UNIT–IV

Protection of Feeders and Transmission Lines

The probability of faults occurring on the lines is much more due to their greater length and exposure to atmospheric conditions. This has called for many protective schemes which have no application to the comparatively simple cases of alternators and transformers. The requirements of feeder & line protection are

i. In the event of a short-circuit, the circuit breaker closest to the fault should open, all other circuit breakers remaining in a closed position.
ii. In case the nearest breaker to the fault fails to open, back-up protection should be provided by the adjacent circuit breakers.
iii. The relay operating time should be just as short as possible in order to preserve system stability, without unnecessary tripping of circuits.

The protection of lines presents a problem quite different from the protection of station apparatus such as generators, transformers and busbars. While differential protection is ideal method for lines, it is much more expensive to use. The two ends of a line may be several kilometres apart and to compare the two currents, a costly pilot-wire circuit is required. This expense may be justified but in general less costly methods are used. The common methods of feeder & line protection are

(i) Time-graded overcurrent protection

(ii) Differential protection

(iii) Distance protection

Shows the symbols indicating the various types of relays

Overcurrent Protection of Feeders:

Overcurrent relays offer the cheapest and the simplest protection for lines. The maximum load currents must be known to determine whether the ratio of the minimum fault current to maximum load current is high enough to enable simple overcurrent operated relays to be used successfully. This criterion is chosen in order to prevent the possibility of misoperation under normal operating conditions. This form of protection can be applied only to simple systems. The relays need readjustment or even replacement whenever a change in the system is made. The operating times are generally large. Overcurrent Protection of Feeders may be divided into two categories.

1. Nondirectional time and current grading
2. Directional time and current grading.

Nondirectional Time and Current Grading:

It is possible to have time-graded systems, current-graded systems or a combination of the two, i.e. current/time-graded systems.

Time-Graded Systems: To ensure selectivity of operation under all circumstances in a radial feeder, the operating time of the protection is increased from the far end of protected circuit towards the generating source. This is very conveniently achieved with the help of definite-time-delay relays, which usually consists of an instantaneous overcurrent relay followed by a timing relay the contacts of which trip the breaker. It has a more accurate time setting which is independent of CT saturation thus allowing closer grading times between successive circuit breakers. As the number of relays in series increase, the operating time increases towards the source. Thus the heavier faults near the generating source are cleared after a longer interval of time, which is a drawback. Its main application is in systems where the fault levels at the various locations do not vary greatly and hence the advantage of the inverse type of relay cannot be used.

Current-Graded Systems: It is based on the fact that the short-circuit current along the length of the protected circuit decreases as the distance from the source to the fault location increases. If the relays are set to pickup at a progressively higher current towards the source then the disadvantage of the long-time delays that occur with time grading can be partially overcome. This is known as **current grading**.

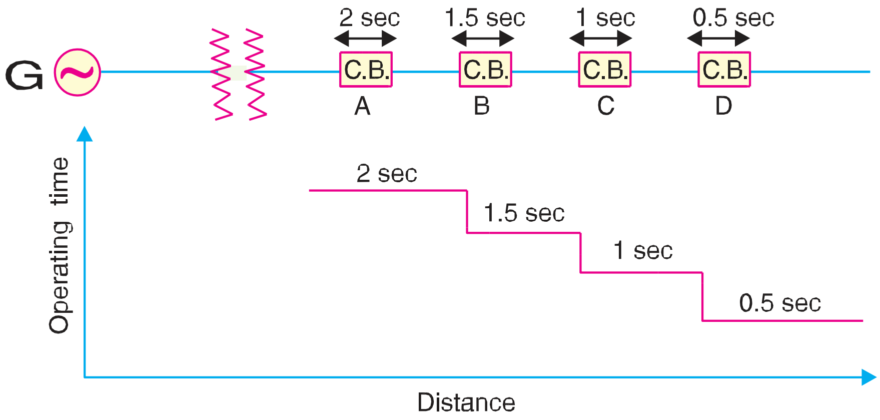
Current/Time-Graded Systems: Current/time grading is possible with inverse-time Overcurrent Protection of Feeders. The most widely used is the IDMT characteristic where grading is possible over a wide range of currents and the relay can be set, within the design limits, to any value of definite minimum time required. Other inverse characteristics, viz. very inverse and extremely inverse characteristics are also sometimes employed for the same purpose. If the fault current reduces substantially as the fault position moves away from the source some advantage can be gained by using very inverse relays instead of IDMT relays. The long operating time at low values of overloads of IDMT relays make extremely inverse relays eminently suitable.

