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System Grounding for Low-voltage Power Systems

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Report on Power Systems Grounding

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Report on Power Systems Grounding

Editor's Note: From a practical standpoint, it should be recognized that two methods of low-voltage system grounding—the solidly grounded neutral and the high-resistance grounded neutral (with or without tracing pulse) methods will best fulfill the majority of application requirements. A summary comparison of these two methods is included in the appendix (Page 34) and chart (Page 38) and the reader is urged to view this material. The high-resistance method is *not* suitable for use on four-wire, three-phase service.

This report was prepared by the Task Force on Low-voltage Power System Grounding, which had the following membership:

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THE NEED FOR THIS STUDY

For many years the recommendation of the General Electric Company for the grounding of low-voltage industrial and commercial power systems has been **solid grounding** of the power system neutral. For special operating or safety requirements, alternative methods of grounding — such as high-resistance grounding or low-reactance grounding—have been advised. On the basis of such recommendations a long-term trend toward the installation of power systems with a solidly grounded neutral developed, with the result that such systems are currently the most widely used in industrial and commercial power system design. These systems have, in general, performed adequately and provided the safety, reliability and continuity of service which had been anticipated from them.

Recently, however, it has been suggested that the high-resistance grounded neutral system is better suited for certain systems—particularly insofar as personnel safety and process continuity are concerned. Proposals to this effect have arisen because of serious injuries or fatalities which have occurred to operating or service personnel during line-to-ground arcing faults in solidly grounded neutral systems.

In response to such proposals General Electric's Energy Systems Operation put together a task force which has restudied the question of power system grounding. As part of its activities, this task force has worked to bring into focus the characteristic features of competing alternative grounding methods.

RESULTS OF TASK FORCE STUDY

The typical features of alternative grounding methods are presented herein, covering individually the characteristics, benefits, drawbacks and typical application areas for each of the available methods of low-voltage system grounding which were studied. Specific recommendations of one method of grounding in preference to another have been avoided, however, in recognition that no single method of system grounding will prove unrivaled and completely satisfactory in all the application situations which may be encountered. In illustration of this, the solidly grounded neutral system is very extensively used in industrial and commercial building applications, yet the so-called "ungrounded" system, when complemented with ground-fault detection and first-quality electrical system maintenance, has provided desirable performance characteristics and adequate service in certain process industries.

Additionally, specific recommendations are not given because it is felt that the comparative merits of the various methods of system grounding, for any given set of customer conditions and objectives, will be self-evident from the listing of the characteristics and features of the individual system grounding methods; and that the power system designer, application engineer, or power distribution equipment sales engineer is best qualified to consult with the customer and advise him on the choice of grounding method for his specific conditions and objectives.

TYPES OF SYSTEM GROUNDING REVIEWED

All the methods of low voltage power system grounding which have been applied or used in significant numbers were covered by the task force review. Grounding methods of very infrequent use, such as the dual-resistance grounding and ground-fault neutralizer methods, were not included in this review. The specific methods of power system grounding which are covered in this report are

1. the ungrounded system.
2. solid neutral grounding.
3. low-resistance grounding.
4. high-resistance grounding.
5. high-resistance grounding with traceable signal to the fault.
6. corner-of-the-delta grounding.
7. mid-phase grounding.
8. low-reactance grounding.

For each of these methods of system grounding the characteristic features, advantages, disadvantages, and typical areas of application, as well as general remarks on the particular system of grounding, are given in the following pages.

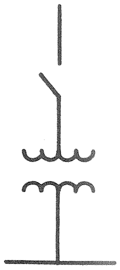
It is appropriate to point out that selection of a specific method of system grounding should not be based on the number of advantages or disadvantages it possesses, since these attributes are not necessarily absolute, and generally have firm meaning and significance only when related to such factors as equipment cost and quality, electrical system maintenance, safety of personnel, damage to equipment arising from ground fault conditions, system protective devices and their settings, power continuity requirements of the process or service being powered, and so forth. In addition, certain attributes are common to most, if not all, of the methods of system grounding; in these instances the attributes may be listed as "characteristic features" in the tabulation, rather than as advantages or disadvantages.

Characteristic Features

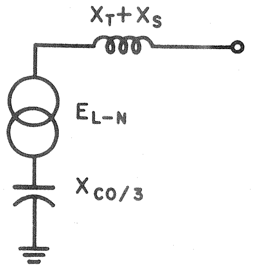
Definition

The ungrounded system is one which has no intentional connection to ground except through potential indicating or measuring devices, or through surge overvoltage protective devices. Although called "ungrounded" this type of system is in reality capacitively coupled to ground through the distributed phase-to-ground capacitance of the windings and phase conductors of the system.

Circuit Schematic and Thevenin line-to-ground equivalent circuit diagram①.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the type indicated

Two-wire, single-phase
Three-wire, three-phase

Grounding equipment required for this method of system grounding.

None required, but potential transformers, a voltage relay and/or ground indicating lights and possibly stabilizing resistors are advisable for ground fault detection.

First cost, relative to a solidly grounded neutral system with phase relaying only.

First cost may be the same, if no ground fault detection; ground fault detection adds to cost. Increased conductor insulation requirements may also add to first cost; see footnote ②.

Current for bolted line-to-ground fault, in percent of bolted three-phase rms fault current, for terminal fault at supply point.

System charging current, $(3\ E_{L-N})/X_{co}$. Less than one percent; usually less than 1 ampere. System charging current rarely exceeds 5 amperes, except on systems having surge capacitors.

Probable level③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault current.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent④	Arc Volts	Restrike Volts
208	2	275	275
480	74	275	375
600	85	275	375

For footnotes see Page 33.

Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).	208-volt systems—small probability, but sustained arcing can occur. 480-, 600-volt systems—high probability; in the order of 1.0.
Shock hazard, phase-to-ground, for (a) No ground fault. (b) Ground fault on phase conductor.	(a) Phase-to-neutral voltage exists from each phase to ground. (b) Line-to-line voltage appears on two phases, for solid fault and no series resonant L-C circuit. With repetitive restrike to ground, or series resonant L-C circuit, voltages to ground well in excess of line-to-line voltage may appear.

Advantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).	Extremely low probability, near zero. A sputtering fault with repeated restrikes may continue indefinitely.
Rms current value for sustained single-phase line-to-ground arcing fault.	Very low value, if fault could be sustained. Single-phase line-to-ground arcing fault in ungrounded system would very likely be self-extinguishing, unless of the sputtering type.
Probability of escalation of single-phase line-to-ground arcing fault into line-to-line or 3-phase arcing fault, in bare bus system.	Very small probability. Probability of escalation would be prominently influenced by closeness of phase conductors.
Automatic tripping by phase (or ground) over-current devices for first line-to-ground fault.	No automatic tripping for the first ground fault occurs, provided a second line-to-ground fault on another phase does not occur before the first one is removed. The faulty circuit continues in operation; in certain process industries and conditions of service this is regarded as an advantage.
Ease of discrimination between an arcing line-to-line fault and normal system load current.	For the usual levels of line-to-line arcing fault currents, discrimination is not difficult. But low-level line-to-line or double line-to-ground arcing faults are possible which will operate phase overcurrent devices only with considerable delay, or not at all. Then burndown may occur.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Basically no flash hazard exists, unless the system has an unremoved ground fault on another phase. This could result in a double line-to-ground fault with serious flash hazard.

