

12 BUS PROTECTION

Although bus protection for new installations is now a simple application problem, this has not always been true, as attested by the many different ways in which protection has been provided. This problem always has been—and still is in many existing installations—primarily a current-transformer problem. A bus has no peculiar fault characteristics, and it would lend itself readily to current-differential protection if its CT's were suitable.

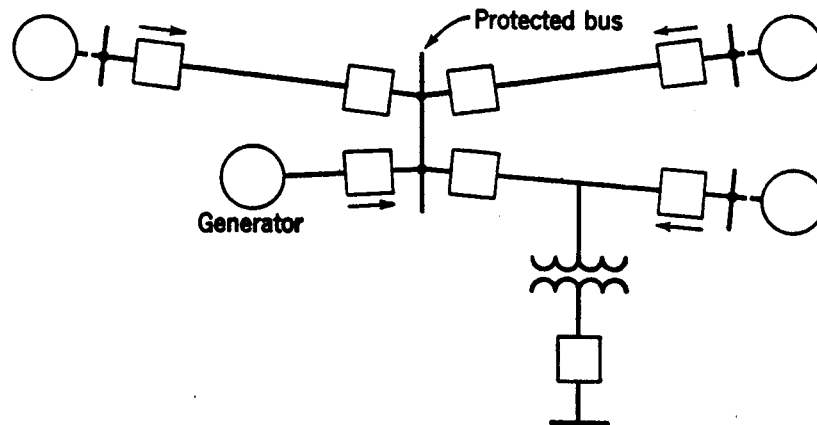


Fig. 1. Bus protection by back-up relays.

Before considering the more modern equipments for bus protection, let us first examine the various forms of protection that have been used and that are still in service; new uses for some of these may still be found infrequently today.

PROTECTION BY BACK-UP RELAYS

The earliest form of bus protection was that provided by the relays of circuits over which current was supplied to a bus, at locations such as shown by the arrows on Fig. 1. In other words, the bus was included within the back-up zone of these relays. This method was relatively slow speed, and loads tapped from the lines would be interrupted unnecessarily, but it was otherwise effective. Some preferred this method to one in which the inadvertent operation of a single relay would trip all the connections to the bus.

THE FAULT BUS¹

The fault-bus method consists of insulating the bus-supporting structure and its switch gear from ground; interconnecting all the framework, circuit-breaker tanks, etc.; and providing a single ground connection through a CT that energizes an overcurrent relay, as illustrated schematically in Fig. 2. The overcurrent relay controls a multicontact auxiliary relay that trips the breakers of all circuits connected to the bus. The maximum effectiveness is obtained by this method when the switchgear is of the isolated-phase construction, in which event all faults will involve ground. However, it is possible to design other types of switchgear with special provisions for making ground faults the most probable. Of course, if interphase faults not involving ground can occur, and if CT's and conventional differential relaying have to be used for protection against such faults, the fault-bus method would probably not be justified.

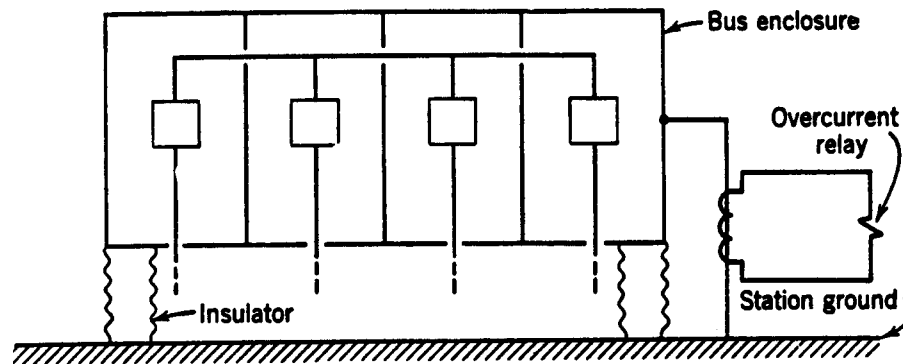


Fig. 2. Schematic diagram of the fault-bus method of protection.

This method is most applicable to new installations, particularly of the metal-clad type, where provision can be made for effective insulation from ground. It has been more favored for indoor than for outdoor installations. Certain existing installation may not be adaptable to fault-bus protection, owing to the possibility of other paths for short-circuit current to flow to ground through concrete-reinforcing rods or structural steel. It is necessary to insulate cable sheaths from the switchgear enclosure or else cable ground-fault currents may find their way to ground through the fault-bus CT and improperly trip all the switchgear breakers. An external flashover of an entrance bushing will also improperly trip all breakers, unless the bushing support is insulated from the rest of the structure and independently grounded.

If a sectionalized bus structure is involved, the housing of each section must be insulated from adjoining sections, and separate fault-bus relaying must be employed for each section. The fault-bus method does not provide overlapping of protective zones around circuit breakers; and, consequently, supplementary relaying is required to protect the regions between bus sections.

Some applications have used a fault-detecting overcurrent relay, energized from a CT in the neutral of the station-grounding transformer or generator, with its contact in series with that of the fault-bus relay, to guard against improper tripping in the event that the fault-bus relay should be operated accidentally; without some such provision, the accidental grounding of a portable electric tool against the switchgear housing might pass enough current through the fault-bus ground to operate the relay and trip all the breakers,

unless the pickup of the relay was higher than the current that it could receive under such a circumstance.

Consideration should be given to the possibility of people being able to make contact between the switchgear housing and ground, to avoid the possibility of contact with high voltage should a ground fault occur; although the ground connection would have very low impedance, high current flowing through it could produce dangerously high voltage. This requirement also makes it desirable to ground all relay, meter, and control circuits to the switchgear housing rather than by means of a separate connection to the station ground.

DIRECTIONAL-COMPARISON RELAYING

The principle of “directional comparison” used for transmission-line relaying has been adapted to bus protection in order to avoid the problem of matching current-transformer ratings and characteristics.² Basically, the contacts of directional relays in all source circuits and the contacts of overcurrent relays in purely load circuits are interconnected in such a way that, if fault current flows toward the bus, the equipment will operate to trip all bus breakers unless sufficient current is flowing away from the bus in any circuit.

This principle has been used only with ground relays, on the basis that most bus faults start as ground faults, or at least that they very quickly involve ground. This greatly reduces the cost of the equipment over that if phase relays were also used; even so, it is still more costly than most relaying equipments for bus protection. Of course, if it saves investment in new current transformers and their installation cost, it would be economically attractive.