Radial feeder Protection

The main characteristic of a radial system is that power can flow only in one direction, from generator or supply end to the load. It has the disadvantage that continuity of supply cannot be maintained at the receiving end in the event of fault. Time-graded protection of a radial feeder can be achieved by using

(i) definite time relays
(ii) Inverse time relays.

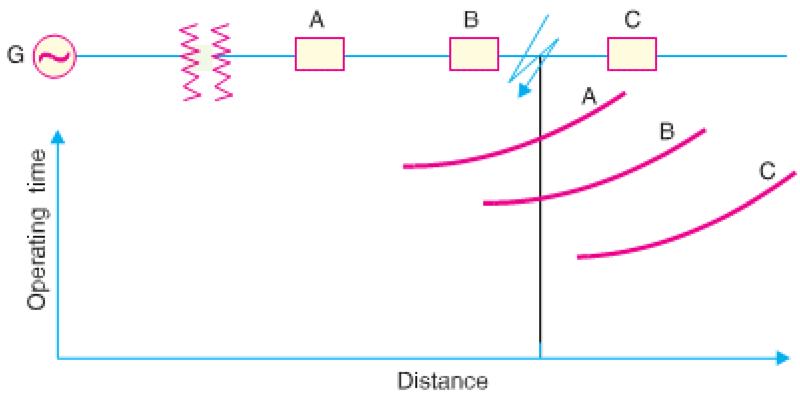
(i) Using definite time relays



The above figure shows the overcurrent protection of a radial feeder by definite time relays. The time of operation of each relay is fixed and is independent of the operating current. Thus relay D has an operating time of 0.5 second while for other relays, time delay is successively increased by 0.5 second. If a fault occurs in the section DE, it will be cleared in 0.5 second by the relay and circuit breaker at D because all other relays have higher operating time. In this way only section DE of the system will be isolated. If the relay at D fails to trip, the relay at C will operate after a time delay of 0.5 second i.e. after 1 second from the occurrence of fault.

The disadvantage of this system is that if there are a number of feeders in series, the tripping time for faults near the supply end becomes high (2 seconds in this case). However, in most cases, it is necessary to limit the maximum tripping time to 2 seconds. This disadvantage can be overcome to a reasonable extent by using inverse-time relays.

(ii) Using inverse time relays.



The above figure shows overcurrent protection of a radial feeder using inverse time relays in which operating time is inversely proportional to the operating current. With this arrangement, the farther the circuit breaker from the generating station, the shorter is its relay operating time.

The three relays at A, B and C are assumed to have inverse-time characteristics. A fault in section BC will give relay times which will allow breaker at B to trip out before the breaker at A.

Directional Time and Current Grading

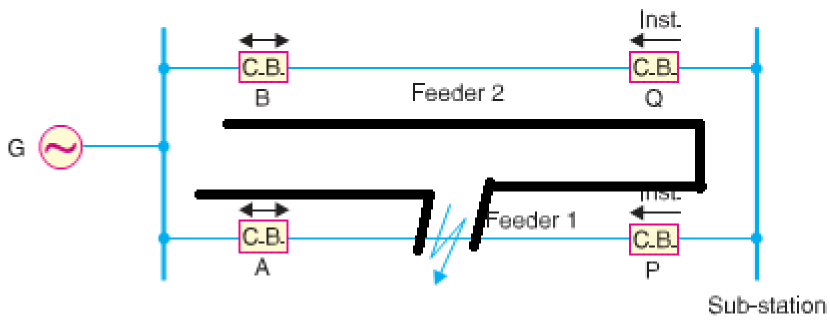
In the plain radial feeders the discrimination is obtained by means of the relay time and current setting adjustments only. To obtain discrimination where feeders other than radial feeders are employed, it is usually necessary to incorporate a directional feature in the protection, as will be clear from the following cases. The following separate cases will be considered:

(a) Parallel feeders,

(b) Ring mains.

Parallel feeders.

Where continuity of supply is particularly necessary, two parallel feeders may be installed. If a fault occurs on one feeder, it can be disconnected from the system and continuity of supply can be maintained from the other feeder. The parallel feeders cannot be protected by non-directional overcurrent relays only. It is necessary to use directional relays also and to grade the time setting of relays for selective tripping's.



The above figure shows the system where two feeders are connected in parallel between the generating station and the sub-station. The protection of this system requires that

i. Each feeder has a non-directional overcurrent relay at the generator end. These relays should have inverse-time characteristic.
ii. Each feeder has a reverse power or directional relay at the sub-station end. These relays should be instantaneous type and operate only when power flows in the reverse direction i.e. in the direction of arrow at P and Q.

