30

Protection of Transmission Lines

Introduction — Choice of Protection — **Over Current Protection** — Time graded non-directional Protection — Setting of Inverse time over current relays — Current graded systems — **Distance Relaying** — Impedance, Reactance, Mho relays — Overreach, arc resistance — Carrier aided distance schemes — **Pilot Wire Protection** — Principle of Merz Price Protection — Voltage balance type — Discriminating factor — Transley system — Limitations of Pilot wire systems — **Carrier Current Protection** — Equipment — **Radio Links** — Summary

30.1. INTRODUCTION*

There are several methods of protection of transmission lines. The first group of *non-unit* type of protection which includes

1. Time Graded overcurrent protection
2. Current Graded overcurrent protection
3. Distance protection. Such non-unit type protections do not have pilots. The discrimination is obtained by coordinating the relays settings. Fuses are used in distribution systems, where relays and circuit breakers are not necessary and fuses are preferable due to their low cost, current limiting features etc.

The other group of protection of line is *unit-type* of protection such as pilot wire differential protection, carrier current protection based on phase comparison method ; etc.

Separate protection are systems are necessary for earth faults because earth faults are more frequent on overhead transmission lines than phase faults, and earth fault current is different from phase fault current in magnitude.

Time and current Graded protection is used where a time-lag can be permitted and instantaneous operation is not necessary, *i.e.*, where time-lag in fault clearance does not cause instability or damage to cables, lines, etc. In addition they are used as a back-up protection to the main unit protection.

Distance relaying is employed where time and graded current relaying is too slow or selectivity is not obtained from them. In other words distance relaying is applied for faster protection. In distance relays there are three main types of measuring units, namely : Impedance, Reactance and Mho type distance relays. Each type has certain advantages and disadvantages. For very short lines reactance type is preferred because it is practically unaffected by arc resistance. For short line resistance is large as compared to the line impedance. For medium length lines, impedance relay is suitable but likely to operate wrongly on severe reactive power surges. Mho type relays are used for phase faults of longer lines.

Distance schemes comprise starting elements, measuring elements, timer elements. There are two broad categories called switched and non-switched schemes. Carrier aided distance schemes include carrier acceleration, carrier blocking and intertripping schemes.

* Ref. Ch. 42 "State Distance Protection of EHV Lines".

Table 30.1. Protection of Transmission Lines.

Type of Protection	*Remarks*
Overcurrent Protection — Time graded or current graded	Applied as main protection for distribution lines and back-up for main lines, where main protection is of distance or other faster type.
— Directional or non-directional	Inverse define minimum time relays preferred for time graded systems. Instantaneous relays for current graded systems.
Earth-fault Protection	Separate earth-fault protection is necessary in addition to phase fault protection. Type of earthing and magnitude of earth fault current should be considered.
	Faster than overcurrent protection. Several combinations of schemes available depending upon length of line.
Pilot wire differential protection.	For important lines of relatively shorter length (a few tens of km).
Carrier Current Protection	Where length of transmission line is long and simultaneous opening of circuit-breakers at both ends is necessary.

*Single shot auto-reclosure schemes are used for high voltage overhead lines.

Unit protection provides fast selective clearing. Pilot wire protection based on differential circulating current principle (Merz-Price) and other types are used for short lines where cost of pilot wires is not prohibitive. Carrier current protection is used for long lines, interconnected lines. It provides a fast relaying. Radio signals of frequency bands 1000—3000 MHz are used U.S.A. for protection of feeders.

Auto-reclosure schemes are incorporated in the protection of distribution lines and transmission lines. Auto-reclosure (Ref. Ch. 44) of distribution lines is mainly for improving service continuity. Whereas Auto-reclosure of transmission lines is mainly for improving system stability (Ref. Sec. 2.13 and 2.14)

The principles of protective relays and protection schemes discussed in Ch. 25 to 29 will be further studied with reference to protection of transmission lines.

PART 30 A. OVERCURRENT PROTECTION OF TRANSMISSION LINES

30.2. NON-DIRECTIONAL TIME GRADED SYSTEM OF FEEDER (OR LINE) PROTECTION (Ref. Ch. 27)

In this system the time setting of over-current relays at different locations is graded. Fig. 30.1 illustrated the principle of time graded overcurrent protection of a radial feeder (line).

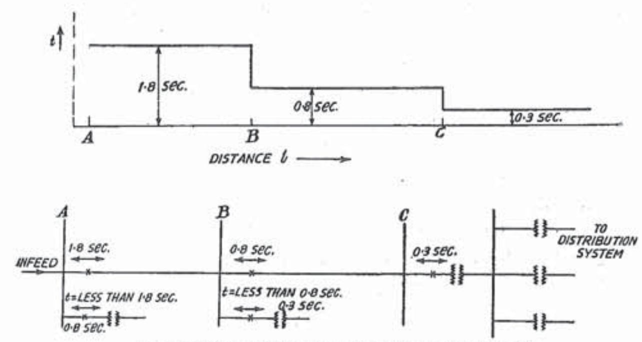


Fig. 30.1. Graded time lag overcurrent protection of a radial feeder (Non-directional).

Fig. 30.1 shows two sections of radial feeder connected between stations *A, B* and *B, C.* The relaying is provided at each station *A, B, C, D.* The arrow marks pointing towards both directions indicate that the relays operate for faults on either sides. The time lag is indicated on the arrow head.

For a fault beyond station *C* the circuit breaker at *C* operates first, *i.e.*, with relay time of 0.3 second. Meanwhile the other relays at station *B* and *A* start operating but after about 0.3 second the fault is cleared and the relays at *A* and *B* get reset. Therefore for faults beyond *C*, only the *CB* at *C* operates. For faults between *B* and *C* only *CB* at *B* operates and likewise. Thus unnecessary tripping is avoided. Secondly by some failure if the relay at *B* fails to operate, the relay at *A* provides, back-up protection.

This system is suitable for radial feeder in which power flow is only in one direction.

Inverse definite minimum time delay relays are extensively used for obtaining combination of current and time gradings.

Time interval of 0.5 sec. is usually found suitable, this covers errors in *CT,* relay and *CB* operating time. Hence operating times of relays in consecutive stations can be 0.3, 0.8, 1.3, 1.8, seconds.

At sub-stations *B* and *A* transformers are shown connected to the station bus. The time setting of the relays in this connection should be less than setting of the relays on the main feeder.

We graded inverse time protection, the characteristic of relays should be taken into account while setting the relays With inverse relays, the time setting and plug setting can be preset. The fault current is calculated. The time interval of 0.5 second is provided between consecutive relays and operating times are calculated. The plug settings and time settings are so arranged that for a fault on last section (beyond *C*), the desired operating times are obtained.

Time graded overcurrent protection for phase faults is supplemented by time graded earth fault protection. The earth fault relay is residually connected. In general, two relays are employed for phase faults and one for earth fault. Since both phase fault and earth fault relays are set for short circuits, they do not detect over-loads of small magnitude. Overload protection may be provided in addition, with long time setting (minutes) and low current setting.

Setting of Inverse Overcurrent Relays for Co-ordination

Step I. Choose pick-up of the relays so that they will operate as follows : (Ref. Sec. 26.6)

1. Operate for short circuits in its own line section.

2. Provide back-up protection to the next line section.

For a phase relay phase to phase fault is assumed. For an earth fault relay, a single line to ground fault is assumed.

The operating time is graded by considering the following aspects :

$$T_A = T_B + CB_2 + O_A + F$$

T_A = Operating time of relay at station *A*

T_B = Operating time of relay at station *B*

CB_2 = Operating time at circuit breaker at station *B*

O_A = Overtravel time at station *A*

F = Factor of safety.

Considering, arbitrarily

T_B = 0.8 second

CB_2 = 0.16 second (assuming 8 cycle Breaker)

O_A = Overtravel time = 0.1 sec

F = Factor of safety = 0.2 sec.

$$T_A = 0.8 + 0.16 + 0.1 + 0.2 = 1.26 \text{ sec.}$$

Hence the time of relay at *A* should be atleast 1.3 seconds.

Overtravel is the travel of a relay moving elements after the actuating force is removed. This overtravel occurs because of inertia of moving parts. Overtravel is important feature of a time-delay relay where selectivity is obtained by time lag. Overtravel of 0.1 sec. is generally assumed for inverse time relays.

The next step in co-ordination is adjustment of time lag of inverse time overcurrent relays to obtain selectivity. The equation given above is used for determining the time settings of relays in the adjoining sections.

The procedure of selecting time setting and plug settings is as follows. The time multiplier setting of the relay at remote and from the source is set to a low value, say 0.1. The interval of 0.4 to 0.5 second is added to select operating times of relays at consecutive stations, as described earlier. Suppose T_0 is the required operating time.

Then, $$T_o = T_m \times TMS$$

where TMS = Time multiplier setting.

T_m = Time from relay characteristic for time multiplier setting of 1 and for plug setting equivalent to maximum fault current.

For example, suppose fault current = 3000 amperes, relay is set to operate for primary current of 300 amperes, then plug setting multiplier is equal to 3000/300 = 10. See from the characteristic of the relay, the operating time of relay for plug setting multiplier of 10. This corresponds to time setting of 1. This time is T_m. Suppose T_m is 2 seconds. From the relay co-ordination point of view, the desired operating time T_0 is say 1 second. Then time multiplier is set to

$$TMS = \frac{T_o}{T_m}$$

which is this case is given by,

$$TMS = \tfrac{1}{2} = 0.5.$$

(Definitions and explanations of *TMS* and *PS* are given in Sec. 26.11, Ref. Sec. 26.6 for plug setting.)

Disadvantages of Graded Time lag Overcurrent Relaying

1. Time lag is to be provided, time lag is not desirable on short circuits.

2. The method is not suitable for ring mains or interconnected lines. It is suitable for radial lines with supply at the one end only.

3. It is difficult to co-ordinate and needs changes with new connections.

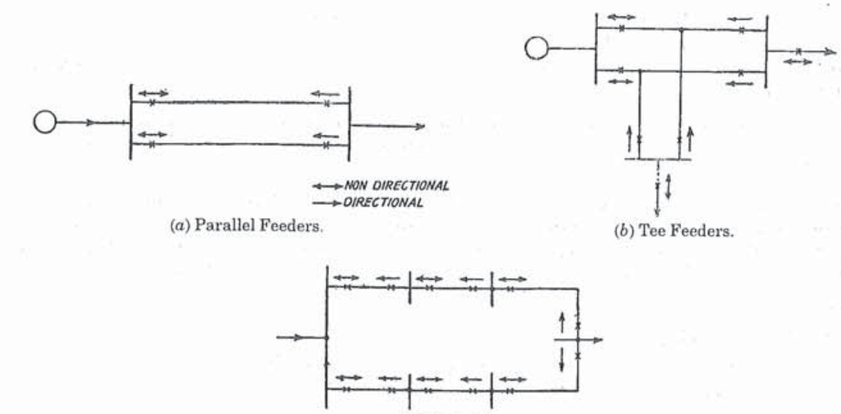
4. It is not suitable for important, long distance transmission lines where rapid fault clearing necessary to ensure stability of systems.