The principal disadvantage of this type of equipment is the greater maintenance required and the greater probability of failure to operate because of the large number of contacts in series in the trip circuit. Another disadvantage is that connections from the current transformers in all the circuits must be run all the way to the relay panel. Of course, if only ground relays were used, only two connections to the CT's of each circuit would be required. If phase relays were used, they would depend on bus voltage for polarization, and, therefore, they might not operate for a metallic short circuit that reduced the voltage practically to zero.

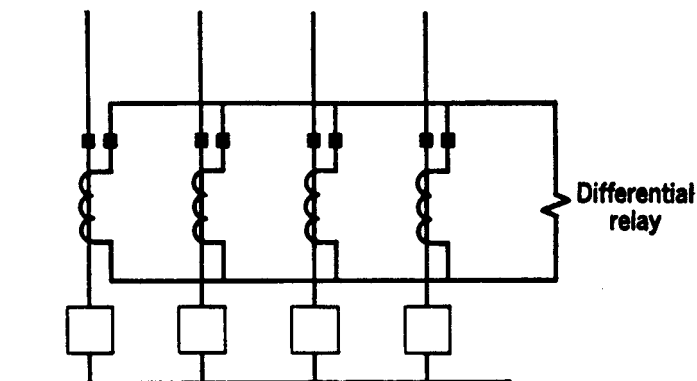


Fig. 3. Bus protection by current-differential relaying.

CURRENT-DIFFERENTIAL RELAYING WITH OVERCURRENT RELAYS

The principle of current-differential relaying has been described. Figure 3 shows its application to a bus with four circuits. All the CT's have the same nominal ratio and are interconnected in such a way that, for load current or for current flowing to an external fault beyond the CT's of any circuits, no current should flow through the relay coil, assuming that the CT's have no ratio or phase-angle errors. However, the CT's in the faulty circuit may be so badly saturated by the total fault current that they will have very large errors; the other CT's in circuits carrying only a part of the total current may not saturate so much and, hence, may be quite accurate. As a consequence, the differential relay may get a very large current, and, unless the relay has a high enough pickup or a long enough time delay or both, it will operate undesirably and cause all bus breakers to be tripped.

The greatest and most troublesome cause of current-transformer saturation is the transient d-c component of the short-circuit current. It is easy to determine if the CT's in the faulty circuit will be badly saturated by a fault-current wave having a d-c component, by using the following approximate formula:

$$B_{\max} = \frac{(\sqrt{2})(10^8) R_2 I_1 T N_1}{A N_2^2}$$

where B_{\max} = maximum flux density in CT core in lines per square inch.

R_2 = resistance of CT-secondary winding and leads up to, but not including, the relay circuit, in ohms.

I_1 = rms magnitude of symmetrical component of primary fault current in amperes.

T = time constant of primary d-c component in seconds.

A = cross-sectional area of CT core in square inches.

N_1 = number of primary turns (= 1 for bushing CT's).

N_2 = number of secondary turns.

For values of B_{\max} greater than about 100,000 lines per square inch, there will be saturation in modern CT's, and for values greater than about 125,000 lines there will be appreciable saturation, the degree being worse the higher the value of B_{\max} . For instantaneous relays, B_{\max} should be no more than about 40,000 lines because the residual flux can be as high as about 60,000 lines. For CT's that are 10 or 15 years old, about 77,500 lines represents saturation flux density.

Considering the effect of the d-c time constant, it will become evident that the nearer a bus is to the terminals of a generator, the greater will be the CT saturation. Typical d-c time constants for different circuit elements are:

Generators	0.3 second
Transformers	0.04 second
Lines	0.01 second

It makes a tremendous difference, therefore, whether the fault-current magnitude is limited mostly by line impedance or by generator impedance.

If the d-c component will not badly saturate the CT's, it is a relatively simple matter to calculate the error characteristics of the CT's by the methods already described, and to find out how much current will flow in the differential relay. Knowing this magnitude of current and the magnitude for which the differential relay must operate for bus faults, one can choose the pickup and time settings that will give the best protection to the bus and still provide selectivity for external faults.

But, if the d-c saturation is severe, and it usually is, the problem is much more difficult, particularly if instantaneous relaying is desired. Two methods of analysis have been presented. One is a method for first calculating the differential current and then determining the response of an overcurrent relay to this current.³ The other is a method whereby the results of a comprehensive study can be applied directly to a given installation for the purpose of estimating the response of an overcurrent relay.⁴ Because of the approximations and the uncertainties involved (and probably also because of the labor involved), neither of these two methods is used very extensively, but, together with other investigations, they provide certain very useful guiding principles.

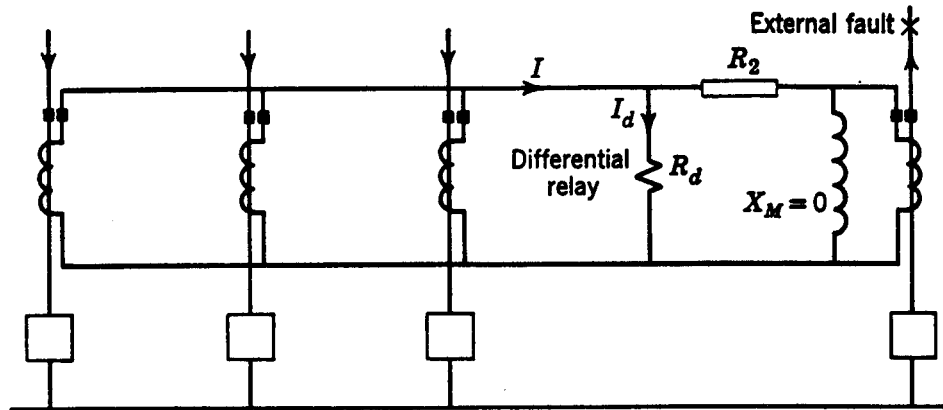


Fig. 4. Distribution of current for an external fault.

