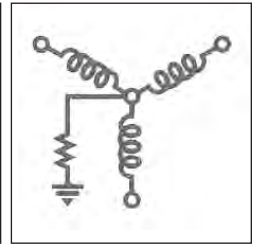
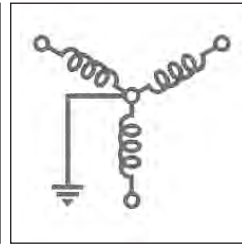
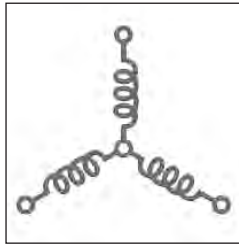
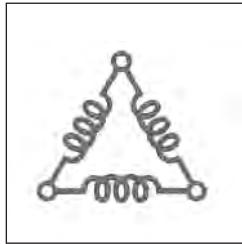




> the power to protect



Ground Fault Protection on Ungrounded and High Resistance Grounded Systems

Application Guide

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1

INTRODUCTION

Ungrounded distribution systems are used in industrial installations, due to their ability to provide continuous service with a ground fault on one phase. A single-phase failure to ground does not cause high current to flow, because the current is limited by the capacitance of the other two phases. However, the voltage-to-ground of the other phases rises by 73%, stressing the insulation of cables and other equipment connected to the system. It is common practice to run a faulted, ungrounded system until it is convenient to shut it down for repairs.

Unfortunately, the ungrounded system is susceptible to a build-up of high voltages (up to six times the nominal system voltage) when the first fault on the system is intermittent. This high transient voltage can initiate a second fault at the weakest insulation point on the system and thus larger, more damaging fault currents can occur. The second phase failure to ground will usually initiate high fault currents flowing between the two insulation failures. The overcurrent devices protecting the circuit involved should operate to clear the fault. However, a phase-to-ground-to-phase fault path impedance between them may create a high resistance arcing fault. The magnitude may not be sufficient to operate the overcurrent devices, and will cause extensive damage to the equipment requiring expensive repairs or an extended shut-down until the equipment can be replaced. Locating and repairing the first ground fault is of prime importance, but in most continuous process plants this is not an easy job since some portion of the operation would have to be shut down in order to isolate the problem area.

2

UNGROUNDING SYSTEMS

An ungrounded system is defined as a system of conductors with no intentional connection to ground except through potential indicating and/or measuring or other very high impedance devices. This type of system is in reality coupled to ground through the distributed capacitance of conductors and transformer or motor phase windings. In the absence of a ground fault the line-to-ground voltage of the three phases will be approximately equal because of the equally distributed capacitance of the system.

2.1 EFFECTS OF GROUND FAULT

Theoretically, in a balanced three-phase system, the currents in all three lines are equal and 120° apart (Figure 2.1(a)). The vector sum of the three capacitive phase currents (I_A , I_B and I_C) is equal to zero at the ground point, which also results in the system neutral being held at ground potential by the balanced capacitive voltages to ground (V_{AG} , V_{BG} and V_{CG}). Thus, although an ungrounded system does not have an intentional connection to ground, the system is actually capacitively coupled to ground.

The ungrounded system can be regarded as a three-wire system only, thus the following discussion is valid for both wye and delta transformer secondaries.

If one system conductor, phase C for example, becomes faulted to ground, then phase C and ground are at the same potential, zero volts (Figure 2.1(b)). The voltages of the other two phases in the reference to ground are increased to the system phase-to-phase voltage. This represents an increase of 73% over the normal line to ground voltage. Furthermore, the voltages to ground are now only 60° out of phase.

FIGURE 2.1 (A): **UNGROUNDED SYSTEM – NORMAL CONDITION**

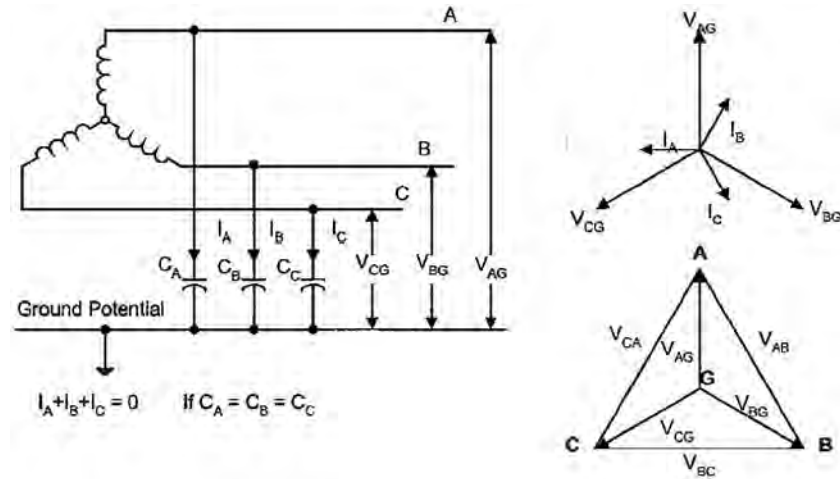
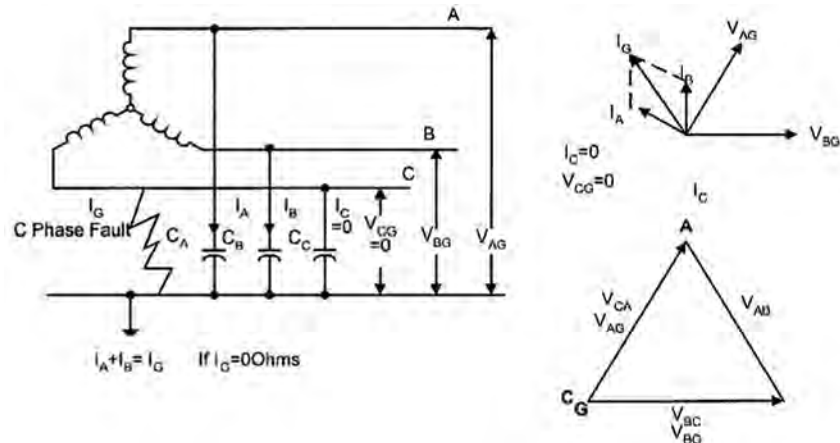


FIGURE 2.1 (B): **UNGROUNDED SYSTEM WITH FAULT ON PHASE C**



Even though the capacitive voltages are unequal during a single line-to-ground fault, the phase-to-phase voltages (V_{AB} , V_{AC} , and V_{BC}) have not changed in magnitude or phase relationship, and the system remains in service. Ground Current in the fault I_G is the vector sum of the two currents I_A and I_B (which are 90° ahead of their respective voltages V_{AG} and V_{BG}) where $I_A = V_{AG}/X_A$ and $I_B = V_{BG}/X_B$.

X_A and X_B are the system capacitive reactances calculated from the capacitances of the elements of the distribution system. (See Appendix 1.) This ground current value is used to determine the maximum ground resistance for high resistance grounding.

If the ground fault is intermittent such as arcing, restriking or vibrating type, then severe overvoltages can occur. Unless the fault disappears as the phase voltage passes through zero, a DC offset voltage will remain on the system capacitance to ground. When the fault reappears the system voltage to ground will equal the sum of the DC offset and the AC component, which will depend on the point of wave at which the fault is re-established. In this manner, the intermittent fault can cause the system voltage to ground to rise to six or eight times the phase-to-phase voltage leading to a breakdown of insulation on one of the unfaulted phases and the development of a phase-to-ground-to-phase fault.

An intermittent type of fault is a very real danger. Therefore, early detection of this condition is of primary importance.

2.2 CODE REQUIREMENTS

Canadian Electrical Code Part I #C22.1-02 rule 10-106(2) for alternating current systems requires wiring supplied by an ungrounded system to be equipped with a suitable ground detection device to indicate the presence of a ground fault.

It should be noted that under rule 10-106, if a system incorporates a neutral conductor it must be solidly grounded.

The C.E.C. Rule 10-1102 also recognizes continuously rated neutral grounding resistor systems up to a maximum of 5 amps. If the value of the ground current exceeds 5 amps, the unit should be regarded as a solidly grounded system and must be cleared on first ground fault. This can be done in various ways e.g. with ground fault relays on the feeders, or a single relay with a current sensor in the grounding resistor.

National Electrical Code 2005 rule 250.21 for alternating current systems requires wiring supplied by an ungrounded system to be equipped with a suitable ground detection device to indicate the presence of a ground fault.

It should be noted that under rule 250.20(B)(2), if a system incorporates a neutral conductor it must be solidly grounded.

The N.E.C. Rule 250.36 also recognizes high-resistance grounded power systems, which use continuously rated neutral grounding resistors for low ground fault current values. This can be achieved various ways, e.g. with ground fault relays on the feeders, or a single relay with a current sensor in the grounding resistor.

3

HIGH RESISTANCE GROUNDING

Overvoltages caused by intermittent fault can be eliminated by grounding the system neutral through an impedance, which is generally a resistance that limits the ground current to a value equal to or greater than the capacitive charging current of the system. This can be achieved on a wye-connected system by a neutral grounding resistor, connected between the wye-point and ground, as in Figure 3.1. In Figure 3.2, a step down transformer may be used for medium voltage systems to allow the use of a low voltage resistor. On a Delta-connected system, an artificial neutral (see Figure 3.3) is required since no star point exists. This can be achieved by use of a

zig-zag grounding transformer as shown, or alternatively, three single phase transformers can be connected to the system and ground to provide the ground path, with secondaries terminated by a current limiting resistor (see Figure 3.4).

FIGURE 3.1: WYE SYSTEM GROUNDING

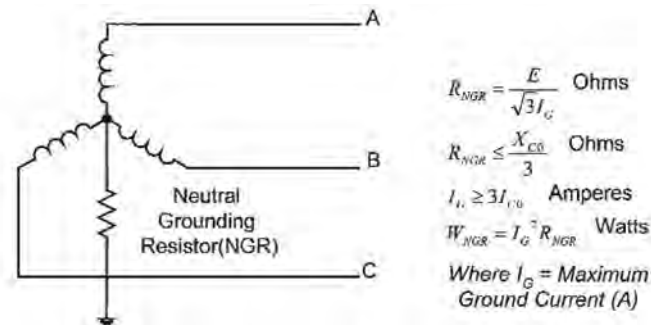


FIGURE 3.2: MEDIUM VOLTAGE WYE SYSTEM GROUNDING

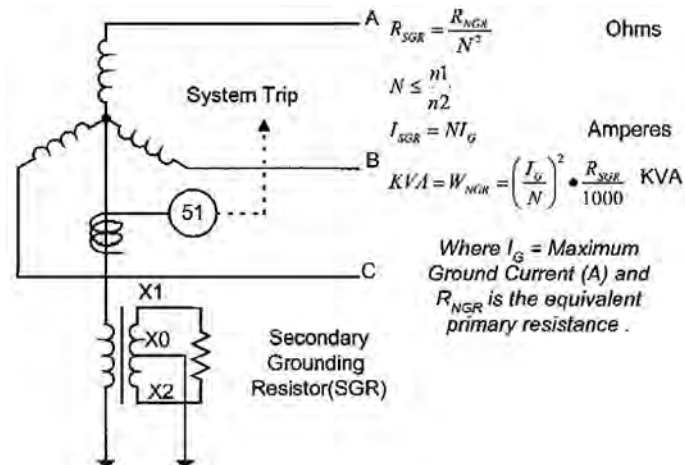


FIGURE 3.3: DELTA SYSTEM GROUNDING

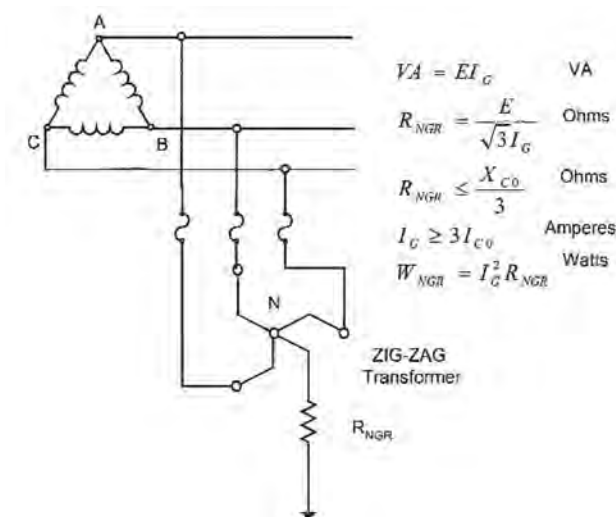
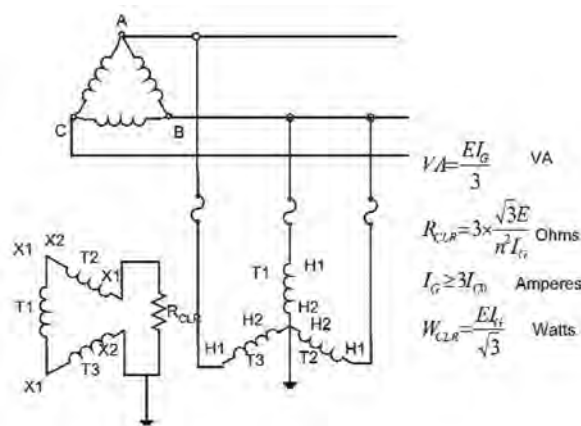


FIGURE 3.4:

DELTA SYSTEM GROUNDING FOR MEDIUM VOLTAGE



3.1 NEUTRAL GROUNDING RESISTORS

If a system has a neutral point, as with a wye-connected transformer or generator, there are two methods for arranging grounding equipment as shown in Figures 3.1 and 3.2.

Figure 3.1 shows the simplest method. This involves a resistor approximately equal or slightly lower in (ohms) value than that of the total capacitive reactance to ground of the system. The resistor is connected directly from the neutral point to ground. Direct connected, line-to-neutral voltage rated neutral grounding resistors (Figure 3.1 Wye System Grounding) can be applied to low-voltage and medium voltage systems up to 15 KV.

The other method, using a single phase transformer connected from the wye point to ground, is shown in Figure 3.2. This method is used to allow the use of a low voltage current limiting resistor, in a medium voltage system.

The transformer is generally rated at system line-to-line voltage on the primary and 120 or 240 volts on the secondary. The resistor selected will have the same equivalent wattage as the direct connected resistor shown in Figure 3.1, but reduced in ohmic value by the square of the turns ratio of the transformer. The transformer/resistor type grounding equipment is used to allow easy adjustment of the Ground Current level by changes in the low voltage secondary resistor value.

3.2 ARTIFICIAL NEUTRALS

On delta connected systems, since there is no wye point available for connection to ground, one must be created by artificial means. This can be done with two grounding transformer arrangements. The grounding transformers may be either zig-zag or wye/delta connected as shown in Figure 3.3 and Figure 3.4 respectively.

The effect of the zig-zag and wye/delta grounding transformers is very similar. First, both provide a low impedance path for the zero-sequence currents so that, under a line-to-ground fault, zero-sequence currents can flow into the ground at the point of the fault and back to the star point of the grounding transformer. Second, the impedance of both types of transformers to normal three phase system current is high, so

that when there is no fault on the system only a small magnetizing current flows in the transformer winding.

In a zig-zag or interconnected star transformer, there are two identical windings on each leg. The windings are cross-connected such that each core leg is magnetized by the currents from two phases. All windings have the same number of turns but each pair of windings on a leg is connected so that their magneto-motive forces (MMF) are equal and opposite. The result is that the common (star) point is forced to remain at an equipotential voltage with respect to each phase. When a ground fault occurs, the voltage across the limiting resistor increases from zero to a maximum of:

$$V = \frac{E}{\sqrt{3}} \text{ Volts, depending on the impedance of the fault.}$$

The KVA rating of the zig-zag grounding transformer is equal to:

$$KVA = \frac{E}{\sqrt{3}} \times \frac{I_G}{1000} \text{ KVA}$$

where E is the rated line voltage in Volts, and I_G is the maximum ground current in Amperes.

Distribution transformers, either three phase or three single phase units connected in wye/delta, can also be used as grounding transformers.

The wye-connected primary should be grounded solidly with the current limiting resistor connected across the broken delta connected secondary windings as shown in Figure 3.4.

The KVA rating of each of the transformers should be equal to one third the rated line-to-line voltage times rated ground current for continuous duty.

This type of grounding transformer arrangement can be used on low and medium voltage systems up to 15 KV. The application of the zig-zag transformer is recommended because the required capacity of the star/ delta transformer is 1.73 times as great as that for the zig-zag transformer for the same performance. When ground current changes are necessary on medium voltage systems due to operational requirements, star/broken-delta connected single phase transformers with secondary Grounding Resistors are convenient, permitting low-voltage modifications to be made. Tapped resistors can be used to allow adjustments to be made as systems become larger with the connection of additional equipment.

