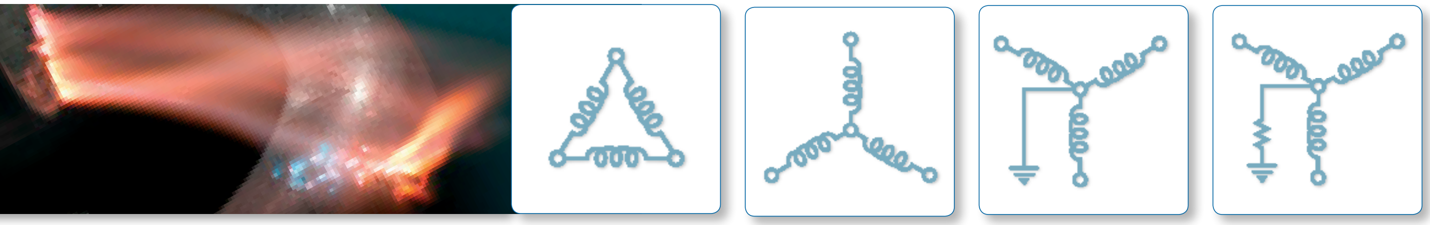
GARD

Unparalleled Protection

Ground Fault Protection on Solidly Grounded Low Voltage Electrical Systems

APPLICATION GUIDE



C-300EA Application Guide, October 2014

ABOUT I-GARD

I-Gard's commitment to electrical safety provides both industrial and commercial customers with the products needed to protect their electrical equipment and the people that operate them.

As the only electrical-safety focused company whose product portfolio includes neutral grounding resistors, high-resistance grounding systems and optical arc mitigation, we take pride in our technologies that reduce the frequency and impact of electrical hazards, such as arc flash and ground faults.

For those customers who have purchased from us over the last 30 years, you know us for the quality and robustness of our products, our focus on customer service and technical leadership. We build on this foundation by investing in developing new products in electrical safety education - including EFC scholarship program - by actively participating in the IEEE community programs on technical and electrical safety standard, and working with local universities at discovering new technologies. We remain unrelenting in our goal of improving electrical safety in the workplace.

Our commitment to excellence is validated by long-standing relationships with industry leaders in fields as diverse as oil and gas, hospitals, automotive, data centers, food processing, aerospace, water and waste water plants, and telecommunications. We provide them with the product and application support required to ensure that their electrical distribution system is safe and reliable.

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1. GENERAL

1. INTRODUCTION

Originally all electrical systems were ungrounded systems. Both AC and DC generator systems were used for power distribution, before the invention of practical transformers. One problem that became evident was that intermittent ground faults caused escalating DC voltages on the power lines to cause insulation failures. This was solved by grounding the systems.

The grounding was achieved by connecting a line to ground (Corner Ground in a Delta system) or if the system had a star point, by grounding that point. Overcurrent and short circuit protection was added to prevent fire and all was well, so they thought, until a series of fires in the United States caused a review of protection systems. The reason, of course, was that arcing faults to ground on the power systems could not activate the short circuit or overload relays due to the low current levels which were within the overcurrent ratings of the breakers. An arcing fault, they discovered could cause complete destruction of a switchboard that was thought to be completely protected, by fuses and thermal-magnetic circuit breakers. Arcing faults are difficult to contain and can spread quickly to other circuits and cause a complete destruction of a switchboard unless steps are taken to prevent this situation. One method that was adopted by the Canadian Electrical Code and National Electrical Code in the U.S. was to include Ground Fault Relay Protection in the System Requirements for Main Service Protection, in addition to overcurrent relay protection.

This, while a step in the right direction, does not completely eliminate the problem of arcing fault damage, as will be seen. The codes require that ground fault relays are required if the ampacity of the service is more than 1000A for systems with voltages between 150 and 750V (or 2000A below 150V). The allowable fault level is 1200A maximum for a delay time not exceeding 1 second at 3000A. This suggesting that inverse characteristics are allowed.

An arcing fault can exist on a 480V or 600V system with current level well below 1200A, in which case the prescribed maximum may not provide much protection. The CEC recognizes this and suggests that multi-stage protection may be required. Although the code refers specifically, and only to, wye-connected solidly grounded systems, as stated already, many delta-connected systems are solidly grounded at the corner or at the centre point of one leg. They are just as prone to destruction by arcing ground faults as are equivalent wye-connected systems, and should be protected by ground fault devices. Fortunately, ground fault protection can be applied in the same way as for wye-connected systems.

2. GROUND CURRENT SENSING

Ground faults on grounded systems are detected using current transformers, commonly called sensors to distinguish them from the metering type CT's, which have to comply with different standards.

The sensors are connected in various ways as follows:

1. the ground return method, when the sensor monitors the ground current flow in the conductor, which connects the neutral to the grounding conductor, and

2. the vectorial summation method, or differential method, where the sensor(s) monitors the outgoing ground currents by making a vectorial summation of the phase and neutral (if any) currents. This method can be either residual, when 3 separate phase sensors and a neutral current sensor are used, or zero sequence, when a single sensor is applied which surrounds all load conductors, but not the ground wire or the shield of the cable. Sometimes a modified zero sequence connection is used with two sensors - one on the 3 line conductors and one on the neutral conductor.

The ground return method can be used only for the incoming main disconnect and only for wye-connected systems. Only the second method can be used for feeders, but it can be used on the incoming mains, instead of (1). The location of a current sensor defines the point beyond which down-stream (in direction of power flow) ground faults can be detected. Consequently, it should be located as close to its associated disconnecting means as possible and is usually mounted immediately down-stream (or up-stream) from it.

Generally, only zero sequence method can operate effectively below trip levels under 100A, due to the accuracy limitations of the line current measurements of current sensors, when used in the other configurations.

For correct application, the following conditions should be checked before the ground current sensing method is selected:

a) The ground return method can be used on radial distribution transformer systems or separately derived multi-source distribution systems.

b) The ground return method should not be used on distribution systems fed from networks. The main service to each system supplied by a network is connected to the common bus and the neutral is grounded in each system, so multiple paths exist for the return of ground fault current to the source. Thus, if the ground current return method is used in a switchboard fed by a network, there is a possibility that the sensor will see only a part of the ground fault current originating in its own system. (The remainder returns through the grounding conductors of other systems fed by the network grounding connection). Furthermore, it may also see some part of the ground fault current originating in any other system fed by the same network. These conditions lead to errors in detection which can result in unwanted tripping of critical breakers.

c) System-grounding points should be restricted to the main switchboard area and/or the supply transformer wye point. Whenever other grounding points can not be avoided, additional ground strap sensors should be applied on these connection points, connected in parallel to those in the switchboard. Ground current may return to the source through any one, or all, grounding points, equally or unequally, and all must be included for an accurate fault current measurement.

d) Vectorial summation sensing method by zero sequence transformers, can be used on any type of distribution systems for feeder and/or main protection when all the phase conductors, and the neutral if used, (but not the grounding conductor or the shield of the cable) are encircled by a sensor. Neutral currents must be summed with line currents or an error will occur on unbalanced systems which will cause unwanted tripping.

e) The neutral must be grounded only on the line side of a zero sequence current sensor or on the load side of the neutral sensors when a dual system is grounded at the neutral tie point. No other ground(s) shall exist on the opposite side.

f) Zero sequence current sensors can be mounted on either the line or the load side of the protected disconnect device.

g) Ground strap sensors should be mounted on the neutral-to-ground bonding jumper.

h) Systems in which multiple individually grounded power sources are used, such as utility and emergency generator systems, need careful consideration. It is usually essential that no tie exists between the neutrals of the sources, e.g. 4 pole transfer switches or tie breakers may be needed.

3. SINGLE GROUND FAULT RELAY

A single ground fault relay on the main disconnect device is the minimum equipment required by the Code. In this case, ground fault protection is provided for all points on the load side of the main disconnect. No provision can be made for selective tripping of ground faults occurring on the load side on the down-stream feeders. Even if the 1200 Amperes maximum current setting, allowed in the Code, is used on the main ground fault relay, tripping of the main disconnect can occur for the ground fault on the load side of the feeder and branch circuits. The single relay application is not recommended where maximum continuity of service is required.

A definite time relay, or inverse time delay relay, such as MGFR can be used for single relay application.

4. SELECTIVE GROUND FAULT PROTECTION

Where maximum continuity of service is essential, selective ground fault protection should be used. A selective ground fault protection system is one in which each disconnecting means is equipped with a ground fault relay, so that only the one nearest the ground fault will be tripped by the ground fault protection. Selective ground fault protection systems may be of the following types:

a) Time Co-ordinated Protection (TCP),
b) Zone Selective Instantaneous Protection (ZSIP),
c) Combination of Both.

4.1 TIME CO-ORDINATED SYSTEM

In this system, the last relay in the branch circuit is an instantaneous relay. The relays closer to the source have increasingly longer time delays, to permit the relay nearest the fault to clear the fault without tripping up-stream relays. In the event of a fault, all up-stream disconnects remain closed and continue to supply the remaining load current.
Each set of ground fault protective devices should have a specified set of time/current operating characteristics with specified tolerances. This is usually presented in the form of a graph plotted on log-log paper. The characteristics can be used to compare against other devices to co-ordinate the system. When ground fault protected disconnects are in series, each down-stream ground fault relay should use a time/current band which at all values of ground fault current will cause the disconnect, to open and clear the circuit before any up-stream disconnect opening mechanism is actuated.

4.2 ZONE SELECTIVE INSTANTANEOUS PROTECTION - ZSIP

A great deal of damage and destruction can be produced by arcing ground faults on grounded systems. Arcing fault damage is directly proportional to the current, arc voltage and fault duration. To minimize damage, any one, or all three, parameters must be kept to a minimum.

$KWC = VA\ I_G\ t/1000$ KWC where VA = Arc Voltage (V), I_G = Arc Current (A) and t = Time duration (Cycles)

The arc voltage can be assumed to be 100V for low voltage applications up to 600V. Also, since it is inverse, the time/current characteristic of the constant KWC curves is a straight line on log-log scale graph. Any damage greater than 10,000 KWC is considered to be unacceptable in most applications.

The magnitude of the fault current and the arc voltage can not be controlled by a protective relay system, since they are determined by the impedance of the faulted circuit and the nature of the arc. Only the fault duration can be controlled by a protective relay, which, ideally, should limit the fault duration to the circuit breaker clearing time, plus the operating time of the relay itself. Operating time of ground fault relays should ensure that arcing faults will be kept below the 10,000 KWC line on a co-ordination plot of the system devices. The Zone Selective Instantaneous Protection (ZSIP), included in I-Gard Relays, achieves the objective of instantaneous response to ground faults and yet is fully selective, thus minimizing damage and providing full system co-ordination. If there is a ground fault on a circuit, protected by a ZSIP Relay, and the magnitude of the fault current exceeds the pick-up setting, the relay will trip instantaneously, providing that the fault is within that relay's zone.

NOTE: A zone is defined as a section of a system protected by a relay and includes all of the system from the load side of the relay's zero sequence current sensor to the line side of any down-stream zero sequence current sensor, if present. See Section 3 for more details of ZSIP operation.