Perhaps the most useful information revealed by these and other^{5,6} studies is the effect of resistance in the differential branch on the magnitude of current that can flow in that branch. Figure 4 is a one-line diagram of the CT's and differential relay for a bus with four feeders, showing an external short circuit on one of the feeders. Figure 4 shows the equivalent circuit of the CT in the feeder having the short circuit. If that CT is assumed to be so completely saturated that its magnetizing reactance is zero, neglecting the air-core mutual reactance, the secondary current (I) from all the other CT's will divide between the differential branch and the saturated CT secondary, and the rms value of the differential current (I_d) will be no higher than:

$$I_d = I \left(\frac{R_2}{R_d + R_2} \right)$$

where R_2 includes the secondary-winding resistance of the CT in the faulty circuit. The effect of relay-coil saturation must be taken into account in using this relation. Of course, the differential current will quickly decrease as the fault-current wave becomes symmetrical. However, studies have shown that, depending on the circuit resistances, the rms value of the differential current (I_d) can momentarily approach the fault-current magnitude (I) expressed in secondary terms. Where this is possible, instantaneous

overcurrent relays are not applicable unless sufficient resistance can be added to the differential branch. The amount of such additional resistance should not be enough to cause too high voltages when very high currents flow to a bus fault. Nor should the resistance be so high that the CT's could not supply at least about 1.5 times pickup current under minimum bus-fault-current conditions. If we assume the CT's in the faulty circuit to be so badly saturated that their magnetizing reactance is zero, and that all the other CT's maintain their nominal ratio, the division of current between the differential relays and the secondaries of the saturated CT's, and the effects of adding resistance to the differential branch, may be calculated assuming symmetrical sinusoidal currents; the results will be conservative in that the differential relays will not have as great an operating tendency as the calculations would indicate.

The foregoing furnishes a practical rule for obtaining the best possible results with any current-differential-relaying application. This rule is to make the junction point of the CT's at a central location with respect to the CT's and to use as large-diameter wire as practical for the interconnections. The fact that the CT secondary windings have appreciable resistance makes it impractical to try to go too far toward reducing the lead resistance. Resistance in the leads from the junction point to the differential relays is beneficial to a certain extent, as already mentioned.

Another rule that is generally followed is to choose CT ratings so that the maximum magnitude of external-fault current is less than about 20 times the CT rating.⁷ Some allow this multiple to go to 30 or more, and others⁸ try to keep it below 10. In an existing installation with multiratio bushing CT's, use the highest turns ratio.

To prevent differential-relay operation should a CT open-circuit, the relay pickup is often made no less than about twice the load current of the most heavily loaded circuit;⁸ if the magnitude of groundfault current is sufficiently limited by neutral-grounding impedance, lower pickup may be required and additional fault-detecting means may be required to prevent operation should a CT open-circuit, such as by the use of an overcurrent relay energized from a CT in the grounded-neutral source, and with its "a" contacts in series with the trip circuit.

Some instantaneous overcurrent relays are used for current-differential relaying, but inverse-time induction-type overcurrent relays are the most common; the induction principle makes these relays less responsive to the d-c and harmonic components of the differential current resulting from CT errors because of saturation. Time delay is most helpful to delay differential-relay operation long enough for the transient differential current due to CT errors to subside below the relay's pickup; from 0.2 second to 0.5 second is sufficient for most applications. The fact that a relay will overtravel after the current has dropped below the pickup value should be taken into account.

Where not all the CT's are of the same ratio, sometimes the practice is to provide current-differential relaying only for ground faults. To accomplish this, auxiliary CT's are connected in the neutral of the CT's of each circuit, and the ratios of these auxiliary CT's are chosen to compensate for the differences in ratio of the main CT's. The ratio accuracy of such auxiliary CT's should be investigated to determine their suitability. Of course, auxiliary CT's might be used to permit phase-fault relaying, but it would be much more expensive. In general, auxiliary CT's should be avoided whenever possible.

PARTIAL-DIFFERENTIAL RELAYING

Partial-differential relaying is a modification of current-differential relaying whereby only the CT's in generating-source (either local or distant) circuits are paralleled, as illustrated in Fig. 5. This is not done because of any advantage to be gained by omitting the other CT's in the purely load circuits, but either because there are no CT's to be used or because those that are available are not suitable for complete current-differential relaying.

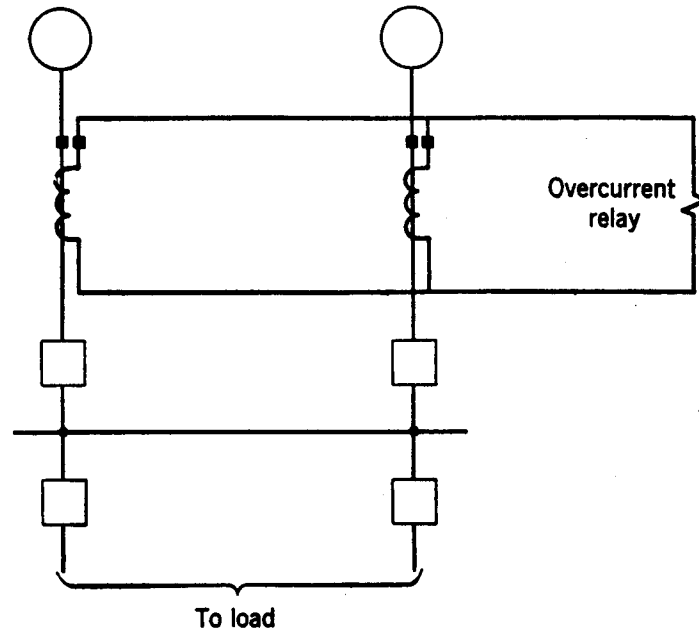


Fig. 5. Partial differential relaying with overcurrent relays.

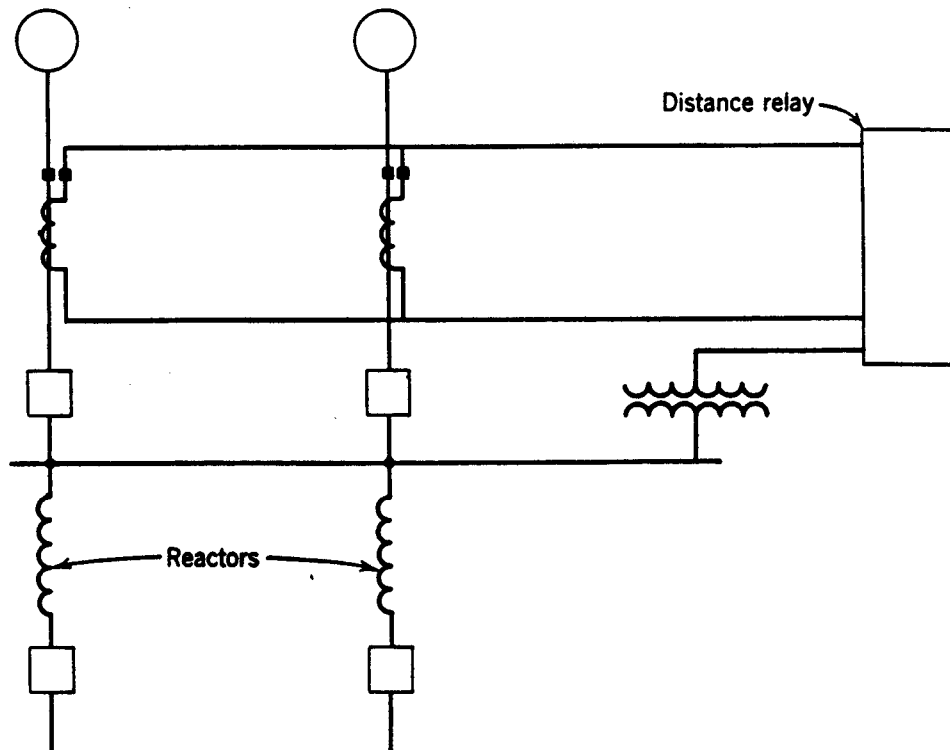


Fig. 6. Partial differential relaying with distance relays.