Disadvantages in Relation to:

Control of transient and steady-state over-voltages from neutral to ground.	The ungrounded system provides no effective control of such overvoltages.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	The ungrounded system phase-to-ground potential may be elevated as high as the normal phase-to-ground voltage on the higher voltage system.

Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	The first or second ground on such a control circuit may start the motor.
Effect of delayed removal of line-to-ground fault on the system (no escalation to line-to-line fault).	All unremoved ground faults put greater than normal voltage on system insulation. Certain unremoved ground faults may result in very severe overvoltage conditions, leading to increased shock hazard and eventually to extensive equipment and circuit outages.
Difficulty of locating the first line-to-ground fault.	Ground fault locating is usually very difficult. It may require much time and repeated shutdowns of unfaulted as well as faulted equipment. Special fault-locating equipment can facilitate pinpointing the fault site.
Cost of system maintenance.	Maintenance costs on the ungrounded system are relatively high because of reduced insulation life and the labor of locating ground faults.
Motor protection.	Ground fault in motor cannot be easily detected and removed until it has burned into another coil, resulting in greater damage.

Typical Area of Application

The ungrounded system has been much used in general industry, and in the process industries, such as the paper, chemical and petroleum industry, and in certain other service or manufacturing operations where the ability of this system to avert immediate shutdown on the occurrence of the first ground fault was desired. The prevention of a non-scheduled shutdown in these instances was intended to avoid severe financial loss in production, substantial contingent damage to equipment, or grave danger to personnel.

General Remarks

The prominent favorable feature of the ungrounded system is its ability to avoid immediate interruption of service continuity when a single ground fault takes place. The vulnerability of the ungrounded power distribution system to insulation failures and increased shock hazard from transient and steady-state overvoltage conditions, however, has led to the gradual diminishment of its use, in favor of the solidly grounded and high-resistance grounded systems. Ungrounded systems with ground fault indicators are still used in specific plants and industries, but such installations require excellent maintenance and housekeeping procedures, and rigorous ground fault detection and removal practices in order to provide service reliability and continuity equivalent to that found in the solidly and high-resistance grounded neutral systems.

The possible requirement for increased conductor insulation in ungrounded systems should not be overlooked; see footnote ②.

For footnotes see Page 33.

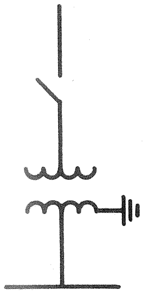
THE SOLIDLY GROUNDED NEUTRAL SYSTEM

Characteristic Features

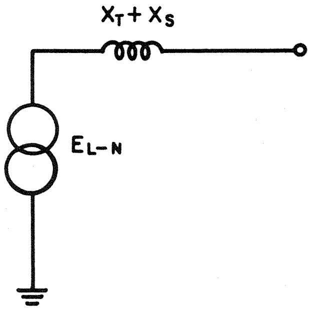
Definition

The solidly grounded neutral system has the neutral point directly grounded through an adequate ground connection in which no impedance has been inserted intentionally, except possibly in the case of low-voltage generator grounding.

Circuit schematic and Thevenin line-to-ground equivalent circuit diagram①.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the type indicated.

Two-wire, single phase.
Two-wire, single phase, 1 side grounded.
Three-wire, three-phase.
Four-wire, three-phase.

Grounding equipment required for this method of grounding⑤.

None for wye-system with neutral available. Grounding transformer is required for delta system⑥.

First cost, relative to a solidly grounded neutral system with phase relaying only.

This is the reference system, using a wye-connected transformer. Ground fault relaying adds to price.

Current for bolted line-to-ground fault, in percent of bolted three-phase rms fault current, for terminal fault at supply point.

Varies; may be 100 percent or more.

Probable level③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault value.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent ④	Arc Volts	Restrike Volts
208	2	275	275
480	74	275	375
600	85	275	375

For footnotes see Page 33.

Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).	208-volt systems—small probability, but sustained arcing can occur. 480-, 600-volt systems—high probability; in the order of 1.0.
Rms current③ for sustained single-phase line-to-ground arcing fault, in percent of three-phase bolted fault value.	Based on 140-volt arc and 375-volt restrike voltages (275 volts @ 208 Y): 208 V—0 percent⑨ 480 V—40 percent* 600 V—50 percent*
Shock hazard, phase-to-ground, for (a) No ground fault. (b) Ground fault on phase conductor.	(a) Phase-to-neutral voltage from each phase to ground. (b) Phase-to-neutral voltage on two phases.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral to ground.	The solidly grounded neutral system effectively controls to safe levels the overvoltages which become impressed on or self-generated in the power system by insulation breakdowns, resonant inductive-capacitive circuits, restriking ground faults, etc.
Automatic tripping by phase and/or ground overcurrent devices for first line-to-ground fault.	System is designed to provide automatic tripping by low-cost phase devices for first ground fault. Solid ground faults or high-level arcing faults to ground will operate the phase overcurrent devices. For low level arcing faults to ground, application of sensitive ground fault relays is required to assure disconnection of faulty circuit before burndown can occur. In many industries and conditions of service this rapid protection of equipment is necessary and desirable, to protect other services and personnel.
Ease of discrimination between an arcing line-to-line or line-to-ground fault and normal system load current.	Usual levels of arcing faults will cause tripping of phase devices. Use of zero-sequence type ground fault relaying is necessary for prompt discrimination between low-level ground faults and normal load currents. Line-to-line arcing faults usually involve ground quickly. Thus ground relays minimize the possibility of arcing-fault burndown.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	Limited to low-voltage system line-to-neutral voltage, approximately.
Shock hazard, from neutral to ground during line-to-ground fault.	Essentially zero voltage for low impedance grounding electrode conductor.

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*Tentative; subject to further investigation. Minimum ground fault current value may be quite low, depending on ground circuit impedance and other factors.

For footnotes see Page 33.

Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Only 58 percent of line-to-line voltage appears on contactor coil. Motor start is not likely.
Difficulty of locating the first line-to-ground fault.	Generally not difficult. Fault is usually self-isolating via phase overcurrent device operation, but ground fault relaying is recommended to isolate very low level faults on high current circuits. Noise, smoke, and flash during fault aid in pinpointing fault site.
Cost of system maintenance.	Minimum, since insulation life is not shortened, and ground faults are readily located.
Motor protection.	A fault to ground in a motor winding can be quickly detected and removed, before extensive damage occurs, by means of phase overcurrent devices or ground sensor relays.

Disadvantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit (no escalation).	208-volt systems—small probability; near zero.* 480-, 600-volt systems—high probability; in the order of 1.0.
Probability of escalation of 1-phase, line-to-ground arcing fault into line-to-line or 3-phase arcing fault (in bare bus system).	High probability, in the order of 1.0, particularly for 480- and 600-volt systems. (Probability of escalation is zero in this system on single-phase circuits serving line-to-neutral connected loads.)
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	A motor already running may not drop out when the "stop" button is pressed. Pushing the "start" button with a ground fault in the control circuit may permit line-to-ground fault current to flow through the push button. This would cause a momentary personnel hazard until a protective device operates. Protective contacts on energized equipment may be bypassed by an accidental ground, preventing equipment shutdown if safety limits are exceeded.
Effect of delayed removal of line-to-ground fault on system (no escalation).	Continuing low-level arcing fault may result in equipment burndowns and delayed restoration of service. Sensitive ground fault relaying can eliminate this problem.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Severe flash hazard for ground fault on any phase of a high capacity system.

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* Not to be construed as being dependably self-extinguishing.

Typical Area of Application

The solidly grounded neutral system is the one most widely used in industrial and commercial service, for serving general industrial loads, and loads affecting public welfare and safety (lighting, elevators, fire pumps, ventilation, etc.) In particular, the solidly grounded neutral arrangement is the most effective in serving three-phase four-wire low voltage power distribution circuits. It has also been used effectively on critical process (so-called non-interruptible) loads.

General Remarks

The prominent characteristics of the solidly grounded neutral system are its effective control of all overvoltage conditions and its immediate segregation of the faulty circuit, by means of economic phase overcurrent trips, on the occurrence of a **sensible** ground fault. Furthermore, the solidly grounded neutral system provides an **effective basis** for protection against destructive low-level arcing faults, since the addition of zero-sequence type relaying to such a system enables the easy detection and removal of such faults.

These characteristics of overvoltage control, immediate fault isolation, and practicable protection against arcing fault burndown help to account for the very extensive use of the solidly grounded neutral system in industrial and commercial power service. Its emphasis on prompt protection for faulty equipment and circuits, thereby increasing service restorability and reducing repair costs and downtime, make it suitable for use wherever extensive damage to electrical equipment and prolonged shutdown of processes or services is to be guarded against.

A particular shortcoming of the solidly grounded neutral system is the very severe flash hazard which exists on the occurrence of an arcing fault involving ground. Where a person may be in close proximity to the fault, or may have been directly instrumental in initiating the fault, a serious personnel hazard then exists. This hazard is sufficient to require that equipment and circuits be worked upon only when de-energized. This safe working practice is also required by the otherwise ever-present voltage hazard. Working on energized equipment requires specially trained crews and safety procedures not normally available in industrial plants or commercial buildings.

The solidly grounded neutral system generally isolates phase and ground faults promptly. In this system, however, equipment burndown may occur if a relatively low-level arcing fault occurs on a high-current circuit. Ground-fault relaying minimizes this possibility.

The prompt removal, in the solidly grounded neutral system, of a circuit in which a ground fault has occurred is considered by some system operators to be a singular imperfection. For these operators the requirement to avoid a disorderly and abrupt shutdown on the occasion of the first ground fault, and to continue to supply power to a critical process or service takes precedence over all other considerations. In situations of this sort high resistance in the neutral connection to ground to limit fault current and avoid tripping on the first ground fault has frequently been employed. See High-Resistance Grounding.

The solidly grounded system permits the use of so-called "100 Percent Level" conductor insulation and in this respect may provide economic advantage over other types of system grounding. See footnote ②.

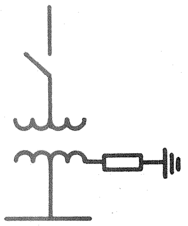
For footnotes see Page 33.

THE LOW-RESISTANCE* GROUNDED NEUTRAL SYSTEM

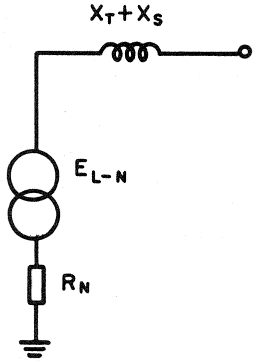
Characteristic Features

Definition	The low-resistance* grounded neutral system is one in which a low-value resistor has been inserted in the neutral connection to ground to limit the current under ground-fault conditions to a level significantly reducing the fault-point damage but still permitting automatic detection and isolation of the fault by ground-fault protection devices.

Circuit schematic and Thevenin line-to ground equivalent circuit diagram ①.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the type indicated.	Two-wire, single-phase. Three-wire, three phase. Footnote ⑦
Grounding equipment required for this method of grounding ⑤.	Neutral resistor for wye systems. Neutral resistor and grounding transformers for delta systems ⑥.
First cost, relative to a solidly grounded neutral system with phase relaying only.	Higher, because of neutral resistor, and because sensitive ground fault relaying is necessary to insure that no ground faults remain unremoved.
Current for bolted line-to-ground fault, in percent of bolted three-phase rms fault current, for terminal fault at supply point.	20 percent and downward to 1000 ampere. Installations with special safety requirements against shock hazard, such as mine power systems, may go as low as 25 amperes.

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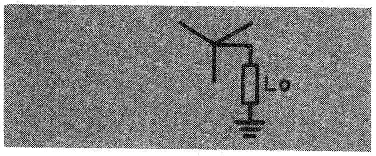
* Not yet defined quantitatively. See entry for "Current for bolted line-to-ground fault . . ." for range of resistor current values.

For footnotes see Page 33.



Probable level ③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault value.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent ④	Arc Volts	Restrike Volts
208	2	275	275
480	74	275	375
600	85	275	375

Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).

208-volt systems—small probabilty, but sustained arcing can occur.
480-, 600-volt systems—high probability; in the order of 1.0.

Rms current③ for sustained single-phase line-to-ground arcing fault in percent of bolted line-to-ground fault values.

Based on 140 volt arc and 375 volt restrike voltages.
208 V—*
480 V—*
600 V—*

Shock hazard, phase-to-ground, for
(a) No ground fault.
(b) Ground fault on phase conductor.

(a) Phase-to-neutral voltage from each phase to ground.
(b) Approximately line-to-line voltage on two phases.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral to ground.

The low-resistance grounded neutral system effectively controls to safe levels the overvoltages generated in the power system by resonant capacitive-inductive circuits, static charges, and restriking ground faults. It may not control certain steady-state overvoltages arising from physical contact with a higher voltage system, from autotransformer extended winding failures, or from faulty series capacitor-welder circuits ⑧.

Automatic tripping by phase and/or ground overcurrent devices for the first ground fault.