30.3. DIRECTIONAL TIME AND CURRENT-GRADED SYSTEM

To obtain discrimination, where power can flow to the fault from both the directions, the circuit breakers on both the sides should trip, so as to disconnect the faulty line. Such case occurs in parallel feeders, ring mains, *T* feeders, interconnected lines. Directional time and current graded systems are suitable in such cases.

Here the directional relays can operate for fault current flowing in a particular direction shown by arrow → (Fig 30.2)

In the diagram, the double headed arrow ↔indicates non-directional relay. In Fig. 30.2 (*a*) a fault on feeder *I* will trip only circuit-breakers at the end of feeder *I.* The circuit breaker at the ends of neighbouring feeder (*II*) would not trip as a main protection.



(a) Parallel Feeders. (b) Tee Feeders.

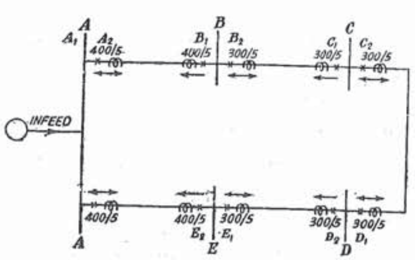
(c) Ring main.

Fig. 30.2. Typical directional protection schemes.

30.4. SETTING OF DIRECTIONAL OVER-CURRENT RELAYS OF A RING MAIN

Fig. 30.3 illustrates the setting of a directional overcurrent relaying for 3 ph. faults. For faults between B and C the relays B_2 and C_1 operate first and BC is disconnected from the ring main. So, also for the faults on other sections, the faulty section is disconnected from the system.

If, in addition to directional overcurrent feature, time lag is necessary to obtain selectivity, the graded time lag is used. The time lag of directional relays is selected such that it is minimum for relay near the source. Fig. 30.4 illustrates the principle.



Maximum Fault Currents 3 Ph. Fault

Via AB	*Via AE*
A = 12000 A	A = 12000 A
B = 8000 A	B = 8000 A
C = 5000 A	C = 5000 A
D = 3000 A	D = 5000 A
E = 2000 A	E = 2000 A

Fig. 30.3. Example of directional over-current relay settings Load connections not shown.

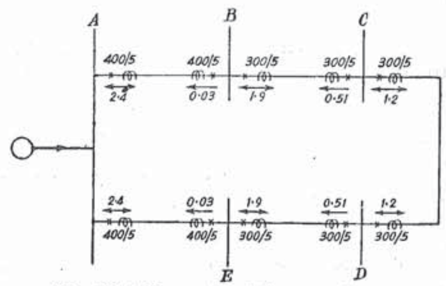


Fig. 30.4. Example of time grading of directional earth fault relays.

30.5. CURRENT GRADED SYSTEMS

An alternative to time grading or in addition to time grading current grading system can be applied when the impedance between two sub-stations is sufficient and current grading can be applied. The long time delays occurring in graded time lag system can be partly avoided. Current graded systems normally employ high speed high set over current relays. They operate at pre-determined setting without a time lag.

Fig. 30.5 illustrates the protection of a radial feeder with instantaneous overcurrent relay.

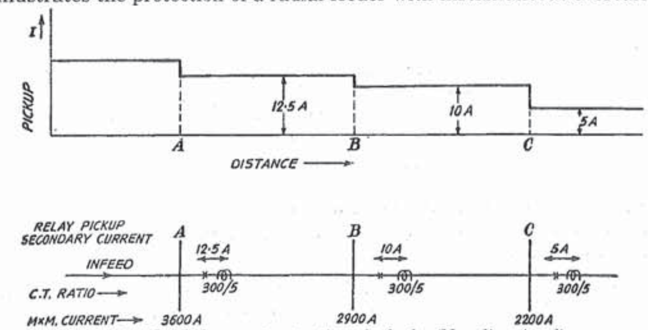


Fig. 30.5. Graded current protection of a feeder (Non-directional).

For a fault beyond C relay at C is actuated. For fault between C and B is actuated. For fault between B and A relay at A is actuated. The current setting diminishes progressively from the source to the remote end of the line.

Difficulty. (*a*) If a fault is very near to station B in section BC, the relay at A may feel that it is in section AB because there may be very little difference in the fault currents and the relays do not discriminate between the fault in the next section and the end of first section. The reason being

1. Difference in fault currents is low.
2. Magnitude of fault currents cannot be accurately determined.
3. The accuracy of relay under transient condition is likely to be different.

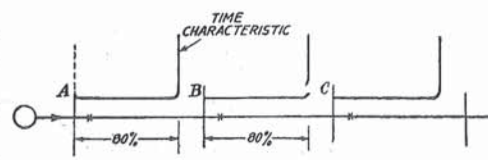


Fig. 30.6. Instantaneous overcurrent protection of line. (It is supplemented by time graded back-up).

Therefore, to obtain discrimination only about 80% lines protected by relay at one station. Since only 80% of line is protected this system should be supplemented by time graded inverse definite minimum time relay system.

(*b*) The fault currents for different types of fault are different. This brings a certain difficulty in relay setting.

(*c*) For ring mains, parallel feeders etc. where power can flow to the fault from either directions, a system without directional control is not suitable.

Instantaneous and IDMT Protection

Instantaneous overcurrent relays in conjunction with inverse definite minimum time (IDMT) relays can be used for high speed protection of radial lines. The coils of instantaneous element and IDMT element are connected in series. Fig. 30.7 illustrates the characteristics of the combination. The instantaneous element has a characteristics like Fig. 30.6.

Such protection can be effectively applied only if the following conditions are satisfied :

— The fault level at the sending end of the line is at least thrice that at the receiving end of the line.

— The changes in the generating station do not change the fault current significantly.

The instantaneous element should be set for more than 150% of maximum fault current at the end of the line section which it protects. For example, the instantaneous element at section A should be set for more than 150% at maximum fault current at section B. Such a margin takes care of transient and over-reach.

Over-reach of Instantaneous Over-current Relay

Over-reach is a tendency of a relay to pickup for faults further away from what is expected from a relay neglecting the d.c. component of a fault current. Magnetic attraction type relays are most affected by over-reach because they are sensitive to d.c. component Certain induction relays are least affected by d.c. component. Percentage over-reach is defined as

$$\text{Percentage over-reach} = \frac{A - B}{B} \times 100$$

where A = relay pick-up current steady state r.m.s. value

B = r.m.s. value of steady state current which when fully offset causes relay pickup.

To take into account the d.c. component, the maximum value of symmetrical value of current for which the relay should not operate, should be multiplied by about 1.25, to obtain relay pick-up setting.

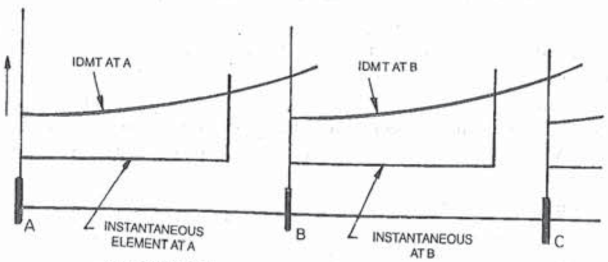


Fig. 30.6 (*a*) Characteristics of the combined instantaneous and IDMT protection.

30.6. DEFINITE TIME OVERCURRENT PROTECTION OF LINES (Fig. 30.7)

Definite time overcurrent relays have adjustable overcurrent elements. When an element picks up it energizes a built-in time element, which initiates a tripping signal after the elapse of the preset time.

The tripping times are so graded that the relay beyond the remote station (C) is set at a shorter time than the relays nearer to the power source. This form of time grading is satisfactory for simple line configurations with single-end in-feed provided that the tripping times at the power source do not become excessively long. Definite overcurrent protection is also employed as back-up protection for generators and transformers.

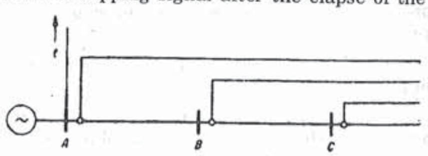


Fig. 30.7. Time graded overcurrent protection with definite time relays.

30.7. EARTH FAULT PROTECTION OF LINES

The general practice is to use a set of two over-current relays for protection against interphase faults and a separate overcurrent relay for single line to ground fault. Separate ground fault (earth fault relays) are generally preferred because they can be adjusted to provide faster and more sensitive protection for single line to ground faults than that provided by the phase (Refer Ch. 27).

Earth-fault currents depend on type of natural earthing. Where no natural point is available, grounding transformer is used.

In case of resonant earthed system or ungrounded systems, the earth-fault currents are minimum (Ref. Ch. 37). Hence conventional earth-fault protection by residual earth-fault relays cannot give a satisfactory protection. Hence a double actuating quantity earth-fault relay is provided at each station. In addition, a directional element is provided to determine in which feeder is the earth-fault. The double actuating quantity relay has one voltage coil energized by residual voltage and current coil energized by residual current.

In case of resistance earth or solid earthed systems, the over-current element connected in residual circuit of CTs is preferred.

The setting of earth-fault relays may be made less than rated full load current of the line.

The earth-fault elements are with inverse characteristics and time-grading is preferred for earth-fault protection of radial feeders.

The practice followed is to apply relays having a setting range of 10 to 40%. A setting of 10% on a 500/5 A ; current transformer means the relay operates for primary earth fault current of

$$\frac{500}{5} \times \frac{10}{100} = 5 \text{ A}.$$

Selection of optimum setting of earth fault relay is difficult. The final setting is determined by test before commissioning.

The procedure for time setting is similar to that of overcurrent relays. However the errors are calculated for each current level and corresponding relays time should be considered.

Directional earth fault relays are used where fault power can be supplied from both ends of protected equipment. Fig. 30.4 illustrates the time graded scheme of ring main based on direction earth fault protection.

30.8. SUMMARY OF OVERCURRENT PROTECTION OF LINES

Overcurrent protection of lines falls into following categories :

— Graded time lag overcurrent protection. In this protection, inverse time relays are employed. This time settings of over-current relays at successive stations are so graded that discrimination is obtained.