Two types of partial-differential relaying have been used, one type employing overcurrent relays and the other employing distance relays. The protection provided by the overcurrent type is much like that provided by back-up relays in the individual source circuits. The overcurrent type must have enough time delay to be selective with the relays of the load circuits for external faults in these circuits. Also, it must have a pickup higher than the total maximum-load current of all source circuits. The only advantages of partial-differential relaying with overcurrent relays are (1) that local protective equipment is provided for bus protection, and (2) that back-up protection is provided for the load circuits.

A second type of partial-differential-relaying equipment uses distance relays.^{9,10} This type is applicable where all the load circuits have current-limiting reactors, as illustrated in Fig. 6. So long as two or more of the load circuits are not paralleled a short distance from the bus, the reactors introduce enough reactance into the circuits so that the distance relays can select between faults on the bus side and faults on the load side of the reactors. In some actual applications, only ground distance relays have been used on the basis that all bus faults will involve ground sooner or later. Because a fault in one of the source circuits that badly saturates its CT's will tend to cause the distance relays to operate undesirably, such a possibility must be carefully investigated. Otherwise, this type of relaying can be both fast and sensitive.

One application has been described in which distance relays were used for station-service bus protection and there were no reactors in the load circuits.¹⁰ Instead, selectivity with the load-circuit relays was obtained by adding a short time delay to the operating time of the distance relays.

CURRENT-DIFFERENTIAL RELAYING WITH PERCENTAGE-DIFFERENTIAL RELAYS

As in differential relaying for generators and transformers, the principle of percentage-differential relaying is a great improvement over overcurrent relays in a differential CT circuit. The problem of providing enough restraining circuits has been largely solved by so-called "multi restraint" relays.⁵ By judicious grouping of circuits and by the use of two relays per phase where necessary, sufficient restraining circuits can generally be provided. Further improvement in selectivity is provided by the "variable-percentage" characteristic,⁵ like that described in connection with generator protection; with this characteristic, one should make sure that very high internal-fault currents will not cause sufficient restraint to prevent tripping.

This type of relaying equipment is available with operating times of the order of 3 to 6 cycles (60-cycle basis). It is not suitable where high-speed operation is required.

As in current-differential relaying with overcurrent relays, the problem of calculating the CT errors is very difficult. The use of percentage restraint and the variable-percentage characteristic make the relay quite insensitive to the effects of CT error. Nevertheless, it is recommended that each application be referred to the manufacturer together with all the necessary data.

A disadvantage of this type of equipment is that all CT secondary leads must be run to the relay panel.

VOLTAGE-DIFFERENTIAL RELAYING WITH "LINEAR COUPLERS"

The problem of CT saturation is eliminated at its source by air-core CT's called "linear couplers."¹¹ These CT's are like bushing CT's but they have no iron in their core, and the number of secondary turns is much greater. The secondary-excitation characteristic of these CT's is a straight line having a slope of about 5 volts per 1000 ampere-turns. Contrasted with conventional CT's, linear couplers may be operated without damage with their secondaries open-circuited. In fact, very little current can be drawn from the secondary, because so much of the primary magnetomotive force is consumed in magnetizing the core.

The foregoing explains why the linear couplers are connected in a voltage-differential circuit, as shown schematically in Fig. 7. For normal load or external-fault conditions, the sum of the voltages induced in the secondaries is zero, except for the very small effects of manufacturing tolerances, and there is practically no tendency for current to flow in the

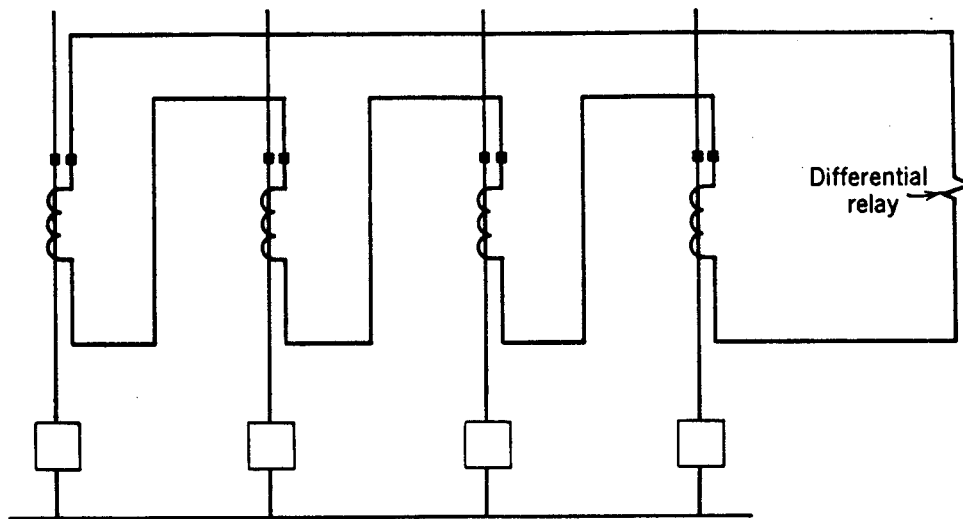


Fig. 7. Bus protection with voltage-differential relaying.

differential relay.

When a bus fault occurs, the voltages of the CT's in all the source circuits add to cause current to flow through all the secondaries and the coil of the differential relay. The differential relay, necessarily requiring very little energy to operate, will provide high-speed protection for a relatively small net voltage in the differential circuit.

