transformer. The characteristic of over-current relays include inverse time characteristic, definite time characteristic.

Earth fault protection responds to single line to ground faults and double line to ground faults. The current coil of earth-fault relay is connected either in neutral to ground circuit or in residually connected secondary CT circuit.

Core balance CTs are used for earth-fault protection.

Frame leakage protection can be used for metalclad switchgear.

Directional over-current relay and directional Earth fault relay responds to fault in which power flow is in the set direction from the CT and PT locations. Such directional relays are used when power can flow from both directions to the fault point.

QUESTIONS

1. State the various applications of over-current relaying. Distinguish between "inverse characteristics" and "definite characteristic".
2. With the help of neat sketches explain the principle of following:
   (*a*) Directional Over-current protection.
   (*b*) Earth fault protection by residual connection.
3. Describe Directional earth fault protection.
4. Discuss the following methods of earth fault protection :
   — Core balance CT — Residually connected E.F. relay
   — Relay connected in neutral-to-ground circuit — Frame leakage protection.
5. Describe the principle of a directional over-current relay. How does it help in discrimination in protection of
   — parallel feeder — ring mains.
6. Explain the back-up relaying with graded time lag over-current relays.
7. Explain the time-setting and plug-setting in an induction type overcurrent relay.

28

Differential Protection

Differential protection — Applications — Circulating Current Differential Protection — Differential protection of 3 Ph. circuits — Biased Differential Relay — Balanced Voltage Differential Protection — Summary.

28.1. 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.

28.2. APPLICATIONS OF DIFFERENTIAL PROTECTION

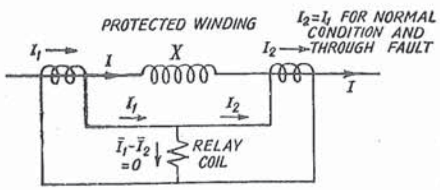
Most differential relays are current differential relays in which vector difference between the current entering the winding and current leaving the winding is used for sensing and relay operation.

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.

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

Fig. 28.1 (*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 l_1 and l_2 circulate in the pilot wires. The polarity connections are such that the currents I_1 and I_2 are in the same direction in pilot wires, during normal conditions or



For Through Fault
Fig. 28.1 (*a*). Principle of circulating current relay of generators, transformers.

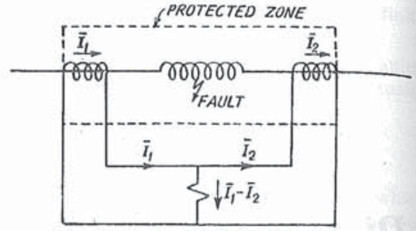


Fig. 28.1 (*b*). Internal Fault : $I_1 - I_2 \neq 0$.

external faults. 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 CT's ratios are such that secondary currents are equal. These currents circulate in pilot wires. The vector differential current $I_1 - I_2$ which flows through the relay coil is zero.

$$I_1 - I_2 = 0 \text{ (normal condition or external faults}$$

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 $I_1 - I_2$ flows through the relay operating coil and the relay operates if the operating torque is more than restraining torque.

The currents I_1 and I_2 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 I_1 and I_2 are as shown in Fig. 28.1 (*a*) for normal condition.

28.4. DIFFICULTIES IN DIFFERENTIAL PROTECTION

1. **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 equi-potential 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.

2. **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 to :

(*i*) Inherent difference in CT characteristic arising out of difference in magnetic circuit, saturation conditions etc.

(*ii*) Unequal d.c. components in the short circuit-currents.

3. **Saturation of CT magnetic circuits during short circuit condition.** Due to these causes the relay may operate even for external faults. The relay may loose its stability for through faults.

To overcome this difficulty, the *Percentage Differential Relay,* or *'Based Differential Relay'* is used. It is essentially a circulating current differential relay with additional restraining coil. The current flowing in restraining coil is proportional to $(I_1 + I_2)/2$ and this restraining current prevents the operation during external faults. Because, with the rise in current, the restraining torque increases and $I_1 - I_2$ arising out of difference in CT ratio is not enough to cause the relay operation. (Ref. Sec. 28.6).

4. **Magnetizing Current Inrush in transformer while switching in.** When the transformer is connected to supply, a large (6 to 10 times full load) current inrush takes place. This certainly causes operation of differential relay current inrush takes place. This certainly causes

operation of differential relay though there is no fault in the transformer. To avoid this difficulty *Harmonic Restraint* is provided for the differential relay. This relay filters the harmonic component from the in-rush current and feeds it to the restraining coil. The magnetizing current contains a large content of several Harmonics. This harmonic content is used for obtaining restraining torque during switching in of transformer.

5. **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 baised differential relay.

28.5. DIFFERENTIAL PROTECTION OF 3-PHASE CIRCUITS

Referring to Fig. 28.2 during the normal conditions the three secondary currents of CT's are balanced and no current flows through the relay coil. During fault in the protected zone, the balance is disturbed and differential current flows through the relay operating coil. The differential current is above the pick-up value, the relay operates. (Ref. Sec. 27.6A).