4

SYSTEM CAPACITANCE

The line-to-ground capacitance associated with system components determines the magnitude of zero-sequence charging current. This value of current is required for proper selection of high resistance grounding equipment.

The capacitance to ground of transformers is negligible. The large spacings between the core and the windings, and shielding effects of the winding adjacent to the core, limit the capacitance to ground to a minimum.

Overhead line and cable capacitance to ground can be very high if considerable lengths are involved. Cable capacitance is many times greater than the capacitance of open-line wire lines. Capacitance of cable, depending upon the conductor size, insulation and construction, can be obtained from the manufacturer for any specific cable type or an approximate value can be calculated using the appropriate formula for the specific cable type. Refer to Appendix 1.

Rotating machines (synchronous motors and generators, and induction motors) are also major contributors to the overall system capacitance to ground. Low voltage machines usually have larger capacitance values than medium voltage units of the same rating because of lesser insulation to ground and a greater conductor and slot surface area. Also, high speed machines have normally lower capacitance than the slow speed ones. Factors such as number and depth of slots, type of insulation, etc. produce wide variations.

The contribution of surge capacitors applied to rotating machinery can be significant. The surge capacitors are connected line-to-ground but selected with rated voltage at least as high as the circuit line-to-line voltage. The positive, negative and zero-sequence capacitance of the 3-phase surge capacitors are equal. The ratings and constants for standard surge capacitors are listed in Table A1.1 in Appendix 1.

Although shunt power capacitors (used for power factor correction) have large positive and negative sequence capacitance, they would have no zero-sequence capacitance unless the wye-point of wye-connected banks is grounded. (On industrial power systems the wye-point of the shunt capacitor banks should never be grounded.)

The charging current of a system can be calculated by summing the zero-sequence capacitance or capacitive reactance of all the cable and equipment connected to the system. From this the current can be calculated from the system voltage, using the formulae listed in Appendix 1. If actual values are not available, graphs and approximation formulae can also be used without considerable errors. (See Appendix 1.) It is preferable to measure the magnitude of the charging current on existing power systems (as described in Appendix 2) for correct grounding equipment selection. The measured values must be adjusted to obtain the maximum current if not all system components were in operation during the tests.

When it is impractical to measure the system charging current, the "Rule of Thumb" method may be used as indicated in Table 4.1. Note that surge suppressors add a significant additional amount of current to the total system leakage.

The charging current of systems 6900 V and above should be carefully calculated for new systems and measured for existing systems to select the correct grounding resistance value. Due to large variations in system arrangements no "Rule of Thumb" sizing can be used.

It is recommended that a calculation check be made when the "Rule of Thumb" method is used to compare the let-through current values with the actual system data.

In Table 4.2, charging current data is listed at various voltage levels. The indicated values are based on published data of component manufacturers, or derived from actual charging current measurements.

TABLE 4.1

RULE OF THUMB VALUES OF SYSTEM CHARGING CURRENT

SYSTEM PHASE-TO-PHASE VOLTAGE	ESTIMATED LET-THROUGH CURRENT VS. SYSTEM KVA CAPACITY WITHOUT SUPPRESSORS	ADDITIONAL CURRENT FOR EACH SET OF SUPPRESSORS
600	1A/2000 KVA	0.5A
2400	1A/1500 KVA	1.0A
4160	1A/1000 KVA	1.5A

TABLE 4.2

DATA FOR ESTIMATING SYSTEM CHARGING CURRENT

SYSTEM VOLTAGE	COMPONENT TYPE		CHARGING CURRENT
UP TO 600V	Cables	600 - 1000 MCM in Conduit - 3 Conductor	0.15A/1000 Ft.
		250 - 500 MCM in Conduit – 3 Conductor	0.10A/1000 Ft.
		1/0- 4/0 in Conduit -3 Conductor	0.05A/1000 Ft.
		1/0- 4/0 on Trays – 3 Conductor	0.02A/1000 Ft.
	Transformers		0.02A/MVA
	Motors		0.01A/1000 HP
2400 V	Capacitors	Surge Suppression	0.78A Each Set
	Cables	Non Shielded in Conduit all sizes – 3 Conductor	0.05A/1000 Ft.
		Shielded all sizes – 3 Conductor	0.30A/1000 Ft.
	Transformers		0.05A/MVA
	Motors		0.10A/1000 HP
4160 V	Capacitors	Surge Suppression	1.35A Each Set
	Cables	X-Linked-Shielded 1/0 - 350 MCM – 3 Conductor	0.23A/1000 Ft.
		X-Linked-Shielded 500 - 1000 MCM - 3 Conductor	0.58A/1000 Ft.
		X-Linked Non-Shielded in Conduit all sizes - 3 Conductor	0.1A/1000 Ft.
6900 V	Capacitors	Surge Suppression	2.25 A Each Set
	Cables	X-Linked-Shielded 1/0 - 350 MCM – 3 Conductor.	0.55A/1000 Ft.
		X-Linked-Shielded 500 - 1000 MCM – 3 Conductor	0.85A/1000 Ft.
	Transformers		0.05A/MVA
	Motors		0.10A/1000 HP
13,800 V	Capacitors	Surge Suppression	2.25A Each Set
	Cables	X-Linked-Shielded 1/0 - 4/0 - 3 Conductor	0.65A/1000 Ft.
		X-Linked-Shielded 250 - 500 MCM – 3 Conductor	0.75A/1000 Ft.
		X-Linked-Shielded 600 - 1000 MCM – 3 Conductor	1.15A/1000 Ft.
	Transformers		.05A/MVA
	Motors		0.15/1000HP

5

SELECTION OF HIGH RESISTANCE GROUNDING EQUIPMENT

For correct application the let-through current of the high resistance grounding equipment should be equal to or slightly higher than the capacitive charging current of the system. The installation of a tapped Grounding Resistor unit should be considered when system expansion is expected at a later date.

The high resistance grounding equipment should have a voltage rating corresponding to the system voltage as follows:

The voltage rating of the Grounding Resistor should be line voltage divided by root 3 (line-to-neutral voltage rating of the system). The voltage rating of the grounding transformer should be the line-to-line voltage rating of the system. All continuously rated, high resistance grounding equipment is designed to operate at that rating provided:

- The temperature of the cooling air (ambient temperature) does not exceed 40°C and the average temperature of the cooling air for any 24-hour period does not exceed 30°C.
- The altitude does not exceed 3300 ft. (1000 m). Standard devices may be applied in locations having an altitude in excess of 3300 ft (1000 m) but the dielectric strength of air insulated parts and the current-carrying capacity will be affected. At or above 3300 ft. (1000 m) the correction factors of Table 5.1 should be applied.

Operation at higher ambient temperatures and altitudes exceeding 15,000 ft (4500 m) or unusual service conditions necessitate special design considerations.

TABLE 5.1

ALTITUDE CORRECTION FACTORS

ALTITUDE		DIELECTRIC STRENGTH CORRECTION FACTOR
Metres	Feet	
1,000	3,300	1.00
1,200	4,000	0.98
1,500	5,000	0.95
1,800	6,000	0.92
2,100	7,000	0.89
2,400	8,000	0.86
2,700	9,000	0.83
3,000	9,900	0.80
3,600	12,000	0.75
4,200	14,000	0.70
4,500	15,000	0.67

5.1 MAXIMUM LET-THROUGH CURRENT VALUE

The let-through current is the maximum controlled current which may flow in a neutral grounding resistor during a line-to-ground fault, for wye or delta systems, and its value can be calculated as follows:

$$I_G = \frac{V_L}{\sqrt{3}R_G}$$

Where I_G = Maximum Ground Current (Let-through current) in Amperes
 V_L = System Line Voltage in Volts
 R_G = Grounding Resistor in Ohms

Note: For broken delta systems, R_G will be the equivalent primary Resistance of the Current Limiting Resistor.

The high resistance-grounding concept (alarm only) can be successfully applied on any low and medium voltage system up to 5kV if the ground fault current does not exceed 10A. Note the 2002 Canadian Electrical Code requires that the faulted circuit be de-energized for resistor systems rated at higher levels than 5A.

Total Ground Current is the vector sum of the Resistor Current and the Capacitive Charging Current I_C .

$$|I_G| = \sqrt{I_R^2 + I_C^2}$$

Particularly on medium voltage systems, at ground fault current higher than 10A, tripping on the first fault will be required to limit the damage. Indefinite persistence of a high resistance ground fault in a motor winding may damage the turn insulation to the extent that a turn-failure occurs, resulting in a shorted turn fault current of many times rated current. At first, phase overcurrent relays may not detect this current since the overcurrent may be slight. The fault current in the short-circuited turn is likely to produce local heating and further damage the insulation to the degree that the fault escalates to a phase-to-phase fault, causing considerable motor damage.

The fault current capacity of the conductor and metallic shield of a cable are related principally to their heat capacities and are limited by the maximum temperature under fault conditions (at conductor 250°C, at shield 150°C). Standard power cable conductor shields, e.g. helically applied copper tape, have very low fault current capacity so a higher than rated sustained ground current will increase the temperature above the limit. After damaging the shield and the insulation, it may escalate to a two phase or three phase fault. Even for low voltage Resistance Grounded systems, it may be desirable to clear the first ground fault with a relay. For example when equipment protection has a higher priority than service continuity.

The high resistance grounding equipment (Zig-zag transformer and Grounding Resistor) should have a continuous duty rating when the service continuity (alarm on first fault) is prime concern. Short time rated devices (10 seconds, 1 minute or 10 minutes) are used on systems where the first fault is cleared automatically with a relay. With these devices the fault must be removed within a time period of the short time rating. Note these devices should be ideally protected by a relay with inverse Time Current characteristics. The relay should be set to pick-up at or below the Maximum Continuous current rating of the Resistor. The time duration will be increased according to $I^2t = K$ (a constant). For example, at 50% rated current, a 10 second rated Resistor can only carry current for 40 seconds. In any case the relay characteristics must co-ordinate with the characteristic de-rating curve of the Grounding Resistor to prevent damage to the resistor.

5.2 OVERCURRENT PROTECTION Where an artificial neutral is used, protection against internal faults should be provided with current limiting fuses or other overcurrent devices of appropriate voltage rating. The overcurrent protection will operate for internal faults but will not operate from the current, that flows in the windings due to a ground fault in another circuit. According to NEC rule 450.5(B)(2), the overcurrent protective device should be rated or set at a current not exceeding 125% of the grounding (auto) transformer continuous current rating and generally about 50% of the rating as per Table 5.2.

TABLE 5.2

RECOMMENDED FUSE SIZES FOR CONTINUOUS DUTY RATED ARTIFICIAL NEUTRAL

ARTIFICIAL NEUTRAL CURRENT RATING	FUSE SIZE AMPS
1A	0.5
2A	1.0
5A	3.0
10A	5.0

It would be preferable to use an overcurrent protective device of adequate short circuit rating which simultaneously opens all ungrounded conductors in lieu of fuses to prevent single phasing. Presently, however, the lowest rating available on the market of high interrupting capacity, low voltage molded case circuit breakers is 15-20A, and the high cost of the medium voltage devices makes their application prohibitive.

If desired, on low voltage systems the protective current limiting fuses can be monitored by a blown fuse relay which may be used directly or through an auxiliary relay to activate the shunt trip mechanism of a circuit breaker or a 3 pole contactor. Short time rated neutral Grounding Resistors should also be protected by inverse current relays as previously described in Section 5.1.

6

SYSTEM INSULATION LEVELS FOR MEDIUM VOLTAGE SYSTEMS

For medium voltage systems above 5kV, the Insulated Power Cable Engineers Association (IPCEA) have requirements in which conductor insulation thickness for a particular voltage is determined by the length of time that a phase-to-ground fault is allowed to persist. Three thickness sizes are specified and are related by the terms 100%, 133% and 173% levels to be applied as follows:

- a) 100% level, where the clearing time will not exceed 1 minute.
- b) 133% level, where the clearing time exceeds 1 minute, but does not exceed 1 hour.
- c) 173% level, where the clearing time exceeds 1 hour.

Obviously the 100% level can be used on any system whether solidly or resistance grounded, providing phase-to-ground faults are cleared in the specified time. This will almost inevitably require fault relaying.

The 133% and 173% levels will apply mainly to ungrounded and high resistance grounded systems, since other forms of grounding will most probably involve ground fault currents that could not be tolerated even for the time permitted. Selection between the 133% and 173% level of insulation will be determined by the time required, after identification of the faulted feeder, to perform an orderly shutdown of the process being served. The effect of full line-to-line voltage appearing on the unfaulted phases of all other system components such as monitors, controllers, switchgear, transformers and capacitors does not require special consideration, but it should be expected that some life may be sacrificed when they operate frequently for extended periods of time.

7

MINING APPLICATIONS

High resistance grounding equipment or permanently installed electrical distribution systems used in mines should be selected and applied as recommended for process industries.

When mobile equipment is connected to the distribution system the grounding equipment and the ground fault protection should be designed to comply with CSA Std. M421-00 Use of Electricity in Mines, which requires that:

Mobile equipment operating at more than 300 volts shall have ground fault protection and ground conductor monitoring.

The neutral be grounded through a neutral grounding device in such a manner as to limit the possible rise of ground fault potential to a maximum of 100 volts.

Although the code requires instantaneous fault clearing in coal mines (Paragraph 6.11.2), time delayed tripping is generally acceptable in other mining operations. Local mining codes should be checked for time delay requirements.

The Grounding Resistor usually has a continuous current rating of 5 amps, 10 amps, 15 amps, 25 amps or 50 amps depending on the particular system for which the resistor is designed. The impedance of the ground wire shall not exceed the values to limit the voltage drop external to the Grounding Resistor to maximum 100 volts.

TABLE 7.1.

MAXIMUM GROUND IMPEDANCE FOR MINING

RESISTOR RATING AMPS	MAX GROUND WIRE IMPEDANCE OHMS	PRODUCT I X R (V)
5	20	100
10	10	100
15	6.5	100
25	4	100
50	2	100

FIGURE 7.1 (A):

CURRENT SENSING - GROUND FAULT PROTECTION.

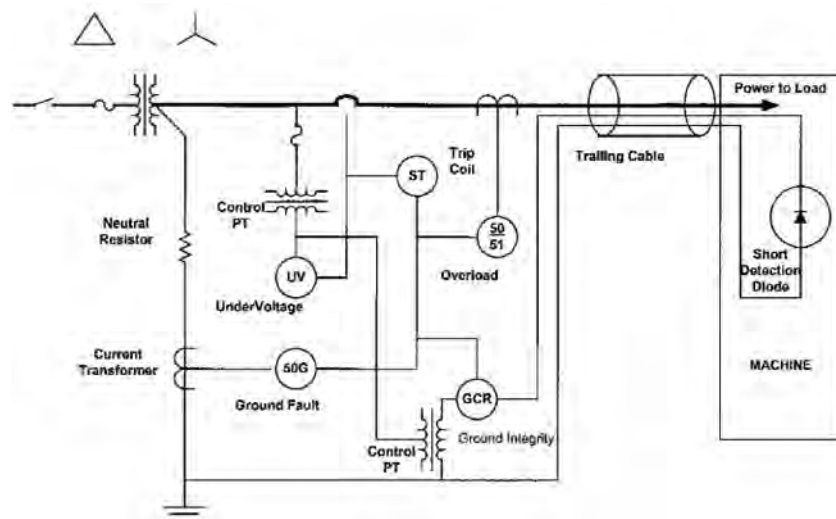
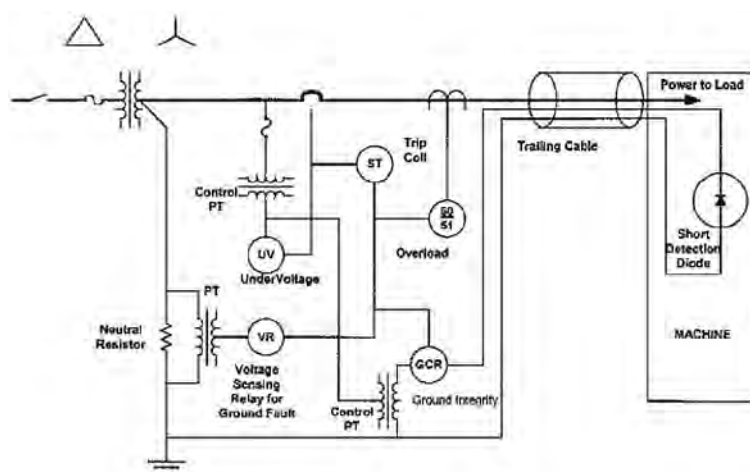


FIGURE 7.1 (B):

VOLTAGE SENSING - GROUND FAULT PROTECTION.