Selectivity between zones is achieved by a signal generated by the first ground fault relay up-stream of the fault, which operates immediately. This signal is sent to all relays further up-stream and restrains them from tripping instantaneously. The fault is then removed by the relay closest to the fault. If this relay, or its associated breaker, fails to clear, for any reason, the next relay up-stream provides selective, time delayed back-up protection. Zone Selective Instantaneous Protection can be applied to any size system. There is no limit, generally, to the number of zones that can be protected in this manner.

All types of MGFR Relays are designed with ZSIP mode included. Probably the most cost effective ground fault protection schemes are the two-zone ZSIP in Unit Substations and the three-zone ZSIP in double-ended substations where all relays are located in the main switchgear. It is almost as easy to install as a time co-ordinated system with all the advantages of the ZSIP system.

4.3. COMBINATION SYSTEMS

Zone selective instantaneous protection and time coordinated ground fault protection can be combined into one system where economic reasons do not permit the extension of the ZSIP to the most down-stream branch circuits and service continuity is still required on certain section(s) of a distribution system at the branch circuit level.

The settings of pick-up current and time delay for sub-feeder and branch circuit relays should be selected to provide optimum ground fault protection and co-ordination with conventional overcurrent devices on the unprotected section of the distribution system.

5. RECOMMENDED SETTINGS

The following general rules are suggested, to establish the settings of ground fault relays as a starting position, in the absence of a formal co-ordination study:

5.1 SINGLE RELAY ON THE MAIN DISCONNECT

5.1.1 PICK-UP SETTINGS

Use 20% of Full Load rating, e.g. 1000A on a 5000A breaker.

5.1.2 TIME DELAY SETTINGS

In time co-ordinated systems, the maximum delay should co-ordinate with the maximum acceptable KWC damage curve and will generally be inverse to achieve this condition. See Section 6.

5.2 MULTI-ZONE TIME CO-ORDINATED SYSTEMS

5.2.1

Use a time setting as short as possible and a current setting of 200 Amperes or less for an individual branch circuit.

5.2.2

Use 0.1 second longer time delay setting for the feeder relays than is used on the branch circuit protection.

5.2.3

Use 0.2 second longer time delay setting for the main disconnect than that of the relay for the next down-stream disconnect. Use 0.1 second longer time delay when the next down-stream disconnect is a molded case circuit breaker rated 800 Amperes or less.

5.2.4

For feeder or main disconnect relay, use a current setting no lower than 150% of the current setting of the next down-stream relay.

5.2.5

Set instantaneous and short time trip of related overcurrent devices to the lowest practical value, bearing in mind the possibility of inrush currents and their duration.

5.3 ZONE SELECTIVE INSTANTANEOUS PROTECTION - ZSIP

5.3.1

Zone co-ordination should be achieved by pick-up and time band settings. Use the same time delay and current settings as recommended for time co-ordinated systems. The interlocking (restraint) circuitry will normally provide approximately 0.03 second time delay for a ground fault occurring anywhere on the system. The longer time delays corresponding to the dial setting will only be necessary in the unlikely event that the nearest relay up-stream of the fault fails to clear, or the breaker fails to open in its predetermined time and the next up-stream relay operates as back-up protection.

6. GROUND FAULT PROTECTION DESIGN

Ground fault protection should be designed concurrently with the overcurrent protection to assure a reliable and well co-ordinated system. Therefore, it is essential that all information, including power sources, grounding methods and connections, together with the system data (voltage, frequency, number of phases and wires), be obtained. The following step by step procedure is recommended to eliminate some application pitfalls:

1. Prepare a complete system diagram, including the neutral and ground conductors.
2. Check where, and which, conductors of the incoming or associated sources are grounded.
3. Determine the approximate short circuit current, (IEEE Buff Book has practical calculations and examples) and the probable arcing ground fault current for every point of the distribution system. Recall that relays on the mains will not necessarily co-ordinate with fuses down-stream.

4. Establish ground fault protection requirements. Examine possible ground-fault current paths, and select the location and the type of the sensors. Check for existing ground fault devices to see if they can be used effectively.
5. In case of parallel ground fault current paths, eliminate the multiple ground points or separate the neutral bus into sections. Use parallel sensors and relay logic control schemes, where necessary, e.g. when tie breakers are closed.
6. Select ground fault protection system components, and check that they meet cost requirements.
7. Detail the ground fault protection system, including the necessary interlocking.
8. Provide the necessary shunt trips, auxiliary switches, etc. required for the system, including a reliable tripping power supply.
9. Determine the current and time settings of the relays by co-ordination study and compare with superimposed KWC curves for arcing faults (straight lines on log-log paper).
10. Detail the changes or modifications required if the system is an existing one.

2. TIME CO-ORDINATED SYSTEMS

1. GENERAL

Ground fault protection, either time co-ordinated (TCP) or zone selective instantaneous (ZSIP) type, can be applied to any of the following distribution systems:

a) Secondary Radial - unit substations,
b) Secondary Selective - multi-transformer supplies with tie connections,
c) Secondary Networks.

The protection system operation, as previously mentioned, will depend upon:

a) system grounding arrangement (number and location of grounding points), and
b) ground fault current sensing method.

The two distinct requirements are connected. The grounding arrangement can affect the sensing method, sensor location(s), the number of required sensors, and the sensitivity of the protective relays and generally the relay operation.

To insure satisfactory operation of the ground fault relays, the correct sensing method should be selected for each relay as follows:

1.1 VECTORIAL SUMMATION

Vectorial Summation (Zero Sequence Current Sensing or residual connection) method must be used for:

a) feeder breaker relays,
b) main breaker relay(s) in network fed substations, and
c) normally closed tie breaker relay(s) if full selectivity is required.

Vectorial summation method can be used for main breaker relays in any substation arrangement.

1.2 DIRECT GROUND

Direct Ground Current Sensing (Ground Strap) can be used for:

a) main breaker relays in unit substations,
b) main breaker relays in double-ended substations when the neutral bus is grounded at the centre only (T ground),
c) normally open tie breaker relays, and
d) normally closed tie breaker relays, if full selectivity is not required.

Note: Residual Sensing with one sensor on each line and a fourth on the neutral (for 4-Wire systems) or Modified Zero Sequence connection with a remote neutral sensor connected in parallel with the main ZSCT, cannot be successfully implemented below 100A pickup normally, because the error in transformation of the sensor becomes significant compared to the threshold current at low pickup levels. For example if the accuracy of the sensor under load is 1% and the load current is say 500A, then the accuracy is ±5A. If the pick-up setting is 20A, then the error is already ±25%, which would be intolerable in most cases. In the case of Ground Strap Sensors in parallel, however, because they have no load current flowing through them – only ground current – the trip level can be reduced to a lower level depending on the sensor accuracy.

2. UNIT SUBSTATIONS

The term "Unit Substation" used here, refers to the distribution systems fed by one transformer only. In unit substations, the number and location of the system neutral grounds has no effect on the sensing method selection. Either vector summation or direct ground current sensing can be applied for the main breaker relay, but only vector summation method can be used for feeder breaker relays as shown in Figure 2.1 and Figure 2.2 respectively.

"GR" in all the figures indicates MGFR Relay.

When direct ground current sensing is used, sometimes it is necessary to have two ground strap sensors installed, one on each system neutral to ground connection, as in Figure 2.2. In this case two sensors are required, and they should be paralleled for total ground current sensing.

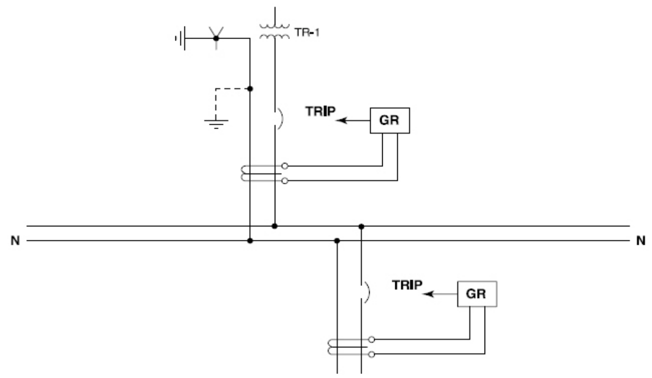


Figure 2.1 Unit Substations - Vectorial Summation Sensing for Main and Feeder Relays

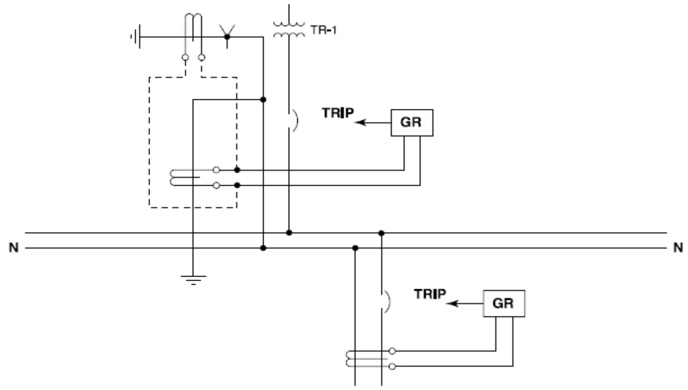


Figure 2.2 Unit Substations - Direct Current Sensing for the Main, and Vectorial Summation Sensing for Feeder Relays

3. MULTI-TRANSFORMER SUPPLIES

The correct application of the ground fault protection to a distribution system, fed by two or more transformers, requires special consideration on one very important factor, the location and number of system neutral to ground connections. This factor influences the cost of the switchgear and the performance of the protection.
Three basic grounding methods may be applied as follows:

a) systems, grounded in the switchboard only, with a single ground connection,
b) systems grounded at the transformers only,
c) systems grounded at the transformers and also in the switchgear.

The grounding methods also control the neutral bus arrangement and dictate whether 3 pole tie breaker(s) can be used for the selected neutral bus arrangement or if the application of 4 pole tie breaker(s) is necessary to prevent nuisance tripping.This may be caused by either circulating neutral currents or undetected parallel ground return paths.

The selection of the ground current sensing is also important, but it may depend on the normal operation condition of the tie breaker(s). When vector summation and direct ground current sensing are used for the main and tie breaker relays respectively, or only direct ground current sensing is applied for the main and tie breaker relays in double-ended substations, nuisance tie breaker tripping should be expected. It may occur when one of the main and the tie breakers are closed and a ground fault occurs on the closed main side. Ground current will return through the ground and the ground strap current sensor of the tie breaker relay will cause the tie to trip.

Full selectivity can be achieved only with vectorial summation current sensing for the main and tie breaker relays. Automatic isolation, using mixed ground current sensing methods, as described above, is recommended for multi-transformer supplies with normally open tie breakers, while fully selective protection (vectorial summation sensing only) must be used with normally-closed tie breakers.

The most common multi-transformer fed systems are as follows:

a) Double-ended substations,
b) Multi-transformer supplied double-ended substations where each pair of the transformers feeds a separate bus section with a tie breaker between bus sections, and
c) Multi-transformer supplies, where each transformer feeds a separate bus section with tie breaker between bus sections.

3.1 DOUBLE-ENDED SUBSTATIONS

The recommended locations of ground current sensors for the main and the breaker (if used) relays are shown in the following diagrams, based on some of the most common neutral bus and grounding arrangements.

THREE POLE TIE BREAKER APPLICATIONS

Figure 3.1.1 – indicates a typical T ground arrangement without tie breaker protection, while Figure 3.1.2 – shows the same system with protected tie.

