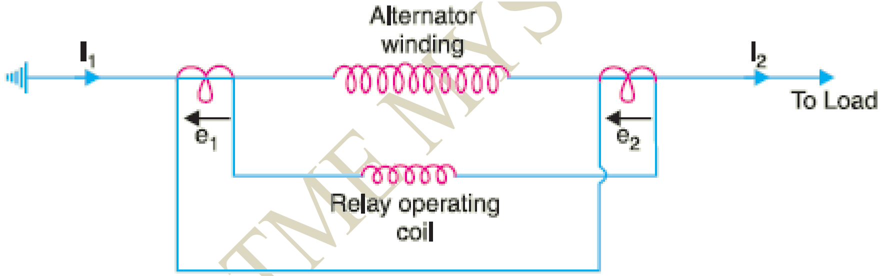


Fig. Operating characteristic of differential relay.

The percentage of biased differential relay has a rising pick-up characteristic. As the magnitude of through current increases, the restraining current increases

3.6 Balanced (Opposed) Voltage Differential Relay

Below fig shows the arrangement of voltage balance protection. In this scheme of protection, two similar current transformers are connected at either end of the element to be protected (e.g. an alternator winding) by means of pilot wires. The secondaries of current transformers are connected in series with a relay in such a way that under normal conditions, their induced e.m.f.s' are in opposition.



Under healthy conditions, equal currents (I1 = I2) flow in both primary windings. Therefore, the secondary voltages of the two transformers are balanced against each other and no current will flow through the relay operating coil. When a fault occurs in the protected zone, the currents in the two primaries will differ from one another (i.e. I1 ≠ I2) and their secondary voltages will no longer be in balance. This voltage †difference will cause a current to flow through the operating coil of the relay which closes the trip circuit.

Disadvantages

The voltage balance system suffers from the following drawbacks :

(i) A multi-gap transformer construction is required to achieve the accurate balance between current transformer pairs.

(ii) The system is suitable for protection of cables of relatively short lengths due to the capacitance of pilot wires. On long cables, the charging current may be sufficient to operate the relay even if a perfect balance of current transformers is attained.

Course outcome: Interpret pilot protection; wire pilot relaying and carrier pilot relaying, Interpret construction, operating principles and performance of differential relays for differential protection

Future Readings
1. http://nptel.ac.in/downloads/108101039/
2. https://www.electrical4u.com/protection-system-in-power-system/
3. http://electrical-engineering-portal.com