The permitted ground wire impedance is the sum of the impedance of the grounding conductor of all trailing cables. The resistance value of the grounding device is normally designed to operate a selected ground relay at the highest sensitivity level to

provide maximum protection. It is recommended that the pick-up of the Ground Fault Relay shall be 5 amps or less when used with a current relay, or 80% when a voltage relay is used.

Typical protection systems are shown in Figure 7.1 (current relay) and Figure 7.2 (voltage relay).

NOTE: The one advantage of using a potential transformer in place of the current transformer for the ground fault protection is that the potential transformer monitors the continuity of the neutral grounding resistor, such that an open circuit in the resistor would cause early operation of the voltage relay (VR). Redundancy is often obtained by the use of both current sensing and voltage sensing.

The trailing cables must conform with Paragraph 4.1.2 of the CSA Std. C22.5-1977. For medium voltage applications and when increased insulation levels are required on low voltage systems, the types SHD and SHD-GC cables should be used. Both types are available with cross-linked polyethylene or ethylene-propylene (EPR) insulation with natural rubber, polyethylene, polychloroprene or polyurethane jacket for 5 KV, 8 KV and 15 KV insulation level. The type SHD cables are made with three uninsulated ground wires, one in each interstice. The type SHD-GC cables are made with one insulated AWG. No. 8 ground check and two uninsulated ground wires, one in each interstice.

When individual power conductor shielding is not required, type G (SGO) portable cables can be used for low voltage applications. The type G cables are made with 3 uninsulated ground wires, one in each interstice.

In each type and size of trailing cable assembly, the size of ground wires conforms with IPCEA recommendations.

Cables operating on circuits over 750 volts or, in coal mines, over 125 volts must have a grounded shielding consisting of tinned copper wire mesh, or the equivalent; and this shielding shall be, throughout the length of the cable, in contact with the interstitial grounding conductor. (Paragraph 4.1.2.10 of CSA Std. C22.5-1977).

8

APPLICATION OF HIGH RESISTANCE GROUNDING WITH NON-SELECTIVE INDICATORS

Most Electrical Codes require that some kind of ground detector such as three wye-connected and grounded voltmeters, neon lamps, resistor or transformer type indicating lights be installed on each ungrounded system. These indicators are connected to the busses through current-limiting fuses to indicate that one of the phases is grounded, somewhere on the system, and hence the term Non-Selective, which means that the indication does not distinguish which branch circuit is faulted.

Since the phase-to-ground voltages change substantially when a ground fault occurs, the presence of the fault is detected by any of these devices by monitoring the phase-to-ground voltages of the system. Under normal conditions, the phase-to-ground voltages are equal because the distributed capacitance of the phases are equal (as discussed in Section 2.1). When a ground fault occurs, the voltage to

ground of the faulted phase is reduced and those of the other two phases increased. Indicator lights connected across the line to ground can, therefore, be used to show the faulted condition, i.e. the light on the faulted phase will turn off to show that phase is faulted.

The conventional ground detectors provide the minimum requirement of phase indication, but cannot stabilize the system voltage. To provide protection against over-voltages to ground due to intermittent ground faults, it is still necessary to apply high-resistance grounding of some type, as previously described.

The I-Gard type GIL ground indicating lamps with appropriate voltage rating can be used for any ungrounded or high resistance grounded low voltage system, as required by the Canadian Electrical Code and the National Electrical Code. For voltages in excess of 600V, three Single Phase Potential Transformers, wye/wye-connected, can be used to match the 240V Indicator (GIL-2) to the system. This basic unit provides the minimum protection by visual indication only and requires constant supervision. Figure 8.1(a) illustrates the next step up and shows a typical system with a GIL indicator unit and a voltage sensing relay connected across the Grounding Resistor. The relay provides an audible Alarm or other function such as a remote lamp, or PLC input. Alarm indication can be obtained from the resistor using the voltage across the resistor or the current flowing through it, as can be seen from Figure 8.1(a), (b) and (d) for wye and delta systems. In the latter two cases, a type MGFR Relay with a ground current sensor, mounted on the connection between either the Wye point and the Grounding Resistor or the Grounding Resistor and ground, can also be used for alarm purposes or for breaker control.

The next level of protection is use of a type GADD Relay, which combines a phase lamp type indication with a voltage relay. (See Figure 8.1(c)). It also provides a visual warning indication in addition to the phase indication. It operates by voltage measurement of the line-to-ground voltages. The system voltage is divided by a resistor network, type DDR2. This resistor network is used by the GADD to match it to systems with different voltages. It divides the system to ground voltages to electronic levels. The type DDR2 Alarm Resistor Unit is a separate component in its own enclosure and not part of the grounding resistor or artificial neutral in any way.

The type DDR2 Alarm Resistor Units are available for direct connection (Figure 8.2(a) and (b)) up to 600V. On systems over 600 Volts line-to-line, it is necessary to use potential transformers to monitor the phase voltages (Figure 8.2(c) and (d)). The Potential Transformers must have a primary rating equal to Line-to-Line voltage with a secondary rating of 120V. High accuracy is not required. The DDR2 burden on the PT is minimal at less than 1VA. The type DDR2-1 Alarm Resistor Unit (rated 120V) is then connected to the secondary of the potential transformers.

FIGURE 8.1 (A): INDICATION ON WYE SYSTEM WITH VOLTAGE DERIVED ALARM FROM VOLTAGE SENSING RELAY.

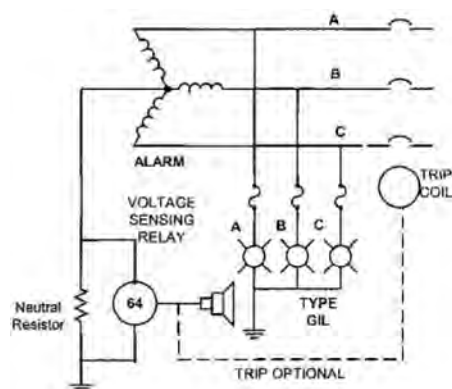


FIGURE 8.1 (B): INDICATION ON WYE SYSTEM WITH CURRENT DERIVED ALARM USING MGFR RELAY.

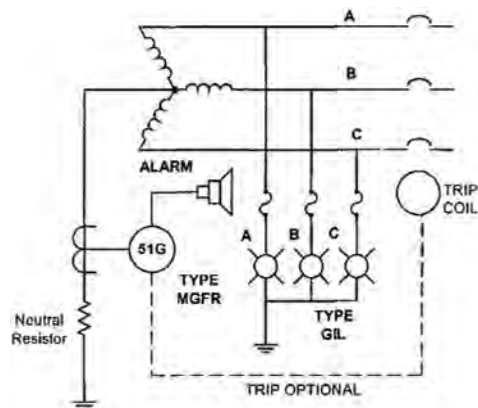


FIGURE 8.1 (C): INDICATION WITH DELTA SYSTEM, AND VOLTAGE DERIVED ALARM WITH GDDR RELAY.

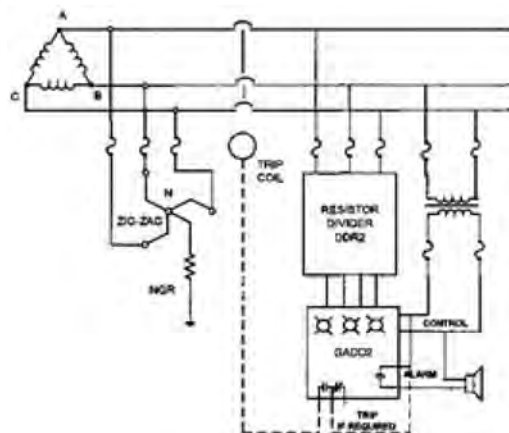


FIGURE 8.1 (D):

INDICATION ON DELTA SYSTEM WITH CURRENT DERIVED ALARM USING MGFR RELAY.

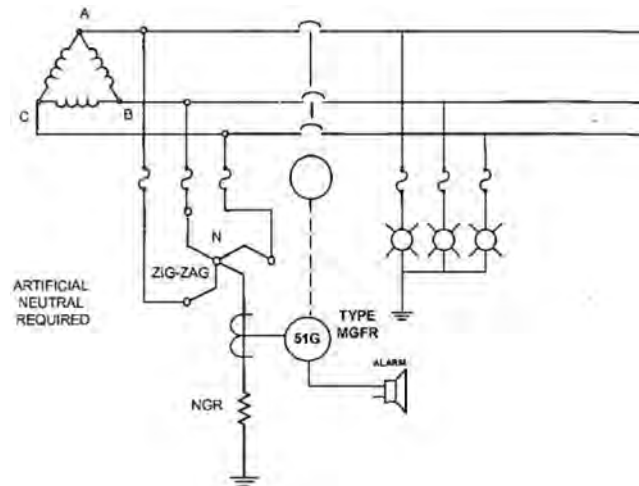


FIGURE 8.2 (A):

DDR2 DIRECT CONNECTION ON WYE SYSTEM.

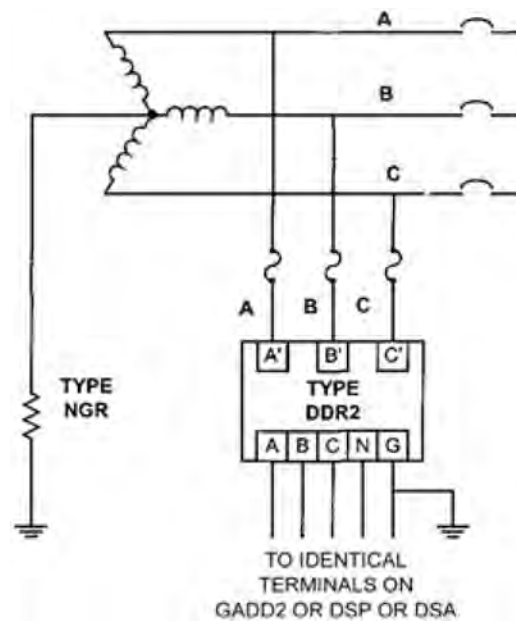
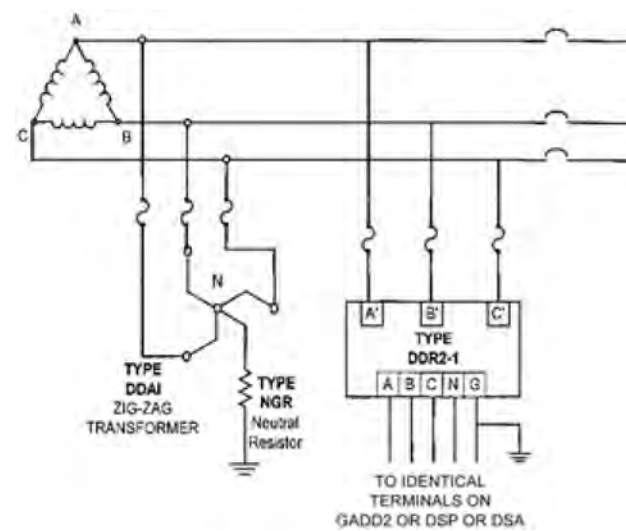


FIGURE 8.2 (B):

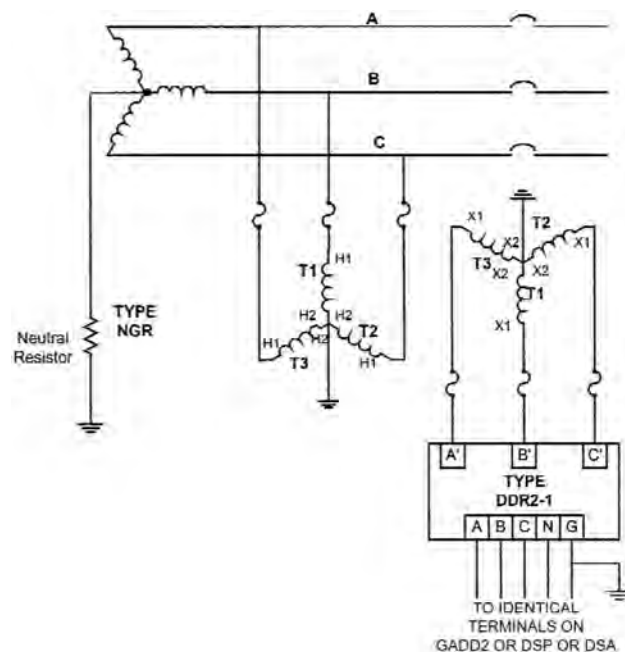
DIRECT CONNECTION ON DELTA SYSTEM FOR DDR2.



MEDIUM VOLTAGE DELTA CONNECTION FOR DDR2-1.



MEDIUM VOLTAGE WYE SYSTEM WITH DDR2-1 CONNECTION.



9

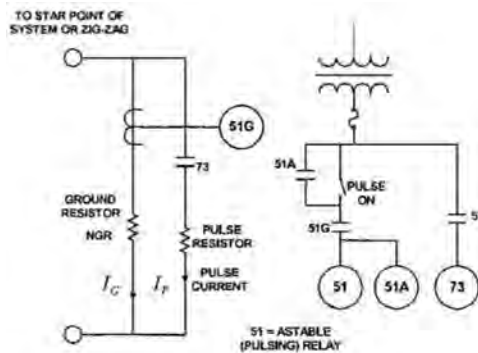
The main advantage of resistance Grounded systems is the ability to continue to use the system with a single fault present. It is, therefore, very important that the first ground fault should be located and removed as soon as possible to prevent unnecessary trip-outs before a second fault develops. Ground fault locating devices are available and may be incorporated in high resistance grounding schemes. One may even use the traditional method of tripping breakers in sequence to see when the

fault disappears, but this defeats one of the principal advantages of the high resistance grounding, i.e. power continuity and the ability to locate a ground fault without shutting down the system.

To take maximum advantage of the full capabilities of the high resistance grounding, there are various systems for locating faults without interruption of the service. For example, the I-Gard Type GM meters and DSA fault indicators can be used to detect which feeder or branch circuit has the fault by lamp indication (DSA indicator) or meter deflection (GM meter). One DSA can be used to detect faults at all levels of the system right down to the individual loads connected to the system to a maximum of 152 branches.

FIGURE 9.2 (A):

WYE-CONNECTED LOW VOLTAGE PULSE SYSTEM.



A cost-effective way to locate faults is by use of a scheme, which uses a clip-on ammeter to trace the fault current. The ammeter is sometimes affected by external fields, which may swamp the ground fault current reading and so an alternative scheme commonly used is to pulse the fault current to make the signal more visible during measurements. Such schemes are shown in Figures 9.2(a) to 9.2(d). The pulse system includes a pulsing contactor to short out a portion of the Grounding Resistor (or adding a second Grounding Resistor in parallel), a cycle timer to energize the pulsing contactor about 20-60 times per minute, and a manual NORMAL/PULSE switch to start and stop the pulsing. It includes a Ground Fault Relay to detect the resistor current to allow the pulse operation, such that it can only pulse when a fault is detected. Such schemes usually include indicator lights to show the status. e.g. NORMAL, FAULTED and PULSE ON. An ammeter is also a useful option.

The current pulse may be anywhere from two to five Amperes higher than the continuous ground fault current. Generally, a 5A pulse in addition to the continuous ground current is recommended, but it should not exceed 10 amps maximum. Figure 9.2(a) indicates a directly connected low voltage, wye system. Figure 9.2(b) uses a step-down transformer for medium voltage wye systems.

FIGURE 9.2 (B):

WYE-CONNECTED MEDIUM VOLTAGE PULSE SYSTEM.

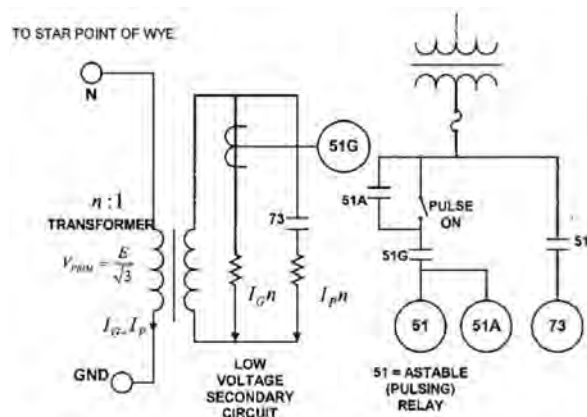


FIGURE 9.2 (C):

ILLUSTRATES THE USE OF A TAPPED RESISTOR FOR ADJUSTMENT OF THE CONTINUOUS CURRENT.

