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Revision Memo

- 12/01** Highlights of this revision are:
1. Updated "References" and added IEEE Std 141.
 2. Revised "Background" section regarding use of high-resistance grounded systems.
 3. Revised definition of "Low Voltage System" and "Ungrounded System".
 4. Revised "The Ungrounded System" and Figure 1.
 5. Revised "The High Resistance Grounded System" section of "The Grounded System" and Figure 3.
 6. Revised "Solidly Grounded System Design" sections dealing with use of "Maximum Distance Tables" to be consistent with GP 16-4-1.
 7. Revised 50GS requirements in "Adequate Ground-Fault Protection" section of "Solidly Grounded System Design".
 8. APPENDIX in previous revision now APPENDIX A and added new APPENDIX B.
 9. Added "Maximum Distance Tables 1A, 1B, 2A, 2B, 3A, 3B & 4 in APPENDIX B.
 10. Reference to International Practices/IPs replaced with Global Practices/GPs.



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SCOPE

This section covers the low-voltage (1000 volts and lower) system ground fault protection practices normally used in ExxonMobil plants. The section includes information on the methods normally used for grounding the low voltage system neutral and on the protective system and component design and application.

REFERENCES

GLOBAL PRACTICES

- GP 16-2-1 Power System Design
- GP 16-4-1 Grounding and Overvoltage Protection
- GP 16-12-1 Switchgear, Control Centers and Bus Duct

OTHER LITERATURE

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BACKGROUND

Early three phase distribution systems in industrial plants were operated with ungrounded neutrals. As ungrounded systems grew larger, in the late 1940s, users found the systems could be subject to damaging transient overvoltages under certain fault conditions. It was found that grounding the system neutral could prevent most of these transient overvoltages.

Per ExxonMobil practices, low-voltage system neutrals may be either solidly grounded or high resistance grounded. Proposals for ungrounded systems and for systems grounded through Petersen coils need the approval of Owner's Engineer. High-resistance grounding may be specified where permitted by regulations. The National Electrical Code of the USA requires solid grounding of low-voltage systems that have line-to-neutral loads. Ungrounded operation is not normally considered in the design of new low-voltage systems because of the risk of excessive overvoltages during arcing ground faults. Low-resistance grounding is not considered for low-voltage systems because it would require sensitive ground-fault protective devices throughout the system, which would be costly.

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BACKGROUND (Cont)

The high resistance grounded system's main advantage over the solidly grounded system is that it allows continuity of service to loads after the first line-to-ground fault has occurred on the supply feeder to the load. Service can continue until a planned shutdown can be made to repair the faulted feeder. On solidly grounded systems, feeders are automatically tripped when the first line-to-ground fault occurs, and the loads on the faulted feeders are shutdown.

For effective operation, users of high resistance grounded systems must commit themselves to a maintenance program to promptly locate and repair first line-to-ground faults. First line-to-ground faults not promptly removed can escalate to double line-to-ground faults with resultant flash hazard to personnel and equipment damage. The same hazard can result if a second line-to-ground fault occurs before the first ground fault is removed.

DEFINITIONS

CHARGING CURRENT

For an individual feeder, charging current is the steady-state **per-phase** current that flows in the feeder due to the inherent capacitances of the feeder and of any electrical equipment connected to the feeder. For individually-shielded cable conductors, the charging current of the conductor is due only to the line-to-ground capacitive reactance, X_{c0} , of the conductors. For individual cables that are not shielded, and for bare-conductor overhead lines, both the line-to-ground and the line-to-line capacitances of the conductors give rise to charging current. For the purposes of this practice, **only the line-to-ground charging current, due to X_{c0} , is relevant.**

For an electrical system, the system's steady-state **per-phase** charging current (herein called I_{c0}) is the sum of all the charging currents associated with that phase. The mathematical quantity that equals three times the system's per-phase charging current to ground is sometimes called the system's total charging current to ground (1 to 2 amperes for most low voltage systems). This quantity (3 times I_{c0}) is equal to the capacitive component of the fault-point ground-fault current during a line-to-ground fault.

EQUIPMENT GROUNDING

An intentional connection to ground from non-current-carrying metal parts of a wiring system or from non-current-carrying metal parts of other electrical apparatus connected to the electrical system; e.g., metal enclosures, motor frames, etc.

GROUND

The term used for the earth and for a conducting connection to the earth - where "earth" is a voltage reference plane which, in theory, is large enough and conductive enough that currents passing through it do not cause a resistive voltage drop. A connection to ground can be intentional as in system and equipment grounding, or it can be unintentional as in a ground fault. The purpose of an intentional connection to ground is to establish and maintain the potential of earth at the connection point (for reference or safety purposes), and to conduct ground-fault current into or out of the earth. References to "ground" or "earth" may be to the earth soil, or to a conducting body, in intimate contact with the earth, that has essentially the same potential as the earth; e.g., ground rods, buried lengths of bare wire, buried metallic water pipes, reinforcing bars in building footings, etc.

HIGH RESISTANCE GROUNDED SYSTEM

A system with a high-value resistor intentionally connected between the system neutral and ground. Normally the resistance value is such that ground fault current is limited to 10 amperes or less.