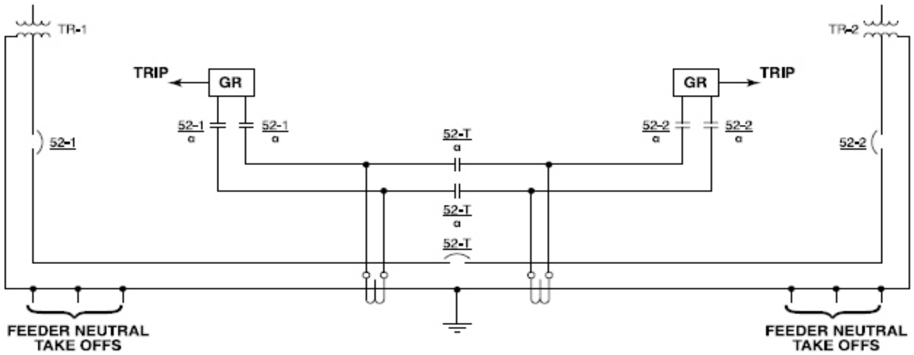


Figure 3.1.1 Double-Ended Substation - T Ground Arrangement Without Tie Breaker Control - Direct Current Sensing

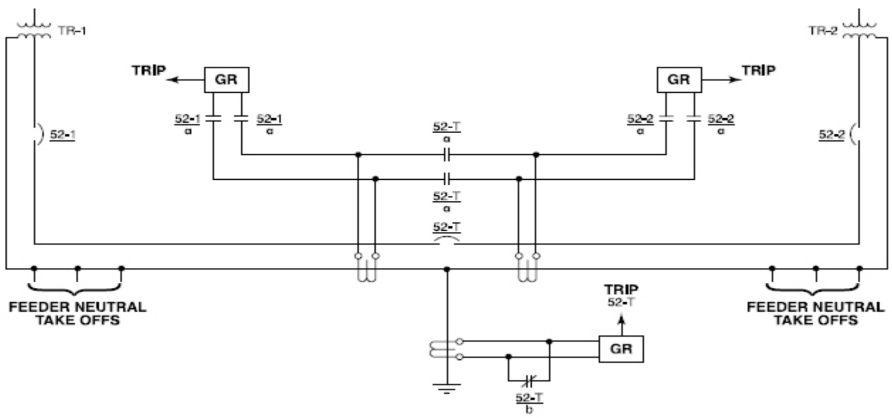


Figure 3.1.2 Double-Ended Substation - T Ground Arrangement with Tie Breaker Control - Direct Current Sensing

Alternatively, Zero Sequence summation can be used to detect faults where access to the grounding buses may not be practical. Figure 3.1.3 indicates such a system. In this case no tie breaker protection is provided and the tie breaker is Normally Open. The breakers would be interlocked to allow closing the tie breaker, only when one of the mains is open. The return path for neutral currents back to the transformer when the tie is closed and must be summed for both halves of the board, hence the need to connect the CT secondaries in parallel when the tie is closed. In order to protect the tie breaker, Figure 3.1.4 – shows a similar arrangement with a protected tie breaker.

Note: If external neutral grounds are used in the transformer section for example, then these must be summed with the main neutral ground strap sensor, using additional sensors, of the same ratio.

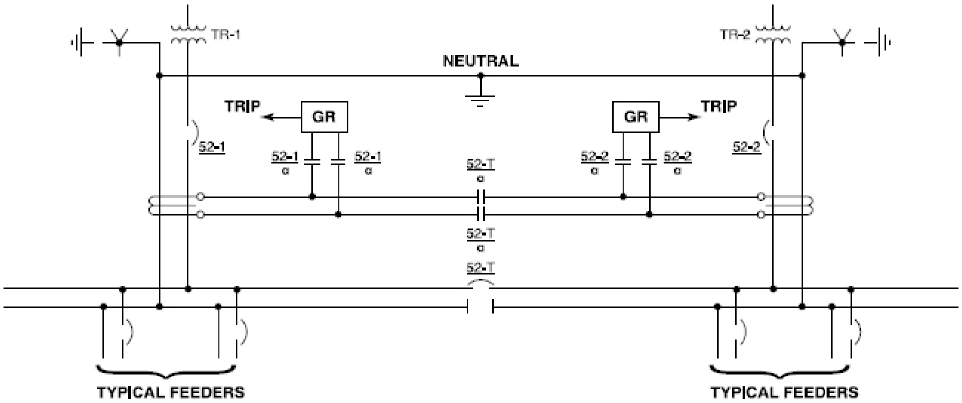


Figure 3.1.3 Double-Ended Substation – Neutral Collector Bus Without Tie Breaker Control – Summation Sensing.

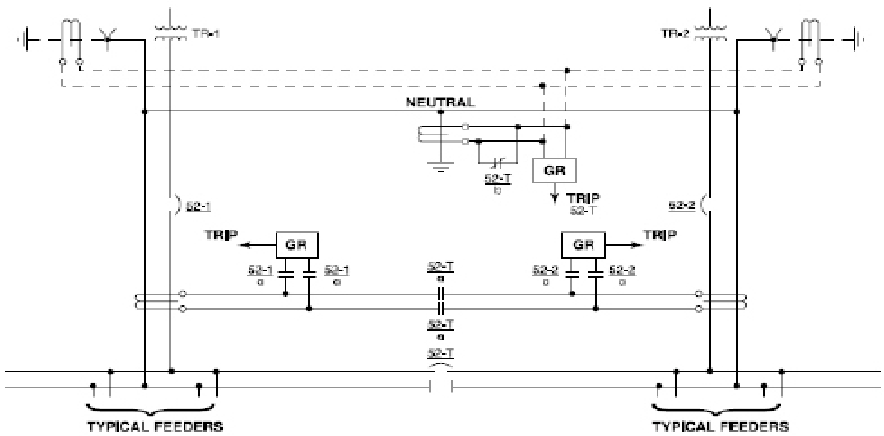


Figure 3.1.4 Double-Ended Substation – Neutral Collector Bus With Tie Breaker Control – Summation Sensing on the Mains, Direct Sensing on the Tie Breaker.

When the tie must provide protection and the ground straps are inaccessible, sensing can be obtained by summation sensing on the tie also. Figure 3.1.5 shows a system with fully selective protected tie.

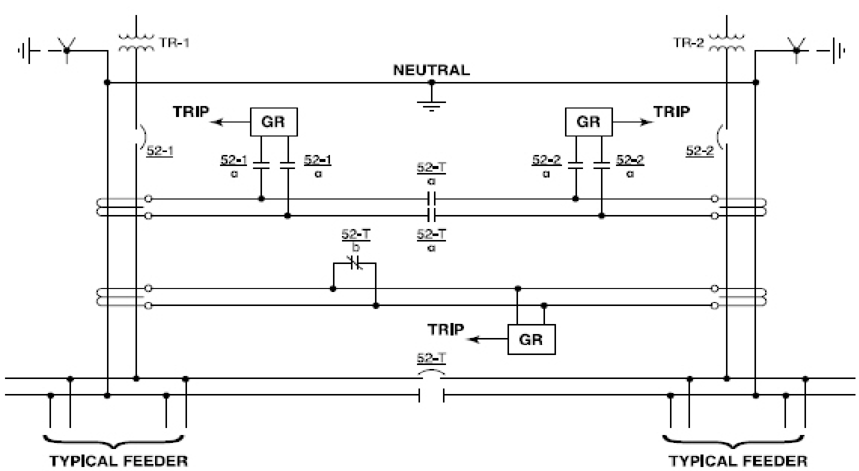


Figure 3.1.5 Double-Ended Substation – Neutral Bus Collector With Tie Breaker Control and Summation Sensing for Mains and Tie.

THREE POLE TIE BREAKER APPLICATIONS

Use of a 4-Pole Breaker for the tie breaker greatly simplifies the relay control logic, but increases the cost of the tie breaker. Figure 3.1.6 shows a typical system, where the neutrals are grounded at the transformers and in the switchboard. No tie protection is provided in this simple system. Summation sensing is used for the main relays. Figure 3.1.7 shows the same system with direct ground current sensing.

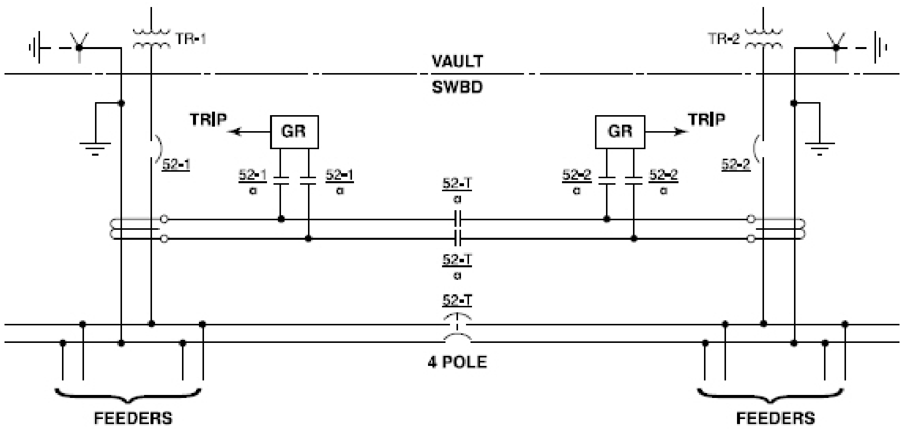


Figure 3.1.6 Double-Ended Substation – 4 Pole Tie Breaker – Neutrals Grounded at Transformers and Switchboard, Without Tie Breaker Control – Summation Sensing.

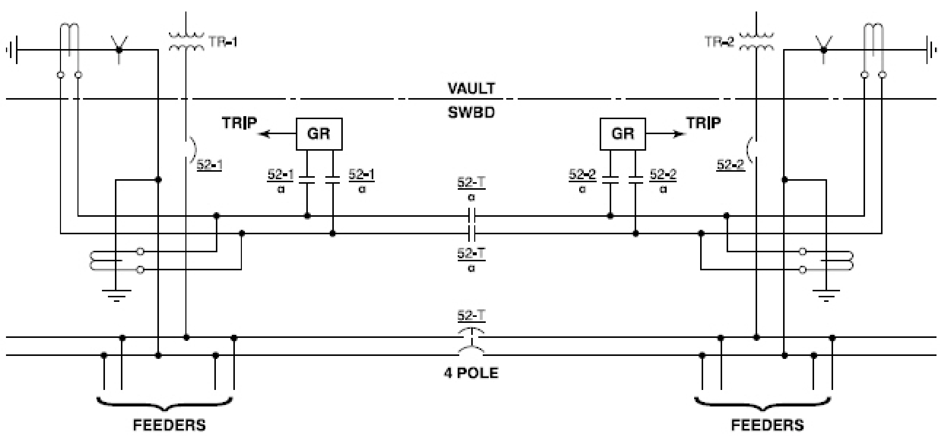


Figure 3.1.7 Double-Ended Substation – 4 Pole Tie Breaker – Neutrals Grounded at Transformers and Switchboard, Without Tie Breaker Control – Direct Current Sensing.

If tie breaker is to provide protection then the circuit can be configured with both summation and direct current sensing as shown in Figure 3.1.8 indicates the requirement where the neutral grounded at the transformer and in the switchboard. Summation sensing is applied to the main relays and direct ground current sensing is used for the tie relay.