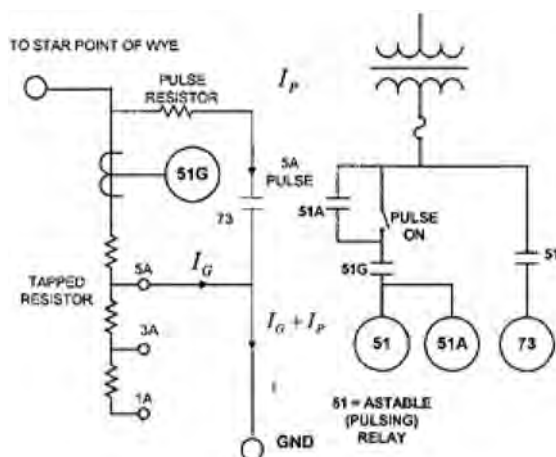
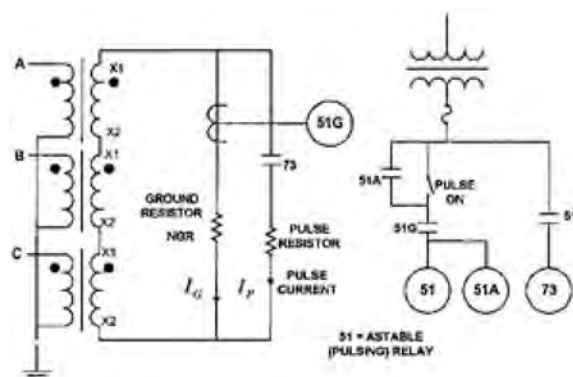


FIGURE 9.2 (D):

SHOWS THE CONNECTION OF A MEDIUM VOLTAGE, BROKEN-DELTA ARRANGEMENT



The clip-on ammeter, required for signal tracing can be purchased from a number of sources. The method is to clamp the probe around all three conductors for a suspected branch circuit and observe on the indicator if a pulsing current is present or not. If it is not, then the branch does not carry fault current and another branch is selected and tested. The process continues until one is located which indicates a fault. The branch circuits of this cable are then tested similarly, and so on, until the fault is located.

NOTE: Tracing the signal on systems where the conductors are in conduits can be more difficult because the fault current tends to return through the conduit of the circuit involved. To the extent that this happens, the return current in the conduit cancels out the tracing current flowing out through the conductor to the point of the fault. Fortunately, this cancellation effect is not usually 100%. The return current may divide into unpredictable paths and return to the source partly on the equipment grounding system (steel structures, etc.).

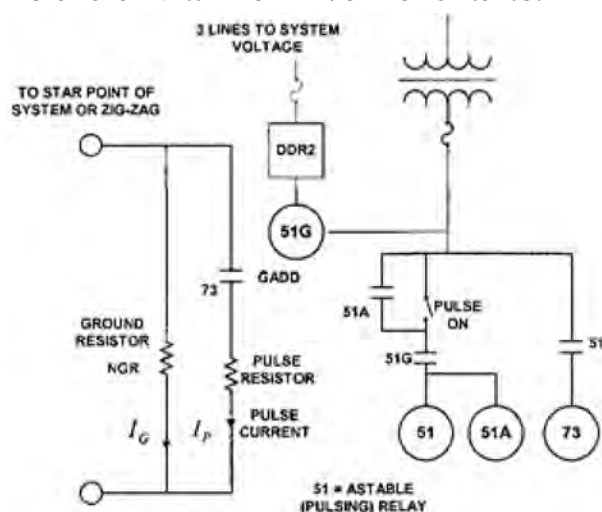
With the recommended very sensitive clip-on ammeters, which are relatively insensitive to other magnetic effects, the definite signature of the pulsing ground fault current can usually be traced.

9.1 HIGH RESISTANCE GROUNDING EQUIPMENT FOR PULSING SYSTEMS	<p>As for all resistance grounded systems, grounding can be applied to any low and medium voltage 3 wire system by a neutral grounding resistor connected between the wye point and ground when the neutral point is available, and by connecting an artificial neutral on a delta connected system. The grounding equipment, however, for pulsed systems must be designed for continuous duty and at rated pulsing current.</p>
9.1.1 NEUTRAL GROUNDING RESISTORS FOR PULSING SYSTEMS	<p>The resistor may be equipped with a centre tap which allows half of the resistor to be shorted out to double the current, or alternatively, a second resistor can be connected in parallel to double the current during the pulse period. In the former case, half of the resistor must be designed to take double the current than the other half, which necessarily increases the size of the unit.</p>
9.1.2 ARTIFICIAL NEUTRAL DEVICES	<p>Artificial neutral devices involve transformers and grounding resistors. The grounding transformers, either standard single phase distribution type or zig-zag three phase auto-transformer type, are usually designed for 5 amps and 10 amps pulsing current. The single phase transformers, used as grounding transformers on medium voltage systems must be rated to take the pulse current as well as the continuous current.</p>
9.1.3 CURRENT LIMITING RESISTORS FOR BROKEN DELTA ARTIFICIAL NEUTRAL	<p>Standard high resistance grounding equipment (neutral grounding resistors and artificial neutrals) can be used on low voltage systems only. To reduce the high cost of the switching (pulsing) contactors on medium voltage systems, it is necessary to apply alternative grounding packages that permit low voltage pulsing such as broken delta, single phase transformers as discussed in Section 3.2.</p> <p>For medium voltage systems a broken delta transformer will be normally employed, as in Figure 9.2(d). The secondaries of the transformers are connected in series with a current limiting resistor. For pulse operation, tapped or dual resistors can be used to increase the current as for low voltage systems. The configurations possible are numerous.</p>

PULSE SYSTEM WITH VOLTAGE RELAY SENSING.



PULSE SYSTEM WITH GADD VOLTAGE SENSING.



Two basic types of Pulsing Systems are available, namely:

- a) Voltage Sensing - See Figure 9.2 (e) and (f)
-
- b) Current Sensing- See Figure 9.2 (a) to (d)

In Voltage Sensing Pulsing Systems, the ground fault is sensed by detection of the voltage shift in line to ground voltages, using a voltage shift relay such as the GADD Relay.

In current sensing pulsing systems, the ground fault is typically sensed by a ground current relay, such as type MGFR through a type T3A current sensor mounted on the neutral to ground connection. The pick-up setting of the Ground Fault Relay should be field adjusted to 50% or higher, but not exceeding 100% of the selected tap value of the current limiting grounding resistor.

Either system can be found in a standalone unit or switchboard cubicle. The grounding resistor is usually incorporated into the pulsing system enclosure. It will be connected to the wye point of the main power transformer (wye system), or artificial neutral (delta system), or the secondary of a broken delta system.

9.2.1 CURRENT SENSING PULSING SYSTEM OPERATION	<p>During normal conditions, with no ground fault on the system, no current will flow in the grounding resistor.</p> <p>When a ground fault occurs anywhere on the system, current will flow in the resistor. This current is sensed by the ground current sensor and operates the ground fault relay. Operation of the ground relay permits the pulsing sequence via an auxiliary relay to be initiated manually by operating the NORMAL/PULSE switch as already discussed. Additional SPDT contacts on the ground relay are available for remote indication and annunciation of a ground. An audible alarm with a silencing relay may also be included.</p> <p>The built-in test circuit provides a functional test, to assure correct operation of the ground fault relay.</p> <p>An optional voltage failure relay for remote alarm and/or blown fuse alarm for the grounding transformers can also be provided.</p>
9.2.2 VOLTAGE SENSING PULSING SYSTEM OPERATION	<p>When a ground fault occurs anywhere on the system, the Alarm Circuit contacts of a GADD unit will pick-up at 50% ground current. These contacts permit the pulsing sequence via an auxiliary relay to be initiated by pressing the PULSING START push-button. The operation of the pulsing circuit is similar to the current sensing.</p> <p>In addition to the normal and fault indications in the fault detection panel, other devices such as an I-Gard DSA unit can provide visual indication of the faulted phase and which feeder has the fault so that the search can be narrowed down to a particular branch circuit.</p>
9.2.3 PULSING MODULE FOR DSP AND DSA UNITS TYPE DS-PM	<p>After the DSP or DSA indicates an alarm condition identifying the faulty feeder and the faulty phase, quite often locating the fault does not get done in a timely manner, thus leaving the distribution system exposed to a second fault on another phase.</p> <p>To help locate the first fault, pulsing systems are used. Yet there are many legacy systems with Type DSP MKII or DSA units where pulsing systems have not yet been installed.</p> <p>An optional card Type DS-PM is available which can be added to the existing DSP or DSA main frame in a designated slot to provide the pulsing control. Used for selective ground fault indication and metering information, DS-PM takes one space in any DSP or DSA rack. An OHMNI-PM Neutral Grounding resistor incorporating the pulsing circuit is installed in place of the existing neutral grounding resistor. The output of the DS-PM is wired to the OHMNI-PM.</p> <p>With the DS-PM installed, when the DSP or DSA shows an alarm and the fault needs to be located, simply start the pulsing and trace the fault, using the special CT with the ammeter. The locating time is generally reduced to an hour. No breaker needs to be tripped. All material can be retrofitted quite simply and cost effectively.</p> <p>Parts required for the retrofit kit for each System:</p> <p>DS-PM Module</p> <p>OHMNI-PM</p> <p>Tracing CT</p>

9.2.4 SLEUTH - GROUND FAULT DETECTION AND PULSING UNIT

Available for 480, 600 and 4160V systems, I-Gard Sleuth unit combines four essential elements:

1. Neutral Grounding Resistor for High Resistance Grounding
2. Hand Held Pulse Tracing Sensor
3. Automatic Pulsing System
4. Ground Fault Sensing Relay

The panel is wall mounted for 2A, 5A and 10A Resistor let-through current up to 600 V and is free-standing, floor-mounted for higher voltage or current. Depending on the accessibility of the Neutral point of the transformer, the unit is supplied with or without the artificial neutral.

9.2.4 TURBO SLEUTH - PORTABLE GROUND FAULT DETECTION AND PULSING UNIT

I-Gard Turbo Sleuth is a portable pulsing ground fault detection system that can be temporarily installed on any 480 or 600 V transformer. Capable of being used without power interruption on any resistance grounded or ungrounded system, Turbo Sleuth provides plant wide fault location capability through a single portable convenient device. Completely compatible with both Wye configured systems on its own or Delta configured systems with its unique add on Zig-Zag artificial neutral, it detects and locates ground faults quickly.

The unit is provided with heavy duty casters and can be rolled in to connect to a live system quickly by twist-lock power connectors. It incorporates the same four essential elements as noted in 9.2.4.

10 SELECTIVE GROUND FAULT LEVEL INDICATION

The high resistance grounding equipment can be regarded as a ground current generator. All of the current generated may be assumed to flow into the ground fault from the supply, returning to the supply via the ground. Zero-sequence current sensors applied to each feeder with a monitoring device can then be used to alarm, indicate, meter, or trip the faulted feeder. Any relay or indicator which uses a zero-sequence current sensor, and which will respond to low ground faults, can be used to provide selective indication in addition to the general ground alarm provided by the voltage dependent, type GADD Relay. Various types of monitors can be used for selective ground fault indication and metering information:

1. Indicating Ammeters, type GM
2. Ground Relays, type MGFR
3. Indication Panel type DSA

10.1 GROUND CURRENT METERS, TYPE GM

The type GM ground current meter and Toroidal (Type T) Sensors, can be used in conjunction with the type GADD ground alarm relay to provide an inexpensive means of selective indication of a faulted feeder on extensive distribution systems. By selective we mean to identify the faulted branch, instead of just signalling a fault somewhere on the system.

High resistance grounding equipment in the form of a neutral grounding resistor or an artificial neutral is required to provide the ground reference current to assist in the sensing of the ground fault.

If GM meters are to be used for meter indication, the full-scale deflection of the meters should be equal to the maximum ground fault current limited by the high resistance grounding. The GM is available in 1A, 2A, 5A and 10A scales.

The application of selective ground fault indication to a system with single power Source (Figure 10.1(a)) and to a double-ended (Two Sources) substation (Figure 10.1(b)) is straightforward.

Type GM meters are used exclusively with Type T current sensors, I-Gard types T2A (2 in. dia.), T3A (3 in. dia.), T6A (6 in. dia.) and T9A (9 in. dia.) toroids.

10.2 GROUND FAULT RELAYS, TYPE MGFR

Each member of the MGFR Relay family is suitable for selective ground fault indication, but due to their relatively high cost, their application is recommended when tripping on the first fault or second fault is also required.

If used for trip on first fault, as in the case of a short-time rated device, the MGFR Relay must not be set to a pick-up level that is close to the maximum ground current of the system. The reason is that it may not trip at all due to tolerance in the settings or other factors. A convenient level is 50% of the maximum ground current, set by the grounding resistor.

If trip only on a double-fault is desired, the MGFR can be used in Figure 10.1(c) with a pick-up setting of 100A. Priority can be achieved by selecting different time delays for the relays so that the relay with the least priority trips first, thus clearing the double-fault situation and leaving the higher priority circuit connected.

For each feeder relay, a correctly sized zero-sequence current sensor should be used, encircling all phase conductors, but not the grounding conductor, shield, or armour of the cable. MGFR Relays are used with current sensors I-Gard types T2A (2 in. dia.), T3A (3 in. dia.), T6A (6 in. dia.) and T9A (9 in. dia.) toroids.

10.3 TYPE DSA GROUND ALARM SYSTEM

One system that combines the voltage alarm and feeder indication in one unit is the I-Gard type DSA Ground Alarm System, which can indicate faults on up to 152 circuits on the system. It can be used as a fault locating tool to indicate faults on branch circuits down to any level instead of having to try to trace faults with a clamp-on probe in a pulsing system. The DSA indicates which branch is affected at a glance. Typical system connections can be seen in Figures 10.3.1 to 10.3.3.

The type DSA Ground Alarm System can be applied to any high resistance grounded three phase electrical distribution system up to 15 KV, where the required auxiliary equipment, such as artificial neutrals or Neutral Grounding Resistors, Alarm Resistor Units and Zero-sequence Current Sensors are properly selected and applied. The system can only be successfully applied when the “alarm only” concept will insure the service continuity, i.e. the system insulation is good, so that a single ground fault will not escalate to a two phase or three phase fault, and effective supervision exists. The type DSA Alarm System can be used, therefore, where second fault tripping is not required, or where second ground fault tripping cannot be achieved. For example, low interrupting capacity circuit opening devices such as motor starting contactors cannot be relied upon to clear the double-fault. Selective ground fault indication will assist the operator to make the necessary operational changes for orderly shutdown (standby unit start up and faulted unit disconnection). Typical application area is large motor control centres or similar distribution arrangements.

The DSA Ground Alarm Units can also be used as second level indication in conjunction with Type DSP Ground Alarm/Trip Unit. The DSP can be used to provide double-fault instantaneous protection for the main feeders with the DSA providing fault location indication on the down-stream branch circuits. See Figure 10.3.3.(a). Alternatively the DSA can be used with the DSP system the other way round, e.g. with the DSA providing indication only on the main feeders and the DSP protecting down-stream equipment from double-fault damage. See Figure 10.3.3.(b). This system is effective where the likelihood of faults on the main bus is remote, and the DSA serves to indicate which feeder is faulted. For example, if feeders serve different buildings the building with the fault is identified by the DSA. The DSP in that building can then be inspected.

See Section 11 for more information on DSP systems.

The DSA is a modular, rack-mounted unit with a base unit (DSA-MF2) capable of holding up to 8 Plug-in modules. Each module can monitor 4 circuits. The system is expandable by addition of an extender frame (DSA-EF) which can hold a further 10 Modules. Up to 3 Extender Frames can be added to the base frame to allow up to 152 circuits

to be monitored. The plug-in ability of the Modules allows for easy serviceability. The type DSA Ground Alarm Unit is specifically designed for selective feeder indication. It provides visual indication and alarm contacts when a ground fault occurs anywhere on the distribution system. It will indicate the faulted phase (A, B, and C phase lamps), and which feeder is faulted (4 lamps on each Feeder Module). It is equipped with an ALARM/METER bar graph display to measure in METER mode the magnitude of the ground fault current as percentage of the maximum ground current of the system. The METER can be used to measure Total System Leakage or individual feeder leakage.

FIGURE 10.1 (A):

SELECTIVE (BRANCH) FAULT INDICATION USING GM METERS AND GADD.

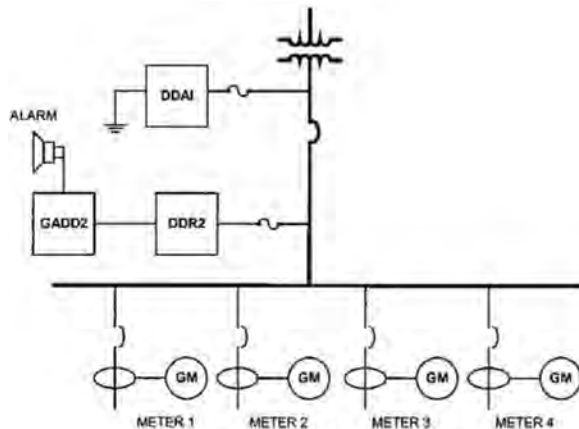


FIGURE 10.1 (B):

SELECTIVE GROUND FAULT INDICATION – DOUBLE SOURCE NORMALLY OPEN TIE.