Suppose an earth fault occurs on feeder 1 as shown in Figure. It is desired that only circuit breakers at A and P should open to clear the fault whereas feeder 2 should remain intact to maintain the continuity of supply. In fact, the above arrangement accomplishes this job. The shown fault is fed via two routes, viz.

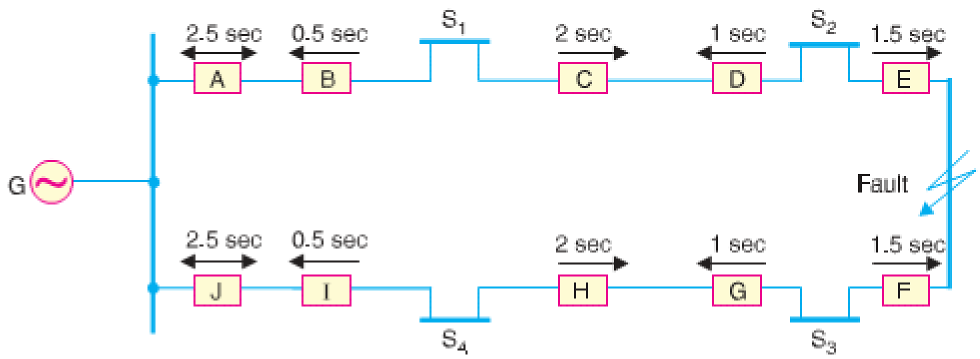
(a) Directly from feeder 1 via the relay A

(b) From feeder 2 via B, Q, sub-station and P

Therefore, power flow in relay Q will be in normal direction but is reversed in the relay P. This causes the opening of circuit breaker at P. Also the relay A will operate while relay B remains inoperative. It is because these relays have inverse-time characteristics and current flowing in relay A is in excess of that flowing in relay B. In this way only the faulty feeder is isolated.

Ring main system:

In this system, various power stations or sub-stations are interconnected by alternate routes, thus forming a closed ring. In case of damage to any section of the ring, that section may be disconnected for repairs, and power will be supplied from both ends of the ring, thereby maintaining continuity of supply.



The following figure shows the single line diagram of a typical ring main system consisting of one generator G supplying four sub-stations S_1, S_2, S_3 and S_4. In this arrangement, power can flow in both directions under fault conditions. Therefore, it is necessary to grade in both directions round the ring and also to use directional relays. In order that only faulty section of the ring is isolated under fault conditions, the types of relays and their time settings should be as follows:

i. The two lines leaving the generating station should be equipped with non-directional overcurrent relays (relays at A and J in this case).
ii. At each sub-station, reverse power or directional relays should be placed in both incoming and outgoing lines (relays at B, C, D, E, F, G, H and I in this case).
iii. There should be proper relative time-setting of the relays. As an example, going round the loop G S_1 S_2 S_3 S_4 G ; the outgoing relays (viz at A , C, E, G and I) are set with decreasing time limits e.g.

A = 2.5 sec, C = 2 sec, E = 1.5 sec G = 1 sec and I = 0.5 sec

Similarly, going round the loop in the opposite direction (i.e. along G S_4 S_3 S_2 S_1 G), the outgoing relays (J, H, F, D and B) are also set with a decreasing time limit e.g.

J = 2.5 sec, H = 2 sec, F = 1.5 sec, D = 1 sec, B = 0.5 sec.

Suppose a short circuit occurs at the point as shown in Figure. In order to ensure selectivity, it is desired that only circuit breakers at E and F should open to clear the fault whereas other sections of the ring should be intact to maintain continuity of supply. In fact, the above arrangement accomplishes this job. The power will be fed to the fault via two routes viz (i) from G around S_1 and S_2 and (ii) from G around S_4 and S_3. It is clear that relays at A, B, C and D as well as J, I, H and G will not trip. Therefore, only relays at E and F will operate before any other relay operates because of their lower time-setting.

Protection of Transmission line

Whenever over-current relaying is found slow or is not selective distance protection should be used. Since the fault currents depend upon the generating capacity and system configuration, the distance relays are preferred to the overcurrent relays.

Scheme of Distance Protection:

In developing an overall Scheme of Distance Protection, it is necessary to provide a number of relays to obtain the required discrimination. Modern practice is to adopt definite distance method of protection applied in 3 zones (steps).

A number of distance relays are used in association with timing relays so that the power system is divided into a number of zones with varying tripping times associated with each zone.

- The first zone tripping which is instantaneous is normally set to 80% of the protected section.