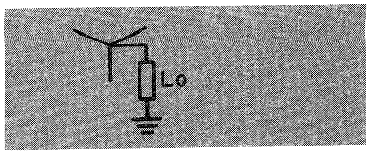
System is designed to provide automatic tripping by ground overcurrent devices for first ground fault. Phase overcurrent devices may also operate, depending on their ratings relative to the resistance-limited fault current. To many power system operators fast tripping on ground faults, which limits fault damage and prevents equipment burndown, is advantageous to system service reliability.

Ease of discrimination between an arcing line-to-line or line-to-ground fault and normal system load current.

Required use of sensitive zero-sequence type relaying permits prompt discrimination between low-level ground faults and normal load currents. Line-to-line arcing faults usually involve ground quickly. Thus ground relays minimize the possibility of arcing-fault burndowns.

* Calculations not completed.

For footnotes see Page 33.



Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Less than line-to-neutral voltage appears on contactor coil. Motor will not start.
Shock hazard, from neutral to ground, during line-to-ground fault.	Essentially zero shock hazard, since the neutral is not run with the phase conductors.
Difficulty of locating the first line-to-ground fault.	Usually not difficult. The smaller circuit phase overcurrent devices will provide self-isolation. The larger circuits must be equipped with ground-fault relaying and will provide rapid fault isolation. Noise, smoke, and flash during fault aid in pinpointing fault site.

Disadvantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).	208-volt systems—small probability; near zero.* 408-, 600-volt systems—high probability; in the order of 1.0.
Probability of escalation of single-phase line-to-ground arcing fault into line-to-line or three-phase arcing fault (in bare bus system).	High probability, in the order of 1.0, particularly for 480- and 600-volt systems.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	May be as high as normal line-to-neutral voltage on the primary system⑧.
Safety hazard arising from ground faults in directly connected control circuits, using line-to-line rated voltage contactor coils.	Pushing "start" button with ground fault on control circuit will permit line-to-ground fault current to flow through push button, causing momentary personnel hazard until protective device operates.
Effect of delayed removal of line-to-ground fault on system (no escalation).	Continuing presence of a ground fault could cause burndown or serious damage of equipment, but ground fault relaying required by this system of grounding should avoid this situation.
Cost of system maintenance.	May be higher than for solidly grounded system, because of shortened insulation life arising from certain types of overvoltage not effectively controlled by this method of system grounding.
Flash hazard to personnel, arising from accidental line-to-ground fault (no escalation).	Serious flash hazard, but less severe than on solidly grounded neutral system. Reduction in hazard is proportional to reduction in bolted line-to-ground fault current. Escalation, which is probable in bare bus system, would cancel any reduction in line-to-ground fault flash hazard.

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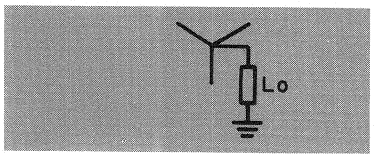
* Not to be construed as being dependably self-extinguishing.

For footnotes see Page 33.



Typical Area of Application

The low-resistance grounded neutral system to date has been used largely in special situations, such as mine power systems, where extraordinary protection against shock hazard on portable equipment is required.

Although the reduction in burning damage and in flash hazard offered by this type of system grounding is significant, it has been infrequently applied in general industrial and commercial building service. In the latter instance the unsuitability of this type of system to serve four-wire three-phase loads has been responsible for its not being used. For general industrial service the application of this system grounding method has been hampered by the lack of sensitive, small, inexpensive ground-fault detectors which can be applied to circuit interrupters on branch circuits and small feeder circuits. Adequate ground-fault protective devices for the larger circuit interrupters on load center substations and distribution switchboards have been available, but not for the smaller circuit interrupters. Consequently, a completely selective operation for ground faults in low-resistance grounded neutral systems would be difficult to achieve economically. Hence applications in general industry have been of the solidly grounded neutral system, to secure maximum probability of selectivity in operation.

It is to be expected that the development of small, sensitive, inexpensive ground-fault protective devices which are compatible with currently available circuit protective devices for low-rated circuits will result in the increased use of low-resistance grounded neutral power systems.

General Remarks

The low-resistance grounded neutral system, when augmented with sensitive ground fault relaying, will provide most of the benefits of solid neutral grounding, plus reduced damage at the fault point, decreased flash hazard, and lower voltage dip on the occurrence of a ground fault.

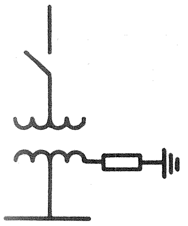
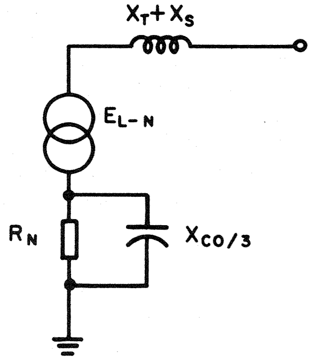
With this type of system neutral grounding the current under ground fault conditions may be severely limited in comparison with the solidly grounded neutral system, making detection of such faults by the larger phase overcurrent devices either impossible or very long delayed. Since a ground fault unremoved from the system will likely cause severe damage or even burndown, the low-resistance grounded neutral system requires the use of ground fault relaying to make its application practicable.

The low-resistance grounded neutral system with sensitive ground fault relaying permits the use of so-called "100 Percent Level" conductor insulation and in this respect may provide economic advantage over other types of system grounding. See footnote ②.

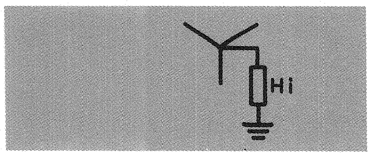
For footnotes see Page 33.

THE HIGH-RESISTANCE GROUNDED NEUTRAL SYSTEM

Characteristic Features:

Definition	The high-resistance grounded neutral system is one in which a high value resistor has been inserted in the neutral connection to ground to limit the resistor current under ground-fault conditions to a value not less than the total system charging current, resulting in a total ground fault current of approximately $\sqrt{2}$ times the charging current. An objective of high-resistance grounding is to avoid automatic tripping of the faulty circuit for the first ground fault.
Circuit schematic and Thevenin line-to-ground equivalent circuit diagram.	 **Circuit**  **Thevenin Equivalent**
Suitable for serving load circuits of the type indicated.	Two-wire, single-phase Three-wire, three-phase Footnote ⑦
Grounding equipment required for this method of grounding ⑤.	Neutral resistor for wye systems. Neutral resistor and grounding transformer for delta systems ⑥. Ground fault indication, which is recommended, requires relay and indicating lights or alarm.
First cost, relative to a solidly grounded neutral system with phase relaying only.	Higher, because of neutral resistor and ground-fault indicating equipment. There may also be increased costs arising from the requirements for conductor insulation; see footnote ②.
Current for bolted line-to-ground fault, for terminal fault at supply point.	Determined by neutral resistor ohmic value, but should not be less than $\sqrt{2}$ times system charging current $(3E_{LN}/X_{co})$; generally less than 1 ampere. System charging current rarely exceeds 5 amperes, except on systems having surge capacitors.