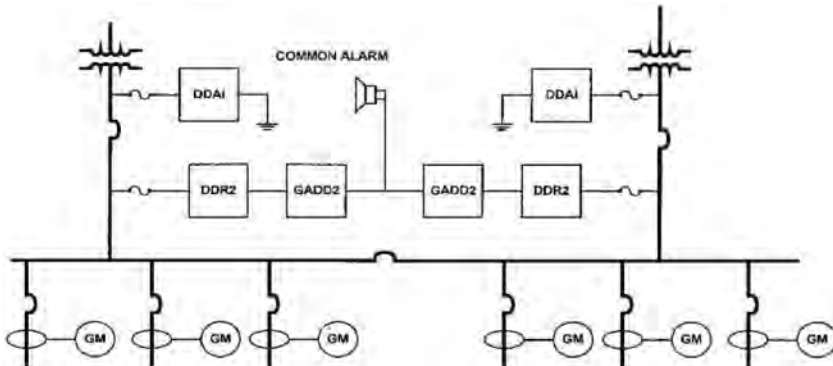
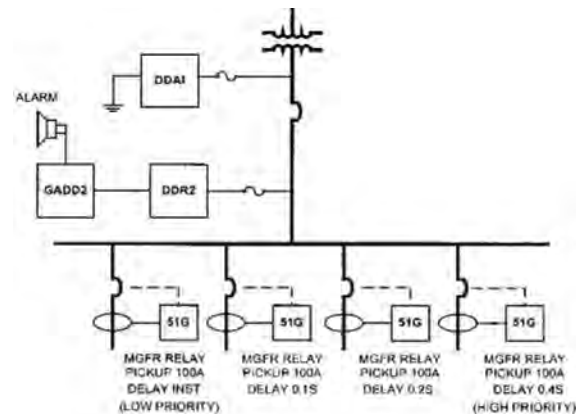


FIGURE 10.1 (C):

SELECTIVE GROUND FAULT INDICATION WITH TRIP ON SECOND FAULT.



The main alarm is designed to operate with a time delay of 0.5 seconds after the voltage and current have reached their pick-up level. This eliminates nuisance alarms due to system transients and sensor output from common mode signals surges.

If a fuse protecting the alarm resistor unit blows, the BLOWN FUSE circuit will provide visual indication and the alarm circuit will be activated. Replacement of the blown fuse will automatically reset the circuit.

It is important to note that if the fuse blows after an alarm has been raised due to a ground fault, the phase light will continue to flash indicating the more serious fault. The blown fuse should always be corrected first and then the system reset to obtain an unambiguous indication of the ground fault condition.

A built-in Self-Test is provided, independently, for each circuit in the 4 circuit feeder modules.

10.3.1 CONSTRUCTION

The plug in modular rack system offers maximum flexibility for “custom-made” systems. Any DSA system can be arranged from the following components (Table 10.1) according to the distribution system requirements:

TABLE 10.1.

DSA COMPONENTS

CATALOGUE NO.	DESCRIPTION
DSA-MF2	Main frame complete with control module (DSA-CM2)
DSA-EF	Extender Frame Complete with interconnecting cable with plugs (DS-CABLE) and 1 - Blanking plate (DS - BP)
DSA-FM	4-Circuit Feeder Module
DS-BP	Blanking Plate to cover unused slots.
DS-MA	Multi-Frame Adaptor to connect more than one Extender Frame
DS-MAC	Adaptor Cable to RESET multiple DSA units from any DSA
DS-EC	Environmental Cover
DS-PM	Pulsing Module

TABLE 10.2

DSA CAPACITY

DSA-MF2	DSA-EF	DSA-MA	CIRCUIT CAPACITY
1	None	None	32
1	1	None	72
1	2	1	112
1	3	2	152

For correct arrangement of any DSA Alarm System, the basic rules are as follows:

1. One Base Unit/Control Module (DSA-CM2) should be provided for each distribution system. Protection of separate power systems cannot be combined in one DSA unit.
2. One Alarm Resistor Unit, type DDR2, with suitable voltage rating should be provided for each Control Module (DSA-CM2).
3. The maximum circuit capacity of the main frame (DSA-MF2) with, and without, extender frame (DSA-EF) is tabulated along with the hardware requirements in Tables 10.1 and 10.2.
4. Toroidal Zero-sequence Current Sensors, such as Catalogue Nos. T2A (2 in. dia.), T3A (3 in. dia.), T6A (6 in. dia.) and T9A (9 in. dia.) can be used without limitation.
5. Rectangular Zero-sequence Current Sensors, such as Catalogue No. R4-17A, R7-13A and R8-26A may also be used, but the let-through current of the high resistance grounding equipment must be 5 amps or more. The positioning of the busbars or cables through the sensor window is important. See document C-4-701, Current Sensors.
6. The maximum cable length to any current sensor should not exceed 1,000 ft. (300 meters) of 14 AWG wire. Maximum ground current allowed by the ground resistors must not change under any configuration of system, i.e. Artificial neutrals cannot be paralleled when systems are joined together by tie breakers, for example. This would cause the Feeder Modules to indicate at the wrong fault level, as they are set for a particular Ground Current in the Control Module.

10.3.2 APPLICATION - GENERAL

When a DSA unit is used on a system, a Neutral Ground Resistor or the Artificial Neutral must be used. The resistor provides ground current for the sensors so that selective indication can be obtained. Without a grounding resistor, no current would flow on the first fault and the Feeder Modules would not indicate.

The basic components for the protection system are as follows:

1. High Resistance Grounding equipment:

- a) Artificial Neutral, type DDAI(W) for delta connected systems, i.e.
 - (i) Grounding transformer(s)
 - (ii) Grounding resistor (or Current Limiting Resistor)
- b) Neutral Grounding Resistor, type NGR(W) on wye-connected system and an Alarm resistor, type DDR2.

2. Ground Alarm Unit:

Type DSA, containing the necessary components as required.

3. Zero-Sequence Current Sensors:

- a) Toroidal types (T2A, T3A, T6A, T9A) for cables,
- b) Rectangular types (R4-17A, R7-13A, R8-26A) for bus ducts or larger group of cables.

Although the selection of the high resistance grounding method seems to be straight forward, the protection requirement on a specific system arrangement may necessitate the application of Artificial Neutrals on wye-connected systems.

When the DSA system is used on a double-ended substation with a Normally Open tie breaker, two neutral grounding resistors, or two artificial neutrals connected to the line sides of the main breakers and two alarm resistor units connected to the busses should be used. The let-through current of each high resistance grounding equipment should be equal to the total capacitive charging current of both systems. The line side connection of the high resistance grounding equipment of the main breaker will ensure that the maximum ground current does not change when the tie breaker is closed. (Assuming that the transformers are never operated in parallel, one main will be open when the tie is closed). This is required for correct DSA operation, since doubling the ground current level would make it impossible to maintain a single alarm level.

In multiple transformer substations separate DSA base and DDR2 units should be installed, i.e. one for each transformer, since each section can be isolated (tie breakers open) and must operate in this configuration as separate systems.

In certain distribution systems, operation requirements can change the number of interconnected systems. When the ON/OFF switching of the grounding devices is not adequate to maintain a single ground current level under all operating conditions, additional resistor control is necessary to vary the let-through current of the individual grounding device.

10.3.3 TYPICAL SYSTEM APPLICATIONS

The following recommended protection schemes are for typical distribution arrangements, but they can be modified to include any special requirements. The schemes can also be applied to any distribution arrangement when the basic, previously listed application rules are logically followed. In industrial power systems, the most commonly used distribution arrangements are:

- a) the secondary radial, and
- b) the secondary selective systems.

Other arrangements such as double bus, close loop secondary, star bus (also called synchronizing bus) are variations of the two basic systems.

10.3.3.1 SECONDARY RADIAL SYSTEMS

Unit substations, with or without standby supply, represent the simplest distribution arrangements. The following protection schemes are suggested for unit substation arrangements:

Figure 10.3.1(a): Unit substation - Selective G.F. Indication - High resistance grounding is provided with a neutral grounding resistor (and DDAI artificial neutral if required) connected at the transformer.

Figure 10.3.1(b): Unit substation with alternate supply - Selective G.F. Indication - High resistance grounding is provided with DDAI because one unit that will be common to both sources has to be connected to the main bus, and thus no wye point is available. Note: If the sources were wye-connected then two Grounding resistors could be used – one on each source.

FIGURE 10.3.1 (A):

UNIT SUBSTATION WITH DSA SYSTEM, SELECTIVE SINGLE LEVEL FAULT INDICATION.

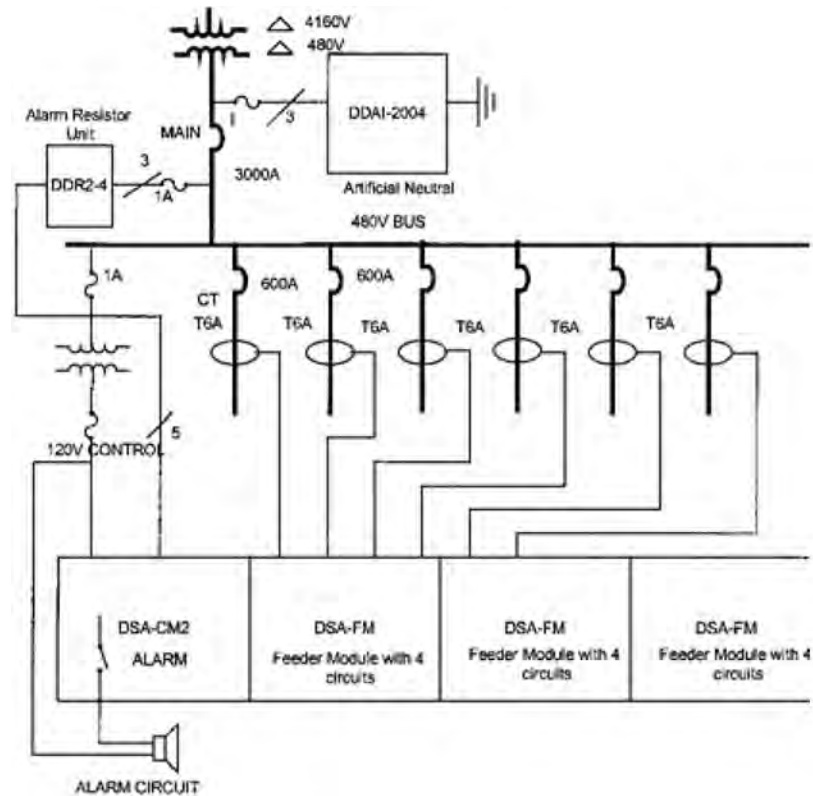
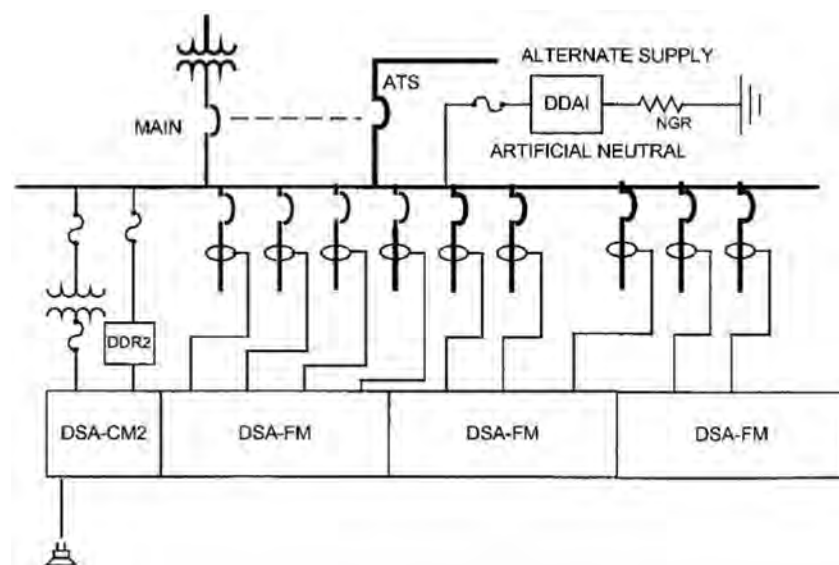


FIGURE 10.3.1 (B):

UNIT SUBSTATION WITH ALTERNATE SUPPLY, SELECTIVE INDICATION WITH DSA SYSTEM FAULT ON ONE PHASE.



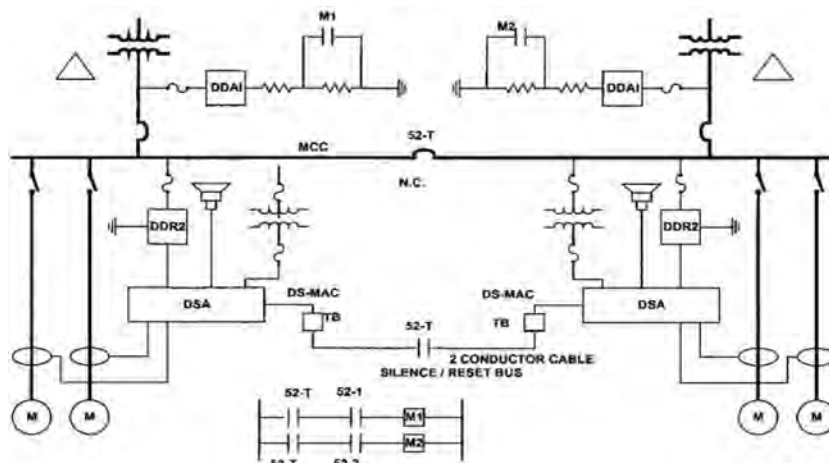
10.3.3.2 SECONDARY SELECTIVE SYSTEMS

Double-ended substations with Normally Closed or Normally Open tie breakers are the basic arrangements to develop any secondary selective system.

Figure 10.3.2 illustrates a typical Double-source board arrangement with a Normally Closed Tie breaker. A DSA is used on both halves of the board to provide selective indication with or without the tie breaker closed. The following points should be noted:

FIGURE 10.3.2:

SINGLE LEVEL DOUBLE SOURCE INDICATION USING DSA.



1. Dual rated Artificial Neutrals should be applied to each supply source. In normal operation (tie breakers closed) the let-through current level of both grounding equipment should be half of nominal. This can be done, by using tapped resistors (tapped at 50%) with twice the nominal resistance for the total resistance value. The two currents in the event of a fault will add together to provide the nominal let-through current. In emergency operation (one open main or open tie) one or both Grounding Resistors should be reduced to half value by shorting out half of the resistance by contactors.

2. This ensures that the let-through current is maintained at the nominal value under all conditions of operation.

a) Open Main/Closed Tie – One resistor only, provides current to both sides of the system

b) Open Tie/Closed Mains – Each resistor provides current to half of the system on each side

3. Single-rated high resistance grounding equipment can be used with a Normally Open tie breaker with main-tie-main interlocks, since only one resistor will be used at a time.

In any case, the use of a shielded 2-wire cable between the DSA frames connects the RESET and Alarm SILENCE controls together when the Tie breaker is closed. This allows both systems to be controlled from one unit, which can be especially useful when the frames are located in different areas. Special connecting cables, DS-MAC, with 30 pin connectors, are used to connect to each frame. The leads from the DS-MAC are then connected to terminal blocks, which provide terminations for the interconnecting cable. The cable length can be up to 1000 feet in length.

10.3.4 COMBINATION
DSA AND DSP

The DSA Ground Alarm unit can be used as second level indication for sub-feeders when the DSP Ground Alarm/Trip unit(s) provide(s) first level protection on the main distribution level (Figure 10.3.3(a)). This allows Instantaneous Trip protection on the main feeders, while faults can be located conveniently down-stream, where they are more likely to occur. Alternatively, as in Figure 10.3.3(b), the DSP can be used on the

down-stream branch circuits to provide double-fault trip protection to the circuits most likely to experience the double-faults. With a DSA on the main feeders, the appropriate systems can be identified in the case of the first fault, thus assisting in the fault location process.