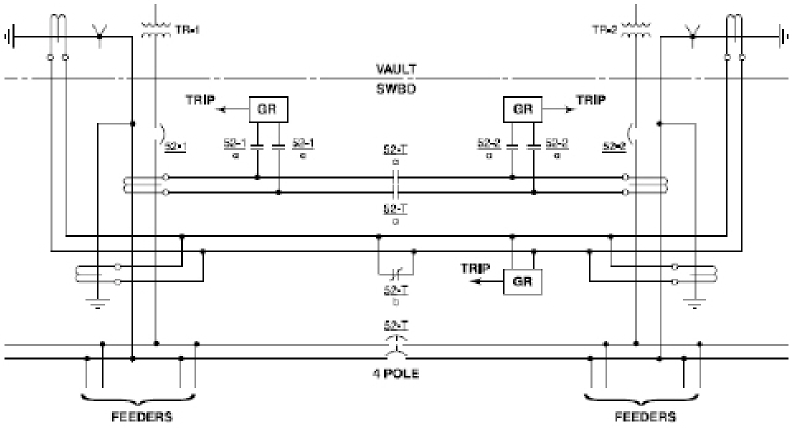


Figure 3.1.8 Double-Ended Substation – 4 Pole Tie Breaker – Neutrals Grounded at Transformers and Switchboard, With Tie Breaker Control – Summation Sensing on Mains, Direct Current Sensing on Tie.

Where direct current sensing is desired in cases where zero sequence sensors can't be used for size or accuracy limitations, the system of Figure 3.1.9 shows essentially the same system, but with direct ground current sensing used for all relays.

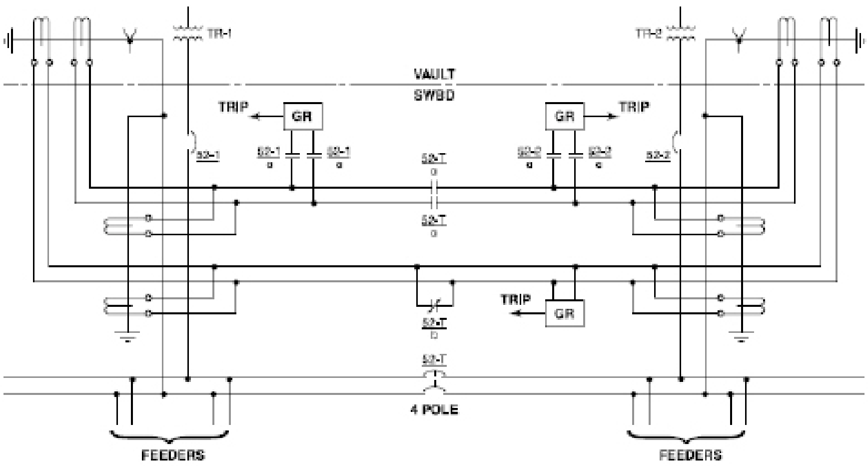


Figure 3.1.9 Double-Ended Substation – 4 Pole Tie Breaker – Neutrals Grounded at Transformers and Switchboard, With Tie Breaker Control – Mains, Direct Current Sensing on Mains and Tie.

A simpler approach might be to place a zero sequence sensor on the bus to control the tie breaker as shown in Figure 3.1.10. This is the same system, as in the previous two diagrams but with summation sensing applied for all relays, using a zero sequence.

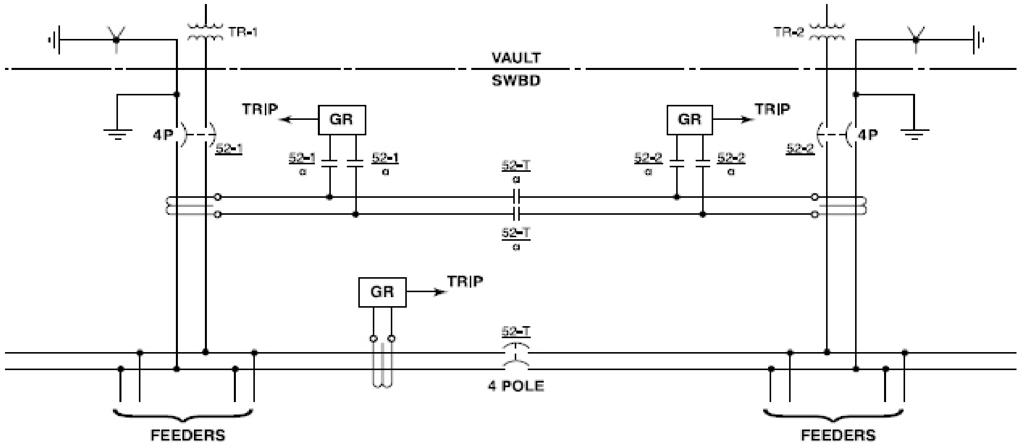


Figure 3.1.10 Double-Ended Substation – 4 Pole Tie Breaker – Neutrals Grounded at Transformers and Switchboard, With Tie Breaker Control – Summation Sensing on Mains with Zero Sequence on the Tie.

3.2. MULTI-TRANSFORMER SUPPLIED DOUBLE-ENDED SUBSTATIONS

When two or more transformers are supplying each half of a double-ended substation, the normal state of the tie breaker (Normally Open (N.O.) or Normally Closed (N.C.)) and the grounding requirements determine which sensing method should be selected. It is necessary to provide ground fault protective relays for the tie breaker and separately for each main breaker to achieve co-ordinated protection.

Figure 3.2.1 indicates the requirements with N.O. tie breaker using collector neutral bus with a single ground in the switchboard. The arrangement permits three-pole tie breaker application. Summation sensing applied for the main relays and direct ground current sensing is used for the tie relay. Note that although the main relays are connected essentially in parallel, that they will each see half of the fault current. If a fault occurs down-stream both zero sequence sensors will 'see' the fault, providing twice the secondary current. Each relay then, will receive half of that current which means that the relays still work properly.

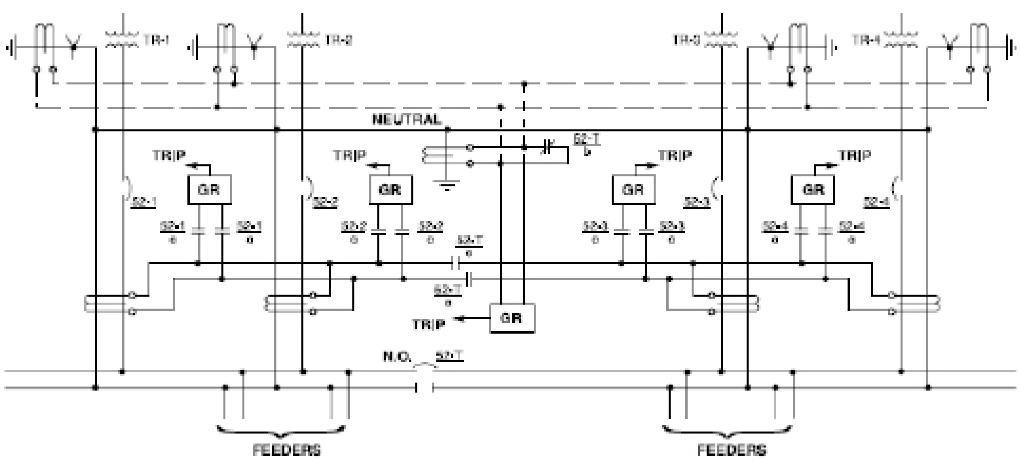


Figure 3.2.1 Multi-Transformer supplied, Double-Ended Substation with N.O. Tie Breaker with Neutral Collector Bus – Summation Sensing for Main, Direct Sensing for Tie.

Figure 3.2.2 shows the requirement with a N.C. tie breaker. The multiple grounding arrangement necessitates 4-pole breaker application as main and ties. For fully selective protection vector summation sensing is used for all relays.

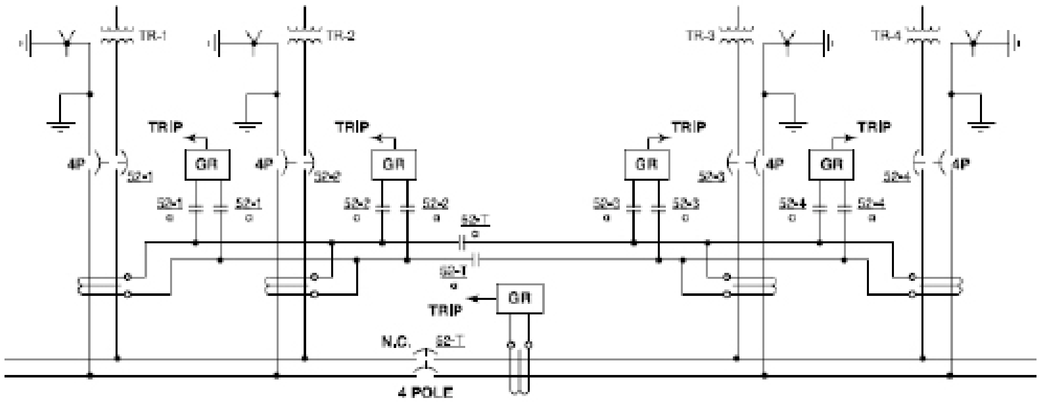


Figure 3.2.2 Multi-Transformer supplied, Double-Ended Substation with N.C. Tie Breaker with Multiple Grounding Arrangement – Summation Sensing for all Relays..

3.3 MULTI-TRANSFORMER SUPPLIES

Where more than two sources with multiple tie breakers are required the use of 3 Pole or 4 Pole breakers for the tie, depends on whether the tie is Normally Open or Normally Closed. The recommended location of the ground current sensors in a multi-transformer fed substation, where each bus section is supplied by a transformer and the adjacent bus sections can be interconnected by tie breakers, is shown in the following diagrams. It is necessary to provide Ground Fault Relays for the tie breakers to achieve co-ordinated protection.

3 MAINS, 2 TIE SYSTEMS

Figure 3.3.1 indicates the requirements with N.O. tie breaker using neutral collector bus with a single ground in the switchboard. The arrangement permits 3 Pole tie breakers application. Summation sensing is used for the main relays and direct ground current sensing applied for the tie breaker relays. If the transformer neutrals are also grounded at the transformers, additional sensors should be installed on these grounding for total ground current sensing. Figure 3.3.2 shows the requirements with N.C. tie breakers. The multiple grounding necessitates 4 Pole breaker application as mains and ties. For fully selective protection vector summation sensing is used for all relays.

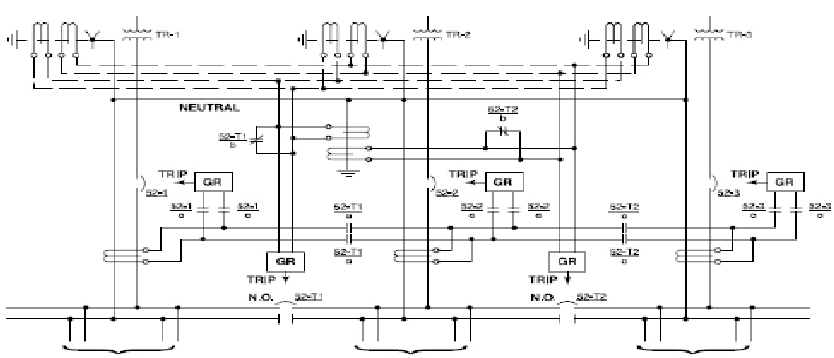


Figure 3.3.1 Multi-Transformer Supplies with 2 N.O. Tie Breakers using Neutral Collector Bus – Summation Sensing for the Main, Direct Ground Current Sensing for the Tie Relays.