LOW RESISTANCE GROUNDED SYSTEM

A system which has a low value resistor intentionally connected between the system neutral and ground. Normally the resistance value is such that ground fault current is within a range of 25 amperes to several thousand amperes.

LOW VOLTAGE SYSTEM

In this section, a system with line-to-line voltages of 1000 volts or less; e.g., 480 V & 575 V in North America, 380 V & 660 V in Europe.

SOLIDLY GROUNDED SYSTEM

A system grounded through an adequate ground connection in which no impedance has been inserted intentionally; e.g., a system supplied by a wye connected transformer whose neutral is connected directly to ground by a metallic conductor.

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DEFINITIONS (Cont)

SYSTEM GROUNDING

An intentional connection, either solid or through impedance, between ground and at least one point in the current-carrying parts of the system. The connection point in the system is usually at the neutral of a power transformer or generator. When system grounding through impedance is used to limit ground fault current in our plants, the impedance is normally resistive and is sized to provide either a high-resistance or low-resistance grounded system.

SYSTEM NEUTRAL

A point in the current-carrying circuit of a system that is usually used for grounding purposes; e.g., the neutral of a wye connected transformer.

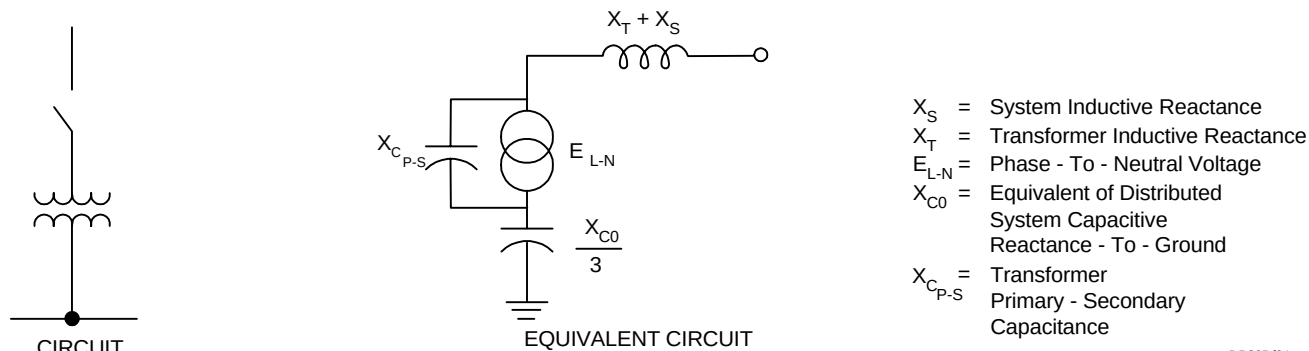
UNGROUNDED SYSTEM

A system without an intentional connection between ground and a point in its current-carrying circuits, except for potential indicating or measuring devices, surge arresters or other high impedance devices.

THE UNGROUNDED SYSTEM

An ungrounded system is one which has no intentional connection between the system and ground. The system is coupled to ground via the distributed capacitance-to-ground of the system conductors, such as the windings of motors and transformers, and the cables of the distribution system. Therefore, the so-called ungrounded system is actually a “capacitively” grounded system. A ground fault on one phase of the system will produce a small flow of current at the fault point supplied from the distributed capacitance of the other two phases. **Figure 1** illustrates the ungrounded system circuit.

FIGURE 1
UNGROUNDED SYSTEM EQUIVALENT CIRCUIT



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The chief advantage of the ungrounded system is that it permits continued operation of a circuit which has a single-line-to-ground fault (the most common fault type) without serious equipment damage or system upset. Ground fault sensing equipment can be used to detect ground faults and to sound an alarm. Orderly shutdowns can be scheduled in order to locate and repair faulted circuits.

There are serious disadvantages associated with the ungrounded system. These are:

- If a ground fault is not located and removed promptly, the possibility exists that the continuous current flow at the ground fault point, although small, will escalate the minimum damage fault into a double line-to-ground or three-phase fault which can cause serious damage. A typical maximum value of this small continuous current flow at the fault point for a 480-volt ungrounded system is 1 to 2 amperes.
- A ground fault on one line causes full line-to-line voltage to appear throughout the system between the two unfaulted lines and ground. This voltage is 73% above the normal value, but conductor and equipment insulation is rated normally to withstand this value. However, if this voltage is applied for long periods, it may result in failure of insulation which may have deteriorated due to age or physical damage.

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THE UNGROUNDED SYSTEM (Cont)

- Ungrounded systems are vulnerable to line-to-ground transient overvoltages (as much as six times normal). The overvoltages can place abnormally high stresses on conductor and equipment insulation. These stresses can cause aged insulation to fail and new insulation to weaken prematurely. More frequent equipment and cable failures can result, and such failures may occur simultaneously in equipment on different circuits.
- While ground fault detection is relatively simple, ground fault location can be difficult and time consuming. Ground-fault location techniques include: de-energizing individual circuits one at a time until the faulted circuit is located; or using a tone or pulse generator and a coupling sensor. These methods are generally inconvenient, and location of grounded circuits may be postponed for long periods.
- If a transformer in an ungrounded system is energized from the primary, with the secondary breaker open, a voltage spike can occur from the secondary side to ground if there is no surge arrester or if the arrester is defective. This is due to the low value of phase-to-ground capacitance when the secondary of the transformer is disconnected from the downstream system. The spike can trigger a flashover and a short circuit.