FIGURE 10.3.3 (A): TWO-LEVEL GROUND FAULT SYSTEM WITH DSP ON MAINS AND DSA ON FEEDERS

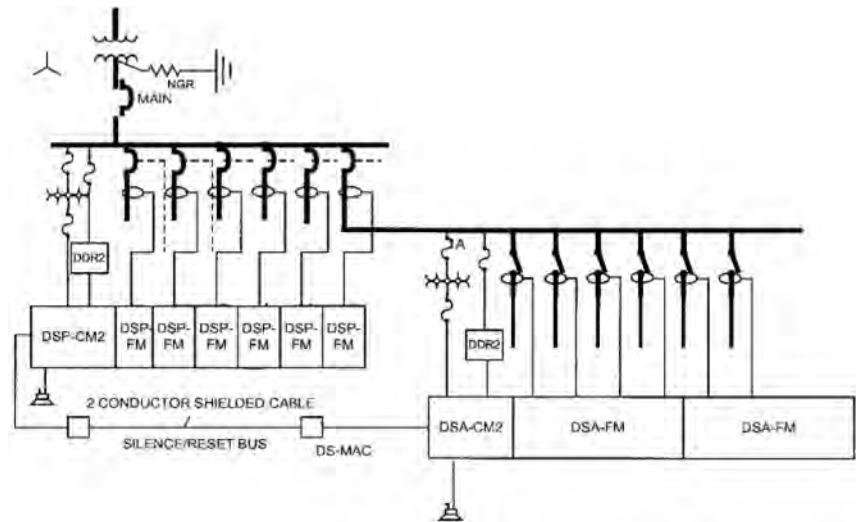
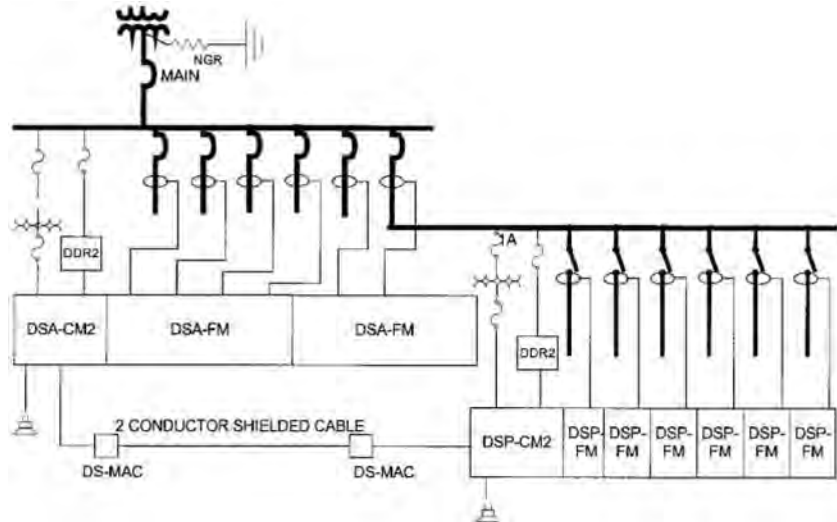


FIGURE 10.3.3 (B): TWO-LEVEL GROUND FAULT SYSTEM WITH DSA ON MAINS AND DSP ON FEEDERS.



11 SECOND GROUND FAULT PROTECTION

As continuity of service is a major advantage of the high resistance grounded systems, they are often operated for long periods of time with a single fault. Even though over-voltages are controlled with properly sized grounding equipment, the possibility of a second fault always exists. If the second fault occurs before the first one is cleared, the ground current is no longer controlled by the Grounding Resistor, but it will be limited by the supply impedance and the ground impedance between the two faults. If the second fault occurs on the same feeder as the first, the phase-to-ground fault changes to phase-to-phase, which cannot be detected by the ZSCT

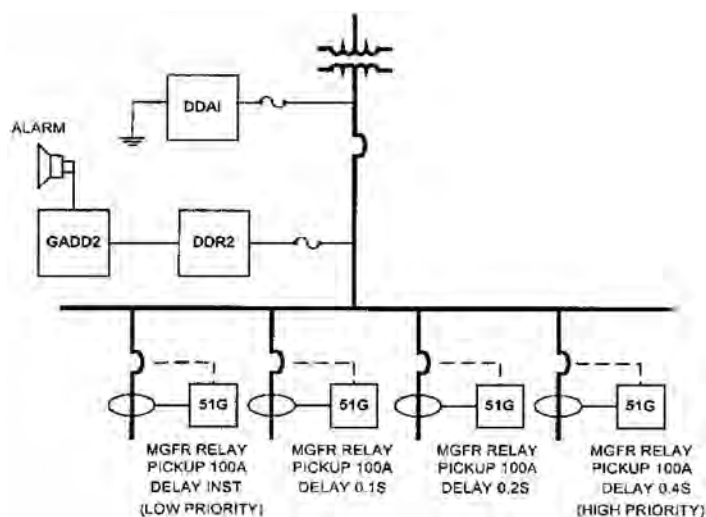
(it is effectively a load current). Thus high current will flow and must be cleared by the overcurrent protection. On the other hand, if the second fault occurs on a different feeder some distance away, or the fault develops into an arcing fault, the ground impedance between the two faults will limit the fault, which cannot be cleared quickly by the overcurrent devices, and it can cause severe damage.

Protection against second ground faults can be provided when each feeder is equipped with a zero-sequence current sensor. Utilizing the sensor outputs through current relays, the protecting feeder breakers can be tripped when the fault current exceeds a predetermined level of say, 10 to 20 times the system charging current level.

Figure 11.1 shows a typical system with a GADD for detection of the first fault. MGFR Relays provide selective indication and second ground fault protection. Indication of fault level appears on the numeric display on the MGFR Relays. Each feeder relay may be set as shown.

FIGURE 11.1:

DOUBLE-FAULT DETECTION WITH MGFR RELAYS



Different time delays can be used to prioritize the feeder branches; however, time delays may cause excessive damage to occur during double-fault, short circuit conditions.

There is a system that provides a simpler solution with greater flexibility: the type DSP Ground Alarm/Trip Unit. The DSP offers an instantaneous trip to minimize damage in the event of a double-fault, while providing a priority selection between different feeder circuits, so that only one feeder trips on the double-fault.

Like the DSA, the DSP is a modular system with a 19 in. rack type mainframe (DSP-MF2) and plug-in units (Modules). The mainframe includes a combination power supply/Control Module in the first three slots of the frame, leaving 8 slots free for the Feeder Modules. Like the DSA, the system is expandable by addition of an Extender Frame (DSP-EF) which can hold a further 10 Modules. Up to three Extender Frames can be added to provide up to 38 Modules. Although they appear similar, the frames of the DSP and the DSA are different. The slots are keyed to prevent installation of DSA Feeder Modules in a DSP frame and vice versa.

The Control Module (DSP-CM2) indicates which phase is faulted, and the magnitude of the fault is provided by a combination ALARM/METER bar-graph indicator. The bar-graph indicates ALARM by lighting up 100%; otherwise it acts as a Level Indicator. An alarm relay is included with Form C contacts to alert the maintenance personnel to the event of a fault on the system.

The Control Module also indicates, with ALARM, if the DDR2 fuses are blown.

To set the Feeder Modules to the correct calibration it is only necessary to set one ground current switch located in the Control Module. The Control Module is identical to that for the DSA system.

Feeder Modules for the DSP are different from those of the DSA, however. They have only one sensor input, but they provide a Form C contact for trip control of circuit breakers. The Module indicates the first fault with a single LED indicator when the ground current in the sensor reaches 50% of the Maximum System Ground Current – as determined by the grounding resistor. TRIP level is fixed at 80A primary sensor current. Time delay may be either instantaneous or delayed depending on the PRIORITY setting of the Feeder Module, compared to that of the other Feeder Module(s) which, in a double-fault situation, must necessarily have ‘seen’ the fault also. To ensure that only the least important breaker trips, a priority system SIFT (Selective Instantaneous Feeder Trip) is employed. The Feeder Modules are set to one of 16 levels of priority selection using a switch located on each Module. When two Modules are required to trip, the one which is set to the lower priority number, trips instantly. If they are set to the same number, then the feeder which faulted first, trips first. Note that a delay of at least 200ms must occur between faults, for the priority system to work. Faults occurring simultaneously, will not be prioritized, and both breakers will trip at the same time.

SPECIAL MODULES

Two other Feeder Modules are offered which provide a trip output on the first fault. These are used in systems where the damage to equipment takes precedence to the continuity of service. The DSP-FM/T trips instantly on first fault and the DSP-FM/TD trips on first fault after a delay, set by the user.

TEST MODULE

Although the Modules are designed to be pulled out of the frame, with the power on, it is not uncommon for a breaker to be tripped when the Module is pulled. In order to check Modules for Priority Setting, a Test Module DSP-TM is available to read the priority of each Module without removing it. The Module requires two slots in the frame to be available. In addition, the Test Module can check the functionality of each Feeder Module and it's SIFT circuit operation. One Test Module can be moved from system to system, but it requires that two blank plates be installed whenever one is removed for an extended period of time, to cover the open slots. The Test Module can also test those Modules in the Extender frames, if any.

11.1 DSP COMPONENTS

1. Each system must have:

- a) One mainframe type DSP-MF2* and Extender Frame(s) DSP-EF, if more than 8 circuits to be protected. Adapter DSA-MA is required if more than one DSP-EF. See Tables 11.1 and 11.2 for components and maximum capacity.

**supplied with DSP-CM2 Control Module*

- b) One DDR2 Resistance Network

- c) One Feeder Module DSP-FM for each circuit

- d) One ZSCT for each circuit

- e) One Grounding Resistor for Wye transformers or, if Delta, one artificial neutral including Grounding Resistor or Current Limiting Resistor (Medium Voltage)

- f) Blank Plates DS-BP as required, for unused slots.

2. Accessories:

- a) Test Module DSP-TM

- b) Interconnecting Cable DS-MAC

- c) Environmental Cover DSP-EC

3. Sensors

The DSP uses the same Zero Sequence CTs as the DSA - See Section 10.3.1 for sensor details.

TABLE 11.1

DSP COMPONENT

CATALOGUE NO.	DESCRIPTION
DSP- MF2	Main frame complete with control module (DSP-CM2)
DSP-EF	Extender Frame Complete with interconnecting cable with plugs (DS-CABLE) and 1 - Blanking plate (DS-BP)
DSP-FM	Feeder Module with SIFT priority selection
DSP-FM/T	Feeder Module Trip on 1st Fault Instantaneous
DSP-FM/TD	Feeder Module Trip on 1st Fault with Adjustable Delay
DSP-TM	Test Module for DSP Feeder Modules
DS-MAC	Adaptor Cable for Priority Bus, Silence and Reset, when combined with other DSP units.
DS-BP	Blanking Plate to cover unused slots.
DS-MA	Multi-Frame Adaptor to connect more than one Extender Frame
DS-EC	Environmental Cover
DS-PM	Pulsing Module

TABLE 11.2

DSP CAPACITY

DSP-MF2	DSP-EF	DSA-MA	CIRCUIT CAPACITY
1	None	None	8
1	1	None	18
1	2	1	28
1	3	2	38

11.2 TYPICAL DSP SYSTEMS

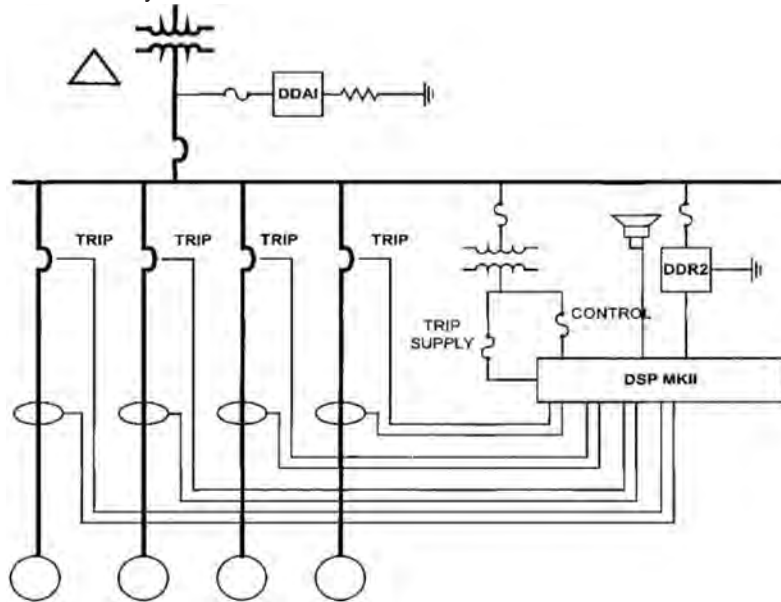
NOTE: The systems may indicate a Delta system, or a Wye system. Either system can be used in any of the diagrams presented. Also with the addition of PTs, medium voltage systems can be created.

Figure 11.2 shows a typical Unit Substation with a single-level protection using a DSP system. A sensor on the Main provides transformer fault protection.

FIGURE 11.2:

UNIT SUBSTATION SINGLE LEVEL DSP PROTECTION.

The Feeder Modules are used to trip breakers in the event of a fault exceeding 80A. This can only occur when there is a double-fault situation. The double-fault might



involve the transformer and one of the feeders in which case only the one faulted feeder will trip. Note that the Main will not trip unless there is a transformer fault. Also a double-fault on the bus or on two feeders will not trip the Main Breaker, because the sensor 'sees' the double-fault as a line-to-line fault which is, to it, a load current. However, usually the fault will be on two of the feeders. The priority system operates to determine the least important (low priority) Module and allows that Module to trip. Obviously, the Main will be set at Priority 15 (highest). The associated breaker 'trips' and clears the double-fault, leaving only a single fault on the system. At that time the tripped Feeder Module will show a flashing red LED (tripped), and the faulted

(higher priority) Module will show a continuous red LED. The ALARM indication will be ON and audible Alarm (if any) will be operated. At this time, an operator will normally SILENCE the Alarm and proceed to locate the faults if possible. Figure 11.3 shows a double-source switchboard with a Normally Open Tie breaker. In this case the two halves of the board operate independently under normal conditions, where both mains are energized. In this case the priorities are set as required for each set of feeders, with important feeders such as Operating Rooms, Elevators, Paper, and Steel Rolling, etc. being set at higher numbers, and low priorities such as Chillers, or Heating, set at lower numbers. It is acceptable to use the same priority number for equal circuits for priority selection. When one of the mains is de-energized for maintenance or black-out, the tie may be closed to allow the other main to provide service. Because of the position of the grounding resistor, up-stream of the main breakers, only one grounding resistor will be used on the system therefore the let-through current of the system remains unchanged. No adjustments have to be made to the DSP system as a result. The tie breaker is associated with an 8-Pole relay which connects the two priority buses together, when the tie breaker is closed. This allows priority levels to be shared across the system of two DSP frames, and the two act as one system.

FIGURE 11.3:

DOUBLE SOURCE, SINGLE LEVEL DSP PROTECTION – NORMALLY OPEN TIE.

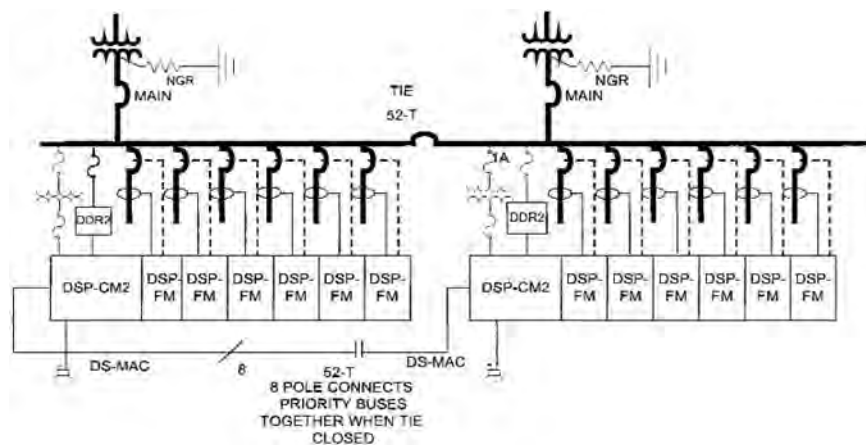
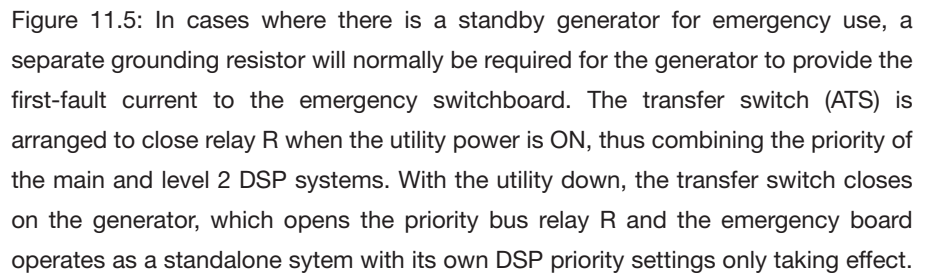


Figure 11.4: This diagram illustrates a two level system with DSP at both levels. In this case it is necessary to switch out the priority buses of those feeders which are switched off to prevent the priority bus from being loaded by the de-energized DSP. This is accomplished by relays R3 and R5 in this scheme.

UNIT SUBSTATION, TWO LEVEL DSP SYSTEM.



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FIGURE 11.5: UNIT SUBSTATION WITH STANDBY GENERATOR AND DSP PROTECTION.