— Graded time lag or graded that directional overcurrent protection.

— This is employed where power flow can be from either sides and simple overcurrent protection does not provide selectivity.

— Protection by instantaneous overcurrent relays.

— Protection by definite time overcurrent relays.

— Separate relays are provided for phase fault protection and earth fault protection. The relays for phase fault protection are co-ordinated independently of relays for earth fault.

PART 30B. DISTANCE PROTECTION OF TRANSMISSION LINES

30.9. INTRODUCTION TO DISTANCE PROTECTION OF H.V. AND E.H.V. LINES (Ref. Ch. 29, Ch. 42)

Distance relaying is considered for protection of transmission lines where the time-lag cannot be permitted and selectivity cannot be obtained by overcurrent relaying. Distance protection is used for secondary lines and main lines.

A distance relay measures the ratio $\frac{V}{I}$ at relay location which gives the measure of distance between the relay and fault location. The impedance (resistance/reactance/admittance) of a fault loop is proportional to the distance between the relay location and the fault point. For a given setting, the distance relay picks up when impedance measured by it is less than the set value. Hence it protects a certain length of line. Hence it is called distance relay.

Measurement. Considering zero fault impedance the voltage at fault point will be zero. The voltage at relay location O will be equal to the voltage drop along the length OF, whereas same current I is flowing in the line at O upto F. If fault had occurred near O, the voltage at O would be different. Current would be more because of the reduction in line impedance. If fault occurred away from O, the voltage at O would be lesser and current would also be lesser. In distance relays the ratio V/I is measured. The current gives operating torque and voltage gives restraining torque. Hence for values of Z above certain setting the relay does not operate. Hence it protects only a certain length of line equivalent to its Impedance setting.

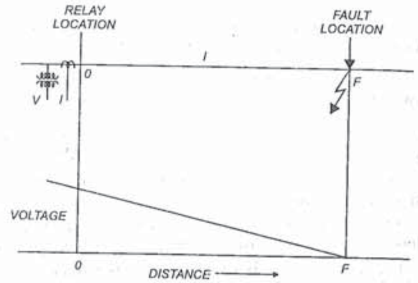


Fig. 30.8. Distance relaying : measurement of distance.

For the impedance measurement there several possibilities however, for distance protection equipment the impedance $Z = V/I$ or the conductance $G = (I/V) \cos \phi$ are generally measured. When planning impedance-dependent protection schemes particular attention must be paid to the influence of the arc resistance on the loop impedance. This arc resistance has ohmic nature and increases the circuit impedance of the short-circuit loop. This falsifies the measurement of impedance by the protection equipment as regards both magnitude and phase relation.

Allowance must be made for the effect of arc resistance when setting the protection equipment. The resulting tripping characteristics represent a modified value between the impedance and conductance measurement. Modern distance protection relays include provisions for matching the degree of arc compensation to the short-circuit angle of the line depending on the application.

The arc resistance is approximately given by

$$R_{arc} = \frac{3 \times 10^4 L}{I^{1.4}}$$

where R_{arc} = resistance of arc, Ohms

L = Length of arc in metres in open standstill air

I = Fault current Amperes.

Due to the extra arc resistance the distance measured by the impedance relays is inaccurate. The distance relay will measure in impedance $Z_f + R_{arc}$, where Z_f is impedance of line.

For short lines, the Z_f is relatively low and R_{arc} is not negligible. Hence measurement of impedance $Z = Z_f + R_{arc}$ does not give accurate measure of distance. For long lines, the R_{arc} is negligible compared with Z. Hence measurement of impedance gives fairly accurate measurement of distance.

A sudden change in loading condition in a power system causes power swings between load point and source. Under certain circumstances, the power swings can cause the operation of distance relays. Hence it is desirable to examine the behaviour of distance relays during power swings.

The principle of measurement in following types of distance relays was described in Ch. 29 :

— Plain Impedance Relay — Directional Impedance Relay
— Mho type distance Relay — Reactance type distance Relay

The application of such relay in practical distance schemes are discussed in this chapter. There is no hard and fast rule regarding these applications. There is overlapping in many areas of applications. (Static Distance Protection : Ch. 42)

30.9.1. Plain Impedance Protection (Ref. Ex. 42.1)

Fig. 30.9, the plain impedance relay does not recognize the direction in which the fault has occurred. Relay is Non-Directional. Hence it will operate for all faults along the line BC and also along BA provided the impedance measured by relay ZB is less than the setting.

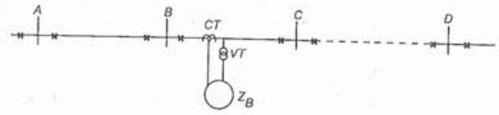


Fig. 30.9. Explaining Impedance Protection.

The relay unit can be high speed (instantaneous) or with time increasing with measured impedance.

The relay will not only operate for faults on section BC but also faults in section AB and faults on busbar in station B. Therefore, discrimination between faults on neighbouring sections is not possible with plain impedance protection.

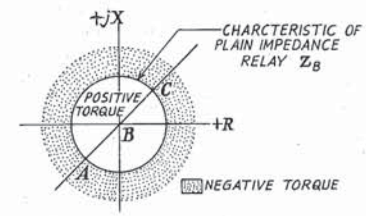


Fig. 30.10. Explaining Plain Impedance Protection.

Plain impedance relay has three major disadvantages :

— Selectivity cannot be obtained as it operates for faults on either sides. Circle covers all four sectors.

— As it measures resistance and reactances, it is affected by resistance of arc, resistance of transmission line.

— It is affected by power swings (fluctuation of reactive power) as the circular characteristic covers a large area on every side of centre wing point comes within circle.

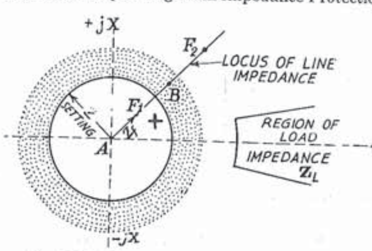


Fig. 30.11. Impedance Relay at 'A' to protect 85% of line AB.

Ref. to Fig. 30.9 for faults near C, in the line BC, the relay at B cannot accurately discriminate between fault in CD and fault in BC. The *fault resistance* will be seen by relays as extension of line length, thereby the relay set for protecting line BC will not operate for faults very near C. This is called *under reach*. Fault resistance is a horizontal line segment on R-X diagram (Fig. 30.14). For a fault near C (Fig. 30.10), such segment will take measured point beyond the circle. Therefore the relay will under-reach (Defn. Sec. 25.8.)

It is a standard practice to set the reach of the first zone of distance relay to cover only about 85% of protected line impedance (Ref. Fig. 30.11).

30.9.2. Directional Impedance Relay

For achieving discrimination between forward and rear faults, the directional impedance relays are used. Directional impedance protection acts only for faults in forward direction. This is explained in Fig. 30.12.

The directional impedance relay Z_B does not operate for faults in zone BA and for faults on busbar B.

Directional Impedance Relay combines the directional element and impedance measuring element in a single case.

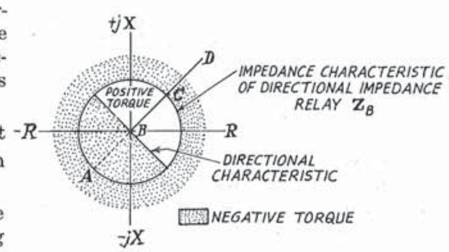


Fig. 30.12. Directional Impedance Relay Characteristics.

The voltage supplied to the directional element is taken from the two phases from which current is not taken. Thereby the function of directional element is not affected by drop of voltage.

Directional Impedance Relays are preferred for phase fault protection of lines of moderate lengths.

30.9.3. Reactance Relay

The main advantage of reactance relay is that is not affected by fault resistance. The characteristic of plain reactance relay is a line parallel to *R*-axis in *R-X* plane. However, the reactance relay is not used by itself. It is generally used along with Mho Relay or offset Mho Relay.

Suppose reactance relay is used along with Mho Starting Relay (Fig. 30.13). The reactance relay measures reactance upto fault point. The voltage drop due to arc (*AB*) does not affect the measurement, as all points on *AB* are in operating region.

Hence such relays are used for protection of short lines having fault currents less than 20 KA. In such lines the effect of fault resistance is predominant.

In case of long lines, the effect of arc resistance is negligible.

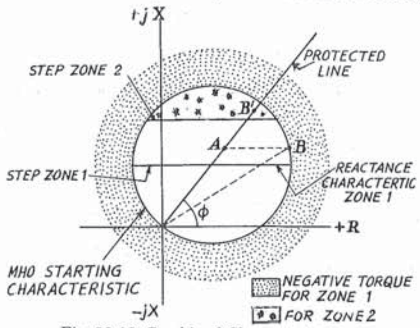


Fig. 30.13. Combined Characteristics of Mho Starter and Reactance Relay.

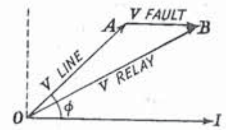


Fig. 30.14. Relay measures Line voltage plus fault voltage.

30.9.4. Mho Relay Admittance Relays (Ref. Sec. 42.14 *b*)

Mho characteristic is a circle passing through origin of *R-X* diagram (Fig. 30.13) Mho relay preferred for phase fault relaying of long lines particularly where severe synchronizing power surges can occur. (Fig. 30.15)

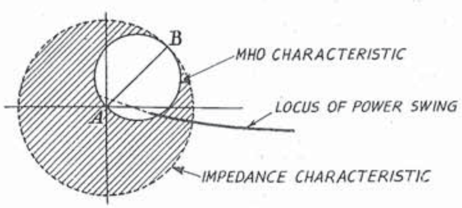


Fig. 30.15. Comparison of Mho characteristic and impedance characteristic under conditions of Reactive Power Swings.

Comparing to impedance characteristic (for protecting line *AB*), the Mho characteristic requires very much less area. Hence many points covered by impedance characteristic are in the negative torque region of Mho characteristic (Figs. 30.15 and 30.16).

Hence Mho relay can remain inoperative during power swings on EHV lines to a greater extent than impedance relay.

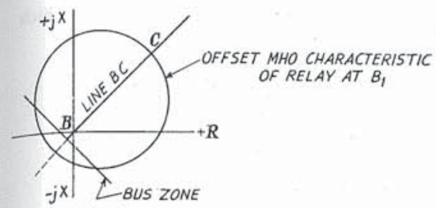


Fig. 30.16 (*a*) Off-set Mho characteristic to cover bus-bar zone.