The application of the linear-coupler equipment is most simple, requiring only a comparison of the possible magnitude of the differential voltage during external faults, because of differences in the characteristics of individual linear couplers, with the magnitude of the voltage when bus faults occur under conditions for which the fault-current magnitude is the lowest. Except when ground-fault current is severely limited by neutral impedance, there is usually no selectivity problem. When such a problem exists, it is solved by the use of additional more-sensitive relaying equipment, including a supervising relay that permits the more-sensitive equipment to operate only for a single-phase-to-ground fault.¹²

CURRENT-DIFFERENTIAL RELAYING WITH OVERVOLTAGE RELAYS

A type of high-speed relaying equipment employing current-differential relaying with overvoltage relays also eliminates the problem of current-transformer saturation, but in a different manner from that described using linear couplers. With this equipment, conventional bushing CT's (or other CT's with low-impedance secondaries) are used, and they are differentially connected exactly as for current relaying already described; the only difference is that overvoltage rather than overcurrent relays are used.¹³

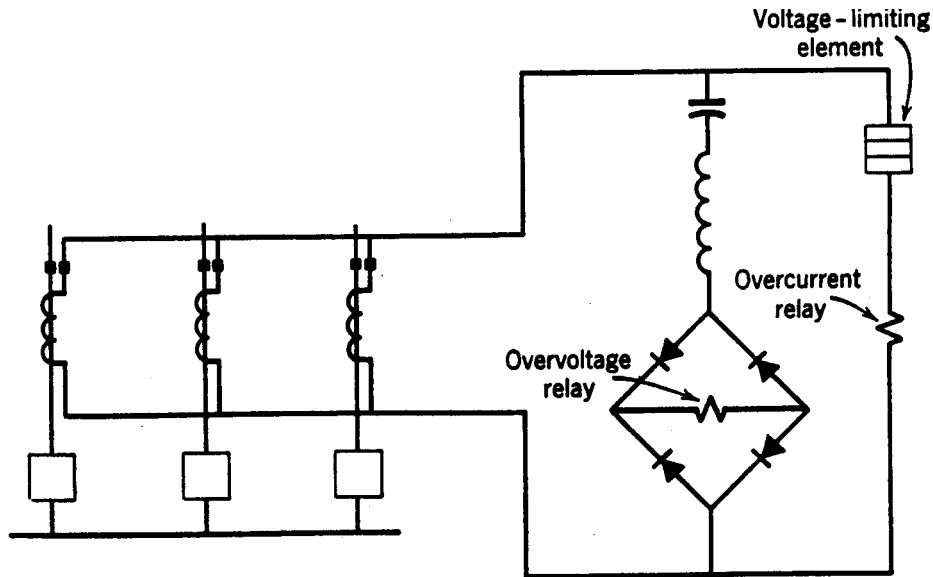


Fig. 8. Bus protection using current-differential relaying with overvoltage relays.

In effect, this equipment carries to the limit the beneficial principle already described of adding resistance to the differential branch of the circuit. However, in this equipment, the impedance of the over-voltage-relay's coil is made to appear to the circuit as resistance by virtue of a full-wave rectifier, as illustrated in Fig. 8. Hence, the efficiency of the equipment is not lowered as it would be if a series resistor were used.

The capacitance and inductance, shown in series with the rectifier circuit, are in series resonance at fundamental system frequency; the purpose of this is to make the relay responsive to only the fundamental component of the CT secondary current so as to improve the relay's selectivity. It has the disadvantage, however, of slowing the voltage response slightly, but this is not serious in view of the high-speed operation of an overcurrent-relay element now to be described.

Because the effective resistance of the voltage-relay's coil circuit is so high, being approximately 3000 ohms, a voltage-limiting element must be connected in parallel with the rectifier branch, or else excessively high CT secondary voltages would be produced when bus faults occurred. As shown in Fig. 8, an overcurrent-relay unit in series with the voltage limiter provides high-speed operation for bus faults involving high-magnitude currents. Since the overcurrent unit is relied on only for high-magnitude currents, its pickup can easily be made high enough to avoid operation for external faults.

The procedure for determining the necessary adjustments and the resulting sensitivity to low-current bus faults is very simple and straightforward, requiring only a knowledge of the CT secondary excitation characteristics and their secondary impedance.

For the best possible results, all CT's should have the same rating, and should be a type, like a bushing CT with a distributed secondary winding, that has little or no secondary leakage reactance.

COMBINED POWER-TRANSFORMER AND BUS PROTECTION

Figure 9 shows a frequently encountered situation in which a circuit breaker is omitted between a transformer bank and a low-voltage bus. If the low-voltage bus supplies purely load circuits without any back-feed possible from generating sources, the CT's in all the load circuits may be paralleled and the transformer-differential relay's zone of protection may be extended to include the bus.

Figure 10 shows two parallel high-voltage lines feeding a power-transformer bus with no circuit breaker between the transformer and the bus. As shown in the figure, a three-winding type of percentage-differential relay will provide good protection for the bus and the transformer.

In Fig. 11, the two high-voltage lines are from different stations and may constitute an interconnection between parts of a system. Consequently, much higher load currents may flow through these circuits than the rated load current of the power transformer. Therefore, the CT ratios in the high-voltage circuits may have to be much higher than one would desire for the most sensitive protection of the power transformer. And therefore, the protective scheme of Fig. 10, though generally applicable, is not as sensitive to transformer faults as the arrangement of Fig. 11. Bushing CT's can generally be added to most power transformers, but it is considerably less expensive and less troublesome if the power transformers are purchased with the two sets of CT's already installed. It is almost axiomatic that, whenever circuit breakers are to be omitted on the high-voltage side of power transformers, two sets of bushing CT's should be provided on the transformer high-voltage bushings. The arrangement of Fig. 11 can be extended to accommodate more high-voltage lines or more power transformers, although, as stated in Chapter 11, it is not considered good practice to omit high-voltage breakers when two or more power-transformer banks rated 5000 kva or higher are paralleled.

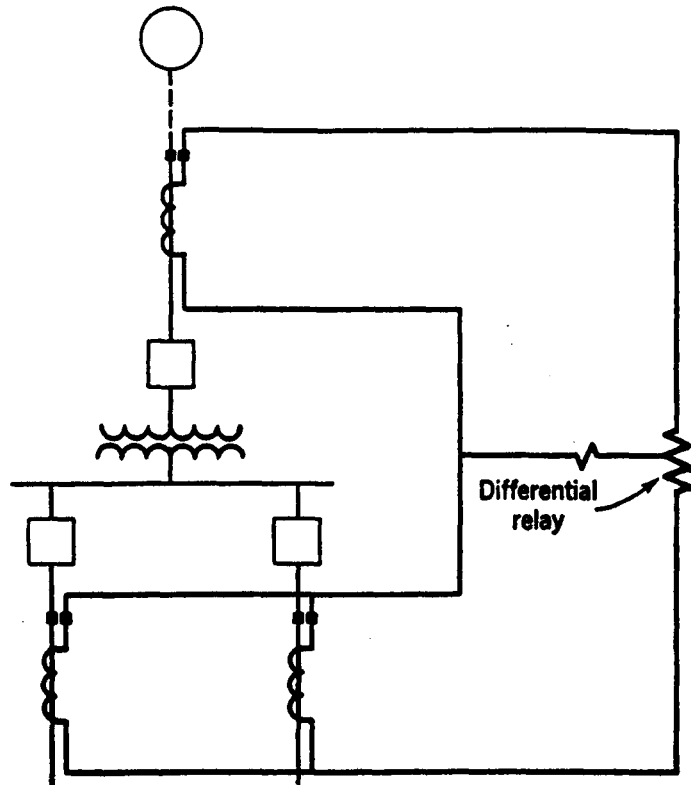


Fig. 9. Combined transformer and bus protection with a two-winding percentage-differential relay.