The well-maintained ungrounded system, in which the first ground fault is promptly located and removed, has the capability for greater service continuity than the grounded system. However, experience indicates that for most plants the grounded neutral system provides adequate service continuity and has other advantages including freedom from transient overvoltages.

THE GROUNDED SYSTEM

NEUTRAL POINT GROUNDING

The most desirable and common method of grounding a system is to make the connection to ground at the system's neutral point. There are other methods such as line grounding and mid-phase grounding, but these methods are rarely used in new systems and will not be covered in this practice.

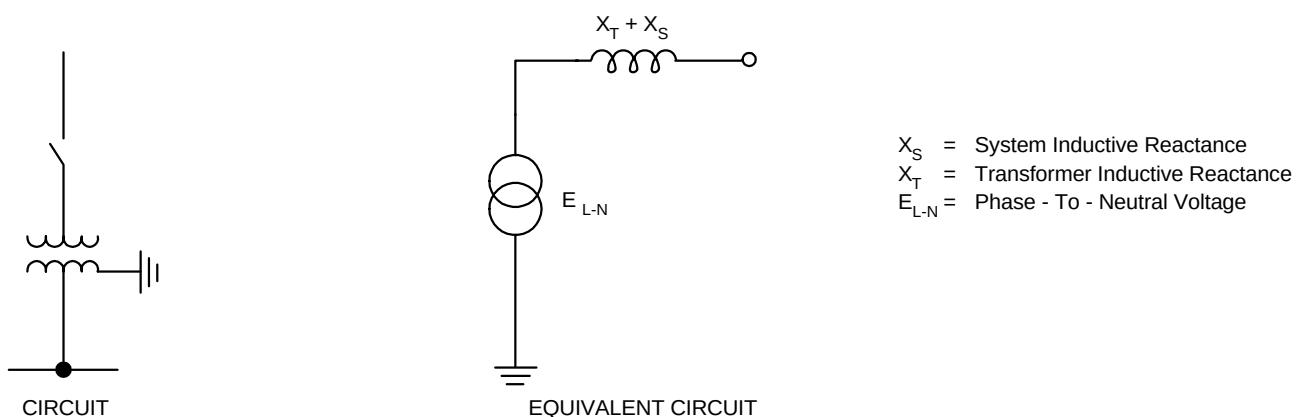
The circuit points for system neutral grounding are obtained in different ways depending on winding configuration of the power sources. In a wye-connected system, the neutral points of the source transformer and/or generator windings are brought outside the equipment enclosure and connected to ground. For a delta-connected power source or for wye-connected sources where the neutral point is not available, zigzag or wye-delta grounding transformers are used to provide the neutral points for system grounding.

ExxonMobil normal practice is to use power transformers with wye-connected secondary windings, or wye-connected generators in systems where there is power generation at the low voltage level. The systems are grounded at the neutral points of these wye-connected sources.

THE SOLIDLY GROUNDED SYSTEM

In solidly grounded systems, the neutral points of one or more power sources are connected to ground without intentional insertion of an impedance. The magnitude of ground fault current is about the same as three-phase fault current. **Figure 2** illustrates the solidly grounded system circuit.

FIGURE 2
SOLIDLY-GROUNDED SYSTEM EQUIVALENT CIRCUIT



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THE GROUNDED SYSTEM (Cont)

The advantages of the solidly grounded system are:

- The magnitudes of transient and steady-state line-to-ground overvoltages are kept within safe limits. For systems having ground fault current approximately equal to three-phase fault current, line-to-ground voltages on unfaulted phases during faults are close to the normal line-to-ground value.
- With properly applied protective devices, ground faults are quickly detected and removed. This fast fault clearing minimizes system upsets and equipment damage.
- The magnitude of ground current is usually high enough so that most phase protective devices are sensitive enough to detect ground faults. As a result, separate ground-fault protection is not always needed.

The disadvantages of solid grounding are:

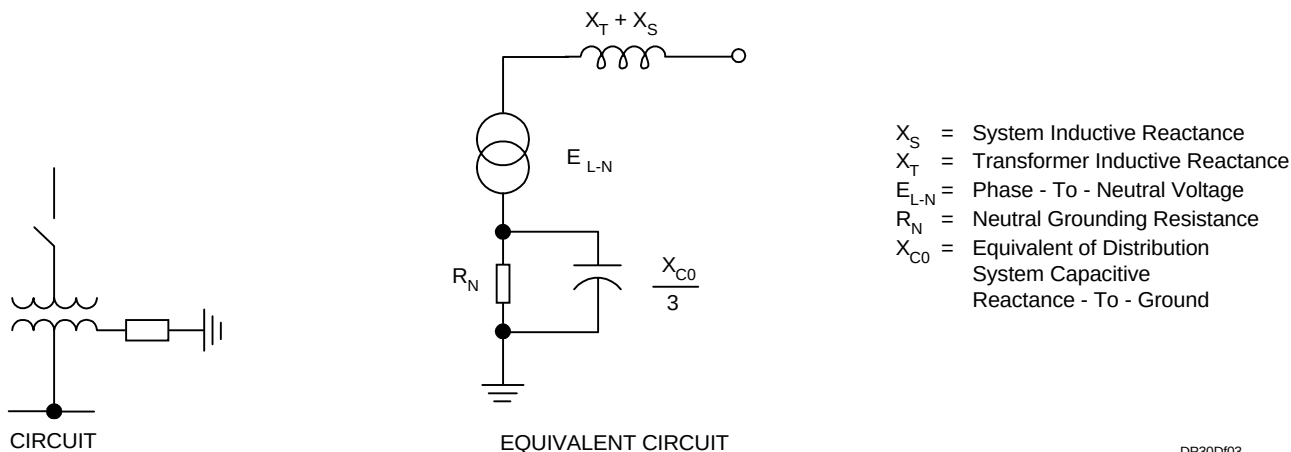
- Although ground faults are quickly isolated, high magnitudes of ground fault current flow before the fault is cleared. Damage at the fault point can be severe, especially if first line protection fails.
- Ground faults cause service interruptions because faulted circuits are disconnected automatically by the protective devices.
- A severe flash hazard to personnel exists where arcing grounds occur. These arcing ground can be self-sustaining and very damaging to equipment if protective devices are not sensitive enough to detect them.

Because the solid grounding method successfully controls overvoltages and provides enough fault current to allow protective devices to quickly and selectively remove faults, it is the most widely used grounding method for low voltage systems. **GP 16-2-1** requires that all low voltage systems be solidly grounded unless high-resistance grounding is specified, or unless alternative methods (ungrounded system or Petersen coil) are approved by the Owner's Engineer.

THE HIGH RESISTANCE GROUNDED SYSTEM

A high resistance grounded system is achieved by inserting a high ohmic value resistance between one or more system neutral points and ground. This resistance is sized to limit ground fault current through the grounding resistance to a value equal to or slightly greater than three times the per-phase system capacitive charging current to ground. The quantity equal to three times the per-phase charging current to ground is sometimes called the total charging current to ground (1 to 2 amperes for most low voltage systems), and is equal to the capacitive component of the ground-fault current during a line-to-ground fault. Protective devices are arranged for detection and alarm. Experience with high resistance grounded systems shows that the total system capacitive charging current to ground for the initial installation and including future expansions should not exceed 3.53 A (preferred) up to 7.07 A (the recommended maximum) where faulted circuits are not disconnected automatically by protective devices. **Figure 3** illustrates the high resistance grounded system circuit. The circuit labeled "Thevenin Equivalent" is an approximate equivalent based on the assumption that the system and transformer reactances are very small compared to R_N and X_{C0} . High resistance grounding is discussed further later in this practice.

FIGURE 3
HIGH-RESISTANCE GROUNDED SYSTEM EQUIVALENT CIRCUIT



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THE GROUNDED SYSTEM (Cont)

The advantages of high resistance grounding are:

- Unscheduled equipment shutdowns caused by line-to-ground faults are avoided because automatic tripping is not used.
- Since very little ground current is allowed to flow, fault point damage is usually small.
- Line-to-ground transient overvoltages, due to inductive-capacitive resonance and repetitive restriking of arcing faults, are limited to safe values (250% of normal or lower). The effectiveness of the system in limiting resonant overvoltages is a function of the ability of the neutral resistance to absorb the energy stored in the system capacitance-to-ground at the instant the fault occurs.
- Arcing grounds are usually self-extinguishing, with limited energy released by the arc.
- Flash hazard for line-to-ground faults is reduced greatly compared to solidly grounded systems.
- The disadvantages of high resistance grounding include:
 1. Ground fault location can be difficult and time-consuming. However, there are detection systems available which trained personnel can use to shorten fault location time.
 2. If a second ground fault occurs on another phase before the first fault is located and cleared, a double line-to-ground fault results with the subsequent damage and automatic tripping of one or two circuits.
 3. System insulation is subjected to higher than normal voltage when a single ground fault occurs. System insulation on the two unfaulted phases will see line-to-line voltage as in the ungrounded system, this may result in failure of weak insulation if the fault remains for longer periods.