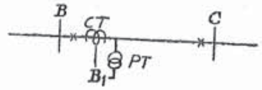


Fig. 30.16 (*b*).

30.9.5. Offset Mho Characteristic (Ref. Sec. 42.7)

The offset Mho characteristic encloses the origin of *R-X* axis. The main applications off-set Mho relay are following :

— Bus bar back-up protection
— Carrier starter unit in carrier Aided Distance Blocking Schemes
— Power Swing Blocking

Referring to Fig. 30.16 the Mho characteristic at B_1 is offset so as to enclose origin *B* and cover the bus bar zone at *B*.

(Hatched Area indicates that impedance characteristic has much more of +ve torque region which is beyond that of Mho characteristic).

Referring to Fig. 30.17 during the power swing locus of impedance measured by relay moves along the curve. As soon as it comes within the positive torque region of the offset Mho characteristic (Point *P*, the offset Mho relay acts and blocks the measuring relay for line *BC*. Therefore, the relay does not operate during power swings. (Details about Power Swing : Sec. 42.9)

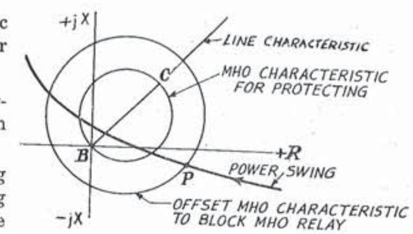


Fig. 30.17. Blocking during power swings.

30.10. DISTANCE SCHEMES

Distance schemes comprise set of protective systems. The choice of Distance scheme depends upon

— distance between relaying points, number of stations in series
— speed of operation desired.
— system configuration.
— other protections provided for the line.
— whether directional feature necessary
— whether high speed auto-reclosure provided.
— stability considerations, etc.

There are several alternative schemes from which choice is made. The schemes may be divided into the following three broad groups:

1. Distance schemes designed for phase faults only.

Ground fault protection provided by overcurrent relays.

2. Non-switched schemes for phase faults as well as earth faults.

Such schemes have separate distance relays for phase faults and earth faults. Thus such schemes have several measuring elements.

3. Switched schemes having a single set of measuring element (for all kinds of fault) to which an appropriate measured quantity is applied according to type of fault.

4. Static distance schemes (Ref. Ch. 42.)

Distance schemes comprise the following components :

— starting elements
— zone timer
— measuring elements
— tripping relays.

30.11. STARTING ELEMENT (FAULT DETECTORS)

Starting Elements are used with distance schemes having one or more measuring elements. The tasks of starting elements are the following :

— To switch the measuring element to correct input quantity, depending upon type of faults, in case of distance relay with single measuring element.
— Selecting of correct phase for tripping instructions, if single phase auto reclsoure is used.
— Changing distance steps or reversing the direction of measuring element after a certain time lag.
— To give non-directional back-up to measuring elements.
— To prepare carrier equipment to receive a possible instruction.

The **starting element** also called fault detector acts first and switches the **measuring element** to appropriate input quantity.

In switched schemes, there is only a single measuring element which is switched to appropriate phase by starting element and their auxiliaries, depending upon the type of fault. The choice of scheme is made from standard schemes (examples in Table 30.1). In non-switched schemes, for each type of fault there is separate measuring element.

Types of Starting Elements

— Overcurrent Starters
— Impedance Starters
— Compounded Impedance type.
— Undervoltage Starters
— Minimum Impedance type.

In the event of a fault the starting elements will operate first and apply the secondary voltage and current of the faulty phase or phase to the measuring element.

For the majority of applications overcurrent staring will be adequate, but where required, for example in a resistance earthed system, undervoltage starting can be added.

When impedance staring is required (see above) the over-current and undervoltage elements are replaced by the impedance starting-elements. These are normally connected to select correctly the faulty phase in the case of phase faults. In the case of an earth fault, the connections of the three impedance starting-element are switched by means of the residual-current starting element to select correctly the faulty phase.

Minimum Impedance Starters

As starting element of distance relays in e.h.v. system minimum-impedance relays are preferred because the minimum short-circuit current in such system at low loads is often less than the maximum service current at peak load. The minimum impedance relay compares the voltage and the current ; its functional principle being described in Figs. 30.18 and 30.19.

For the protection of long and/of heavily loaded ones, the voltage applied to minimum-impedance relays can be compounded to enable the starting elements to earth further along the line. At the same time a much heavier load can be carried without the starting elements picking up.

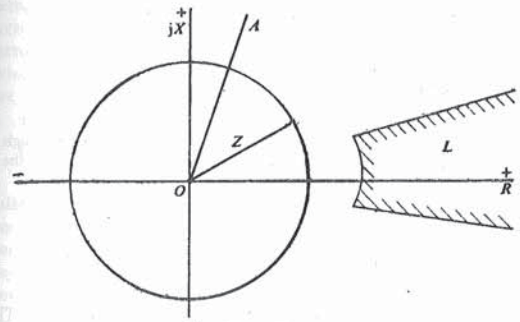


Fig. 30.18. Characteristics of an impedance relay on *R-X* plane.

30.12. STEPPED CHARACTERISTIC

The distance relays of early day used to have Inverse characteristic of Distance *vs.* Time. Now such characteristic is no more preferred and distance relays have *stepped characteristic.*

The stepped characteristic may be either single stepped (Fig. 30.11) or three stepped, (Fig. 30.12).

Single Stepped Distance-Time Characteristic

Single step distance relays can be used where high set instantaneous overcurrent relays cannot be used. The typical applications of single-step distance protection are protection of transformer feeder, protection of single section transmission lines, protection of bus bars etc. The conventional distance measuring element has instantaneous time-distance characteristics. The operating time becomes infinite at relay reach point. The distance relay is set for a value say Z corresponding to length of line L. Then if a fault occurs within length L, the ideal distance relay operate instantaneously.

However the d.c. component of wave, fault resistance, influence the relay measurement and cause over-reach or under reach.

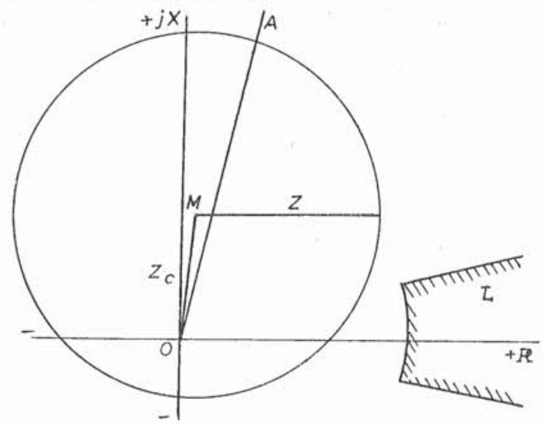


Fig. 30.19. Characteristics of a modified impedance relay in the *R-X* plane.

Over-reach. When short circuit occurs, the current wave has d.c. component which causes a distance relay to over-reach, *i.e.* to operate for a large impedance than desired. The tendency to over-reach is minimized by adjusting the voltage to 90 to 80% of its normal value.

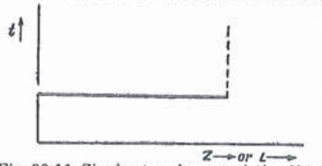


Fig. 30.11. Single-step characteristic of high speed impedance relay : above certain Z, the relay is inoperative. For smallest Z the relay operates in time t_1.

Effect of arc resistance, Under-reach. The arc resistance is approximately given by

$$R_{arc} = \frac{2.9 \times 10^4 L}{I^{1.4}}$$

where R_{arc} = Resistance of arc, Ohm

L = Length of arc in m. in open standstill air

I = Fault current Amperes.

Due to the extra arc resistance the distance measured by impedance relays inaccurate. The distance relay will measure an impedance $Z_f + R_{arc}$, where Z_f is impedance of line.

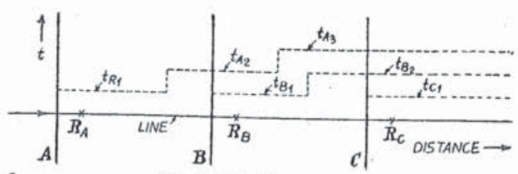
By adding Z_f and R_{arc} the measured point on *R-X* diagram goes out of impedance circle and relay does not operate even though the fault in within the protection zone. This is called *Under-reach.*

30.13. THREE STEP DISTANCE-TIME CHARACTERISTIC

The transmission lines having successive line sections can be protected by means of three-zone distance protection schemes. By such schemes, quick protection can be obtained and back-up of the sections as well as adjoining lines/bus bars can also be provided.

Referring to Fig. 30.12, the distance relay R_A, located at section A has a 3-step characteristic given by dashed line marked tA_1, tA_2, tA_3, tA_1, is called the first step and covers about 80 per cent of the first line section *AB*, and gives instantaneous protection. tA_2 is the second step of relay at station A (R_A) and covers the remaining portion of section *AB* and about 20 to 50 per cent of the next section (*BC*). The third step having timing TA_3 covers the entire remaining line. The steps are obtained by one of the following methods :

— Changing taps on auxiliary voltage transformer,
— Switching resistance in relay restraint circuit at pre-set time intervals by means of time-element.
— Separate measuring element for zone 2 and zone 3.



AB = Section I
Beyond C = Section III
RA, RB, RC = Relays
tB_1, tB_2 = Times RB stages.
BC = Section II
A, B, C = Stations
tA_1, tA_2, tA_3 = Times of RA stages
tC_1 = Times of RC stages.

Fig. 30.12. Three step characteristic of distance relay.

30.14. POWER SWINGS (Ref. Sec. 42.9)

Sudden change in load conditions in the system cause power swings between the load and generating station. The starting elements (*SE*) in distance scheme generally respond to power swings. Overcurrent *SE* is readily affected. During power swings, there is a heavy flow of equalizing current in transmission lines, current caused by swing flows equally in all phases causing the over-current *SE* to pick up in all phases. Minimum impedance *SE* responds to ratio V/I. During power swing, voltage also drops at certain points of the system in addition of equalizing currents. Therefore, such starting relay of all three phases can pick up during heavy power swing.

Thus overcurrent *SE* or impedance *SE* operate during power swings.

Hence the measuring element (*ME*) has to decide whether to operate the relay or to block it.

In general distance relays having mho characteristic are less susceptible to power swings because of their narrow characteristic. Generally during power-swings an out-of-step blocking relay operates. If measuring element operates within a certain time after operation of blocking relay, then tripping is allowed. Modern distance relays are stable lover a wide range of power swings, they do not trip unselectively, if power swing reverts to normal condition fairly soon. If the condition prevails, the relay trips (Ref. Sec. 30.8.5.)