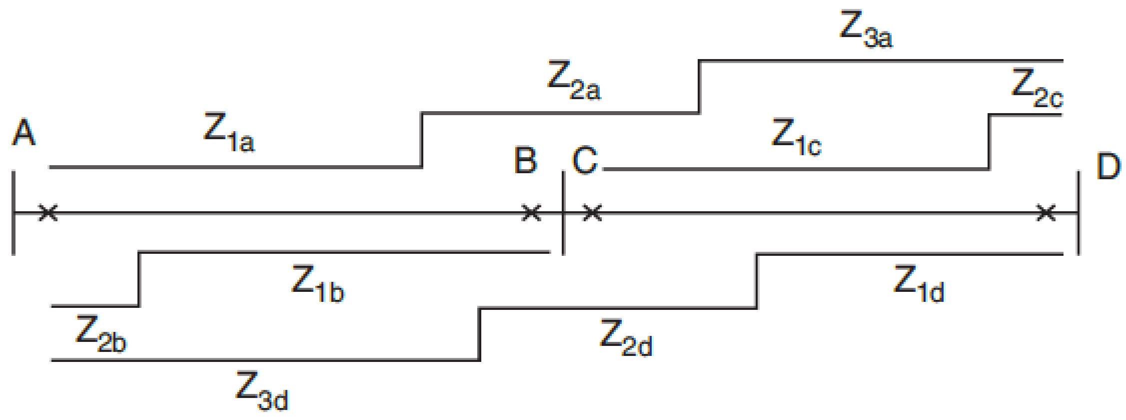
- The zone 2 protection with a time delay sufficient for circuit breaker operating time and discriminating time margin covers the remaining 20% portion of the protected section plus 25 to 40% of the next section. Also in the Scheme of Distance Protection the Zone 2 also provides backup protection for the relay in the next section for faults close to the bus.

- Zone 3 with still more time delay provides complete backup protection for all faults at all locations.

3 Zone protection using Distance Relays

Consider the following figure which consists of two line sections AB and CD; it is desired to provide distance protection scheme.

The protection scheme is divided in three zones. Say for relay at A, the three zones are Z_{1a}, Z_{2a} and Z_{3a}. Z_{1a} corresponds to approximately 80% length of the line AB and is a high speed zone. No intentional time lag is provided for this zone. The ordinate shown corresponding to Z_{1a} gives the operating time in case the fault takes place in this zone. It is to be noted here that the first zone is extended only up to 80% and not 100% length of the line as the relay impedance measurement will not be very accurate towards the end of the line especially when the current is offset.



3-zone protection

Second zone Z_{2a} for relay at A covers remaining 20% length of the line AB and 20% of the adjoining line. In case of a fault in this section relay at A will operate when the time elapsed corresponds to the ordinate Z_{2a}.The main idea of the second zone is to provide protection for the remaining 20% section of the line AB. In case of an arcing fault in section AB which adds to the impedance of the line as seen by the relay at A, the adjustment is such that the relay at A will see that impedance in second zone and will operate. This is why the second zone is extended into the adjoining line. The operating time of the second zone is normally about 0.2 to 0.5 second.

The third zone unit at A provides back up protection for faults in the line CD, i.e., if there is a fault in the line CD and if for some reason the relay at C fails to operate then relay at A will provide backup protection. The delay time for the third zone is usually 0.4 to 1.00 sec.

In case the feeder is being fed from both the ends and say the fault takes place in the second zone of line AB (20% of the line AB), the relay at B will operate instantaneously (because it lies in the first zone of BA) whereas the fault lies in the second zone of the relay at A. This is undesirable from stability point of view and it is desirable to avoid this delay. This is made possible when the relay at B gives an intertrip signal to the relay at A in order to trip the breaker quickly rather than waiting for zone-2 tripping.

Introduction to Carrier-Current Protection:

In modern high-power electrical systems it is necessary to have quick-acting protections on long transmission lines. The requirements to be met by such protections are fully satisfied by the circulating current differential protection with its high sensitivity, quick action and independence upon the settings of the adjoining-section protections. Not with standing this, owing to the need for installing interconnecting conductors (cables), circulating current differential protections are confined to lines up to 8 or 15 km long.