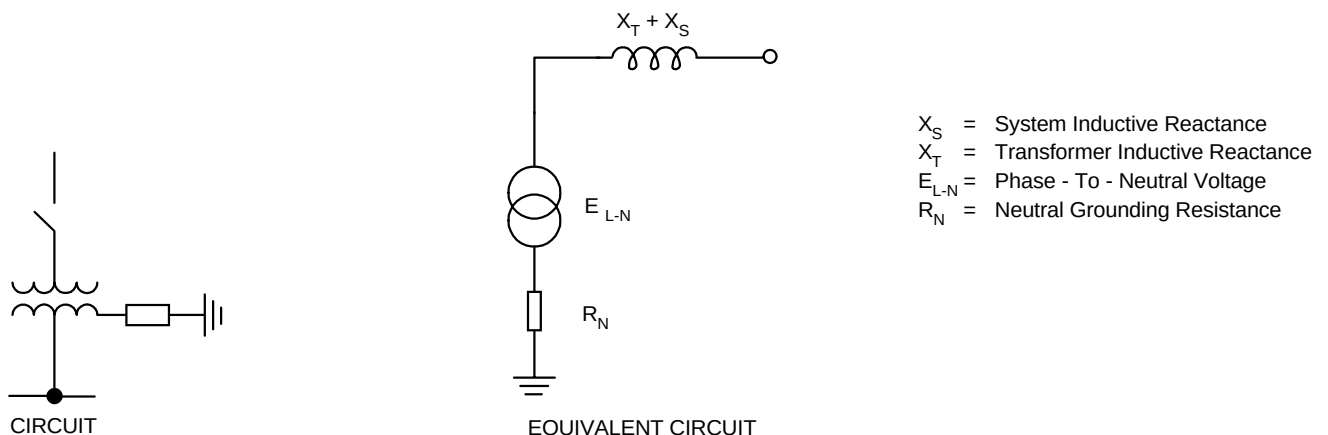
Although solid grounding is the most widely used low voltage grounding method, high resistance grounding is sometimes used where an immediate service interruption, due to a ground fault, is undesirable.

OTHER SYSTEM GROUNDING METHODS

Low resistance and low reactance grounding of the system neutral are two other methods which can be used on low voltage systems. However, these methods have not been used in ExxonMobil plants and their use is generally uncommon.

Low resistance grounding is accomplished by inserting a low ohmic value resistance between the system neutral point and ground. The resistance value is selected to limit ground fault currents to 20% of three-phase fault current and lower, with a minimum of about 400 amperes. Protective devices are arranged to trip when ground faults occur. **Figure 4** illustrates the low-resistance grounded system circuit.

FIGURE 4
LOW-RESISTANCE GROUNDED SYSTEM EQUIVALENT CIRCUIT



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This method has the advantages that transient overvoltages are kept within safe limits and due to the lower fault current and the use of ground fault protective devices, fault damage is reduced compared to damage on a solidly grounded system.

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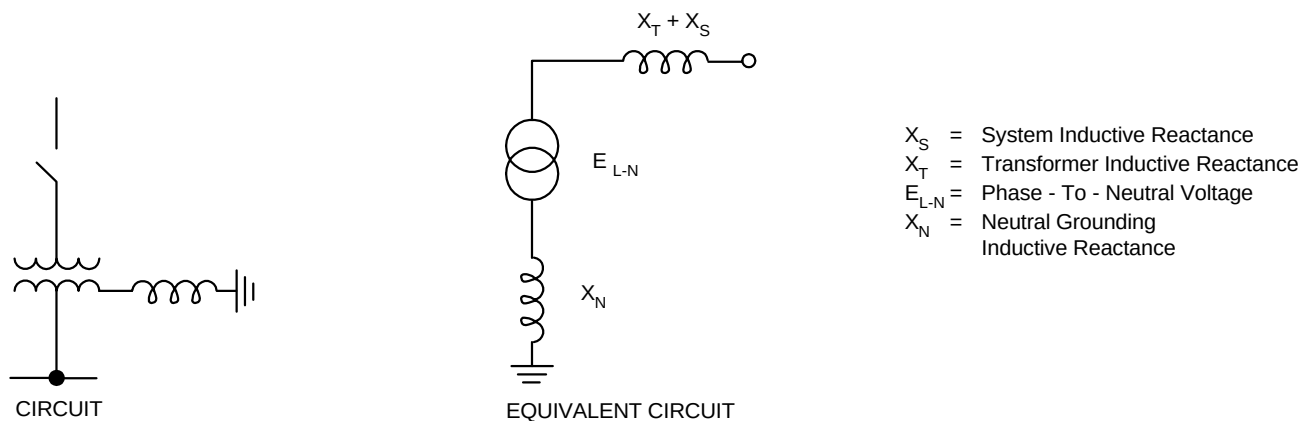
THE GROUNDED SYSTEM (Cont)

The disadvantages of the low resistance grounded system are the additional cost of ground fault protective devices required to provide selective protection, the more severe flash hazard compared with that of a high resistance grounded system, and the unscheduled equipment shutdowns caused by the automatic tripping of faulted circuits.

To date, low resistance grounding has not found wide application in low voltage systems because of the high cost of obtaining selective ground fault protection. This method may find wider acceptance for low voltage applications when small and inexpensive ground fault relays are developed. These relays must be sensitive and compatible with circuit protection used on motor controllers, small feeders, and branch circuits.

Low reactance grounding is accomplished by inserting a low ohmic value reactor between a system neutral point and ground. The reactor is sized to limit ground-fault current levels to between 25% and 100% of three-phase fault levels (usually closer to 100%). **Figure 5** illustrates the low reactance grounded system circuit.

FIGURE 5
LOW-REACTANCE GROUNDED SYSTEM EQUIVALENT CIRCUIT



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This method is not often used in low voltage systems. It does have some applications, however, such as when low voltage generation is present. In a solidly grounded system with generators, the ground fault current may be larger than three-phase fault current (for close-in, bolted faults on the generator). To reduce fault current, reactance grounding is sometimes used.