30.15. CARRIER ASSISTED DISTANCE PROTECTION (Ref. Sec. 30.19)

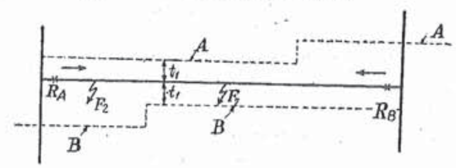
While protecting a transmission line the following are the desirable features :

— Simultaneous opening of circuit-breakers at both ends of the line for internal faults.
— Simultaneous reclosure.
— Discrimination between internal and external faults.
— Single pole switching.
— Independent phase relaying, etc.
— Distance relays are used in conjunction with carrier channel.

30.15.1. Carrier Transfer (Intertripping)

Carrier signal is transmitted to the other end of the section to bring about simultaneous tripping of the line-section. This is called Transfer trip or Intertrip technique. After the tripping, the auto-reclosure relays takes over.

With stepped time-distance characteristics of distance relays, the first distance step (R_A) is generally to cover about 80 per cent of first line section. The relay at remote end (R_B) is arranged in a similar way, but in opposite direction (Fig. 30.13).



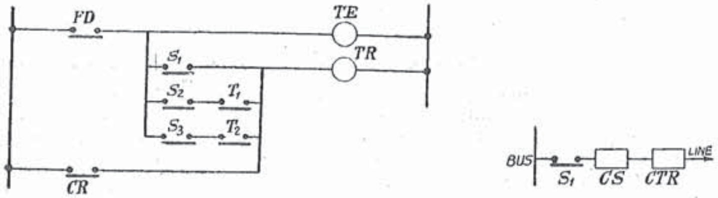
R_A, R_B = Distance relays
A = Characteristic of R_A
B = Characteristic of R_B.

Fig. 30.13. Explaining Carriers Transfer.

Carrier transfer is explained by means of Fig. 30.13. If fault occurs in the middle of the section, the distance relays at both end (R_A and R_B) will trip with time t_1 of the first step. However, if the fault occurs near the end of the line section, (say F_2 near R_A), the relay at P remote end (R_B) will operate with time t_2 whereas relay at local end (R_A) will operate with time t_1 resulting in non-simultaneous operating of circuit-breakers at both the ends. This is not desirable from stability and auto-reclosure considerations.

The nearer relay (R_A in this case) is therefore, made to send a carrier signal to the remote end (R_B) to bring about simultaneous tripping of the circuit-breakers at both ends. After operation of the relays and circuit-breakers, auto-reclosure relay takes over.

The scheme for carrier transfer is illustrated in Fig. 30.14. The relay step 1-circuit initiates the transmission signal sent by the carrier transmitter via the line Fig. 30.14 (*b*). The step 1 relay S_1 initiates the carrier transfer in addition to completion of the trip circuit at local end. A similar set arrangements are provided the remote end.



(*a*) Trip Control Circuit. (*b*) Carrier starting for Transfer Signal.

FD = Fault Detector	S_1, S_2, S_3 = Steps	*CTR* = Carrier Transmitter
TE = Time Element	T_S, T_2 = Timer Elements	S_1 = Zone 1 Relay
TR = Tripping Rehay	*CR* = Carrier Receiver	*CS* = Control Circuit (*a*)

Fig. 30.14. Scheme of carrier receiver transfer relaying.

30.15.2. Carrier Blocking Scheme (Directional Comparison Method)

In this case the distance step is arranged to over-reach. Provision is made to prevent the tripping of the circuit-breakers for faults on next section.

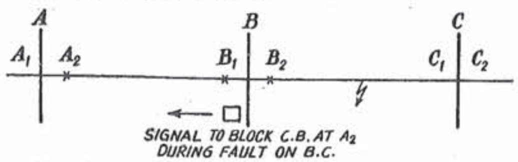


Fig. 30.15 (*a*) Directional comparison, or Carrier Blocking.

The principle is as follows : "The direction of fault power at two ends of the protected line is compared by means of directional relays. Under internal fault conditions the direction of the fault power must be outwards at one end and inwards at the other end. Under through fault condition the fault must be fed into the line at only one end. (Ref. Fig. 43.13)

The primary protection is given by distance relays. The directional comparison relaying operates in conjunction with the distance relays.

When fault power is flowing outward from the line at one end, the directional relay at that end actuates a carrier signal which block at its local end and at the other end. Suppose fault occurs in adjacent line *BC*.

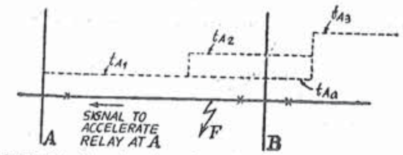
The directional relay at B_1 will actuate and it will send signal to station *A*. Thereby the tripping of CB's at A_1 and B_1 is blocked. If short circuit occurs in the section *AB* no signal is sent to block tripping A_2 and B_1.

Thus carrier signal is sent only during fault conditions.

Depending upon the kind of distance relay, various circuit arrangements may be used. During fault on *BC* very near to B_2, the distance relay at A_2 will start as it is set with an over-reach of about 20% over the length *AB*. However, a time delay is provided such that a relay at the A_2 does not operate earlier than receiving blocking signal. If no blocking signal is received, the fault is internal for zone *AB* and relay at A_2 operates. Thus carrier blocking schemes should have a slight time delay for their first step. By using first blocking signals, this time delay can be cut down. Carrier Blocking schemes have an advantage that the signal is transferred over healthy line.

30.15.3. Carrier Acceleration

In this scheme, a signal received from a relay at opposite end is used to extend the first step from about 80% to about 150% of the reach (length of the protected line) by shunting the timer element of zone 2. The contacts of timer of zone 2 relay are shunted by normally open carrier receiver relay contacts. Thus all faults within protected section can be cleared approximately at the time of first zone. Fig 30.16 explains this principle. For faults near *B*, in section *AB*, a carrier signal is sent from section *B* to station *A*. The relay at station *A* is accelerated and the second step timer is shunted. Thereby the second zone time is reduced from tA_2 to tA_1. A similar characteristic (not shown) is provided at *B* in direction *BA*.



tA_1, tA_2, tA_3 = Original steps
tA_a = Characteristic due acceleration.

Fig. 30.15 (*b*) Carrier Acceleration.

30.16. DISTANCE SCHEMES FOR SINGLE POLE AND TRIPLE-POLE AUTO-RECLOSING (Ref. Sec. 44.8)

Distance relays can be arranged in conjunction with single phase or three phase auto-reclosure. In case of switched schemes, the pole selection is made by starting element auxiliaries. In non-switched schemes, it is provided by respective phase measuring elements and their auxiliary elements. However all the three measuring elements may be tripped to ensure whether the fault is on more than one phase.

30.17. CONNECTIONS OF DISTANCE RELAYS

Distance Relays are connected in the secondary circuit of CT's and VT's. The connections should such that the impedance measured by the relay should be proportional to the distance between relay location and the fault, for all types of faults.

The voltage supplied to relay coil (V_r) must be proportional to the voltage drop upto fault point. The current supplied to relay coil (I_r) should be proportional to fault current. To achieve this, the distance relays should be connected such that they cover the fault loop.

In three phase systems the faults can be

— phase to phase fault.
— phase to earth fault
— Double phase to earth fault.
— Three phase fault.

Phase to phase fault can occur between *R—Y*, *Y—B*, *B—R*. To cover these faults, distance relay should have three measuring elements (in one casing). Alternatively, a single measuring element switched over to appropriate voltage and current. Fig. 30.16 illustrates a typical connection for phase fault protection. In this scheme there are three measuring elements.

The current coils are connected in star to three secondaries of line CT's. The voltage coils are connected in delta across secondaries of line VT's.

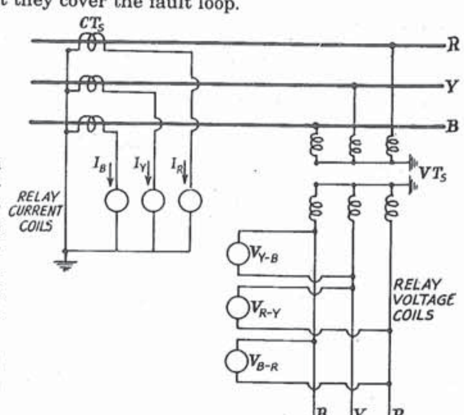


Fig. 30.16. Connections of Distance Relay for Phase Faults.

Connections of distance Earth fault relay (Not shown) are different from the Distance phase fault relays.

PART 30C. PROTECTION OF LINES BASED ON UNIT PRINCIPLE

The unit protection responds to internal faults only. The use of channel to compare conditions at the terminals of a power line, provides the only selective means of high-speed clearing of end zone faults. In many ways pilot protection is analogous to differential protection of buses, transformers and machines.

The advantages of high speed simultaneous clearing of all terminals are :

— Limits the possibilities of conductor burn down due to over-loading and in general minimizes damage to the line.

— Improves transient stability of system by quick disconnection of faulty line.

— Permits high speed reclosing, which is successful, will improve transient stability or minimize outage time or poor voltage conditions on portions of the system load (Refer Ch. 44)

Unit type feeder protection includes pilot wire protection and carrier current protection. Merz-Price or differential circulating current protection was widely used in U.K and U.S.A. In earlier years d.c. pilot schemes were used. Now they are replaced by A.C. pilot schemes discussed in this section.

30.18. PILOT WIRE PROTECTION USING CIRCULATING CURRENT DIFFERENTIAL RELAYING

The differential circulating current protection principle can be readily applied to feeder protection. Two CT's are connected in each protected line, one at each end. Under healthy/external fault conditions the secondary currents are equal and circulate in pilot wires. The relay is connected between equipotential points of pilot wires. For external faults and normal condition the differential current $I_1 - I_2$ of two CT's is zero and relay does not operate. During internal faults this balance is distributed and differential current flows through the relay operating coils.

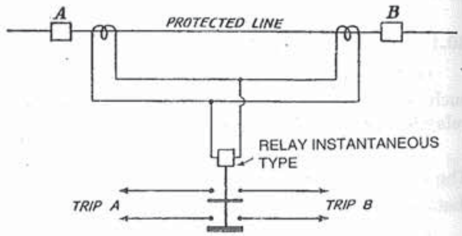


Fig. 30.17. Pilot wire protection of line.

The circuit-breakers at two ends separated by a long distance, there is a need to have relaying going at each end associated circuit-breaker. In line protection (Fig. 34.17), relaying point falls in the middle of the line. This means added difficulties.

To solve this problem the circuit is modified (Fig 30.18) by providing two relays, one at each end.