For footnotes see Page 33.



Probable level③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault value.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions calculated values are:

System Volts	Fault Current, Percent④	Arc Volts	Restrike Volts
208	2	275	275
480	74	275	375
600	85	275	375

Probability of sustained arcing for line-to-line fault on single-phase circuit (no escalation to three-phase fault).

208-volt systems—small probability, but sustained arcing can occur.
480-, 600-volt system—high probability; in the order of 1.0.

Shock hazard, phase-to-ground, for
(a) No ground fault.
(b) Ground fault on phase conductor.

(a) Phase-to-neutral voltage from each phase to ground.
(b) Approximately line-to-line voltage on two phases.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral to ground.

The high-resistance grounded neutral system effectively controls to safe levels the overvoltages generated in the power system by resonant capacitive-inductive circuits, static charges, and repetitive restrike ground faults. It does not control certain steady-state overvoltages such as those arising from physical contact with a higher voltage system, from autotransformer extended winding failures, or from faulty series capacitor-welder circuits.

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).

Extremely low probability, near zero. Arcing line-to-ground fault would be difficult to initiate and would very likely be self-extinguishing.

Rms current value for sustained single-phase line-to-ground arcing fault.

Very low current value, if fault could be sustained. Single phase line-to-ground arcing fault in high resistance grounded neutral system would likely be self-extinguishing.

Probability of escalation of single-phase line-to-ground arcing fault into line-to-line or three-phase arcing fault, in bare bus system.

Very small probability. Escalation probability would be prominently influenced by closeness of phase conductors.

Automatic tripping by phase overcurrent devices for the first ground fault.

No automatic tripping for the first ground fault occurs, provided a second line-to-ground fault on another phase does not occur before the first one is removed. The faulty circuit continues in operation; in certain process industries and conditions of service this procedure is considered necessary and advantageous.

For footnotes see Page 33.

Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Less than line-to-neutral voltage appears on contactor coil. Motor will not start.
Shock hazard from neutral to ground, during line-to-ground fault.	Essentially zero shock hazard, since the neutral is not run with the phase conductors.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Basically no flash hazard exists, unless the system has an unremoved ground fault on another phase. This could result in a double line-to-ground fault with serious flash hazard.

Disadvantages in Relation to:

Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	May be as high as normal line-to-neutral voltage on the primary system.
Ease of discrimination between line-to-ground or line-to-line arcing faults and normal system load currents.	Line-to-ground arcing faults are indistinguishable from load currents, but are very likely to be self-extinguishing. Arcing line-to-line faults would usually cause tripping of phase-overcurrent devices. At times their current level may be so low, however, as to go undetected and cause equipment burndown.
Effect of delayed removal of line-to-ground fault on the system (no escalation to line-to-line fault).	All unremoved ground faults put greater than normal voltage on the system's insulation. System continues in operation, but with continued damage at the point of fault. While this damage is greatly limited, in a relative sense, its prolongation in equipment with multi-turn coils may cause eventual turn-to turn or phase-to-phase failures and result in severe damage, requiring motor restacking and/or rewinding.
Difficulty of locating the first line-to-ground fault.	Frequently as difficult as for the ungrounded system. May require many hours and repeated shutdown of faulty zone equipment. Special fault-locating equipment can facilitate pinpointing the fault site.
Cost of system maintenance.	Will be somewhat higher than for the solidly grounded neutral system because of the adverse effect of greater than normal voltage (during presence of ground fault) on insulation life and because locating ground faults increases maintenance costs.

Typical Area of Application

The high-resistance grounded neutral system has been applied in the process industries and in other situations where control of transient overvoltages is desired but an immediate service interruption on the first ground fault is to be avoided. In these instances the objective is to prevent a disorderly shutdown of equipment which might result in severe financial losses, or hazards to personnel or equipment. A collateral benefit lies in the virtual elimination of personnel flash hazard arising from accidental faults to ground.

General Remarks

The underlying reasons for the application of high-resistance neutral grounding (see typical Area of Application) are the same as those for the use of an ungrounded system, except that transient overvoltage control is also a prime objective when employing the resistance method of grounding. Any advantages to the power system user which exist in the ungrounded method of operation may also be secured, along with transient overvoltage control, when using the high-resistance grounded neutral system.

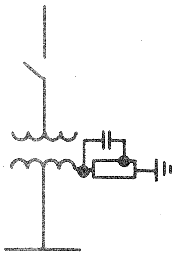
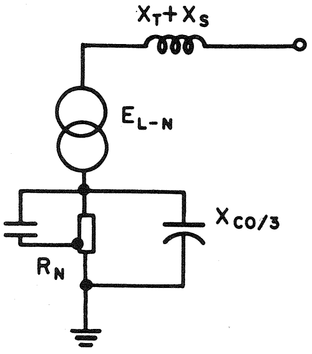
In comparison to the solidly grounded neutral system during ground faults, high-resistance grounding affords essentially zero flash hazard, arc blast and voltage dip during ground faults, provided simultaneous ground faults on different phases do not occur. The difficulty of locating ground faults on this system, however, increases the probability of a second ground fault shutting down two circuits simultaneously.

Since unremoved ground faults in this type of system continue to liberate energy at the fault point which may eventually cause further breakdown in the insulation system, it is essential to monitor the high resistance grounded neutral system for ground faults and to remove them with all possible expediency. Furthermore, while a ground fault remains on this system it loses its original characteristics and becomes essentially a "corner-of-the-delta" grounded system with serious flash hazard, arc blast, voltage dip, and the probability of fault escalation should a second ground fault occur.

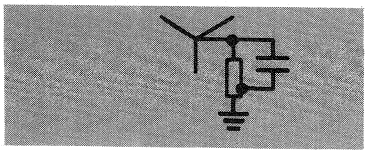
As the neutral point is elevated to essentially normal line-to-neutral voltage above earth during a ground fault, this grounding method is not suited to 4-wire 3-phase systems.