Since ground-fault current levels are approximately equal to three-phase fault levels, this method is similar to the solid grounding method as far as advantages and disadvantages are concerned.

SOLIDLY GROUNDED SYSTEM DESIGN

FAULT CURRENT MAGNITUDE - GENERAL

In order to design an effective protective scheme for a solidly grounded system, the designer must know the range of possible ground fault currents. This range is generally considered to lie between the maximum bolted line-to-ground fault and a line-to-ground fault with arc resistance at the end of an outgoing feeder. The maximum ground fault current must be checked against the line-to-ground fault-interrupting capability of interrupting devices. The minimum fault current due to an arcing ground fault at the end of a feeder is used to determine the adequacy of the feeder's ground fault protection.

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SOLIDLY GROUNDED SYSTEM DESIGN (Cont)

The general equation for calculating ground-fault current is:

$$I_{L-G} = \frac{3E_{L-N}}{Z_1 + Z_2 + Z_0} \quad \text{Eq. (1)}$$

where:	I_{L-G}	=	Single-line-to-ground fault current
	E_{L-N}	=	System line-to-neutral voltage
	Z_1	=	System equivalent positive sequence impedance
	Z_2	=	System equivalent negative sequence impedance
	Z_0	=	System equivalent zero sequence impedance

Note: All sequence impedances are in complex form ($Z_1 = R_1 + jX_1$), and can be in either ohms or per unit, depending on the calculation. In the general case, Z_0 includes the $R_0 + jX_0$ of phase conductors and windings between the relevant neutral and the fault point, **plus** three times any impedances that exist **only in the ground return path** between the fault point and the relevant neutral; e.g., $3Z_N$ (neutral grounding impedance), $3Z_F$ (fault impedance), $3R_{GR}$ (ground return path resistance). X_0 of the phase conductors takes account of the inductive reactance between the phase conductors and the ground return path.

The use of this equation or modifications of this equation are discussed below.

Example 1 in the **APPENDIX A** is a calculation of ground fault current using this equation for a bolted fault at the end of a feeder on a solidly grounded system. **Example 1** makes the simplifying assumption that all impedances upstream of the faulted cable are small enough that they can be assumed to be zero.

MAXIMUM (BOLTED) LINE-TO-GROUND FAULTS

Although bolted line-to-ground faults rarely occur, they are important because they cause maximum ground current flow. The magnitude of this current depends on the line-to-neutral source voltage and the impedances of the sequence networks, per **Eq. 1**. For the maximum line-to-ground fault current at a main source bus of a solidly grounded system, the impedances of the ground return path are all assumed to be zero. Typically, the maximum ground fault current in our solidly grounded systems is somewhat greater than the maximum three-phase fault current.

ADEQUATE GROUND-FAULT PROTECTION PER GP 16-4-1

GP 16-4-1 specifies the basis for determining if circuit ground fault protection is adequate, per the following statement:

“The combined impedance of the ground return path and the supply circuit line conductors shall be low enough to insure operation of the circuit overcurrent protective device in less than two seconds on a single line-to-ground fault at the load end of the circuit. An arc voltage of 40 volts in phase with the line-to-neutral source voltage shall be assumed at the point of fault.”

Our general practice is **not** to provide ground-fault relays on low-voltage circuits if the above basis is satisfied by the phase overcurrent devices. When ground fault relays are applied, the basis in the statement is almost always satisfied by high-sensitivity 50GS relays. The 50GS function of a motor multifunction protective relay (MPR) satisfies this requirement, provided a zero sequence (toroid type) current transformer is used. The adequacy of ground fault protection should be verified if a 51N relay protects a low-voltage circuit. If local regulations regarding ground fault protection are more restrictive than **GP 16-4-1**, the local requirements shall be followed. For example, some codes may require ground-fault relays on all motors of a certain size or larger.

The adequacy of ground-fault protection in low-voltage solidly-grounded systems should be determined, to the extent possible, via the use of the “Maximum Distance” tables in **APPENDIX B**. These tables are discussed below.

MAXIMUM DISTANCE TABLES - APPENDIX B

APPENDIX B provides tables for use in determining the maximum circuit distances allowed by our practices for various cable installations in solidly grounded low-voltage systems. The maximum distances in the tables are based on the “two second, 40-volt arc” criterion discussed above, and are presented as a function of the rating of the overcurrent-device, device operating speed, and the sizes of conduits, cables, and ground-return conductors.

The notes associated with the tables describe how to use the tables; however, clarification is provided below regarding the tables and their use. (Because the “A” tables deal only in ft and the “B” tables deal only in meters, references to distances in these tables are presented in only the units used in the specific table.)