Another method (Fig. 30.19) is by using split pilot principle which uses a three core cable as pilot.

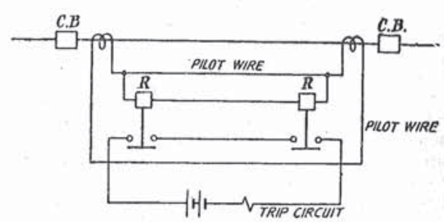


Fig. 30.18. Use of two relays, one at each end.

Pilot wire Relaying using voltage balance. In this method the secondary currents are replaced by or converted to an equivalent voltage source of fairly low impedance. The equivalent at two ends are compared as shown in Fig 30.20. For healthy condition, no current flows through the relay coils. During internal fault current circulates through relay coil. Voltage balance system is basically a differential system (Ref. Sec. 28.7).

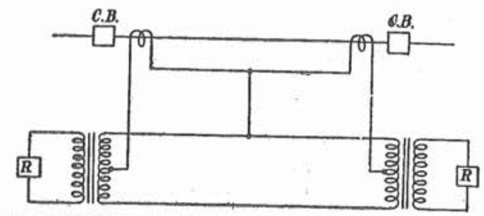


Fig. 30.19. Pilot wire relaying with split pilot connection using 3-core cable for pilot connections.

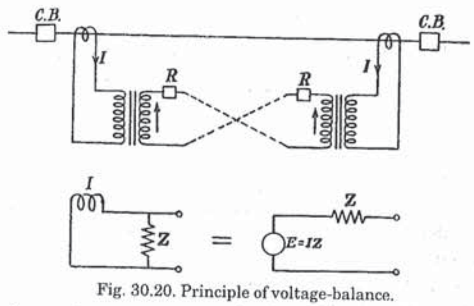


Fig. 30.20. Principle of voltage-balance.

Discriminating Factor. Operating current at one terminal or an internal fault to an external fault with same primary current applied from that terminal.

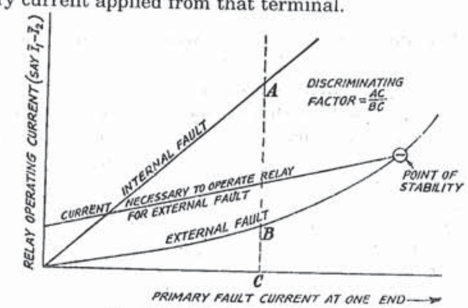


Fig. 30.21. Discrimination factor.

Referring to Fig. 30.22, consider a current differential scheme.

Let I_o be relay operating current, I be the primary current at one end. Keeping primary current I the same, let I_{OI} be the current in relay for internal fault and I_{OE} be current in relay for external fault. Then I_O is plotted against fault current. The ratio of I_{OI} and I_{OE} gives discrimination factor. It is observed that beyond a certain value of fault current, the relay loses stability and operates for external faults. (Ref. Fig. 30.12—Point of Stability)

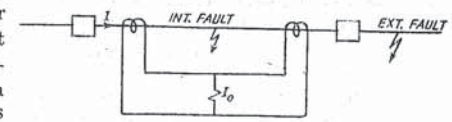


Fig. 30.22. Current differential scheme.

Transley System. This is based on differential balance voltage principle. It has telephone lines as pilot wires. Advantages of higher currents can be used. Arrangement consist of induction relays at either ends. Schematic diagram is shown in Fig. 30.23.

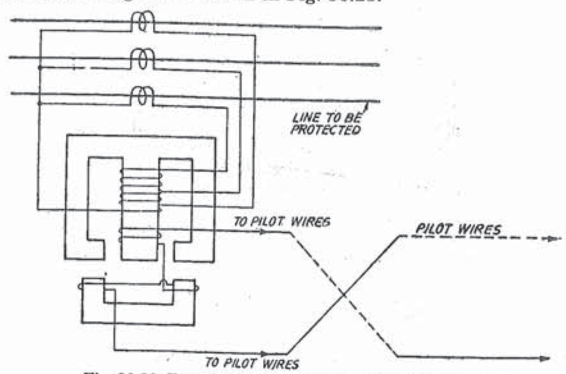


Fig. 30.23. Transley system of balance voltage protection.

Limitations of Pilot Wire Protection of Line. Pilot wire protection needs additional expenditure of Pilot wires, the Pilot wires need supervision to check. Open circuits and short circuits on Pilot wires lead to relay failure.

The Pilot wires are put at the same time along with power conductors. In cable systems, Pilot cables are put in the same trench of power cable.

For short lines of less than 16 km the Pilot wires give most economical form of high speed relaying. For lines upto 16 km Pilot wire protection is popular. It used even for lines upto 50 km. in rare cases. Beyond the length of 16 km. carrier current Pilot relaying is more economical and preferable.

Voltages are induced in pilot wires due to the field of power conductors. This voltage should be limited to 5—15 volts.

Overhead Pilot wires are exposed to lightening and high voltage surges. They must be protected by means of lightning arresters. Similarly they should not come in contact with power circuit. According to the rules the voltage across Pilot is limit to about 200V and current to 200mA.

Pilot Supervision. If Pilot circuit opens or shorts, relaying system fails. The effect as follows :

Pilot fault	*Circulating current scheme*	*Balanced voltage scheme*
Short circuit	Fails to trip for internal faults.	Trip on full load.
Open circuit	Trip on full load.	Fails to trip on internal faults.

To avoid this trouble, automatic supervision is usually applied along with overcurrent fault detectors to prevent wrong tripping.

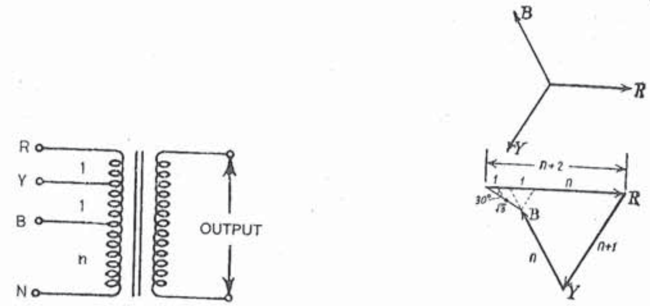
Summation Circuits

The need to economize in the pilot cores has resulted in the use of current summation devices so that the polyphase line currents may be reproduced as a single-phase quantity. This enables the comparison over the pilot channel to the effected on single phase basis and the pilot cores to be reduced to a minimum of two.

Most summation devices include transformers and can, therefore, be used to reduce the burden imposed by the Pilots on the current-transformer by changing the impedance levels. A further advantage is the possibility of isolating the current-transformers from the Pilots. This enables the current-transformers to be earthed and the Pilots to be without earth.

Summation-transformers

The most common device in use is the "Summation-transformer", which is shown in its simplest form in Fig 30.24. A common primary-winding is connected to the line current-transformer outputs, each phase energizing a different number of turns, from line to neutral. The arrangement gives an equivalent secondary output for the various types of fault, as shown by the table of Fig 30.24 ; these can easily be derived for any tapping arrangement by construction of the equivalent ampere-turn vector diagram. Such devices are not perfect as there are complex fault-conditions, such as 2 : 1 : 1 fault-distribution on Y-B-R phase with equal R-Y and Y-B sections, which will give no output. Another example of the limitations of summation transformers is a double earth fault with a resistance earthed neutral. In the ratio of phase fault current to earth fault current is of the right order, it is possible with some double earth-fault, for the output to be zero or very small.



Equivalent output for Equal fault-current.

$R\text{-}N = n + 2$ $Y\text{-}N = n + 1$ $B\text{-}N = n$

$R\text{-}Y = 1$ $Y\text{-}B = 1$ $B\text{-}R = 2$

3-phase $= \sqrt{3}$

Fig. 30.24. Summation-transformer.

SEC. 30D. CARRIER CURRENT PROTECTION OF TRANSMISSION LINES.

30.19. CARRIER CURRENT PROTECTION

This type of protection is used for protection of transmission lines Carrier currents of the frequency range 30 to 200 kc/s in USA and 80 to 500 kc/s (kHz) in UK are transmitted and received through the transmission lines for the purpose of protection.

The schematic diagram of carrier current protection is given in Fig. 30.25.

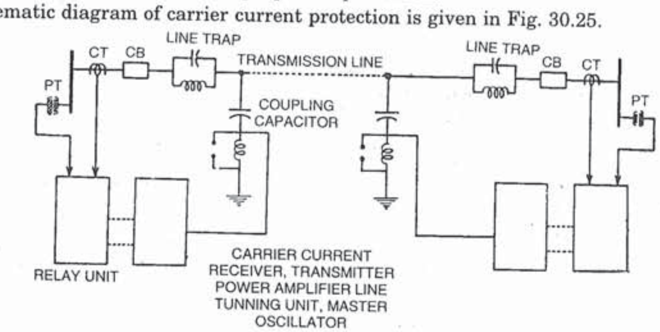
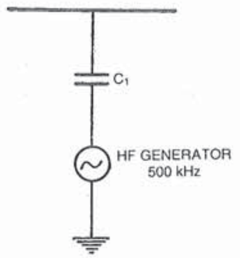


Fig. 30.25. Scheme of carrier current relaying.

Each end of the line is provided with identical carrier current equipment consisting of transmitter, receiver, line-tuning unit, master oscillator, power amplifier, etc.

1. **Coupling capacitor.** The carrier equipment is connected to the transmission line through 'Coupling Capacitor' which is of such a capacitance that it offers low reactance $\left(\frac{1}{\omega C}\right)$ to carrier frequency but high reactance power frequency. For example, 2000 pF capacitor offers 1.5 megahoms to 50 Hz and 150 ohms to 500 KHz.

Thus coupling capacitors allows carrier frequency signals to enter the carrier equipment but does not allow 50 Hz power frequency currents to enter the carrier equipment. To reduce impedance further a low inductance is connected in series with coupling capacitors to form a resonance at carrier frequency.



$Z = \frac{1}{\omega C_1}$

= 1.5 mega ohms for 50 Hz.
= 150 ohms for 500 kHz.

Fig. 30.26. Function of coupling capacitor.

2. **Line Trap Unit.** Line trap unit is inserted between busbar and connection of coupling capacitor to the line. It is a parallel tuned circuit comprising L and C. It has a low impedance (less than 0.1 ohm) to 50 Hz and high impedance to carrier frequencies. This unit prevents the high frequency signals from entering the neighbouring line, and the carrier currents flow only in the protected line.