THE HIGH-RESISTANCE GROUNDED NEUTRAL SYSTEM WITH TRACEABLE SIGNAL TO FAULT

Characteristic Features:

Definition	The high-resistance grounded neutral system with traceable signal to fault, is one in which a high-value resistor has been inserted in the neutral connection to ground to limit the resistor current under ground-fault conditions to a value not less than the total system charging current, resulting in a total ground fault current of approximately $\sqrt{2}$ times the charging current. An objective of this type of grounding is to avoid tripping of the faulty circuit for the first ground fault. In addition this system is equipped with ground-fault indicators and a means of pulsing a traceable signal onto a grounded phase to aid in rapid location of system faults to ground while the system is energized.
Circuit schematic and Thevenin line-to-ground equivalent circuit diagram.	 Circuit  Thevenin Equivalent
Suitable for serving load circuits of the type indicated.	Two-wire, single-phase. Three-wire, three-phase. Footnote ⑦.
Grounding equipment required for this method of grounding⑤.	Neutral resistor for wye systems. Neutral resistor and grounding transformer for delta systems⑥. Ground fault indicating equipment, plus signal pulsing and tracing equipment are required for either wye or delta system arrangements.
First cost, relative to a solidly grounded neutral system with phase relaying only.	Higher, because of neutral resistor and ground fault indicating, pulsing and tracing equipment. There may also be increased costs arising from the requirements for conductor insulation; see footnote ②.
Current for bolted line-to-ground fault, for terminal fault at supply point.	Determined by neutral resistor ohmic value, but should not be less than $\sqrt{2}$ times system charging current ($3E_{LN}/X_{co}$); generally less than 1 ampere. System charging current rarely exceeds 5 amperes, except on systems having surge capacitors. The pulsing current used for fault tracing may be two or more times the normal ground fault current.

For footnotes see Page 33.



Probable level③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault value.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent④	Arc Volts	Restrike Volts
208	2	275	275
408	74	275	375
600	85	275	375

Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).

208-volt systems—small probability, but sustained arcing can occur.
480-, 600-volt systems—high probability; in the order of 1.0.

Shock hazard, phase-to-ground for

(a) No ground fault.
(b) Ground fault on phase conductor.

(a) Phase-to-neutral voltage from each phase-to-ground.
(b) Approximately line-to-line voltage on two phases.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral to ground.

The high-resistance grounded neutral system effectively controls to safe levels the overvoltages generated in the power system by resonant capacitive-inductive circuits, static charges, and restriking ground faults. It does not control certain steady-state overvoltages such as those arising from physical contact with a higher voltage system, from autotransformer extended winding failures, or from faulty series capacitor-welder circuits.

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).

Extremely low probability, near zero. Arcing line-to-ground fault would be difficult to initiate and would very likely be self-extinguishing.

Rms current value for sustained single-phase line-to-ground arcing fault.

Very low current value, if fault could be sustained. Single-phase line-to-ground arcing fault in high-resistance grounded neutral system would likely be self-extinguishing.

Probability of escalation of single-phase line-to-ground arcing fault into line-to-line or three-phase arcing fault, in bare bus system.

Very small probability. Escalation probability would be prominently influenced by closeness of phase conductors.

Automatic tripping by phase overcurrent devices for the first ground fault.

No automatic tripping for the first ground fault occurs provided a second line-to-ground fault on another phase does not occur before the first one is removed. The faulty circuit continues in operation; in certain process industries and conditions of service this procedure is considered necessary and advantageous.

For footnotes see Page 33.

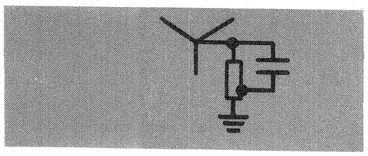
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Less than line-to-neutral voltage appears on contactor coil. Motor will not start.
Shock hazard, from neutral-to-ground, during line-to-ground fault.	Essentially zero shock hazard, since the neutral is not run with the phase conductors.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Basically no flash hazard exists, unless the system has an unremoved ground fault on another phase. This could result in a double line-to-ground fault with serious flash hazard.
Difficulty of locating the first line-to-ground fault.	Very little difficulty. Pulsed signal aids in locating fault with system energized, but some skill in use of tracing equipment is required.
Cost of system maintenance.	Approximately the same as solid grounding. Tracing ground faults adds cost, and insulation life is reduced by unremoved ground faults, but fault damage arising from ground faults is reduced.

Disadvantages in Relation to:

Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	May be as high as normal line-to-neutral voltage on the primary system.
Ease of discrimination between line-to-ground or line-to-line arcing faults and normal system load currents.	Line-to-ground arcing faults are indistinguishable from load currents, but are very likely to be self-extinguishing. Arcing line-to-line faults would usually cause tripping of phase-overcurrent devices. At times their current level may be so low, however, as to go undetected and cause equipment burndown.
Effect of delayed removal of line-to-ground fault on the system (no escalation to line-to-line fault).	All unremoved ground faults put greater than normal voltage on the system's insulation. System continues in operation, but with continued damage at the point of fault. While this damage is greatly limited, in a relative sense, its prolongation in equipment with multi-turn coils may cause eventual turn-to-turn or phase-to-phase failures and result in severe damage, requiring motor restacking and/or rewinding. This possibility is minimized by the use of ground fault tracing equipment, which facilitates locating the fault site and helps to lessen the time that the ground fault remains on the system.

Typical Area of Application

The high-resistance grounded neutral system with tracing pulse has been applied in the process industries and in other situations where control of transient overvoltages, coupled with a reduction in flash hazard, is desired but where an immediate service interruption on the first ground fault is to be avoided, and a means of subsequently tracing the fault location with the system energized is wanted. The objectives in these instances are to prevent a disorderly shutdown of equipment which might result in severe financial losses or hazards to personnel or equipment, and to minimize personnel injuries from arc flash during accidental line-to-ground faults.



General Remarks

The fundamental objectives in the use of the high-resistance grounded neutral system with a fault-tracing pulse are several: The avoidance of an immediate service interruption on the occasion of the first ground fault, the minimizing of flash hazard to personnel arising from accidental ground faults in equipment, a substantial reduction in the risk of equipment burndown arising from ground faults, and the ability to trace the location of a ground fault without de-energizing the system. An additional benefit is a reduction in voltage dip during ground faults, provided simultaneous ground faults on different phases are not encountered.

The facility of quickly locating ground faults with the pulsing and tracing equipment on this system tends to lessen the probability of a second ground fault shutting down two circuits simultaneously.

Since unremoved ground faults in this type of system continue to liberate energy at the fault point which may eventually cause further breakdown in the insulation system, it is essential to monitor the high-resistance grounded neutral system for ground faults, to trace them promptly with the fault locating equipment, and to remove them with all possible expediency. While a ground fault remains on this system it loses its original characteristics and becomes essentially a "corner-of-the delta" grounded system, with serious flash hazard, arc blast, voltage dip and the probability of fault escalation should a second ground fault occur.

As the neutral point is elevated to essentially normal line-to-neutral voltage above earth during a ground fault, this grounding method is not suited to 4-wire, three-phase systems.