3 MAINS, 2 TIE SYSTEMS

Figure 3.3.1 indicates the requirements with N.O. tie breaker using neutral collector bus with a single ground in the switchboard. The arrangement permits 3 Pole tie breakers application. Summation sensing is used for the main relays and direct ground current sensing applied for the tie breaker relays. If the transformer neutrals are also grounded at the transformers, additional sensors should be installed on these grounding for total ground current sensing. Figure 3.3.2 shows the requirements with N.C. tie breakers. The multiple grounding necessitates 4 Pole breaker application as mains and ties. For fully selective protection vector summation sensing is used for all relays.

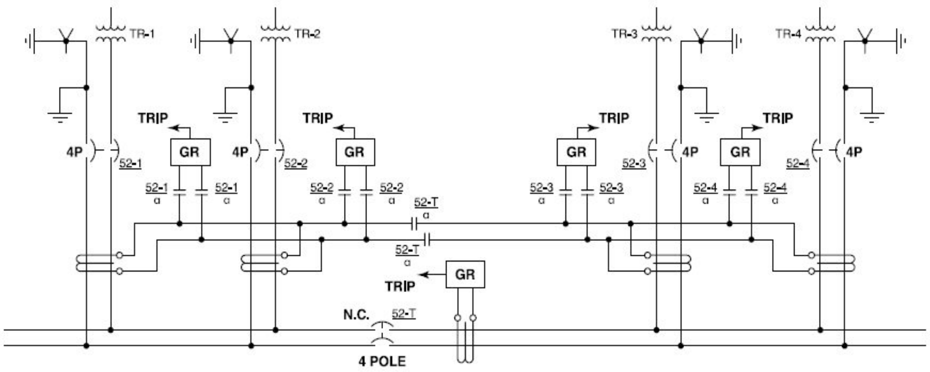


Figure 3.3.2 Multi-Transformer Supplies with 2 N.C.Tie Breakers With Multiple Grounding Arrangement – Summation Sensing for all Relays.

3 MAINS, 3 TIE SYSTEMS

When it is desirable to supply any load from any source in an emergency situation, three tie breakers are required in a 3 Source system. Figure 3.3.3 shows an arrangement, similar to the system shown in Figure 3.3.1, but incorporating the additional requirements associated with the third tie breaker. This arrangement is suitable for 3 Pole tie breaker application. The tie breakers are Normally Open. For a Normally Closed tie breaker operation the system of Figure 3.3.4 provides power from any source to any load with fully selective protection. This system requires the use of 4 Pole breakers preserve simplicity. Figure 3.3.3 Multi-Transformer Supplies with 3 N.O. Tie Breakers using Neutral Collector Bus – Summation Sensing for the Main, Direct Ground Current Sensing for the Tie Relays. 20 3-Mains, 3-Tie Systems to preserve simplicity.

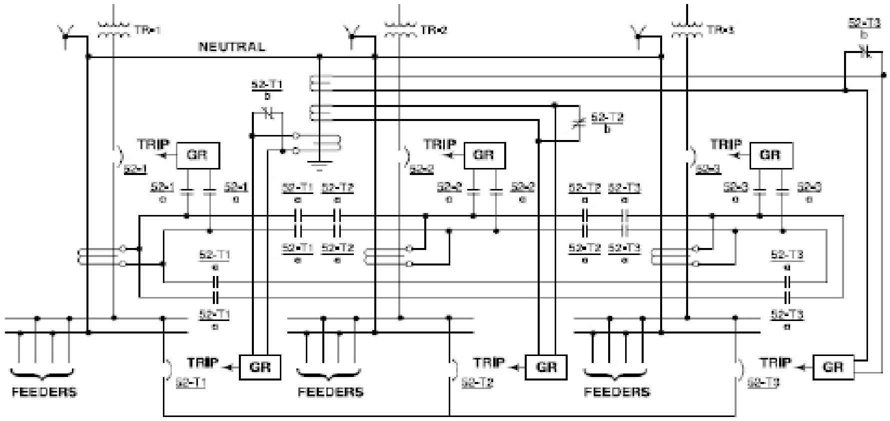


Figure 3.3.3 Multi-Transformer Supplies with 3 N.O.Tie Breakers using Neutral Collector Bus – Summation Sensing for the Main, Direct Ground Current Sensing for the Tie Relays.

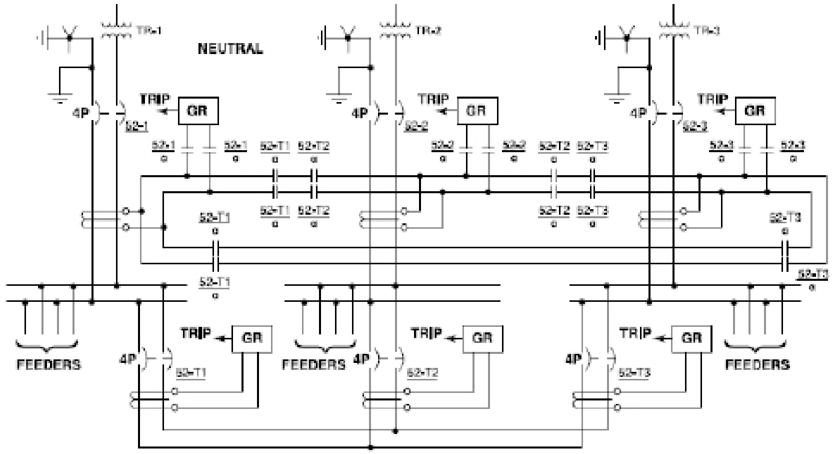


Figure 3.3.4 Multi-Transformer Supplies with 3 N.C. Tie Breakers with Multiple Grounding Arrangement – Summation Sensing for all Relays.

4. NETWORK SUPPLIES

When double or multiple connections are provided from a low voltage network system to a distribution system and interconnection(s) between the distribution sections are required, the interconnecting tie breaker(s) are always of 3 Pole design. The neutral bus in the switchboard is not continuous throughout the board, but installed in sections, separated at the tie breaker(s). Figure 4.1 indicates fully selective G.F. protection using vector summation sensing method for all relays.

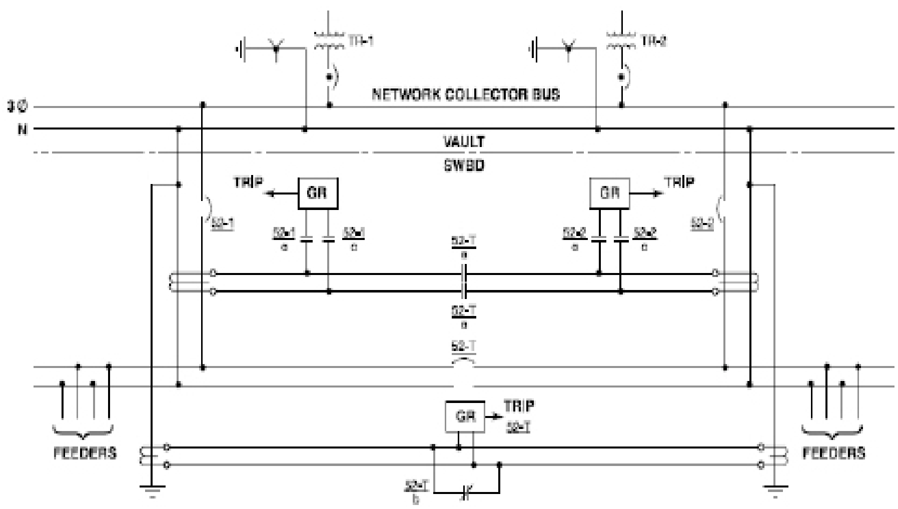


Figure 4.1 Network Supplies – Summation Sensing on all Relays.

5. ELECTRICAL SYSTEMS WITH STANDBY OR EMERGENCY POWER

When the electrical system has multiple neutral-to-ground connections, e.g. the main and Standby/Emergency power supplies are separately grounded, the neutrals of the two systems must be separated to assure proper ground fault current sensing. Interconnecting neutrals provide a parallel path for the fault currents and only part of the currents will return on the equipment ground to the source. The other part will return on the neutral through the alternate source grounding to the source and will be seen as normal neutral current by the sensor, thereby, causing incomplete sensing of the total fault current. The sensor can not distinguish between ground fault current and normal neutral current.

Similarly the normal unbalanced current in the neutral may bypass the sensor and return on the equipment ground back to the source neutral through the alternate source grounding electrode. Thus, an unbalanced load would effect the sensitivity of the ground fault protection and could cause a trip-out, even though a fault does not exist.

The incomplete sensing and nuisance tripping can be eliminated by 4 Pole transfer switch application (Figure 5.1), which will also classify the Standby/Emergency supply as a separately derived system.

The Canadian Electrical Code does not require, nor is it general practice to provide additional ground fault protection where the essential loads are energized from a separately derived power system, such as an engine-driven generator set.

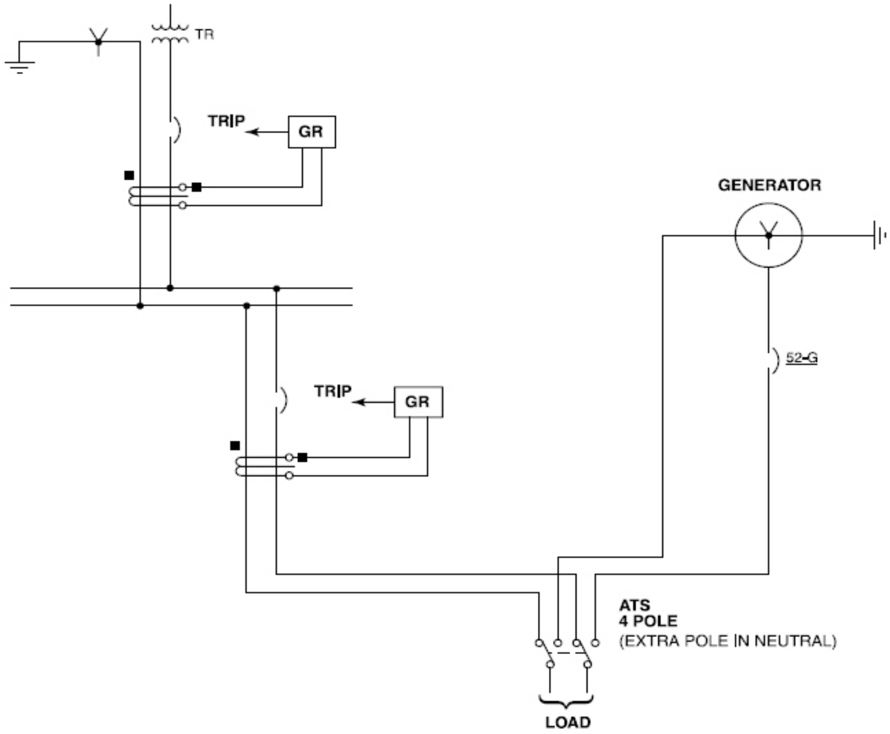


Figure 5.1 Typical Standby/Emergency System.