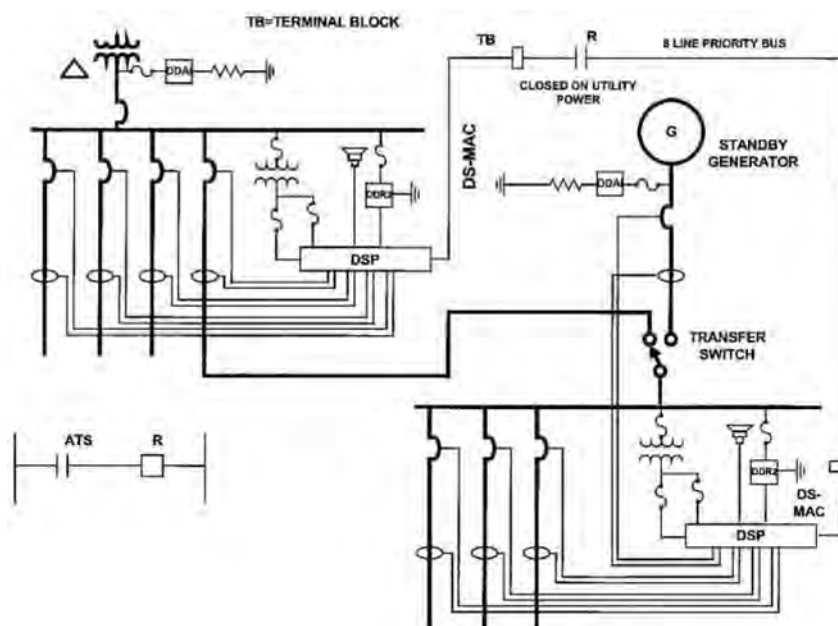


FIGURE 11.6: DOUBLE SOURCE, SINGLE LEVEL DSP PROTECTION WITH NORMALLY CLOSED TIE BREAKER.

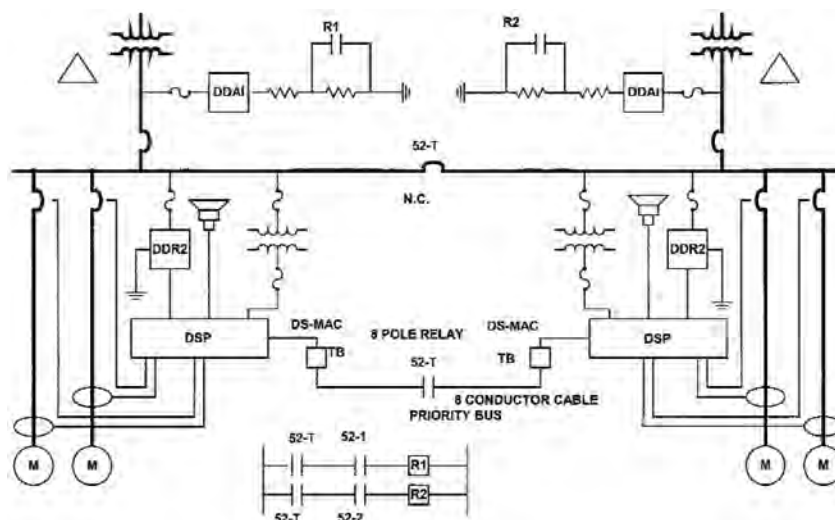
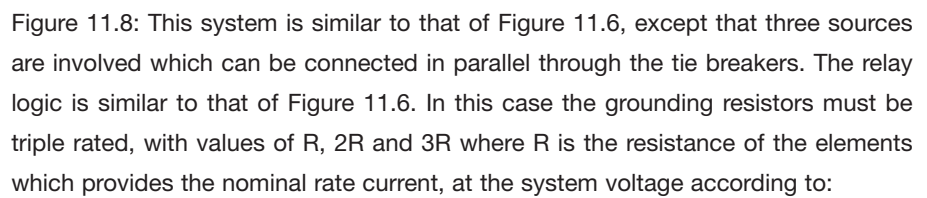


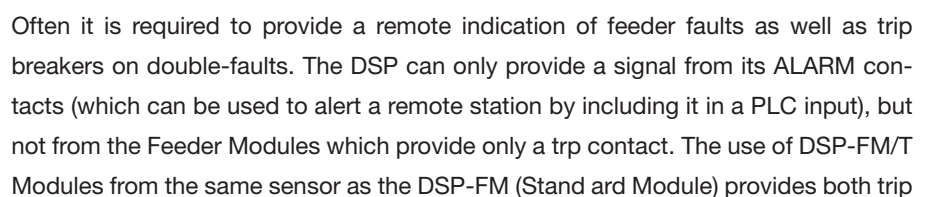
Figure 11.7: The system shown in Figure 11.7 illustrates the use of Extender Frames to increase the number of circuits protected. Note that the Extender Frame can be connected at any level, and not just at the second level.

DOUBLE SOURCE, SINGLE LEVEL DSP PROTECTION WITH NORMALLY OPEN TIE
BREAKER SHOWING EXTENDER FRAME CONNECTION.



$$I_G = \frac{V_L}{\sqrt{3}R_G} \text{ Amperes}$$

TRIPLE SOURCE, SINGLE LEVEL DSP PROTECTION WITH NORMALLY CLOSED TIE BREAKERS.



(Double-Fault) and alarm (Single Fault) contacts, although it takes two slots in the mainframe to do this. The DSP-FM/T trips on first fault and the contacts can be used to drive a PLC or remote lamp indicator.

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FUSION - THE COMBINATION OF SOLID AND HIGH RESISTANCE GROUNDING

Type FSR Resistors: 3 Phase, 3 Wire industrial power systems are solidly grounded to provide a low ground fault path impedance so that in case of ground fault, sufficiently high magnitude of fault current will flow to allow phase overcurrent devices to trip. Settings on these devices are time-current coordinated to provide selective tripping of the device closest to the fault. However, a major portion of the distribution system is affected if the fault is not in the utilization equipment but in any of the major feeders. Such faults, because of coordinated time settings are left on the system for a long time and are known to cause lot a of arcing ground fault damage. They can be catastrophically destructive. Such damage to the equipment and consequential loss of revenue due to down-time can be avoided. If the system is resistance grounded and if the ground fault current is limited to 5 Amps, such low fault currents can be carried continuously at the point of fault without causing further damage. The power continuity to the process is maintained with the system faulted. A shut down can be planned to service and remove the fault, thus avoiding the revenue loss.

On 3 phase 3 wire systems where first fault trip out is desired when the fault is in the load, having an effectively grounded system allows sufficient ground fault current to flow to cause the nearest, often the first, over current device to trip, thus isolating the faulty load.

The current limiting fuse provides such a ground path for the fault current level to flow. Time-current coordination and selectivity is maintained when the size of the fuse is suitably larger than the overcurrent device. For example a 15 A breaker or a 15 A fuse near the load and a 100 A Fuse in the FSR.

Should the fault occur in a higher part of the distribution system the fuse in this case would be faster than the overcurrent device in the distribution equipment thus opening and allowing the fault current to shift to the resistor. The resistor controls the fault current to a value which can be safely carried continuously. The fault is annunciated and can be repaired at a suitable time, thus power flow to loads is maintained by not causing a trip or shutdown. There are many processes and installations where this mode of operation is desirable.

FSR is not suitable to be used in 3 phase, 4 wire systems with single phase or unbalanced loads, as the Electrical Codes require that the neutral remain at ground potential at all times. The neutral can rise to 347 V in 347/600V system when FSR is used so FSR is not applicable and not permitted on 3 phase 4 wire systems.

FSR is also not suitable for 3 phase 3 wire systems where first fault trip is not desired and where power continuity is important. Because FSR effectively grounds the system, upon occurrence of a fault it opens, and the resistor now controls the current, maintaining the power flow to the load.

In such applications, FSR does not add anything to the system which would be more effectively served by other resistive grounding techniques. The Fusion solution to system grounding combines both the solidly grounded functionality and resistance grounded system characteristics. Application of Zero-Sequence sensors with I-Gard Type DSA or DSP ground the existing fault alarm or trip unit will indicate faulted feeder and faulted phase. The fault can thus be quickly located by using one of the several I-Gard pulsing systems and repaired at a planned shut down.

13 HARMONICS

Certain electrical equipment, such as Variable Frequency Drives (VFD), transformers with high exciting currents, converting apparatus (rectifiers, inverters), and arc discharge lighting equipment (fluorescent, mercury vapour, and sodium vapour types) produce harmonics in the load currents. The harmonics do not contribute to ground current as long as there is no fault on the system. The current levels are usually very small and have negligible effect on ground fault relaying. If, however, a ground fault occurs on the DC side of the rectifiers used in VFDs and DC systems, it will not be detected by any of the normal ground fault detectors, because it produces a DC ground current, which cannot be measured by a current transformer. Faults occurring on the variable frequency output of the Variable Frequency Drives require a ground fault relay which can operate over the frequency range of the drive.

14 THE DESIGN PROCESS

The ground fault protection system is an important step in the protection design, and it should be fully incorporated to form the total protection scheme. Therefore, it is required that all the necessary information be available before the design.

A complete single line diagram, containing the transformer data, type and size of the interrupters, the type and current rating of the overcurrent devices, the cable size, type and length of all feeders, load types and sizes, etc., is required for the ground fault protection system design. Additional information, such as operating modes and interlocking systems, special switching arrangement, etc., may influence the design if it is known. The level of supervision can also be a major factor: unattended systems may require fully automatic protection schemes, while selective indication may be sufficient for attended ones, where preventative and corrective maintenance can be scheduled.

The following step-by-step procedure is recommended:

1. Become familiar with the system, by studying the single line diagram and discussions with end-user.

-
2. Decide if the system requires:

 - a) Indication only (GIL or GM)
 - b) Alarm Only (GADD or GIL)
 - c) Alarm + Indication only (DSA)
 - d) Alarm + Indication and Second Fault Trip (DSP)
 - e) Alarm + Double-Fault Trip (GADD + MGFR)
 - f) Fault Locating Equipment
 3. Select a protection scheme which is suitable for the system under all operating conditions e.g. Ties Open, Closed, Interlocked.
 4. If no charging current data is available, make the approximate calculations, using the data in this guide, or "Rule of Thumb". Select the grounding resistor and/or DDAI Artificial Neutral.
 5. Select the system components (see the DDR2 and ZSCT data sheets).
 6. Contact I-Gard for pricing or budgetary costing.
 7. Detail the system, its operation, changes or modifications required on the existing system, and the list of components, including material to be supplied by the end-user.
-

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CATALOGUE SHEETS

Additional information is available in the following Catalogue Sheets:

Type MGFR Relays

Type GADD Ground Alarm Relays

Type GM Ground Current Meters

Type GIL Grounding Indication Lamps

Type DSA Ground Alarm System

Type DSP Ground Alarm/Trip Unit

Type NGR Grounding Resistors and DDAI Artificial Neutrals

Type DDR2 Alarm Resistors

Type DS-PM Pulsing Unit

Zero-Sequence Current Sensors

Stop Light

Sleuth

Turbo Sleuth

Fusion

Gemini

APPENDIX I

In charging current calculation the following formulae are used:

CAPACITIVE REACTANCE	$X_c = \frac{10^6}{2\pi f C_0}$	ohms/phase
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ZERO-SEQUENCE CAPACITANCE	$C_0 = \frac{10^6}{2\pi f X_c}$	$\mu\text{F/phase}$
----------------------------------	---------------------------------	---------------------

CHARGING CURRENT	$3 I_{C0} = \frac{2\sqrt{3}\pi f C_0 E}{10^6}$	Amperes
-------------------------	--	---------

WHERE	f = Frequency in Hz. C_0 = Capacitance to Ground in μF E = Line-to-Line System voltage
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CABLE CAPACITANCE The capacitance of any type of cable may be calculated from the specific inductive capacitance (also called SIC, dielectric constant, or permittivity) as follows:

Single conductor cable or 3-conductor shielded cable:

$$C_0 = \frac{0.00736\varepsilon}{\text{Log}_{10}\left(\frac{D}{d}\right)} \quad \mu\text{F/1000Ft}$$

For 3-conductor unshielded cable:

$$C_0 = \frac{0.00834\varepsilon}{\text{Log}_{10}\left(\frac{D_1}{d}\right)} \quad \mu\text{F/1000Ft}$$

C_0 = capacitance to ground per phase in μF per 1000 feet.

ε = specific inductive capacitance of insulation.

D = outer diameter of the cable insulation for single conductor cable.

D_1 = $d + 3c + b$ for three conductor cable.

d = diameter of the conductor

c = thickness of insulation of conductor

b = thickness of belt insulation

Values of ϵ at 15°C (60°F)

Air	1.0
Impregnated Paper	3.0 - 5.0
Varnished Cambric (VC)	4.0 - 6.0
Varnished Dacron Glass (VDG)	2.3
Vulcanized Rubber	2.7 - 6.5
Magnesium Oxide (M1)	6.0 - 9.0
Silicon Rubber (SR)	3.2 - 3.5
Polypropylene(EPM or EPDM)	2.2 - 2.5
Butyl Rubber (IIR)	3.6 - 3.8
Ethylene Propylene Rubber (EPR)	3.5 - 3.8
Styrene Butadiene Rubber (SBR)	3.5 - 3.8
Versatol	3.5 - 4.0
Polyvinyl Chloride (PVC)	3.5 - 4.6
Polyethylene (PE)	3.7 - 8.0
Kynar	7.7
Vinyl	5.8 - 6.0
Polytetrafluoroethylene	2.1 - 2.5
Nylon	3.5 - 4.6
Polychloroprene - Neoprene	8.0 - 10.0
Geoprene	8.0 - 10.0
Polyurethane	5.6 - 7.6

CHARGING CURRENT ESTIMATION For rough estimation, the following approximate capacitance values can be used:

TRANSFORMERS $C_0 = 0.01 - 0.001 \mu F$

OVERHEAD LINE $C_0 = 0.01 \mu F/\text{mile}$

CHARGING CURRENT
$$3I_{C0} = \frac{2.14(LE)}{1000\sqrt{3}}$$

Where:

L = Line length in ft./1000

E = line-to-line operating voltage in kV.

CABLE Typical C_0 values are plotted in Figure 1.1 for paper or varnish cambric insulated cables. Ten percent of the values may be used for single conductor nonshielded cables when in metallic conduit.

The approximate charging current of a motor can be calculated by the following formula:

$$3I_{C0} = 0.05 \frac{HP}{RPM} \quad \text{Amperes}$$

SURGE CAPACITORS

Surge capacitors, if connected from line to ground, contribute to the charging current also. Standard ratings and constants are tabulated in Table 1.1. The charging current of non-standard surge capacitors also can be calculated:

$$3I_{C0} = \frac{2\sqrt{3} \pi f C E}{10^6} \quad \text{Amperes}$$

E = line voltage (V)

C = capacitance in $\mu\text{F}/\text{phase}$

FIGURE A1.1: CABLE CAPACITANCE

FIGURE A1.3:

MOTOR CAPACITANCE TO GROUND VALUES.

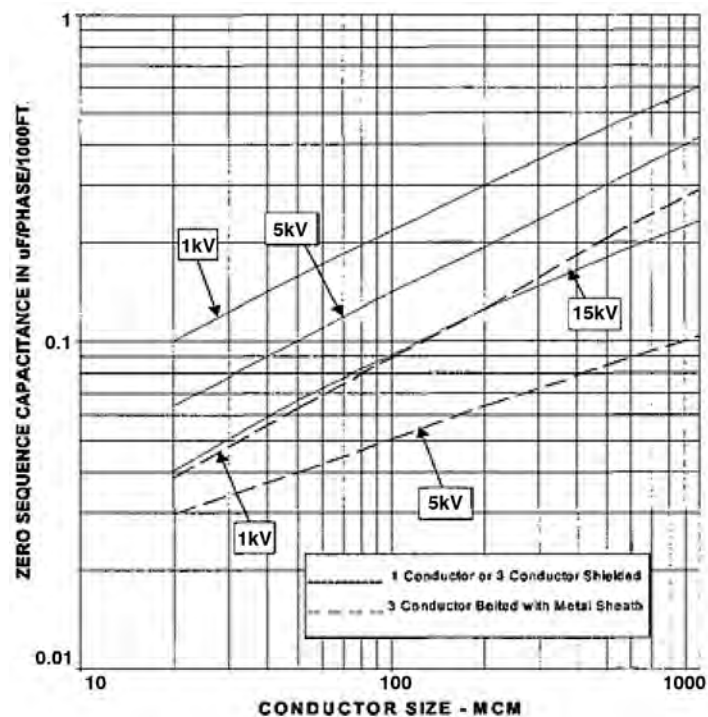


FIGURE A1.2:

CABLE CHARGING CURRENTS FOR COMMON CABLE SIZES.