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

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

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

Carrier Current Protection of Transmission Lines

Carrier current protection scheme is mainly used for the protection of the long transmission line. In the carrier, current protection schemes, the phase angle of the current at the two phases of the line are compared instead of the actual current. And then the phase angle of the line decides whether the fault is internal and external. The main elements of the carrier channel are:

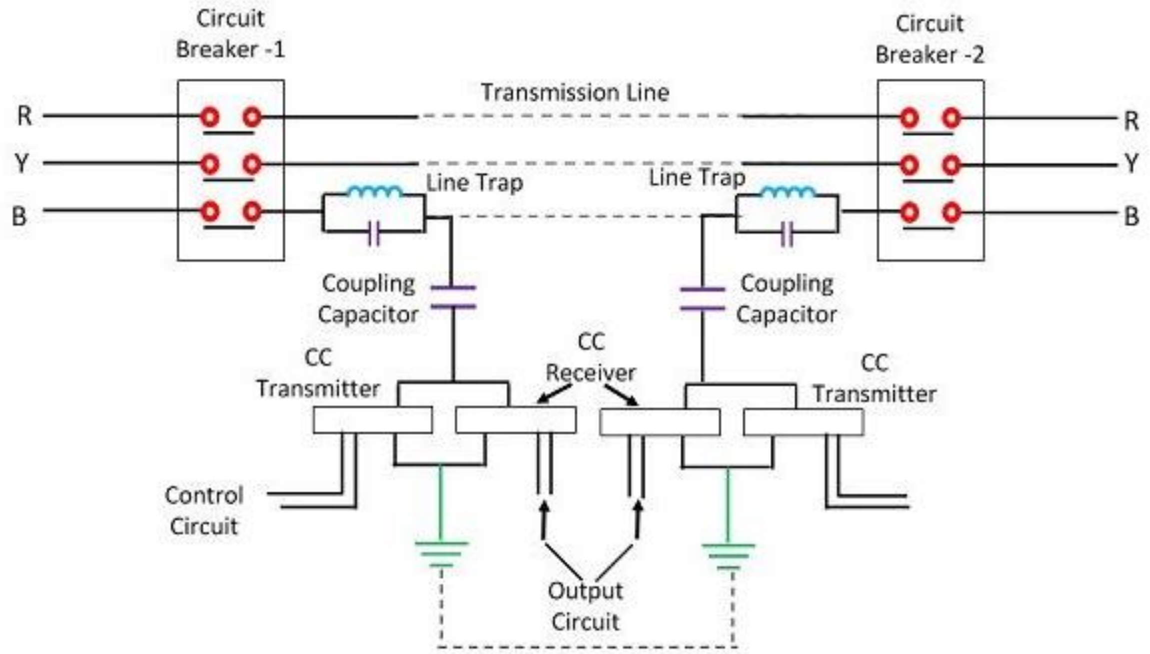
i. Transmitter
ii. Receiver
iii. Coupling equipment and
iv. Line trap.

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

Each carrier-current receiver receives carrier current from its local transmitter as well as from the transmitter at the distant end of the line. In effect, the receiver converts the received carrier current into a dc voltage that can be used in a relay or other circuit to perform any desired function. The voltage is zero when carrier current is not being received.

Line trap:

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



Carrier Current Protection of Transmission Lines

Coupling capacitors:

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

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

Methods of Carrier-Current Protection:

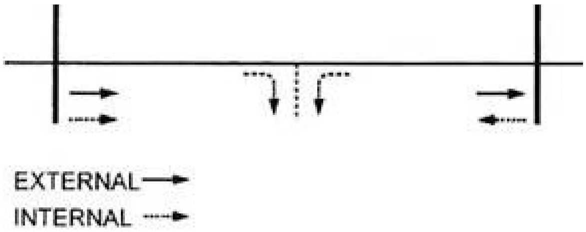
There are different methods of carrier current protection and basic forms of carrier protection are:

(i) Directional Comparison Protection

(ii) Phase-Comparison Carrier Protection.

Directional Comparison Protection:

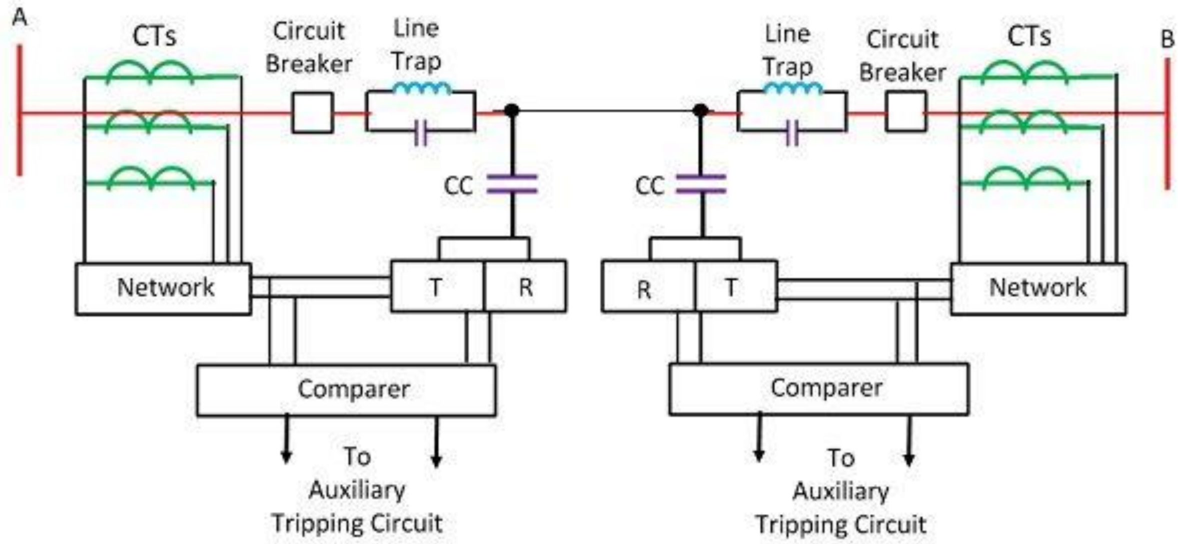
The protection operates on the basis of comparison of the fault-power flow directions at the two ends of the protected line. Operation takes place only when the flow of power at both ends of the line is in the bus-to-line direction, a condition which will evidently only arise in event of a fault on the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