It is recommended that no ground fault protection is applied to any emergency system where the capacity of a generator is 500 kW or less. This is a trade-off in possible electrical equipment damage, in order to keep the essential circuits in operation, as decided by an operator.

Ground Fault protection for the Generator itself can be desirable under the following conditions:

a) The capacity of a single generator is over 500 kW, but less than 2000 kW,

b) The emergency system consists of two generators operating independently,

c) The generator has sufficient capacity to back-up operation (interlocked tie breaker prevents parallel connection).

In this case it is advisable to provide a ground fault protection for the stator windings as illustrated in Figure 5.2(A). The relay(s) will not “see” external ground faults and operate(s) on internal generator fault only, eliminating costly repairs due to internal faults.

For generators of 2000 kW and over, the application of differential protection (either constant or variable percentage type), is recommended, as shown in Figure 5.2B.

The probability is that practically all generator faults will be single-phaseto- ground. Therefore, the application of automatic neutral circuit breakers, or alternatively, 4 Pole generator breakers is recommended when differential protection, or restricted ground fault protection is applied.

This will minimize the damage. Additionally, the field winding breaker should be opened (if used) and/or the diesel should be shut-down, reducing the generator voltage to zero in a very short time.

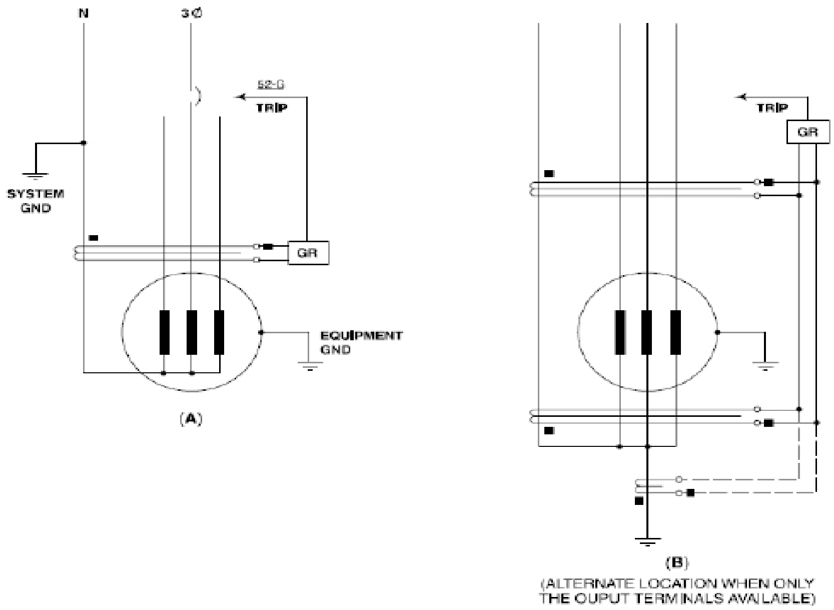


Figure 5.2 Ground Fault Protection for Stator Winding of Generator
a) Single Sensor Method b) Differential Method

In multiple generator installations the 4 Pole or the neutral breaker will also isolate the generator neutral from the neutral bus for increased safety during maintenance and/or repair. When ground fault protection is specified for large standby systems, where load requirements necessitate parallel operation of two or more generators, selective protection can not be arranged, due to the number of parallel ground current return paths.

Non-selective ground fault protection may trip-out operating generators, at once, if one of the large feeder breakers fails to clear a down-stream fault and the fault current returns on multiple system grounds equally. In a case when the current is unequally divided, one of the generators will trip on ground fault and the others on overload conditions. The application of high resistance grounding is recommended as the most suitable grounding method for multiple parallel operating generators which can provide the maximum service continuity required for standby systems even with a single ground fault.

I-Gard Type DSP-MKII Ground Fault Alarm and trip system will provide selective ground fault indication with priority second fault tripping for the distribution system, including the generators under all operating modes. Three-phase overcurrent relays and a shunt trip device should be provided on each protected circuit. Single-phase loads should be supplied with separate single-phase or three-phase delta/grounded wye-connected transformers.

6. AUXILIARY SWITCH REQUIREMENT

As shown on the preceding diagrams, Ground Fault Relays for certain applications require auxiliary switch contacts on the main and tie breakers to do the following functions:

a) Transfer sensor output from one relay to the other for total fault current sensing,

b) Connection of two or more sensors for summation and zero output (under normal conditions),

c) Short-out sensor when its breaker is open, and

d) Prevent unnecessary relay tripping and remove relay burden from the sensor when its breaker is open and two, or more, sensors are parallel connected.

The maximum auxiliary switch requirements are listed as follows:

TABLE 6.1 AUXILIARY SWITCH REQUIREMENTS ARE LISTED AS FOLLOWS:

	UNIT SUBSTATION	DOUBLE-ENDED SWITCHBOARD	3 MAINS, 2 TIES	3 MAINS, 3 TIES
Main Breaker	None	2 "a" contacts	2 "a" contacts	2 "a" contacts
Feeder Breaker	None	None	None	None
Tie Breaker	None	2 "a" contacts 1 "b" contact	2 "a" contacts 1 "b" contact	4 "a" contacts 1 "b" contact

7. RELAY AND SENSOR TYPES

7.1 MGFR RELAYS

MGFR Relays are designed to be used in Grounded and High Resistance Grounded Systems to detect and clear faults from Main Breaker to Branch circuit. They cover a pick-up range from 10mA to 1200A in 5 versions. Pick-up settings are adjustable. Time Delay is also adjustable and is available in fixed or Inverse Delay Mode of operation. Instantaneous relay operation, when required, can be arranged by switching the operation mode from TCP to ZSIP by means of a jumper on the terminal block. This versatility allows the MGFR Relay to co-ordinate, effectively, with up-stream and downstream devices.

The MGFR Relays can be operated by a wide range of current sensors both for ground strap sensing and zero sequence sensing of ground fault currents. The R1-3 ground strap current sensors can be applied to theground strap between the neutral and the equipment ground bus. Zero sequence current sensors, that encircle the phase conductors and the neutral in the circuit being protected, are available in two designs. Toroidal zero sequence current sensors type T (series A) are intended for use with cable conductors and the rectangular zero sequence current sensors type R and RZ are intended for use on bus bars. Split core Sensors are available in two toroidal sizes. Figure 7.1 shows a typical Time co-ordinated system using MGFR Relays.

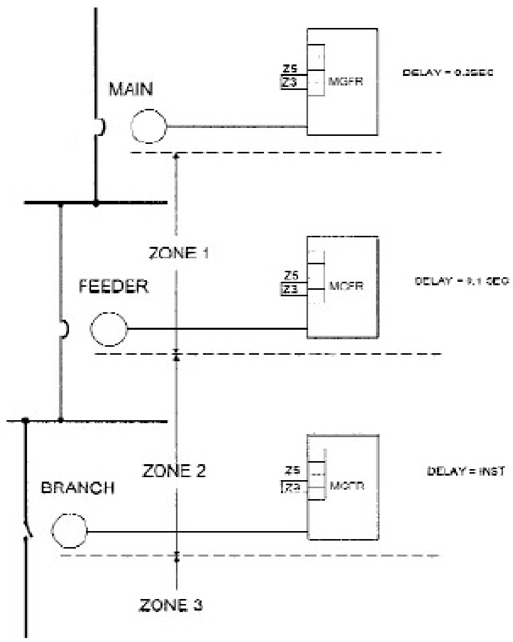


Figure 7.1 Typical Time Co-ordinated Relay System Using MGFR Relays.

7.2 CURRENT SENSORS

Any of the following sensors can be used as Ground Strap Sensors, however R1-3 Sensor is intended specifically for this purpose. It is intended to be mounted on the neutral-to-ground connection. Zero Sequence Summation sensors must encircle all the phase conductors and the neutral (if it exists), but not the grounding wire or the shield of the cable. Although the relays themselves are not phase dependent, it is important to observe polarity of Sensors when connecting them in parallel. All sensors should be installed with their polarity marks towards the supply. This ensures correct output cancellation or addition required for various sensor connections used for main and tie breaker relays.

The available ground current sensors are listed in Table 7.1.

TABLE 7.1 SENSOR DIMENSIONS

CAT NO.	INCHES	MM	COMPATIBLE RELAYS
T2A	1.875 DIA	48 DIA	GM Meter; DSP-OHMNI; MGFR; SENTRI
T3A	2.75 DIA	70 DIA	
T3A-SI	2.75 DIA	70 DIA	
T6A	5.75 DIA	146 DIA	
T6A-SI	5.75 DIA	146 DIA	
T9A	8.75 DIA	222 DIA	
T9A-S	8.75 DIA	222 DIA	
R417A	4.25 x 17.625	108 x 448	
R7-13A	7.5 x 13.5	191 x 343	
R8-26A	8 x26.5	203 x 674	
RZ 5-11	4.5 x 11	114 x 280	SENTRI
RZ 5-21	4.5 x 21	114 x 534	
RZ 5-31	4.5 x 31	114 x 788	
RZ 5-35	4.5 x 35	114 x 890	
RZ 10-11	10.5 x 11	267 x 280	
RZ10-21	10.5 x 21	267 x 534	
RZ 10-31	10.5 x 31	267 x 788	

There are general requirements for locating rectangular ZSCS's on bus bar connections, in switchboards. Any current carrying bus bars must be kept as far from the current sensor as possible, since a current carrying bus bar placed parallel to the sensor will produce noise voltage, which may cause nuisance tripping when no ground current flows. As a guideline the clearances (X) of Table 7.2 and Figure 7.1 should be applied:

TABLE 7.2 RECOMMENDED MINIMUM SPACINGS FOR SENSORS

LOAD CURRENT (A)	CLEARANCE (X)
600	4" (101.6 mm)
1000	6" (152.4 mm)
2000	8" (203.2 mm)
3000	10" (254.0 mm)
4000	12" (304.8 mm)

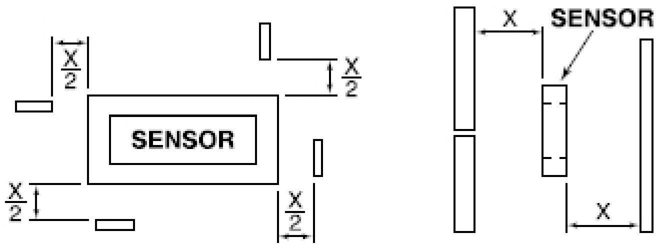


Figure 7.2 Spacing of Conductors from Sensors

These requirements are also applicable to the toroidal ZSCS's. However, one-half the clearances can be used except for lower load currents when the clearances can be reduced to a minimum of two inches (50.8 mm). For type RZ sensors, up to 3000 Amperes, use toroidal clearances. For over 3000A use rectangular clearances.

7.3 FUNCTIONAL TEST

It is recommended that a Self-Test circuit should be provided for every Ground Fault Relay not equipped with built-in test function. The test circuit can be arranged for either primary or secondary current injection. When operation of the circuit-interrupting device is not required at each time the test is performed, a momentary "Trip/No Trip" switch which does not prevent normal Tripping function, should be installed in the test circuit.