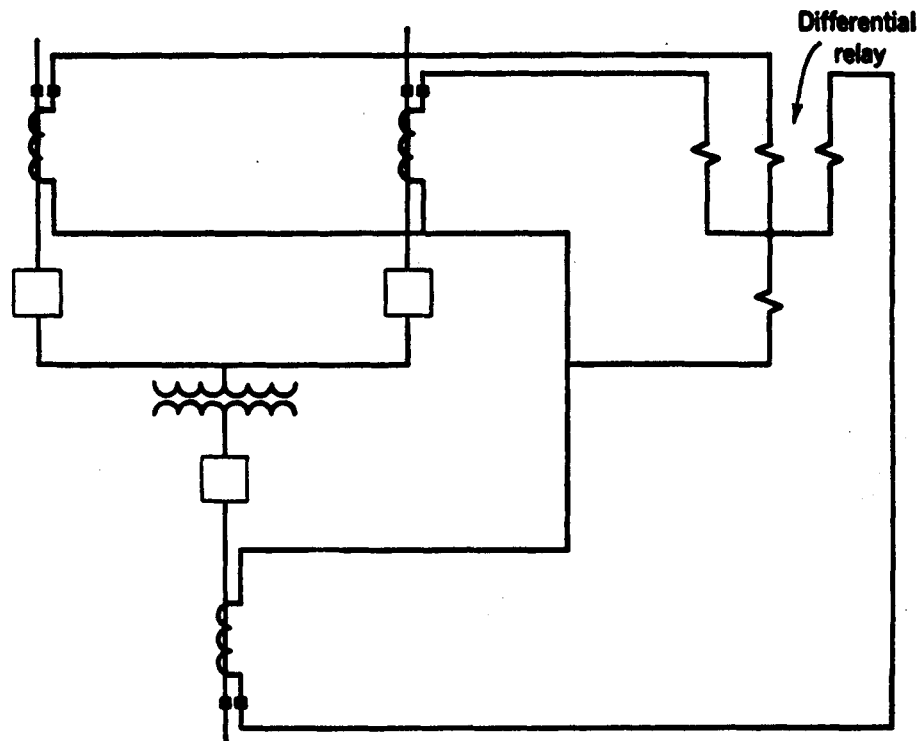


Fig. 10. Combined transformer and bus protection with a three-winding percentage-differential relay.

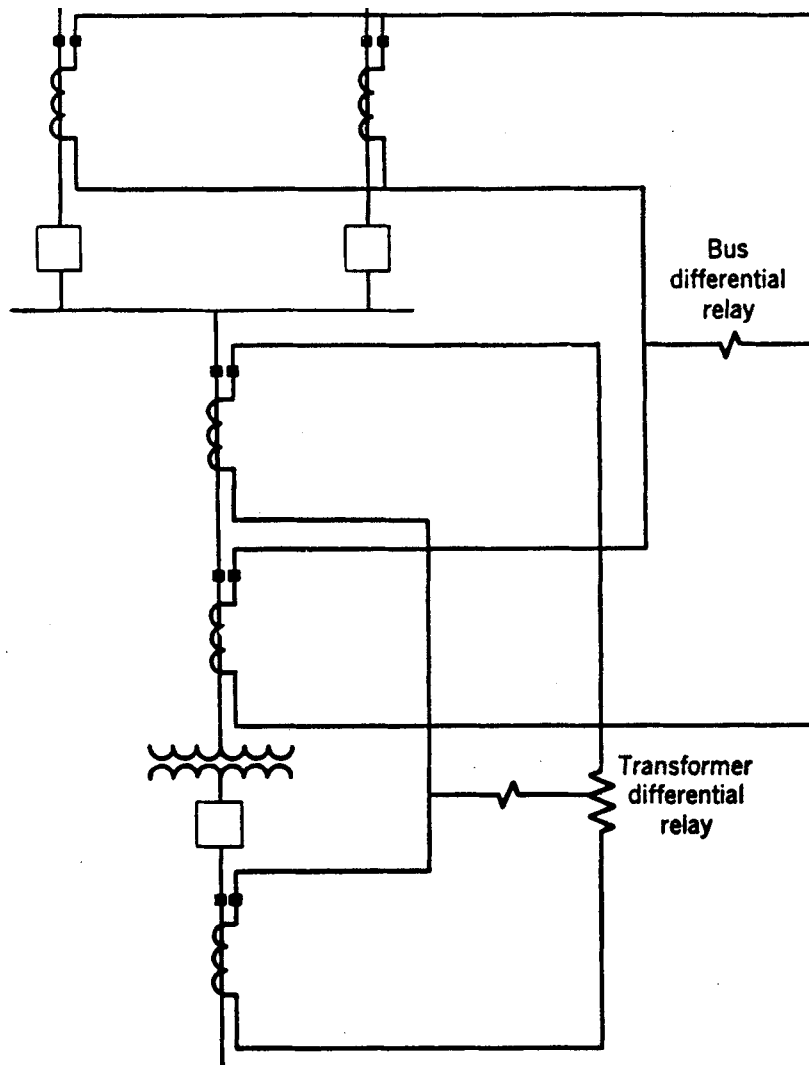


Fig. 11. Preferred alternative to Fig. 10 when high-voltage lines are from different stations.

Figure 12 shows a protective arrangement that has been used for the combination of two power transformers as shown. It could not be extended to accommodate any more transformers or high-voltage circuits, and it does not provide as sensitive protection as the arrangement of Fig. 11, but it saves one set of bushing CT's and a set of bus-differential relays.