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Clarifications on Use of Maximum Distance Tables

Clarifications on the use of the “Maximum Distance” tables in **APPENDIX B** are provided as follows:

- The tables assume that the impedance upstream of the cable circuit is negligibly small compared to the cable impedance. This assumption is usually valid, but if the upstream impedance is not negligible compared to the cable-circuit impedance, the tables are not directly applicable, and calculations must be performed to take account of upstream impedances. See “When System Impedance Cannot Be Neglected” below.
- The word “Rating” in the heading of each table means “Relay Pickup” (expressed in line-side amperes) when a relay is involved. The word “Rating” is correct for fuses and molded case circuit breakers.
- The notes in the tables refer to protective device operation at a **nominal setting** of 10 times their rating. The words “at a nominal setting of” mean “at a current of”. For example, a fuse characterized by **Factor B** in **Table 1** must operate in less than 2 seconds at a current of 6 times its rating. In **Tables 2** and **3**, the words “divided by device setting” at the end of the next to last sentence of **Note 1** mean “divided by the multiple of device rating at which device operates in just under 2 seconds.”
- The **actual maximum-total-clearing time characteristic** of a protective device must be used to determine the maximum circuit length allowed under the 2-seconds rule of **GP 16-4-1**. **Note 1** of **Tables 2** and **3** indicates how to adjust the table distances upward for protective devices that totally clear a fault within 2 seconds at multiples of rating less than 10. The table distances would have to be adjusted **downward** if there were an MCCB protecting a feeder (without contactor switching), and the MCCB had a 2-second maximum-total-clearing time at a multiple of rating greater than 10. The distances in **Tables 1A** and **1B** cannot be adjusted by the current-ratio method of **Note 1** in **Tables 2** and **3**. Distance data in **Table 1A** or **1B** must be interpolated or extrapolated when it becomes necessary to adjust distance data in these tables. Use of the distance tables is discussed below.

WHEN SYSTEM IMPEDANCE CANNOT BE NEGLECTED

Distance data in the “Maximum Distances” tables is based on the assumption that the impedance upstream of the cable is negligible. A ground fault relay must be added if the actual circuit distance is greater than the maximum allowable distance per the tables. However, if the actual circuit distance is less than the distance determined using the tables, the effect of upstream impedances on table distance should be evaluated if either of the following conditions apply:

- The actual circuit distance is between 90% and 100% of the maximum distance determined using the tables, or,
- The load on a feeder is greater than 10% of the local transformer's OA capacity. Before doing this comparison, adjust the transformer OA capacity downward. If the total impedance upstream of the local transformer is more than 5% of the local transformer impedance; i.e., adjust the transformer capacity downward by the ratio of the transformer's impedance divided by the sum of the transformer impedance plus the upstream impedance.

IMPEDANCE-RELATED ADJUSTMENTS OF TABLE DISTANCES

When the effect of impedance upstream of the cable circuit should be evaluated (per the above), either a short circuit calculation should be performed (as discussed later), or the following method should be used to adjust distances in any of the tables to account for impedance upstream of the cable.



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For each maximum distance ($L_{\max}$) in any of the tables, there is an inherent total-circuit maximum impedance ($Z_{\max}$), which is equal to 237 V divided by the 2-second-clearing current used in the table. The 2-second-clearing current used in **Tables 2** and **3** is equal to the Device Rating times 10. The 2-second-clearing current used in **Tables 1A** and **1B** is equal to the Device Rating times either 10 or 6 or 4, depending on the Trip Setting Factor used to determine $L_{\max}$. To the extent source impedance Z_S , upstream of the cable, uses up some of the total-circuit maximum impedance, the maximum cable-circuit distance in the table must be adjusted downward. The adjusted maximum distance can be closely approximated via the following equation:

$$L'_{\max} = L_{\max} \left(1 - \frac{Z_S}{Z_{\max}} \right)$$

where: $L_{\max}$ is the maximum distance for a cable circuit found by using the table
 $L'_{\max}$ is the adjusted maximum distance
 Z_S is the magnitude of the impedance upstream of the cable circuit, expressed in ohms and referenced to the low-voltage side of the transformer
 $Z_{\max}$ is the magnitude of the maximum allowable impedance upon which $L_{\max}$ is based. $Z_{\max}$ is equal to 237V divided by the 2-second-clearing current used in the table (as explained in the paragraph above).

The upstream impedance, Z_S , for a line-to-ground fault can be determined via symmetrical components (Z_1 plus Z_2 plus Z_0 , all divided by 3). However, when the impedances upstream of the local transformer are negligible, Z_S can be assumed to be equal to Z_T (the impedance of the local transformer).

Note: The biggest impedance-related reductions in table distances occur with the smaller transformers and the higher-rated protective devices. The following table shows example percent reductions in table distances for two local transformer sizes (5% impedance) and two protective device ratings (2-second operation at 10 times rating). The local transformers are assumed to be the only significant upstream impedance.