3. ZONE SELECTIVE INSTANTANEOUS PROTECTION SYSTEMS

1. GENERAL

The Zone Selective Instantaneous Protection (ZSIP) system provides a higher ground fault protection than the conventional time co-ordinated system because it eliminates the "waiting period" (time delay), which is necessary with conventional methods to achieve selectivity, by instantaneously tripping of the faulted circuit while preserving complete selectivity.

Where there are multiple levels on the power system, or zones, there is a need fr coordination of the zones so that higher levels are unaffected by downstream faults whenever possible. The branch circuits are like a tree branch and all of the relays will "see" the fault current in a particular branch when the fault is downstream.

Usually coordination is done by setting protective relay time delays progressively higher, with upstream relays set to maximum delays, to prevent nuisance tripping of main breakers. This can cause unnecessary damage, should a fault develop at a high level, requiring the time delay to expire before clearing the fault. A better way is to use zone selective interlocking protection scheme, where the relays are all set for Instantaneous Trip Protection but are wired together and downstream relay will signal to the upper zones that it will clear the fault and block them from tripping. This interlocking scheme is referred to as a ZSIP (Zone Selective Instantaneous Protection) or ZSI (Zone Selective Interlocking). This scheme provides coordination with instantaneous clearance of arcing faults thus preventing major damage at all levels in the system.

ZSIP reduces the damage produced by arcing ground faults on grounded systems. The damage is reduced to such an extent that location of the breakdown remains evident, but replacement of any components may not be necessary and virtually eliminates destruction.

The extent of the damage has a direct relationship to the amount of electrical energy, which is allowed to pass into the arcing faults. Note that overcurrent devices such as fuses or breakers cannot generally clear arcing faults since the current may be within the rating of the device.

ZSIP system detects ground fault currents at a fraction of the continuous rating of the devices and removes them instantly without destroying the selectivity of the system, reducing the let-through arc energy to the fault. Let-through energy can be expressed in kW cycles and is a product of the fault arc voltage, RMS value of fault current and the duration of the fault expressed in cycles.

The destruction of equipment and melting of metal are as follows, based on actual observation of damage under test conditions and supported by calculations based on specific heats of various metals:

a) 100 kW Cycles. Location of fault identifiable by observation, there will be spit marks on metal and smoke marks.
b) 2000 kW Cycles. Little damage - likely not even hardware has to be replaced. Equipment can usually be restored by cleaning smoke marks and repairing punctures in the insulation.
c) 6000 kW Cycles.This is the recommended maximum let-through.
d) 10,000 kW Cycles. Fault will probably be contained by a metal enclosure.
e) 20,000 kW Cycles. Fault will probably burn through a single thickness enclosure and spread to other sections of gear.
f) Over 20,000 kW Cycles. Considerable destruction in proportion to the let-through energy occurs.

The following Figure 1 (a), (b) and (c) shows the effect of ZSIP on the reduction of the let-through kW Cycles of arc energy.

a) Feeder protected by HRC Type fuses and no provision for ground fault protection.

b) Same feeder with conventional type ground fault protection (time separation to provide selectivity).

c) Same feeder with ZSIP system applied.

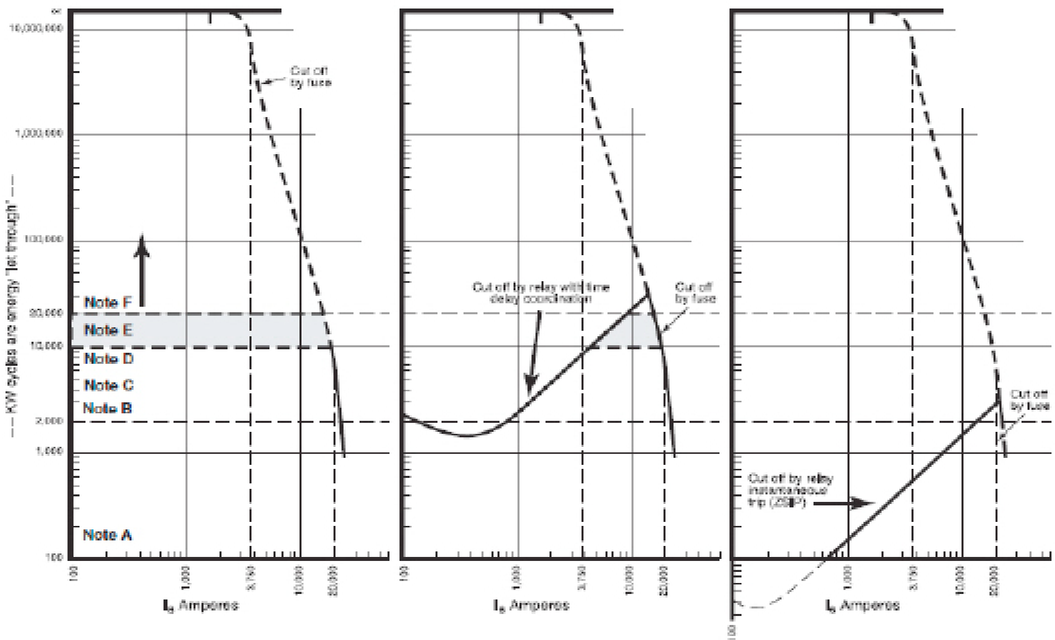


Figure 1 Damage Level of Three Relay Systems with Fuse Overcurrent Protection.

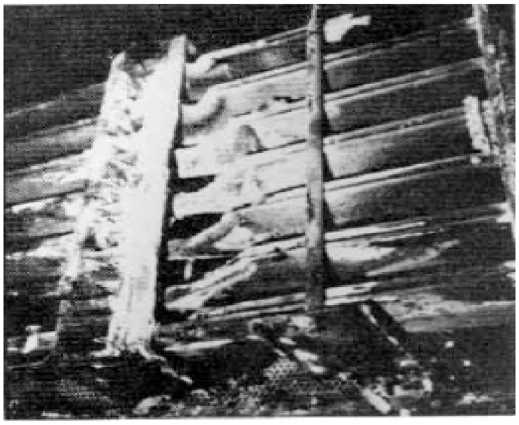
From the examination of these diagrams, it becomes evident that:

1. When ground fault protection is not provided, the fuse will let-through an enormous amount of energy spread over a long period and spreading of the fault is inevitable.

2. When conventional ground fault protection is provided, an appreciable reduction of let-through energy is achieved.

3. When ZSIP system is applied, the maximum let-through is within the acceptable limits and spread over a narrow range of fault currents. In the above example the circuit was protected by an HRC fuse. In the case of a circuit protected by a circuit breaker, the let-through values may be even greater, due to the fact that the circuit breakers are not generally current limiting.

Arcing damage of equipment is illustrated in illustration 1.



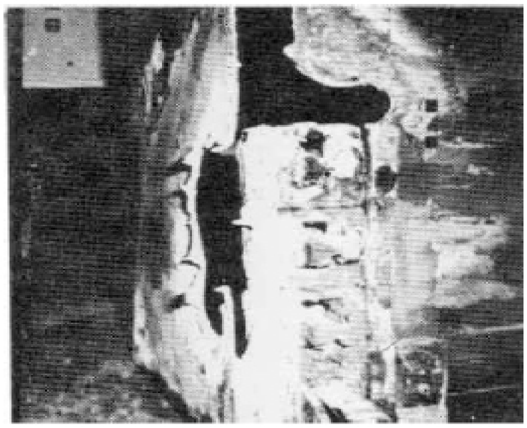


Illustration 1 (a) No Ground Fault Protection

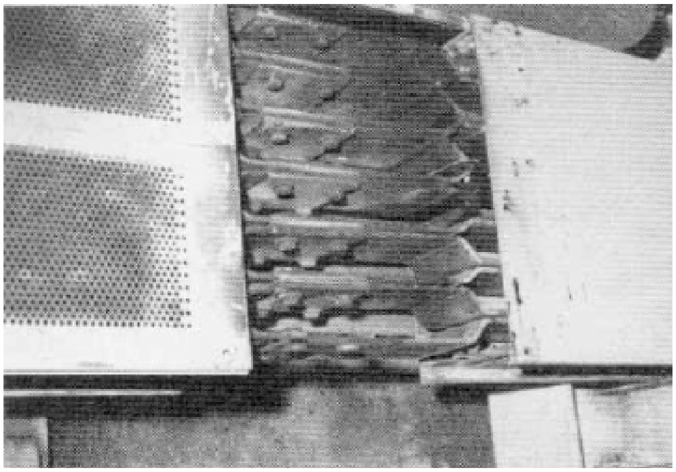


Illustration 1 (b) Standard Ground Fault Protection

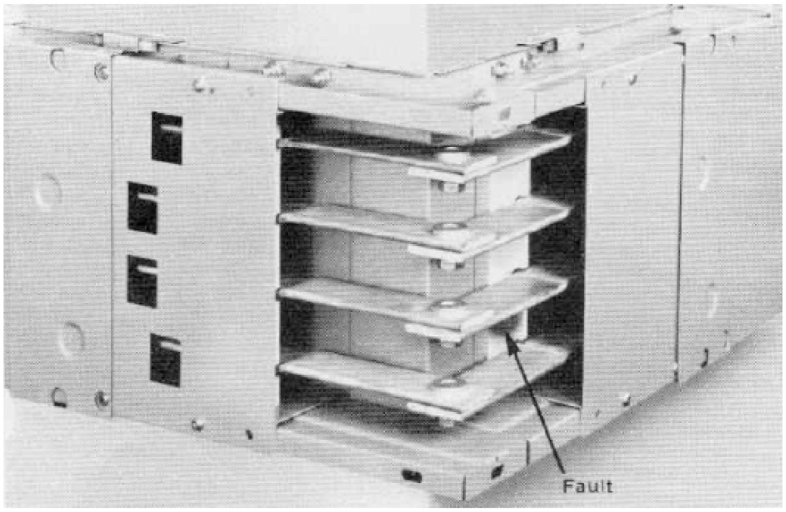


Illustration 1 (c) ZSIP Fault Protection

The difference between a conventional “time delay” selective system and the ZSIP system is illustrated in Figure 1.4 and Figure 1.5. Each diagram shows a three-zone system, where zones represent sections of a distribution system between zero sequence current sensors, e.g. zone (1) covers the main switchboard bus and all feeder breakers; zone (2) covers all load side connections of feeder breakers and the sub-feeder breakers themselves, etc.

Selectivity is provided by a “restraining signal” generated by a relay in a “down-stream zone”, and transmitted to a relay in the “up-stream zone”. When a number of relays are used in a “down-stream zone” the restraining signal outputs of all of these relays are parallel connected. Therefore, only one pair of control wires is required between the zones regardless of the number of relays in each zone.

In the event of a failure by a “down-stream” relay or interrupting device to clear a fault the “up-stream” protective device will act as a back-up and will clear the fault after the pre-selected time.