Secondary of CT is never left on-open circuit.

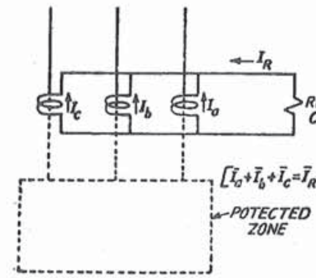
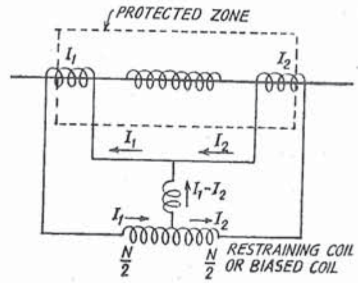


Fig. 28.2. Differential Protection of 3-phase circuit.



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

Fig. 28.3. Per cent Differential Relay. (Biased Differential Relay.)

28.6. BIASED OR PER CENT 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. (Refer the previous paragraph). The percentage differential relay has an additional restraining coil connected in the pilot wire as shown in Fig. 28.3.

In this relay the operating coil is connected to the mid-point of the restraining coil. The total number of ampere turns in the restraining coil becomes the sum of ampere turns in its two halves, *i.e.* $\frac{I_1 N}{2} + \frac{I_2 N}{2}$ which gives the average restraining current of $\frac{I_1 + I_2}{2}$ in N turns. 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. 28.4.

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.

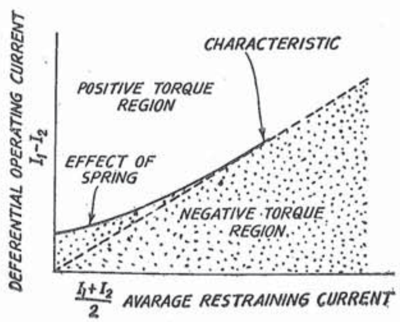


Fig. 28.4. Operating characteristic of differential relay.

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

28.7. SETTINGS OF DIFFERENTIAL RELAYS

The circulating current differential relay has two principle settings namely,

— Setting of operating coil circuit
— Setting of restraining coil circuit.

Setting of Operating Coil Circuit (Basing setting). The percentage setting of (Basic Setting) of operating coil circuit is defined as the ratio:

$$\%\text{Basic Setting} = \frac{\text{Smallest current in oprerating coil to cause operation}}{\text{Rated current of the operating coil}} \times 100$$

(when the currnet in restraining coil is zero)

Setting of Operating Coil Circuit (Pick-up Value). It is defined as the ratio:

$$= \frac{\text{Current in operating coil for causing operation}}{\text{Current in restraining coil}} \times 100$$

$$\%\text{Pick-up Value} = \frac{I_1 - I_2}{(I_1 + I_2)/2} \times 100$$

While determining this setting the factors to be considered include

— CT errors
— Resistance of pilot wires
— Tap-changing
— Stability for through faults.

In case of power transformers, percentage basic setting is of the order of 20% and percentage Pick-up Value is of the order of 25%.

28.8. BALANCED VOLTAGE DIFFERENTIAL PROTECTION

Fig. 28.5 illustrates the principle of differential protection based on balanced voltage principle. In this system the secondaries of CT's are connected such that for normal conditions and through fault conditions, the secondary currents of CT's on two sides oppose each other and their voltage are balanced [Fig. 28.5 (*a*)]. During internal fault, the condition changes as illustrated in Fig. 25.8 (*b*) and an equivalent current $(I_1 + I_2)/2$ flows through relay coils at each end.

The current transformers used in such protection are with air gap core so that the core does not get saturated and overvoltages are not produced during zero secondary current under working normal condition.

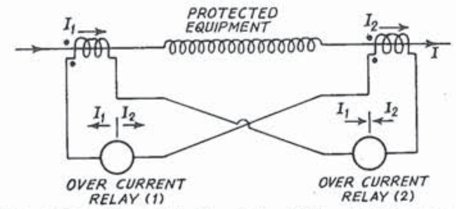


Fig. 28.5 (*a*). Through fault condition Differential Protection based on balanced voltage principle.

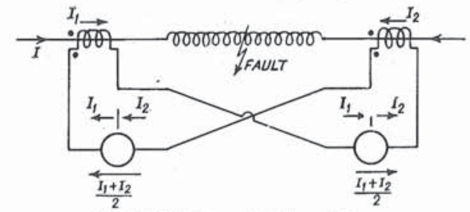


Fig. 28.5 (*b*). Internal fault condition.

QUESTIONS

1. Define 'Differential protection'. Describe the principle of circulating current differential protection.

2. Draw neat sketches illustrating the principle of circulating current differential protection. Indicate polarities of CT's and direction of currents for internal faults.

3. State the difference between Circulating Current Differential Protection and Balanced Voltage Differential Protection with reference to behaviour of CT's.

4. Explain the 'Differential Protection'. State the various applications of differential protection.