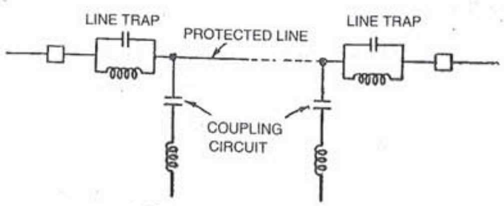


Fig. 30.27. Line Trap Units.

3. **Protection and Earthing of Coupling Equipment.** Overvoltages on power lines are caused by lightning, switching, faults, etc. produce stress on coupling equipment and line trap unit. Non-linear resistors in series with a protective gap is connected across the line trap unit and inductor of the coupling unit. The gap is adjusted to spark at a set value of overvoltage.

Base of coupling unit is earthed by earth rod in the vicinity to obtain low earth-resistance. Carrier panel usually installed in relay room is connected to station earthing system.

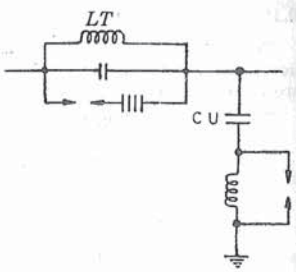


Fig. 30.28. Protective gap for line trap and coupling capacitor.

4. **Electronic Equipment.** There are generally identical units at each end :

(*i*) Transmitter unit. (*ii*) Receiver unit (*iii*) Relay unit.

(*i*) **Transmitter unit.** Fig. 30.29 gives the general arrangement of power line carrier protection scheme.

Frequencies between 50 to 500 kHz are employed in different frequency bands. Each band has certain band width (say 150—300kHz, 90—115kHz).

Carrier frequencies are generated in *oscillator*. The oscillator can be tuned to a particular frequency selected for the application. Or it can be a crystal oscillator with which the operation for a particular band width can be achieved by selecting on appropriate crystal. The output voltage of the oscillator is held constant by voltage stabilizers.

The output of the amplifier is fed into the *amplifier** to overcome the losses in the transmission path between the transmitter and receiver at remote end of the line. Signal attenuation comprises.

- losses in coupling equipment which are constant in the given frequency range.
- line losses which vary with length of line, frequency weather conditions, tee of connections of the line, the size and type of line. The h.f. losses of underground line are higher than overhead line.

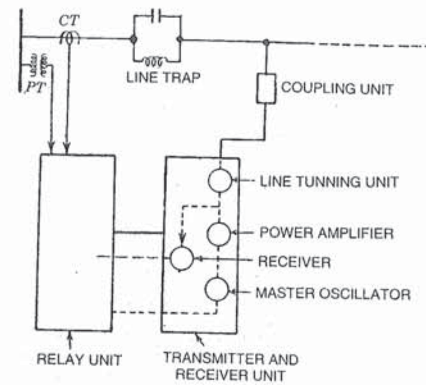


Fig. 30.29. (*a*) Schematic Diagram of Carrier Current Units.

The losses in overhead line are affected by weather. In fair weather the attenuation is about 0.1 dB/kHz at 80 kHz rising 0.2 dB/km at 380 kHz. The output of amplifier is of the order of 20 W for a 250 km line. The amplifier should be designed for maximum power over a selected bandwidth.

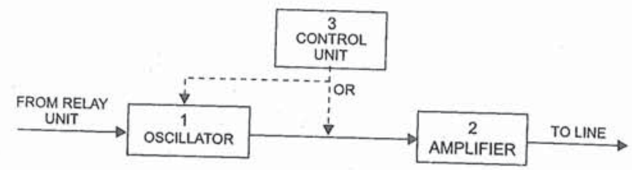
The *control* of transmitter can be achieved by different methods depending upon the type of protection desired.

Amplifier constantly energized transmission initiated by energizing the oscillator. In this method the oscillator stability and response time is a constraint.

Amplifier and oscillator constantly energized and the signals are initiated by interconnecting the oscillator to the amplifier. The control circuit switches the device which interconnects the oscillator to the amplifier.

(*ii*) **Receiving unit.** The high frequency signals arriving from remote end are received by Receiver. The receivers, the signal sand feeds to carrier receiving relay unit (Fig. 30.29). Receiving unit comprise.

- An attenuator, which reduces the signals to a safer value.
- Band pass filter, which restricts the acceptance of unwanted signals (signals from adjacent sections, spurious signals.)
- Matching transformer or matching element to match the impedances of line and receiving unit.



1. Oscillator generates high frequency signals.
2. Amplifier amplifies the signals.
3. Control unit controls the initiation action.

Fig. 30.29. (*b*) block diagram of transmitting unit.

* Amplifier increase the signals to be transmitted. Attenuator weakens the signals received.

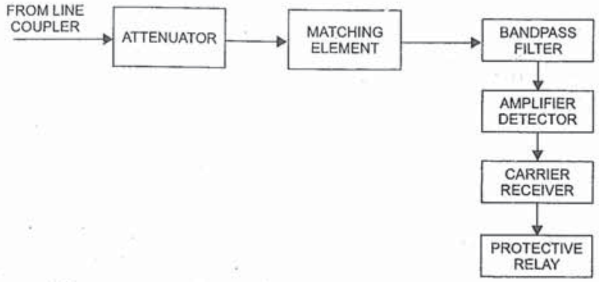


Fig. 30.30. Block diagram of receiving unit.

The spurious signals are caused by short-circuits, radio interference. To avoid the mal-operation due to noise, a setting above 2 milliwatts recommended is given to the receiver. This setting is above the noise level. To avoid operation due to spurious signals, the carrier signals should have higher power level (20 W) and receiver should be set at a higher level (5 milliwatts). Before feeding the signals to amplifier detector, the signals should be attenuated to avoid overloading.

(*ii*) **Frequency spacing.** Different frequencies are used in adjacent line sections. The wave-traps ensure that the carrier signals do not enter the next line section. The receiver filters filter-out other frequencies.

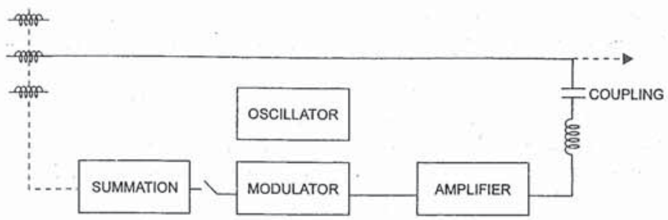


Fig. 30.31. Block diagram of modulator.

The choice of frequency bands for various sections should be co-ordinated.

(*iv*) **Modulation of high frequency signal.** The modulator modulates 50 Hz signals and the modulated signal is fed so the amplifier and is then transmitted *via* coupling unit (Fig. 30.31).

The process involves taking half cycle of current and producing the requisite blocks of carrier (Fig. 30.32) by turning the oscillator on. The level of line current at which the oscillator is made on to produce the carrier blocks should be theoretically constant. However, in practice there is a critical minimum current.

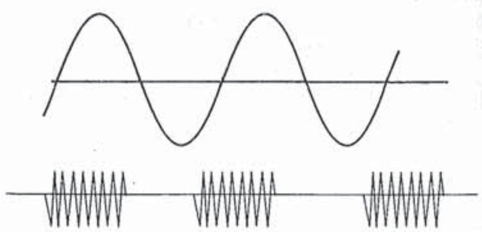


Fig. 30.32. Modulation of line current into high frequency blocks.

30.20. PHASE COMPARISON CARRIER CURRENT PROTECTION

There are different methods of carrier current protection such as :

(1) Directional comparison method*.

* Refer Sec. 30.14 for distance-carrier schemes, Carrier Transfer/Blocking etc.

(2) Phase comparison method.

Phase comparison method compares the phase relation between current entering in the protected zone and current leaving the protected zone. The magnitudes of currents are not compared. Phase comparison provides only main protection. Back up protection should be provided in addition. In one of the phase comparison methods signals are sent from each end of the line and received at the other end. The signals are related to the current flow in the main line, as they are derived from CT secondary current. When there is no fault, the signal is sent for alternate 1/2 cycles from each end which result in continuous signal over the line half the cycle from one end, remaining half from the other. The same condition holds good from an external fault. During internal fault the current in one of the lines reverses in phase or differs in phase and remains below the fault detector setting, so that carrier is sent only for half the time. *The relay is arranged to sense the absence of signal in the line.* Depending upon the setting, the tripping occurs when the phase angle between the two signals reaches a certain value.

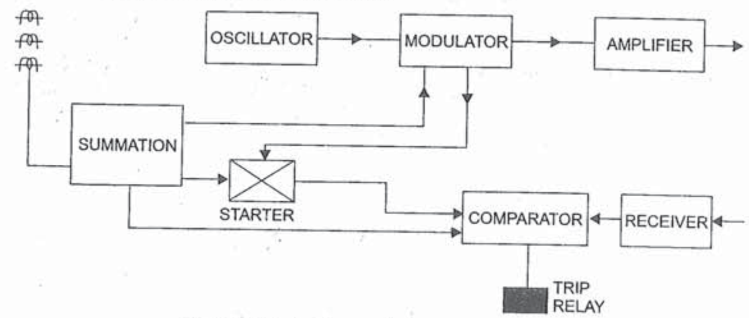


Fig. 30.33. Block diagram of phase comparison circuit.

Referring to Fig. 30.34, for internal fault condition shown on right hand side, the transmitted signals and received signals are almost in phase. The comparator compares these signals. Due to absence of signals for alternate half cycles, the comparator gives output causing operation of trip relay.

Carrier signals are transmitted to the line from both ends. For external faults the effect produced by the sum of these two signals is similar to that obtained when a continuous high frequency carrier is available on the line, and the protection is designed to remain stable under the condition. The sum of these two signals on all internal faults produces and effect similar to the periodic suppression of such a continuous carrier, the duration of each suppression being proportional to the phase-displacement between the primary current at both ends. The protection is designed to operate for phase-displacements greater than a normal angle 30°. Thus for phase-displacements of less than 30° the protection will stabilise. This angle is usually referred to as the stabilsing angle of the protection (angle X in Fig. 30.34 (*b*)).

Fig. 30.34 (*a*) illustrates the two extreme cases with symmetrical fault conditions. The external-fault condition is implied by the fact that the primary current at both ends is in phase and the internal fault condition by the fact that the two primary currents are 180° out of phase.

As a first step to produce the required carrier-signals the secondary current at one end only (end B) is made 180° out of phase with the primary current by the reversal of the current-transformer connections. Thus for external faults the secondary currents at the two ends are 180° out of phase with each other. (Fig 30.34 (*b*)).