EXAMPLES OF PERCENT REDUCTIONS IN MAXIMUM DISTANCES

DEVICE	500 kVA TRANSFORMER	1000 kVA TRANSFORMER
125 A Device	12%	6%
70 A Device	7%	3.5%

The following **example** illustrates the need for evaluating the effect of upstream impedance on distances found in the Maximum Distance tables:

A 500 kVA, 480 V transformer, with $Z_T = 5\%$, has an impedance of 0.023 ohms reflected to the 480 V secondary side. Assume a 480V, 100 HP motor, a 2 in. steel conduit ground return, a **400-ft circuit length**, and a 150 A protective device that totally clears a fault in 2 seconds at 1500 A (10 times rating). Assume all other upstream impedances are negligible. The maximum allowable circuit distance in **Table 1A** is **450 ft** (150 A device, 2 in. conduit, TSF = A); however, the load is more than 10% of the transformer rating and the effect of the transformer impedance should be checked. The inherent impedance, $Z_{\max}$, in the table is 0.158 ohms (237 V divided by 1500 A). Per the calculation below, the adjusted maximum distance is **384 ft**, which is about a 15% reduction in allowable distance. Since the actual circuit length exceeds this adjusted limit, a ground fault relay should be added.

$$L'_{\max} = L_{\max} \left(1 - \frac{Z_S}{Z_{\max}} \right) = 450 \left(1 - \frac{0.023}{0.158} \right) = 450 (0.854) = 384 \text{ feet}$$

The adjustment factor of 0.854 applies only to the distance of 450 ft because $Z_{\max}$ is different for each different distance in any of the tables.

USE OF **TABLES 1A** & **1B** - STEEL CONDUIT

Tables 1A and **1B** are to be used when rigid steel conduit is the ground return conductor. The distances in these tables are a function of the conduit size, and the protective device's "Trip Setting Factor" (TSF) and nominal rating - which together define the current a given device requires to operate within 2 seconds.

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The size of the line conductor is not a factor in the steel-conduit distance tables. **Note 2** of these tables gives percent increases in maximum distances when there is a ground-return conductor in the conduit. Distances in **Tables 1A** and **1B** **cannot** be adjusted per the ratio method described in **Note 1** of **Tables 2** and **3**, because the impedance of steel conduit varies with current.

Depending on actual circuit and protective-device parameters, one of the following uses of the data in **Tables 1A** and **1B** will apply:

- The distance data in the tables may be **used without interpolation or extrapolation** when it is obvious that a ground fault relay is either needed or not needed, per the guidelines in the next section, entitled “**Use of Table 1A / 1B Distance-Data - Without Interpolation or Extrapolation**”.
- If it is not obvious from the table whether or not a ground fault relay should be added per the guidelines in the next section, the following procedures should be used:
 - + The distance data in the tables should be **interpolated** if the protective device's actual 2-second clearing current is within the range of 2-second-clearing currents inherent in the table (see below).
 - + The distance data in the tables should be **extrapolated** if the actual 2-second clearing current is outside the range of 2-second-clearing currents inherent in the table.
 - + In all cases, the distance data in the tables may have to be adjusted if the impedance upstream of the cable is not negligible (as explained above).

USE OF **TABLE 1A / 1B** DISTANCE-DATA - WITHOUT INTERPOLATION OR EXTRAPOLATION

To use the distance data in **Tables 1A** and **1B** without interpolation or extrapolation, use the following procedures and guidelines (substitute “pickup” for “rating” when the protective device is a relay):

1. **Determine the actual multiple of device rating** at which the circuit's protective device **totally** clears a fault in 2 seconds.
2. Given the circuit's conduit size and phase protective-device rating, compare the actual circuit distance against the distances found in **Table 1A** or **1B**, per the following guidelines:
 - When there is no data in the table for the device rating and conduit size, interpolation or extrapolation of distance data will be required, unless otherwise noted.
 - **If the actual multiple of device rating (per 1. above) is greater than 10:**
 - + The circuit **does** need a separate ground fault relay if the actual circuit distance is greater than the distance for $TSF = A$.
 - + If the actual circuit distance is less than the distance for $TSF = A$, interpolation or extrapolation of the table data will be required.
 - **If the actual multiple of device rating is less than 10 and greater than 6**, compare the actual circuit distance to the distances for Trip Setting Factors (TSFs) A and B:
 - + The circuit **does not** need a separate ground-fault relay if the actual circuit distance is less than 90% of the smaller distance ($TSF = A$). Note: If there is no distance data for the device rating, the circuit **does not** need a separate ground-fault relay if the actual circuit distance is less than 90% of the “ $TSF = A$ ” distance for the next smaller conduit size that has distance data for the given device rating.
 - + The circuit **does** need a separate ground-fault relay if the actual circuit distance is greater than the larger distance ($TSF = B$).
 - + If the actual distance is between the larger distance and 90% of the smaller distance, interpolation is required and the effect of upstream impedances should be checked.
 - **If the actual multiple of device rating is less than 6 and greater than 4**, compare the actual circuit distance to the distances in the table for $TSF = B$ and $TSF = C$:
 - + The circuit **does not** need a separate ground-fault relay if the actual circuit distance is less than 90% of the smaller distance (for $TSF = B$). Note: If there is no distance data for the device rating, the circuit **does not** need a separate ground-fault relay if the actual circuit distance is less than 90% of the “ $TSF = B$ ” distance for the next smaller conduit size that has distance data for the given device rating.
 - + The circuit **does** need a separate ground-fault relay if the actual circuit distance is greater than the larger distance (for $TSF = C$).

If the actual distance is between the larger distance and 90% of the smaller distance, interpolation is required and the effect of upstream impedances should be checked.