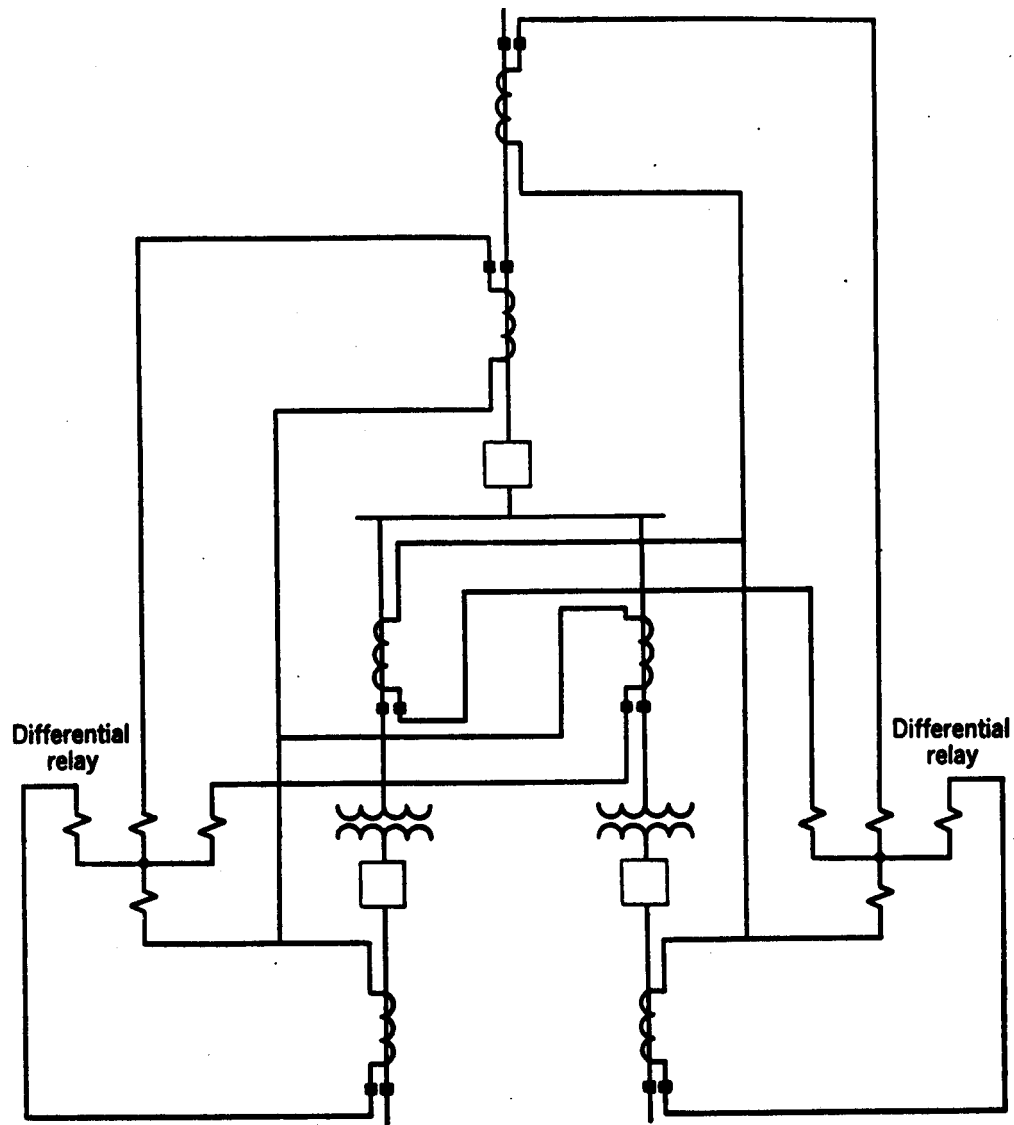


Fig. 12. Complete protection of two transformers and a bus with two three-winding percentage-differential relays.

RING-BUS PROTECTION

No separate relaying equipment is provided for a ring bus. Instead, the relaying equipments of the circuits connected to the bus include the bus within their zones of protection, as illustrated in Fig. 13. The relaying equipment of each circuit is indicated by a box lettered to correspond to the protected circuit, and is energized by the parallel-connected CT's in the branches that feed the circuit.

A separate voltage supply is required for the protective relays of each circuit. Also, the CT ratios must be suitable for the largest magnitude of load current that might flow around the ring, which might be too high for the desired protection of a given circuit.

THE VALUE OF BUS SECTIONALIZING

Although the design of busses does not fall in the category of bus relaying, it is well to keep in mind that bus sectionalizing helps to minimize interference with service when a bus fault occurs. For some busses, sectionalizing is an essential feature of design if stability is to be maintained after a bus fault. With bus sectionalizing, each bus section can be protected separately, and the likelihood of a fault in one section interfering with the service of another section is thereby minimized.

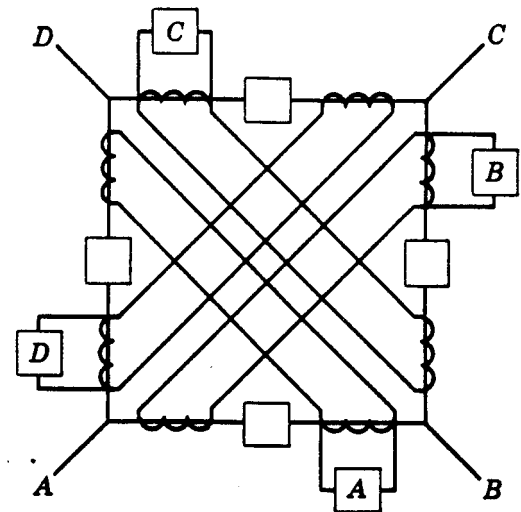


Fig. 13. Protection of a ring bus.

BACK-UP PROTECTION FOR BUS FAULTS

If one or more bus breakers fail to trip in the event of a bus fault, back-up protection is provided by the relaying equipments at the far ends of the circuits that continue to feed current directly to the fault.

Occasionally, relaying equipment is provided at a bus location for back-up protection of adjoining circuits. This is done only when it is impossible to provide the desired back-up protection in the conventional manner described in Chapter 1. This matter is treated further under the subject of line protection.

GROUNDING THE SECONDARIES OF DIFFERENTIALLY CONNECTED CT'S

The intent here is to emphasize the fact that differentially connected CT's should be grounded *at only one point*.¹⁴ In spite of the fact that various publications have warned against separately grounding the CT's of each circuit, the survey reported in Reference 7 found separate grounding to be practiced by many. Metering practices have been so strongly ingrained that people have replaced grounds that were purposely omitted from differentially connected CT's.

The correct practice is to interconnect the neutrals of all differentially connected CT's with the same kind of *insulated* wire as that used for the other CT interconnections. Then, the neutral interconnection is grounded at *one point only*. Since the grounding is for the protection of personnel, the best place to make the ground is at the differential-relay panel where connection is made to the neutral of wye-connected relay coils.