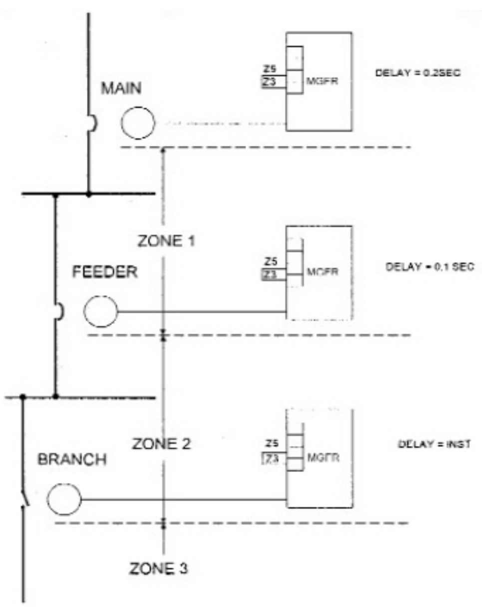


Figure 1.4 Typical Time Delay Co-ordinated Connection.

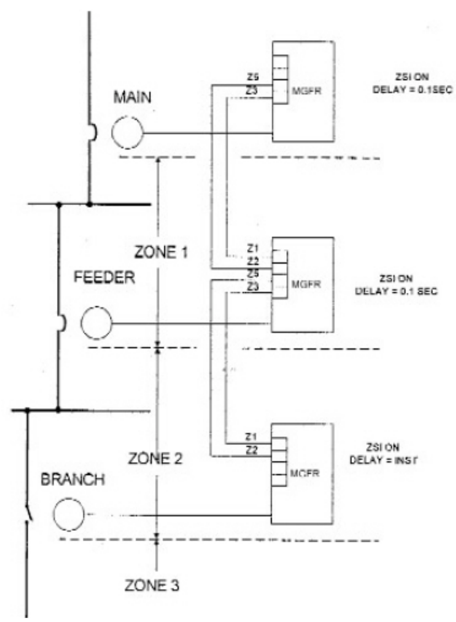


Figure 1.5 Typical 3-Zone ZSI Connection.

2. ZONE SELECTION

The Zone Selective Instantaneous Protection can be applied to any size system. The MGFR Ground Fault Relays in ZSI mode can be used. There is no limit to the maximum number of zones that can be protected with MGFR Relays. Furthermore the ZSI outputs of down-stream and inputs of up-stream relays can be connected in parallel when necessary.

NOTE: Zone is defined as a section protected by a relay and includes all of the system from the load side of the relay’s zero sequence current sensor, to the line side of any down-stream zero sequence current sensor, if present.

The consideration to what extent should ZSIP be applied to a system is cost versus the degree of protection achieved. The relationship between cost and the “degree” of protection is determined by the degree of required selectivity of trip-outs due to ground faults.

Naturally there is a definite point of “diminishing returns” for each specified system where the cost of additional relays may not be justified by the additional protection it will offer.

In many instances, such a point will be reached, while retaining full selectivity when ground fault protection is extended to 200 amp circuits. The damage that will have to be accepted is the damage created by the “let-through” energy that is permitted to pass by the overcurrent devices below 200 amp rating. Naturally if the ground fault protection is cut-off at higher rating than 200 Amperes, the damage that has to be accepted will correspond to the “let-through” energy of the overcurrent devices above 200 Amperes.

The most cost effective ground fault protection schemes are the two-zone ZSIP in Unit Substations and the three zone ZSIP in double-ended switchboards.

3. BASIC CONDITIONS FOR ZSIP APPLICATION

As mentioned previously, the MGFR Relay is suitable for ZSIP operation. For ZSIP application, the number and location of the system grounding points, neutral bus arrangement including tie breaker requirement (if used) and the ground fault current sensing methods should be selected.

4. RELAY TYPES

4.1 TYPE MGFR RELAYS

The MGFR Relays are highly suitable for ZSIP application. These relays are capable of restraining up-stream relays. If the down-stream relay “sees” the fault it sends the signal up to the Restraint Input terminal of the up-stream relay. This prevents the up-stream relay from Instantly Tripping while the down-stream relay eliminates the fault. See Figure 1.5 for typical three-zone system.
In the ZSIP mode, the response of the MGFR Relays to a ground fault is determined by the signal from a down-stream relay or the absence of such a signal.
The responses are as follows:

a) No signal at restraint in terminal. No down-stream relay senses a ground fault; so the fault is within this relay’s zone. Tripping is instantaneous regardless of the time band setting.
b) Signal received at the restraint in terminal. The ground fault is outside this relay’s zone. If a down-stream relay or protective device fails to clear the fault, this up-stream relay will trip in accordance with the time-band setting.

4.2 GUIDE POINTS FOR ZSIP APPLICATION

For correct ZSIP application and operation, the following guide points are recommended.

4.2.1

Maximum distance between MGFR Relay at the extreme ends of the zones should not exceed 2000 ft. (600 meters). For longer restraint circuit lengths consult factory.

4.2.2

One pair of 14 AWG wires per conduit should be used for restraint signal transmission. Use of a common conduit for power and signal circuits is not recommended. Signal wires must be installed in separate conduit.

4.2.3

The breaker(s) should be provided with Shunt Trip coils.

4.2.4

In a ZSIP system all relays in the chain should be set for ZSIP operation.

4.2.5

Zone co-ordination should be achieved by time-delay separation. The interlocking (restraint) circuitry will normally provide approximately 30 milliseconds time delay for a ground fault occurring anywhere on the system. Longer time delays, corresponding to the dial setting, may be selected while within the ZSIP mode but will only be invoked when the nearest ZSIP Relay up-stream of the fault, fails to clear and the next up-stream relay operates as backup protection. It is recommended that a delay of at least 0.1 second is selected for all but the most down-stream relay in a ZSIP chain of relays, which can be instantaneous.

4.2.6

Down-stream ZSIP outputs can be connected in parallel as in the case of a number of feeders restraining the same main breaker relay.

4.2.7

Up-stream inputs can also be parallel connected when, for example, there are two Main Breakers involved.

5. MULTIPLE SOURCE SYSTEMS

On double-ended substations or other multiple source systems with tie breakers the ZSIP signals must be routed from the down-stream feeder breaker relays to control both the tie breaker(s) and the Main Breakers when the tie is closed. This involves the use of semiconductor diodes to steer the signals to the next up-stream device so that the system is co-ordinated properly.

Figure 5.1 shows a typical Main-Tie-Main system where the tie breaker is Normally Open. The MGFR Relays are connected so that the tie breaker is restrained by the feeder breakers from either side when one of the Main Breakers is open. The feeder breaker relays provide restraint to the Mains when the Tie breaker is open. Also when the tie breaker is closed it restrains the Mains instead of the feeder breaker relays such that a three zone system is formed from Main to Tie to Feeder.

6. AUXILIARY SWITCH REQUIREMENTS FOR ZSIP CONTROL

Auxiliary switch contacts, are used, either to disconnect the restraint signal input to the main relays when the main breakers are open, preventing coincidence tripping during ZSIP performance tests, or to parallel-connect restraint signals when the tie breaker is closed. Steering Diode assemblies are necessary for double and multiple source substations to direct the restraint signals to the proper up-stream breakers instantly, to cover the various possible configurations. See Table 6.1.

RELAY CATALOGUE NUMBER TABLE

RELAY TYPE	RANGE	APPLICATION
MGFR - 20 - ZB	1 to 20A	Down-stream close to load
MGFR - 200 - ZB	10 to 250A	Distribution feeders
MGFR - 1200 - ZB	100 to 1200	Feeders in Main Switchboard or Switchgear
MGFR - SE - ZB	100 to 1200A	Service Entrance

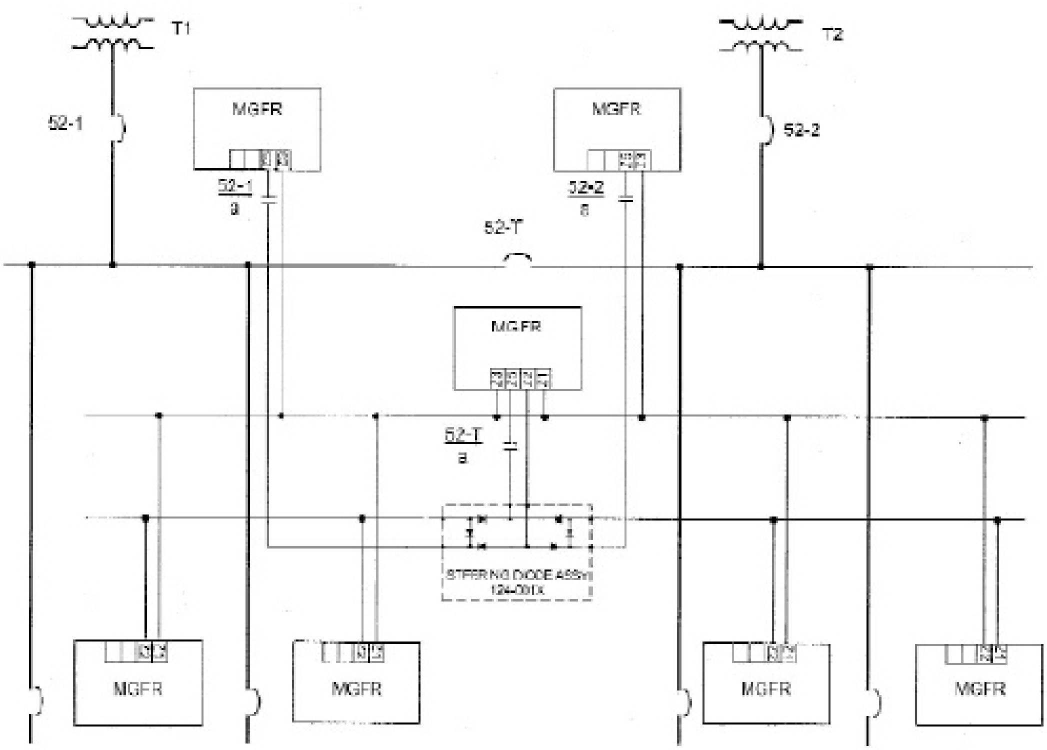


Figure 5.1 Typical Main-Tie-Main ZSI Connection using MGFR Relays.

TABLE 6.1 CONTACTS REQUIRED FOR ZSIP SIGNAL HANDLING

	UNIT SUBSTATION	DOUBLE - ENDED SWITCHBOARD	3 MAINS, 2 TIES
Main Breaker	None	2 "a" contact	2 x 124-006X2 "a" contacts
Feeder Breaker	None	None	None
Tie Breaker	None	2 "a" contacts	2 "a" contacts
Steering Diode Assembly	None	1 x 124-001X	2 x 124-001X

7. FIELD TESTING OF ZSIP SYSTEMS

Field testing during installation and commissioning is recommended to ensure that the installation is correctly wired and is satisfactory. Consult I-Gard to obtain a detailed test procedure.
I-Gard provides resistors to create current limited faults so that the relays can pick up and demonstrate the ground fault protection and the implemented Zone Selective Instantaneous Protection function. By applying such test faults at various locations in the distribution system proper operation is verified of the Zone Selection and coordination, the breaker trip circuits, sensor wiring, wiring of restraint signals and operating times of relays. Such field testing can be repeated at designated maintenance intervals to ensure satisfactory operation.

OTHER APPLICATION GUIDES

- High Resistance Grounded Systems (C-400EA)
- Neutral Grounded Systems (C-100EA)
- Conversion Guide (C-406EA)
- HRG Protection: Consultant Specification Guide (C-398EA)

NOTES

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C-300EA APPLICATION GUIDE

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