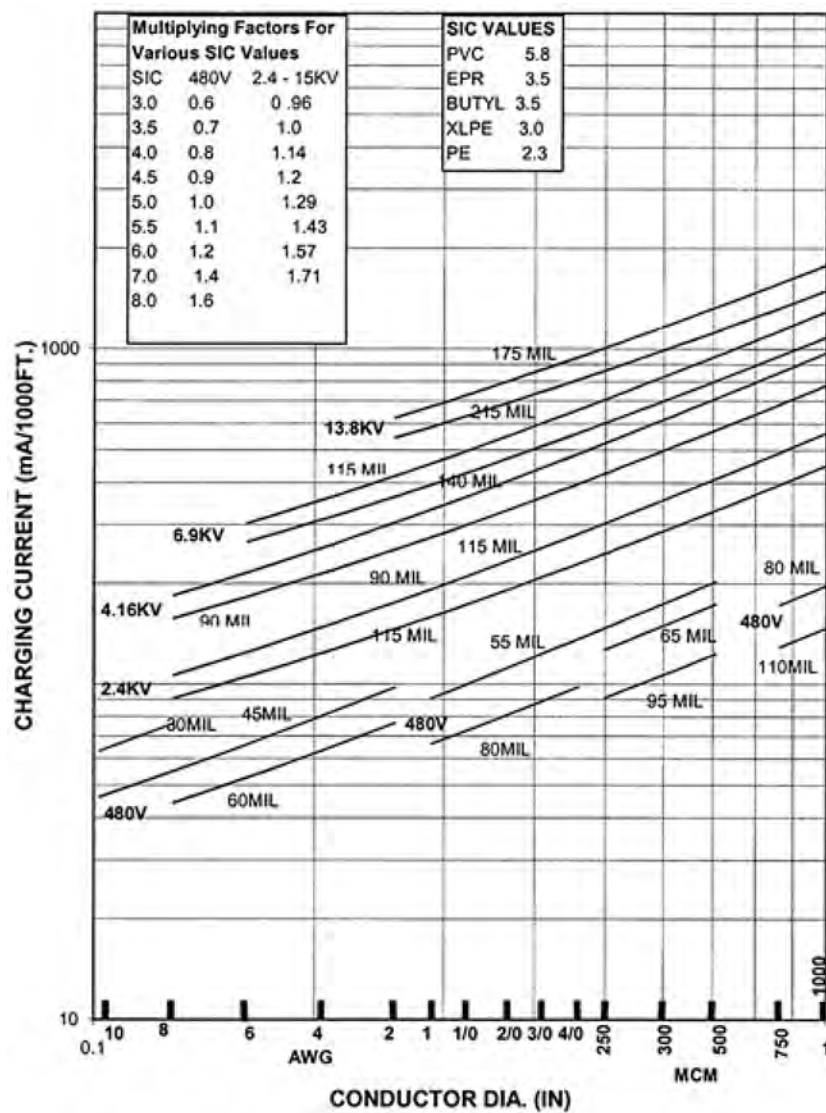
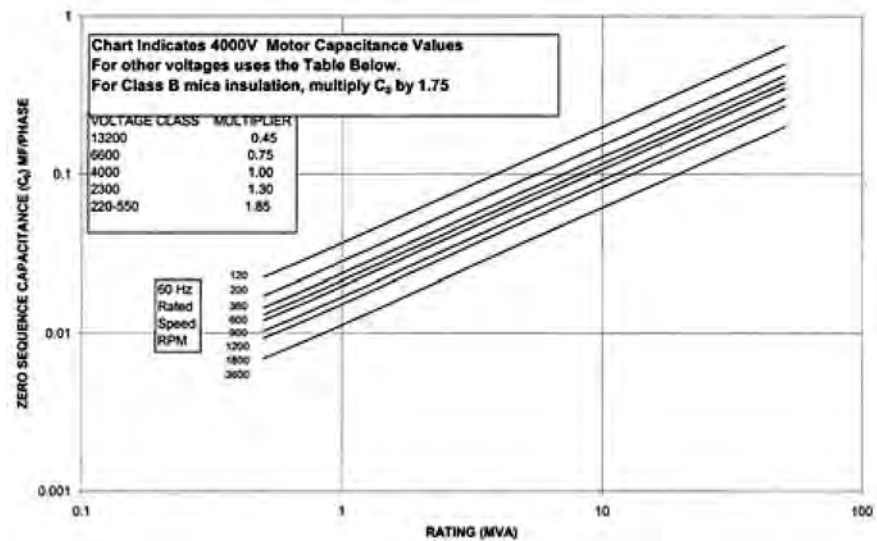


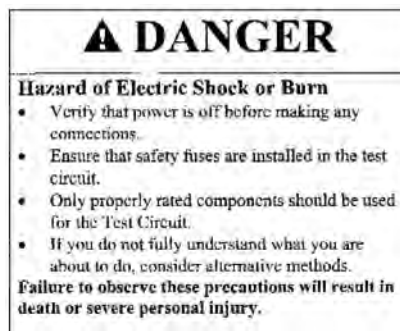
TABLE A1.1

SURGE CAPACITOR VALUES

RATED VOLTS	CAPACITANCE $\mu\text{F}/\text{POLE}$	CAPACITANCE REACTANCE OHMS/POLE	$3I_{C0}$ AMPS.
480	1.00	2650	0.313
600	1.00	2650	0.393
2400	0.50	5300	0.783
4160	0.50	5300	1.360
4800	0.50	5300	1.566
6900	0.50	5300	2.250
11500	0.25	10600	1.875
13800	0.25	10600	2.250

APPENDIX 2

CHARGING CURRENT MEASUREMENT



The measurement of system charging current, $3I_{C0}$, is a relatively simple procedure but, as on all occasions when one deals with energized distribution systems, a careful consideration of the problem followed by the use of the proper precautions is essential.

On low voltage systems, the charging current can be measured by intentionally grounding one phase as shown in Figure A2.1.

The apparatus required for measurement on low voltage systems consists of an ammeter with ranges up to 10 amps, an HRC fuse and a disconnecting switch with adequate continuous and interrupting rating, such as a QMQB switch or a circuit breaker connected in series as shown in the diagram. The fuse is provided for equipment and personnel protection against the occurrence of a ground fault on one of the other phases while the measurement is being made. For this test, the entire system should be energized if possible.

It is recommended that a properly rated variable resistor should also be connected in the circuit to minimize transient changes in the system charging current when the phase conductor is brought to ground potential by progressively decreasing the resistance to zero.

With the resistance set for maximum, the current should be limited to half the estimated charging current (Table A2.1).

$$R = \frac{2E}{\sqrt{3} \cdot 3I_{C0}} \quad (\text{Ohms}), \text{ where}$$

$3I_{C0}$ = the estimated charging current.

TABLE A2.1

TYPICAL CHARGING CURRENTS

SYSTEM VOLTAGE	CHARGING CURRENT ($3I_{C0}$) AMPS/1000 KVA OF SYSTEM CAPACITY
480	0.1 - 2.0
600	0.1 - 2.0
2400	2.0 - 5.0
4160	2.0 - 5.0
13800	5.0 - 10.0

NOTE: Contribution of surge capacitors are not included in Table A2.1.

An essential requirement is a firm electrical connection to one phase of the system. As the measurement can be made anywhere on the system one of the best ways is to de-energize a part of the system, bolt or clamp the ground, bolt or clamp on the electrical apparatus to one phase, and then re-energize the system. During the tests it is required that the entire system be energized.

The test procedure should adhere to the following sequence. All resistance of the variable resistors should be in before closing the disconnect switch ahead of the fuse. After closing the disconnect switch slowly, reduce the resistance to zero, the ammeter will indicate the system ($3I_{C0}$) charging current. It is advisable to have several ranges available on the ammeter but the disconnecting switch should always be opened before a range change is made to eliminate the possibility of opening the circuit with the range switch.

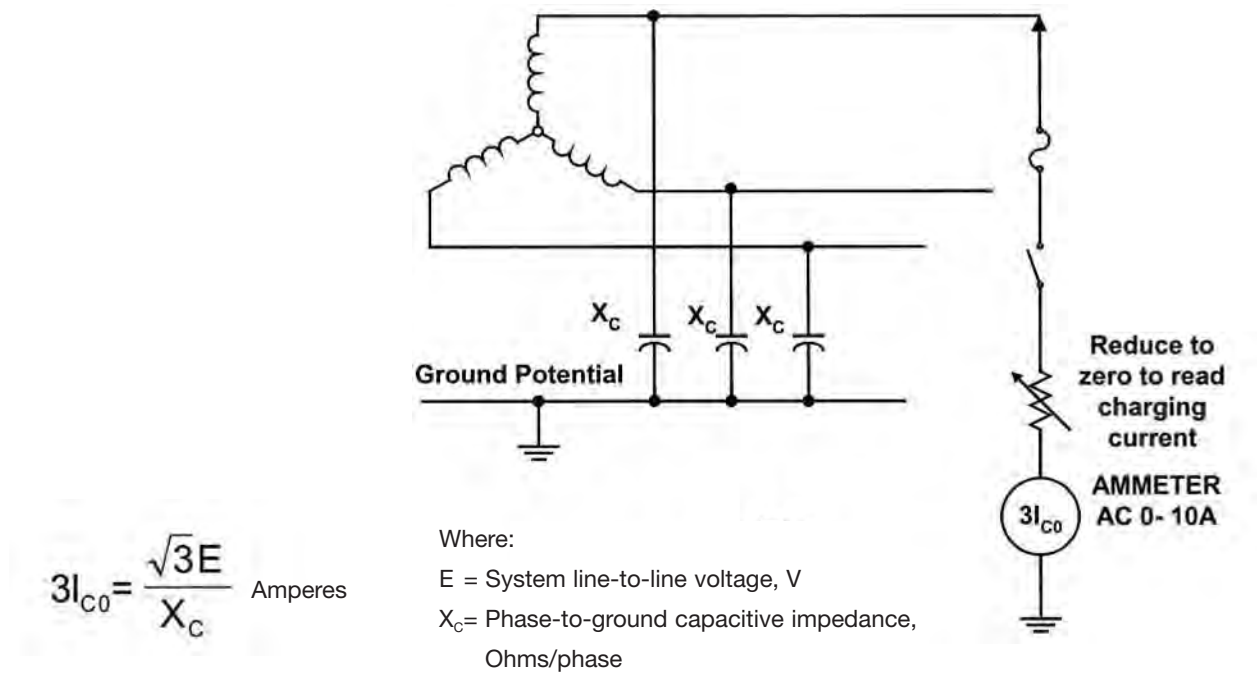
To remove the test connections, the sequence should be reversed. First, increase the resistance to maximum, and then open the disconnecting switch.

Although the three phases usually have approximately equal charging currents, all three should be measured, and the average value used.

By using properly rated equipment, similar measurements may be made on medium voltage systems also.

FIGURE A2.1:

MEASUREMENT OF CHARGING CURRENT.



SUMMARY

GROUND FAULT PROTECTION ON UNGROUNDED AND HIGH RESISTANCE GROUNDED SYSTEMS

INTRODUCTION

Ungrounded distribution systems are used in industrial installations due to their ability to provide continuous service with a ground fault on one phase. A single phase failure to ground does not cause high current to flow because the current is limited by the capacitance of the other two phases, but the voltage to ground of the other phases rises 73% stressing the insulation of cables and other equipment connected to the system. It is a common practice to run a faulted ungrounded system until it is convenient to shut it down for repairs.

Unfortunately, an ungrounded system is susceptible to a build-up of high voltages (up to six times the nominal system voltage) when the first fault on the system is of the intermittent arcing type. This high voltage can initiate a second fault at the weakest insulation point on the system. A second fault to ground on the same feeder will usually cause high fault currents to flow between the two insulation failures. The overcurrent devices protecting the circuit involved should operate to clear the fault. However, a phase-to-ground-to-phase fault on two different feeders with a high ground path impedance between them, or insulation failure that may not be complete, causes a high resistance fault to develop, resulting in smaller magnitudes of current flowing into the faulted areas. The magnitude will not be sufficient to operate the overcurrent devices, and will cause extensive damage to the equipment, requiring expensive repairs or an extended shutdown until the equipment can be replaced.

Locating and repairing the first ground fault is of prime importance, but in most continuous process plants this is not an easy job, since some portion of the operation would have to be shut down in order to isolate the problem area.

Overvoltages caused by intermittent arcing faults, can be held at phase-to-phase voltage by grounding the system neutral through a resistance, which limits the ground current to a value equal to or greater than the capacitive charging current of the system. This can be achieved on a Wye-connected system by a neutral grounding resistor, connected between the Wye point and ground, and on a Delta-connected system by applying an artificial neutral.

SYSTEM CAPACITANCE

The line-to-ground capacitance associated with system components determines the magnitude of zero-sequence charging current. This value of current is required for proper selection of high resistance grounding equipment.

The charging current of a system can be calculated by summing the zero-sequence capacitance or determining capacitive reactance of all the cable and equipment connected to the system. From this the current can be calculated. If actual values are not available, graphs and approximation formulae can also be used.

SELECTION OF HIGH RESISTANCE GROUNDING EQUIPMENT

For correct application the let-through current of the high resistance grounding equipment should be equal to or slightly higher than the capacitive charging current of the system. The installation of a tapped ground resistor unit is recommended when a system expansion is expected at a later date or the designer is unsure of the charging current value.

In Canada, the high resistance grounding concept can be applied on any low and medium voltage system if the ground fault current does not exceed 5 Amperes, by Canadian Electrical Code.

In the USA, the high resistance grounding concept can be applied to any low voltage system (< 1000V) if the ground fault current is limited to a "low value" by NEC. A "low value" is considered to be 10A or less.

At higher ground fault currents values, tripping on the first fault is required to limit the burning damage on systems.

The high resistance grounding equipment should have a continuous duty rating when the service continuity is prime concern. Short time rated devices (10 seconds, 1 minute or 10 minutes) can also be applied, but the fault must be removed within the time period of the short time rating.

THE DESIGN PROCESS

The ground fault protection system is usually the last step in the distribution system design, but it should be considered from the beginning, and implemented in the total protection scheme. Therefore, it is required that all necessary information be available before commencing with the design, if possible.

A complete single line diagram, containing the transformer data, type and size of the interrupters, the type and current rating of the overcurrent devices, the size, type and length of all feeders, load types and sizes, etc., is required for the ground fault protection system design. Additional information, such as operating modes and interlocking systems, special switching arrangements, etc., will influence the design. The state of supervision can also be a major factor: unattended systems may require fully automatic protection schemes, while selective indication may be sufficient for attended ones, where preventative and corrective maintenance is scheduled in weekly or monthly periods.

**NOTES ON SELECTING DEVICES
UNGROUNDING AND HIGH
RESISTANCE GROUNDED
SYSTEMS**

1. Indication of which phase has been grounded anywhere on the system.

Use: Ground Indicating Lights Type GIL or preferably Ground Alarm Relay Type GADD

2. Indication of which phase and provision of selectable alarm pick-up as percentage unbalance in the phase to ground voltage due to fault on one phase.

Use: Ground Alarm Relay Type GADD, with Alarm Resistor Unit Type DDR2.

3. To provide a source of fault current, and at the same time reduce transient over-voltages caused by intermittent ground faults on ungrounded systems, neutral grounding resistors are required (Type NGR). If the transformer secondary is star (Wye) connected, only the NGR will be necessary; however, if the secondary winding is Delta connected then a zig-zag transformer with a grounding resistor is recommended. The two together compose the artificial neutral (Type DDAI). On indoor 1A and 2A units up to 600V, the resistor and zig-zag transformer are combined in one enclosure. All others require the use of two separate devices.

Use: NGR and DDAI

4. For alarm and indication of which feeder and which phase is required, then use of a comprehensive type DSA multi-circuit alarm unit is required. A Neutral Grounding Resistor Type NGR and/or Artificial Neutral, and DDR-2 Alarm Resistor Unit, is essential. Up to 32 feeders are provided in one relay frame and it can be extended by using extender frames.

Use: Type DSA, DDR-2 and NGR or DDAI.

5. In the high resistance grounded system, power continuity is critical, and it is expected that the system will continue to operate with one ground fault. To provide protection in the event of a subsequent ground fault on another feeder and another phase.

Use: Type DSP System Protection unit with Neutral Grounding Resistor and DDR-2 Alarm Resistor unit.

6. On high resistance grounded systems where there are few circuits, alarm only on first fault and trip only on double-fault.

Use: MGFR Ground Fault Relay along with items indicated in 2 and 3.

NOTE: Zero-sequence Current Sensors type R (Rectangular window) or type T (Toroidal) are applied to detect ground fault current on individual feeders being monitored. Toroidal are preferred when possible.

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