The reason why the ground should be made at only one point is to avoid improper relay operation and damage to the CT interconnections. If grounds are made at two or more locations, circulating currents may be caused to flow in the differential circuit because of differences of potential between the grounding points, owing to the flow of large ground currents during ground faults.

AUTOMATIC RECLOSING OF BUS BREAKERS

A few installations of outdoor automatic substations, whose busses are not enclosed, employ automatic reclosing of the bus breakers. In at least one installation, a single circuit connected to a generating source is first reclosed and, if it stays in, the remaining, circuits are then reclosed—all automatically. Somewhat the same philosophy applies to outdoor open busses as to transmission lines, namely, that many faults will be non-persisting if quickly cleared, and, hence, that automatic reclosing will usually be successful. However, substations are generally better protected against lightning than lines, and their exposure to lightning is far less. Hence, one can expect that a larger percentage of bus faults will be persisting.

PRACTICES WITH REGARD TO CIRCUIT-BREAKER BY-PASSING

Most users of bus-differential protection take the bus protective-relaying equipment completely out of service, either automatically or manually, and do not substitute any other equipment for temporary protection, when circuit breakers are to be by-passed for maintenance purposes or when any other abnormal set-up is to be made.⁷ Of course, the bus still has time-delay protection because the back-up equipment in the circuits connected to the bus should function for bus faults.

Others use a wide diversity of temporary forms of bus relaying.⁷

ONCE-A-SHIFT TESTING OF DIFFERENTIAL-RELAYING EQUIPMENT

Most power companies make maintenance checks once every 6 to 12 months or longer, but a few follow the practice of testing their bus-differential-relaying CT secondary circuits every shift for open circuits or short circuits. This can be done with permanently installed testing equipment arranged to measure current in the relay operating coils, and to superimpose on the circuit a testing current or voltage, as required. Where fault detectors are employed to supervise tripping, the equipment is sometimes arranged to sound an alarm if a CT circuit should open and cause a differential relay to operate.

Such testing is felt by some to be particularly desirable where the differential relay's pickup is high enough so that the relays will not operate on the current that they will get during normal load conditions if an open circuit or a short circuit should occur in a CT secondary circuit. Such trouble would not be discovered until after the relays had operated undesirably for an external fault or had failed to operate for a bus fault.

Of course, the only difference between bus-differential CT circuits and the CT circuits of relaying equipment protecting other system elements is that for the bus there are more CT's involved and that a larger part of the power system is affected. It is not that the bus equipment is inferior to the other, but that the consequences of failure are more serious.

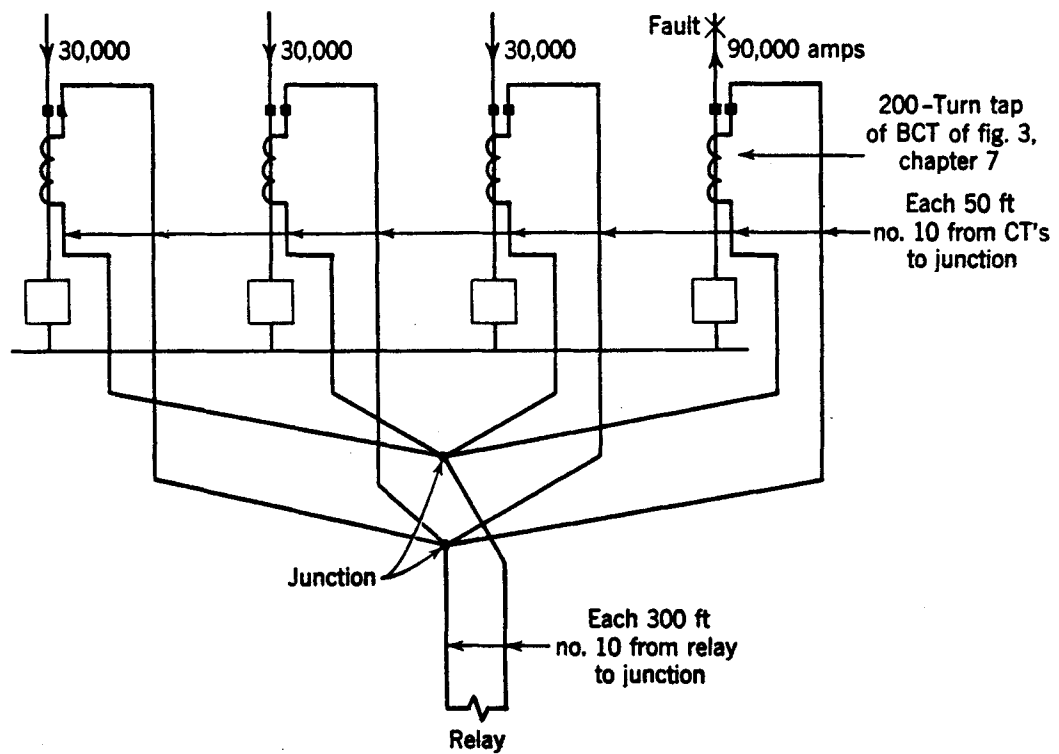


Fig. 14. Illustration for problem. Assume resistance of no. 10 wire is 1.018 ohms per 1000 ft at 25° C

PROBLEM

Given a bus-differential-relaying equipment as shown in Fig. 14, using $\frac{4}{16}$ -ampere inverse-time-overcurrent relays whose time-current characteristics are shown in Fig. 3 of Chapter 3. The total short-circuit current to a bus fault under minimum generating conditions will be 5000 amperes; and it has been decided to adjust the relays to pick up at 2400 amperes (12-ampere tap). For an external three-phase fault involving the current magnitudes and directions as shown, the breaker in the faulty circuit will interrupt the flow of short-circuit current in 0.3 second by virtue of other protective relaying equipment not shown.

In view of the large magnitude of external-fault current, it is suspected that the differential relays may tend to operate, and, if so, they are to be adjusted to have a 0.5-second time delay so as to be selective with the faulty-feeder relaying equipment. What time-lever setting should be chosen for this purpose?

Assume that each CT in the faulty feeder saturates completely so as to have no secondary-current output, and that the total output current of the other CT's divides between the saturated CT's and the relays. Take into account the fact that the other CT's will have ratio error, and for this purpose assume that their primary currents are symmetrical. Also, take into account the fact that the relay coils saturate and, hence, that their impedance decreases as shown in the accompanying table when current of large magnitude flows in each coil.

Multiple of Pickup Current (4-amp. tap)	Coil Impedance, ohms
1	0.3
3	0.15
10	0.08
20	0.07

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