Direction of Current flow for External and Internal faults

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

Phase-Comparison Carrier Protection

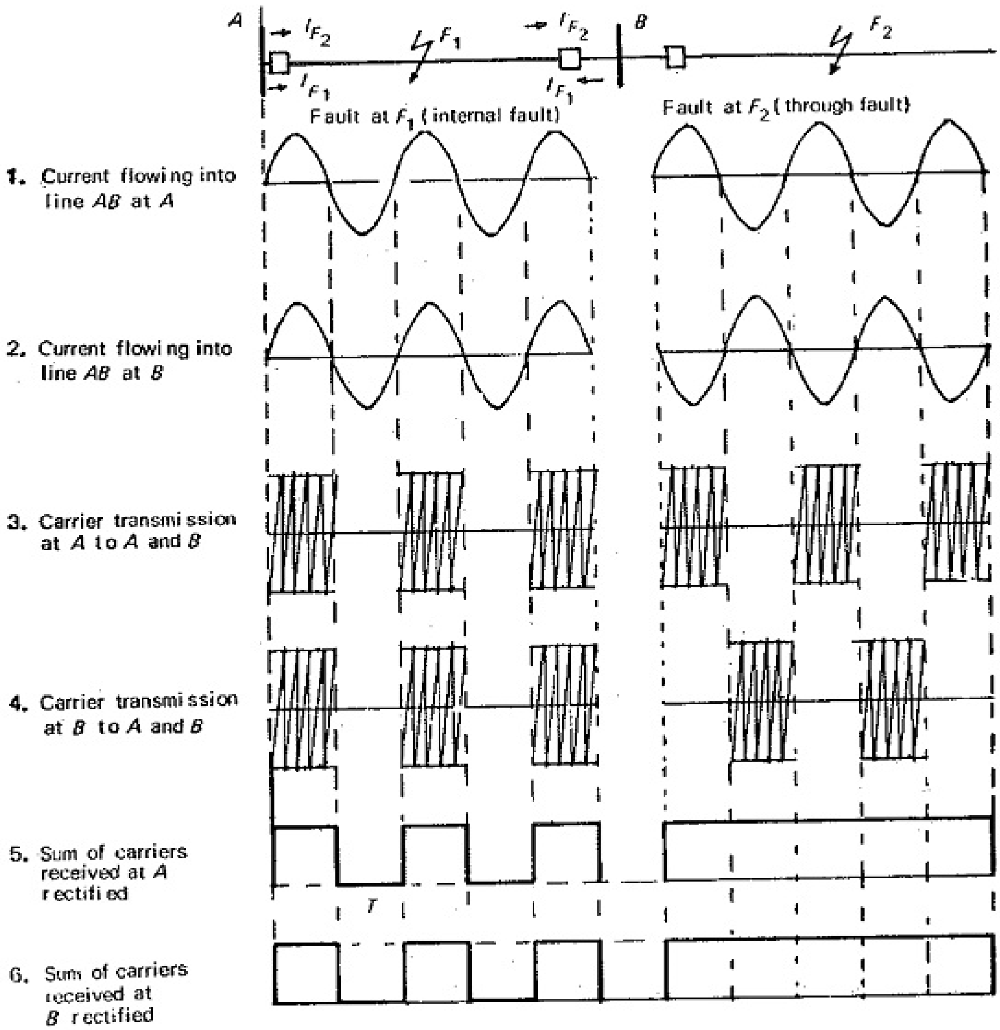


Schematic Representation of Phase-Comparison Carrier Protection

This system compares the phase relation between the current enter into the pilot zone and the current leaving the protected zone. The current magnitudes are not compared. It provided only main or primary protection and backup protection must be provided also. The circuit diagram of the phase comparison carrier protection scheme is shown in the above figure.