It will be seen that the carrier-signal produced at both ends takes the form of a continuous carrier which is periodically suppressed. In other words, a high frequency signal is only transmitted on alternative half-cycles of the power-frequency corresponding say to the period when the secon-

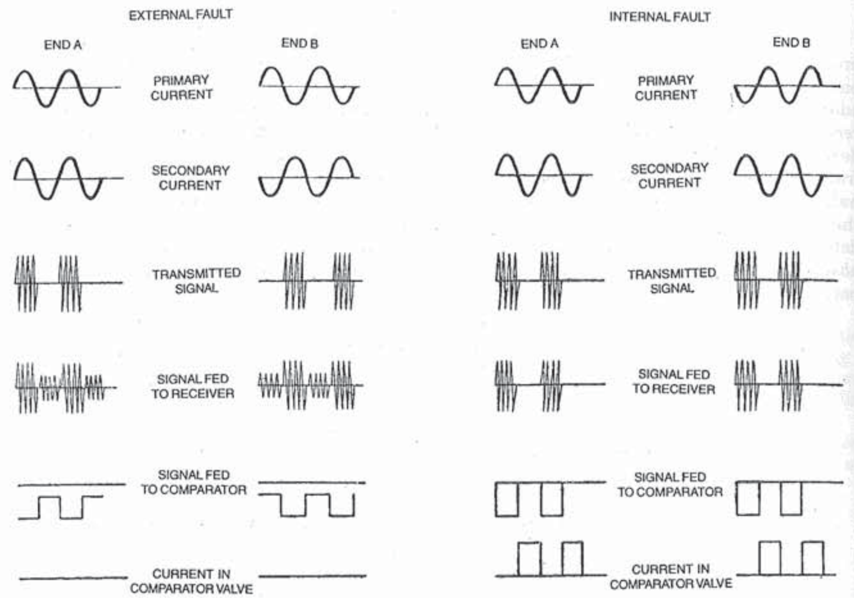


Fig. 30.34 (*a*). Diagram illustrating the working principle phase comparison method.

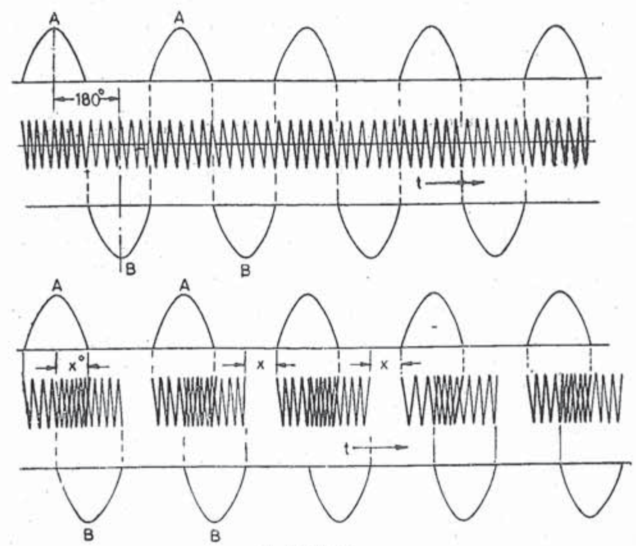


Fig. 30.34 (*b*)

dary current is positive. The type of high frequency signals is achieved by a process of modulation, whereby the normally consistent magnitude of a high frequency carrier is made to vary in accordance with a square wave-shaped derived from the power current and having the same period (Ref. Fig. 30.32).

30.21. APPLICATIONS OF CARRIER CURRENT RELAYING

Pilot channel such are carrier current over the power line provides simultaneous tripping of circuit-breakers at both the ends of the line in one to three cycles. Thereby high speed fault clearing is obtained, which improves the stability of the power system. Besides there are several other merits of carrier current relaying. These are :

1. Fast, simultaneous operating 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 synchronizing power surges does not occur, yet during internal fault clearing is obtained.

5. For simultaneous faults, carries current protection provides easy discrimination.

6. Fast (2 cycle) and auto-reclosing circuit-breakers such as air blast circuit-breakers require faster relaying. Hence, the carrier current relaying is best suited for fast relaying in conjunction with modern fast circuit-breakers (Ref. Table 44.1)

7. **Other uses of carrier equipment.** The carrier current equipment is used for several other applications besides protection. These are :

(*a*) **Station to station communication.** In power station, receiving stations and sub-stations telephones are provided. These are connected to carrier current equipment and conversion can be carried out by means of "Current Carrier Communication".

(*b*) **Control.** Remote control of power station equipment by carrier signals. (Ref. Sec. 46.1)

(*c*) Telemetering (Ref. Sec. 46.5)

30.22. RADIO LINKS OR MICROWAVE LINKS

Radio links are used for all forms of protections otherwise based on power line carrier or pilot wire. The transmission is generally by line of sight and this must take into account the curvature of the earth and topology of the route cover which the transmissions takes place. The suitable range is about 60 km.

Frequency bands used are of the range 80—170 MHz, 470 MHz, 1500 to 7500 MHz. The transmitters and receivers are controlled in the same manner as the carrier current transmitter and receiver. With radio links (microwave pilots) the signals are sent by line of light antenna equipment. Thus the coupling and trapping units are eliminated. In U.S.A., radio links are used for communications, remote control and protection.

These are most expensive, but give fast and reliable service.

Summary

Lines or feeders can be protected by several methods. Each method has some advantages and some limitations. The classes of protective relays used for line protection; roughly in ascending order of cost and complexity are :

— Instantaneous overcurrent — Time-overcurrent
— Directional overcurrent — Distance
— Pilot (pilot wire, power line carrier, or microwave).

Graded time lag and grade current overcurrent protection is used for single radial feeders where time lag can be permitted.

Distance relaying is based on measurement of impedance between relay location and fault point. It has three types namely impedance type, reactance type, mho type. The relay operates if the impedance is below the set value. Distance relay is used where time lag cannot be permitted. Differential protection is of unit type. It gives fast relaying. Pilot wire differential relaying used for lines upto 40 km of length.

QUESTIONS

1. Describe with the help of neat sketches the graded time lag protection of a radial feeder. What are the disadvantages of such a protection in case of the following?
   (*a*) Parallel feeders (*b*) Interconnected lines (*c*) Fast relaying.
2. Explain the principle of distance relaying applied to protection of radial transmission line Distinguish between reactance, impedance and mho relays as regards their applications to distance protection.
3. In what way is distance relaying superior to overcurrent relaying in case of feeder protection.
4. Distinguish between unit protection and non-unit protection. What are the various methods of protecting a transmission line by unit protection and by non-unit protection?
5. Explain with the help of neat sketches the set-up of carrier current relaying employed in transmission line protection.
6. Explain the principle of
   (*a*) Line trap unit (*b*) Coupling unit.
7. Explain the phase comparison method of carrier current protection.
8. Explain the directional comparison method of carrier current protection. Why should it be used in impedance or other type of non-unit protection?
9. What are the merits of carrier current relaying ? Where is it used ? Compare pilot wire relaying with carrier current protection.
10. Explain why carrier current protection in suitable for important interconnected lines.
11. Explain the schemes of pilot wire relaying employed
    (*a*) Circulating current method (*b*) Voltage balance method.
    What are the difficulties in circulating current protection of feeder.
12. State the applications of power line carrier signals.
13. Select suitable relaying method under the following conditions. Give reasons for your selection.
    Case (*a*) Protection of radial feeder from a power station to receiving station. Length of the feeder about 500 km. There are two stations in between. Time lag cannot be permitted.
    (*b*) An interconnecting line between two power station 16 km apart.
    (*c*) A feeder in case (*a*), but for following conditions.
    The line is fed from both the ends and fast relaying is desired for internal faults.
    (*d*) Distance protection of a feeder of
    (*i*) Medium length (*ii*) Short length (*iii*) Very long feeder
    State what type of distance protection will be suitable.
14. Discuss the various methods of protection of a transmission line with reference to advantages and disadvantages of each method.
15. Explain the principle of any one of the following :
    1. Carrier transfer 2. Carrier blocking (Directional comparison)
    3. Carrier acceleration
16. Explain the 3-steep characteristic of distance relay.
17. Explain the difference between 'switch' and 'non-switch' distance schemes.
18. Explain the functions of starting element, measuring element and time in distance protection.
19. Explain how power-swing affects distance relays.

31

Protection of Induction Motors

Introduction — Abnormal conditions — Under voltage protection — Contactors — Circuit Breaker — Motor protection — Single phasing protection — Short Circuit protection — Grounding — Protection of motors in general — Summary.

31.1. INTRODUCTION

The type of protection used for a particular motor depends on the switchgear used for its control (starting, stopping, speed variation, etc.) In general two basic protections are provided for every motor which are :

1. Thermal overload protection 2. Short circuit protection.

The switchgear used for motor control falls in two distinct classes:

(*i*) Contactor starters with H.R.C. Fuse and thermal over current relays.

(*ii*) Circuit-breakers and associated protective relays.

Contactors and fuses are used for motors upto approximately 150 kw. For larger motors, circuit-breakers are used.

Contractors are available for a wide range of a.c and d.c. duties (Ref. Sec. 15.10).

In general contactors can be used where current to be interrupted is limited to about six times rated current. The rated current is a little higher than the full load current of the motor (Ref. sec. 15.13).

Direct acting overload trip devices such as thermal overload relay can be incorporated with the contactor starter. The protection against short circuits is provided by HRC Fuses. The fuse selection depends upon starting current. The fuse should blow at currents more than those which can be interrupted by the contactor.

In case of voltage loss the coil is de-energised and the contactor opens. The motor has to be started again. Hence the contactor starter provides no volt release. Generally start, stop, reverse buttons are provided along with the starter. Large motors are provided with various relaying schemes and a circuit-breaker. The circuit breaker is air-break type or vacuum or SF_6. Air-break type circuit-breakers are more popular. The closing mechanisms are manually operated or solenoid operated or spring closing type. Solenoid closing is suitable for remote controlled motors and larger motors. Generally overload trip devices operating direct on the tripping mechanisms form and integral part of the circuit-breaker.

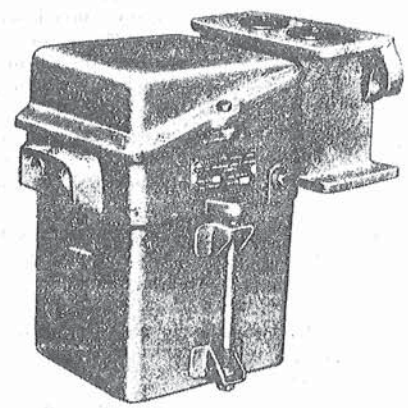


Fig. 31.1. Oil immersed direct on line starter.
(*Courtesy* : Jyoti Ltd., India.)