The transmission line CTs feeds a network that transforms the CTs output current into a single phase sinusoidal output voltage. This voltage is applied to the carrier current transmitter and the comparer. The output of the carrier current receiver is also applied to the comparer. The comparer regulates the working of an auxiliary relay for tripping the transmission line circuit breaker.

The phase comparison pilot-relaying operates on the principle of comparing the phase position of the currents at the two ends of the protected section. The Phase Comparison Carrier Protection of these currents is made over carrier channels. During normal conditions or through faults the currents entering the line at one end differ in phase-by approximately 180° from those entering the line at the other end. Therefore, the relaying quantities at the two ends are about 180° apart. However, during an internal fault the relaying quantities' at the two ends have a phase difference of nearly 0°.



Carrier Phase Protection

The above Figure illustrates the method of Phase Comparison Carrier Protection. It can be seen that a carrier signal is transmitted only during. The positive half cycle of the current wave.

The current flowing into the line section at breakers A and B is shown in positions 1 and 2 both for internal and through faults separately. The carrier transmission at A and B is shown in positions 3 and 4 for the two fault locations. The carrier transmissions, at A from A and from B are added and rectified to give an output signal as shown in position 5. When the signal has a zero value for a specified time as at T, the circuit breaker is tripped by auxiliary equipment. Whereas for a nonzero value of the signal throughout the entire cycle the breaker is prevented from tripping.

Similar behaviour at breaker B results in a trip signal for fault at F_1 and no signal to the trip circuit for fault at F_2 as shown in position 6. So for fault between A and B both the breakers at A and B trip, whereas for fault outside A-B none of the breakers at A and B trip.

It may be noted that with this phase comparison arrangement, a trip signal is available with a fault in the line section, but none is available if the fault is exterior. In the event of failure of the carrier equipment, the affected line section will be opened even though no fault exists on it.

Advantage of Carrier Current Protection

The following are the advantage of the carrier current protection schemes. These advantages are

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

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

Protection of Busbars:

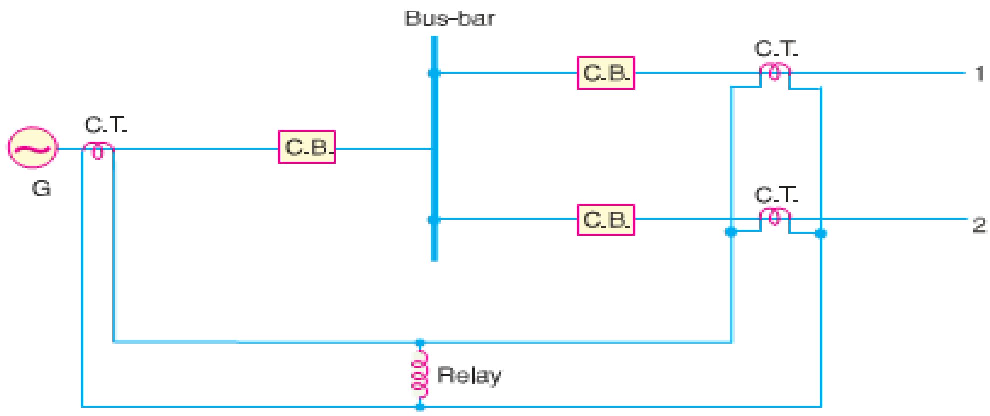
Busbars in the generating stations and substations form important link between the incoming and outgoing circuits. If a fault occurs on a busbar, considerable damage and disruption of supply will occur unless some form of quick-acting automatic protection is provided to isolate the faulty busbar. The busbar zone, for the purpose of protection, includes not only the busbars themselves but also the isolating switches, circuit breakers and the associated connections. In the event of fault on any section of the busbar, all the circuit equipment's connected to that section must be tripped out to give complete isolation.

The standard of construction for busbars has been very high, with the result that bus faults are extremely rare. However, the possibility of damage and service interruption from even a rare bus fault is so great that more attention is now given to this form of protection. Improved relaying methods have been developed, reducing the possibility of incorrect operation. The two most commonly used schemes for busbar protection are:

i. Differential protection
ii. Fault bus protection

Differential protection:

The basic method for busbar protection is the differential scheme in which currents entering and leaving the bus are totalised. During normal load condition, the sum of these currents is equal to zero. When a fault occurs, the fault current upsets the balance and produces a differential current to operate a relay.

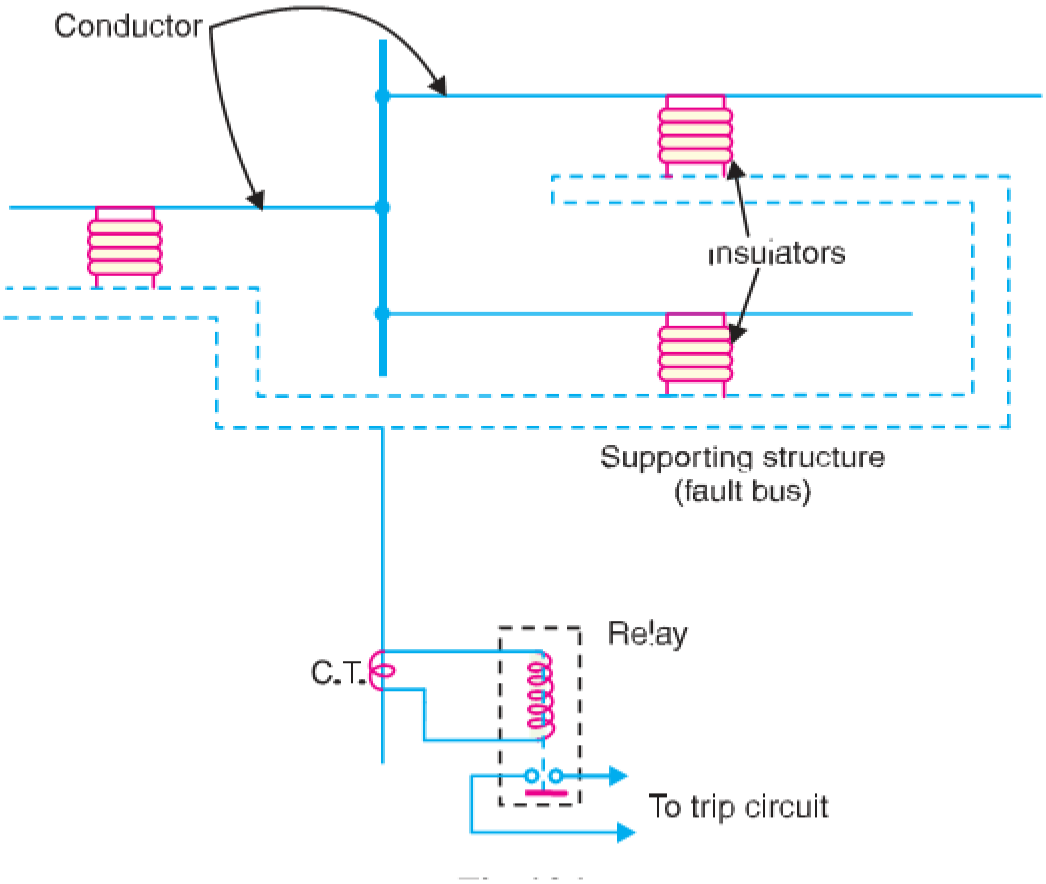


Single line diagram of current differential scheme

The above figure shows the single line diagram of current differential scheme for a station busbar. The busbar is fed by a generator and supplies load to two lines. The secondaries of current transformers in the generator lead, in line 1 and in line 2 are all connected in parallel. The protective relay is connected across this parallel connection. All CTs must be of the same ratio in the scheme regardless of the capacities of the various circuits. Under normal load conditions or external fault conditions, the sum of the currents entering the bus is equal to those leaving it and no current flows through the relay. If a fault occurs within the protected zone, the currents entering the bus will no longer be equal to those leaving it. The difference of these currents will flow through the relay and cause the opening of the generator, circuit breaker and each of the line circuit breakers.

Fault Bus protection:

It is possible to design a station so that the faults that develop are mostly earth-faults. This can be achieved by providing earthed metal barrier (known as fault bus) surrounding each conductor throughout its entire length in the bus structure. With this arrangement, every fault that might occur must involve a connection between a conductor and an earthed metal part. By directing the flow of earth-fault current, it is possible to detect the faults and determine their location. This type of protection is known as fault bus protection.



Schematic arrangement of fault bus protection

The above figure shows the schematic arrangement of fault bus protection. The metal supporting structure or fault bus is earthed through a current transformer. A relay is connected across the secondary of this CT. Under normal operating conditions, there is no current flow from fault bus to ground and the relay remains inoperative. A fault involving a connection between conductors and earthed supporting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of relay will trip all breakers connecting equipment to the bus.