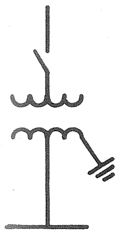
CORNER-OF-THE-DELTA GROUNDED SYSTEM

Characteristic Features:

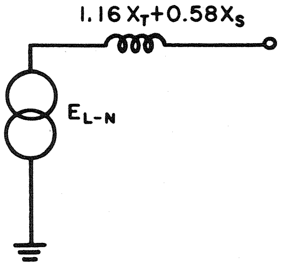
Definition

The corner-of-the-delta grounded system is one in which an identified phase conductor is directly grounded through an adequate ground connection in which no impedance has been inserted intentionally.

Circuit schematic and Thevenin line-to-ground equivalent circuit diagram.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the character indicated.

Two-wire, single-phase.
Two-wire, single-phase, 1-side grounded.
Three-wire, three-phase.

Grounding equipment required for this method of grounding⑤.

None, but grounded-phase identification is necessary throughout the system.

First cost, relative to a solidly grounded neutral system with phase relaying only.

Approximately the same, as wye and delta transformers cost about the same.

Current for bolted line-to-ground fault, in percent of three-phase rms fault current, for terminal fault at supply point.

Varies; may be as high as 87%.

Probable level⑤ of sustained single-phase line-to-line arcing fault current, in percent of bolted three-phase fault value.

Value is function of system voltage as well as of arc and restrike values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent④	Arc Volts	Restrike Volts
208	2*	275	275
480	74	275	375
600	85	275	375

* Corner-of-the-delta grounding is not likely on 208-volt systems, but value is given to permit estimating current for 240-volt systems, for which calculations were not made.

For footnotes see Page 33.

Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).	208-volt systems—small probability, but sustained arcing can occur. 480-, 600-volt systems—high probability; in the order of 1.0.
Rms current③ for sustained single-phase line-to-ground arcing fault, in percent of three-phase bolted fault value.	Based on 275 volt arc and restrike voltages of 275 volts (208-volt system) or 375 volts (480-, 600-volt systems) 208 V— 2 percent④* 480 V—74 percent 600 V—85 percent
Probability of escalation of single-phase line-to-ground arcing fault into three-phase arcing fault (in bare bus system).	Probability is high, but fault starts as line-to-line fault and escalation to 3-phase fault produces only moderate current increase.
Shock hazard, phase-to-ground, for (a) No ground fault. (b) Ground fault on phase conductor.	(a) Line-to-line voltage on two phases. (b) Line-to-line voltage on unfaulted phase, zero volts on others.
Control of transient and steady-state overvoltages from neutral to ground.	The corner-of-the-delta grounded system effectively controls to safe levels the overvoltages which become impressed on or self-generated in the power system by insulation breakdowns, resonant inductive-capacitive circuits, restriking ground faults, etc. It continuously impresses, however, 1.73 times normal line-to-neutral voltage between two conductors and ground.
Automatic tripping by phase and/or ground overcurrent devices for the first line-to-ground fault.	System is designed to provide automatic tripping by phase devices for the first ground fault. For very low level arcing faults to ground the application of sensitive ground fault relays will help assure disconnection of the faulty circuit before burndown can occur. In many industries and conditions of service this rapid protection of equipment, service, and personnel is necessary and desirable.
Ease of discrimination between arcing line-to-line or line-to-ground fault and normal system load current.	Usual levels of arcing faults will cause tripping of phase devices. Line-to-line arcing faults usually involve ground quickly. Thus use of ground fault relays permits prompt discrimination between low-level arcing faults and normal load currents, minimizing the possibility of arcing-fault burndown.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	Limited to secondary line-to-line voltage, approximately.
Shock hazard, from neutral-to-ground during line-to-ground fault.	Essentially no hazard, since neutral of system voltage triangle is not normally run with this system.

* Value for 208-volt system is given to permit estimating current for 240-volt corner-of-the-delta grounding systems, for which calculations were not made.

For footnotes see Page 33.

Difficulty of locating the first ground fault.	Generally not difficult. Fault is usually self-isolating via phase overcurrent device operation, but ground fault relaying may be advisable to isolate low-level faults on high current circuits. Noise, smoke, and flash during fault aid in pinpointing fault site.

Disadvantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).	240-volt systems—small probability.* 480-, 600-volt systems—high probability; in the order of 1.0.
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Pushing the "start" button with a ground fault in the control circuit may permit line-to-line fault current to flow through the push button, causing a momentary personnel hazard until the protective device operates. On properly wired control circuits an accidental ground will not start the motor or prevent its shutdown if running.
Effect of delayed removal of line-to-ground fault on system (no escalation).	Continuing low-level arcing fault to ground may result in equipment burndown and delayed restoration of service.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Severe flash hazard, equivalent to arcing line-to-line fault, for accidental ground on a "hot phase."
Cost of system maintenance.	Somewhat above that for the solid neutral grounding method, because of 73 percent higher insulation stress on two phases. Ground faults are easily located.

Typical Area of Application

The corner-of-the-delta method of grounding is not widely used in industrial systems. Its application generally has been made only in delta systems⑥ where the benefits of a grounded system are desired to be secured at minimum cost.

General Remarks

For new systems the corner-of-the delta grounding method offers no special advantages, since the solidly grounded neutral system provides the same and additional benefits at the same or less cost, and without many of the disadvantages of corner-of-the-delta grounding.

This method of grounding requires positive identification of the grounded phase throughout the distribution system. In addition, all instrumentation, metering and motor overload relays must be connected to the "hot" phases to avoid having accidental grounds upset their registration or operation. A ground fault on the grounded conductor cannot be readily detected but will result in stray ground currents even in the absence of additional faults on the system.

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* Not to be construed as being dependably self-extinguishing.

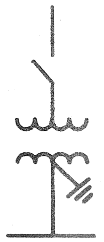
THE MID-PHASE GROUNDED SYSTEM

Characteristic Features

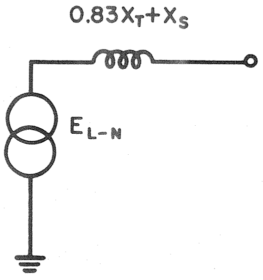
Definition

The mid-phase grounded system is a delta system in which the mid-point of one phase of the supply transformer has been tapped and solidly grounded.

Circuit schematic and Thevenin line-to ground equivalent circuit diagram.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the type indicated.

Two-wire, single-phase.
Two-wire, single-phase, 1-side grounded.
Three-wire, single-phase, mid-phase grounded.
Three-wire, three-phase.

Grounding equipment required for this method of grounding ⑤.

None, but the mid-point of one phase of the power source must be available, and the highest voltage conductor must be identified at any point where a connection is to be made.

First cost, relative to a solidly grounded neutral system with phase relaying only.

Approximately the same.

Current for bolted line-to-ground fault in percent of three-phase rms current, for terminal fault at supply point.

Varies; may be as high as 120 percent.

Probable level③ of sustained single-phase line-to-line arcing fault current in percent of bolted three-phase fault value.

Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions calculated vaues are:

System Volts	Fault Current, Percent④	Arc Volts	Restrike Volts
208	2*	275	275
480	74	275	375
600	85	275	375

* Mid-phase grounding is not likely on 208-volt systems, but value is given to permit estimating for 240-volt systems, for which calculations were not made.

For footnotes see Page 33.

Probability of sustained arcing for line-to-line fault on single-phase circuit (no escalation to three-phase fault).	240-volt systems—small probability, but sustained arcing can occur. 480-, 600-volt systems—high probability; in the order of 1.0.
Rms current③ for sustained single-phase line-to-ground arcing fault, in percent of bolted three-phase fault value.	Based on 275 volt arc and restrike voltages of 275 volts (208-volt system) or 375 volts (480-, 600-volt system).* 240 V— 2 percent. 480 V—64 percent. 600 V—74 percent.
Probability of escalation of single-phase line-to-ground fault into three-phase arcing fault (in bare bus system).	Probability is high, but fault starts as relatively high level line-to-mid-phase fault, and escalation to three-phase fault produces only moderate increase in fault current.
Shock hazard, phase-to-ground, for	
(a) No ground fault.	(a) 1.5 times line-to-neutral (geometric) voltage on one phase; .87 times line-to-neutral on other two phases.
(b) Ground fault on phase conductor.	(b) .87 times line-to-neutral voltage on one phase; line-to-line volts on the other.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral-to-ground.	Mid-phase grounding effectively controls to safe levels the overvoltages which become impressed on or self-generated in the power system by insulation breakdowns, resonant capacitive-inductive circuits, restriking ground faults, etc. It continuously impresses, however, 1.5 times normal line-to-neutral voltage between one conductor and ground.
Automatic tripping by phase and/or ground overcurrent devices for the first line-to-ground fault.	System is designed to provide automatic tripping by phase devices on the first ground fault. For very low-level arcing faults to ground the application of sensitive ground fault relays will help assure disconnection of the faulty circuit before burndown can occur. In many industries and conditions of service this rapid protection of equipment, service, and personnel is necessary and desirable.
Ease of discrimination between arcing line-to-line or line-to-ground fault and normal system load current.	Usual levels of arcing faults will cause tripping of phase devices. Line-to-line arcing faults usually involve ground quickly. Thus use of ground-fault relays permits prompt discrimination between low-level arcing faults and normal load currents, minimizing the possibility of arcing fault burndowns.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	Limited to .87 times secondary line-to-line voltage, approximately.
Shock hazard, from neutral-to-ground during line-to-ground fault.	Essentially no hazard, since neutral of system voltage triangle is not normally run with this system.

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* Tabulated values are estimates based on line-to-line fault calculations for 208-, 480- and 600-volt systems.

For footnotes see Page 33.

Difficulty of locating the first ground fault.	Generally not difficult. Fault is usually self-isolating via phase overcurrent device operation, but ground fault relaying may be advisable to isolate very low-level faults on high current circuits. Noise, smoke, and flash during fault aid in pinpointing fault site.

Disadvantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).	240-volt systems—small probability.* 480-, 600-volt systems—high probability; in the order of 1.0.
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Situation depends on how control is wired with respect to the "high" leg. In worst case approximately 87 percent of line-to-line voltage could appear on the contactor coil, causing a motor start. In other cases an accidental ground may create a hazard to personnel by causing a momentary short-circuit through the "start" button when it is pressed, or by preventing a running motor from being shut down by the "stop" button or by a safety contact.
Effect of delayed removal of line-to-ground fault on system (no escalation).	Continuing low-level arcing fault to ground may result in equipment burndown and delayed restoration of service.
Flash hazard to personnel arising from accidental line-to-ground fault (no escalation).	Serious flash hazard for accidental ground on any phase.
Cost of system maintenance.	Somewhat above that for the solid neutral grounding method, because of 50 percent higher insulation stress on one phase. Ground faults are easily located.

Typical Area of Application

The mid-phase method of system grounding is infrequently used in industrial systems. Its application has been made largely in systems made up of banks of single-phase transformers with a mid-tap available.

General Remarks

For new systems the mid-phase grounding method offers no special advantages, since the solidly grounded neutral system provides the same and additional benefits at the same or less cost.

This method of grounding requires positive identification of the "hottest" phase throughout the system.

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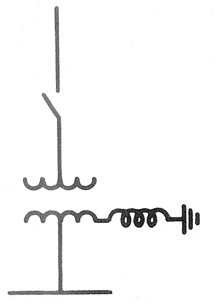
* Not to be construed as being dependably self-extinguishing.

THE LOW-REACTANCE GROUNDED NEUTRAL SYSTEM

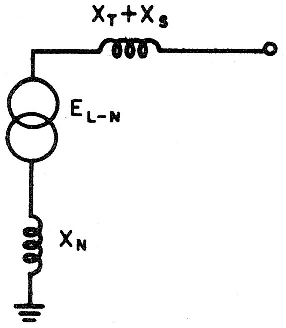
Characteristic Features:

Definition	The low-reactance grounded neutral system is one in which a low-value reactor has been inserted in the neutral connection to ground to limit the current under ground-fault conditions to a value not less than 25 percent nor more than 100 percent of the three-phase bolted fault value.

Circuit schematic and Thevenin line-to-ground equivalent circuit diagram.



Circuit



Thevenin Equivalent

Suitable for serving load circuits of the type indicated.	Two-wire, single-phase. Three-wire, three-phase. Four-wire, three-phase.*
Grounding equipment required for this method of grounding⑤.	Neutral reactor is required.
First cost, relative to a solidly grounded neutral system with phase relaying only.	Higher, because of neutral reactor.
Current for bolted line-to-ground fault, in percent of bolted three-phase rms fault current, for terminal fault at supply point.	System is designed to produce current in the range 25–100 percent of three-phase value.
Probable level③ of sustained single-phase line-to-line arcing fault current, in percent of three-phase bolted fault value.	Value is function of system voltage as well as of arc and restrike voltage values. For particular conditions, calculated values are:

System Volts	Fault Current, Percent④	Arc Vots	Restrike Volts
208	2	275	275
480	74	275	375
600	85	275	375

For footnotes see Page 33.

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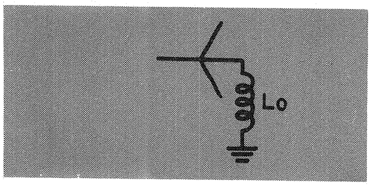
* Only in exceptional cases, where ground fault current ≅100 percent of three-phase bolted fault value and $X_N << X_O$, where X_O = total system zero sequence reactance.



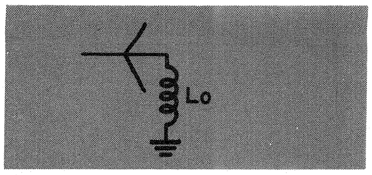
Probability of sustained arcing for line-to-line fault on single-phase circuit extension (no escalation to three-phase fault).	208-volt systems—small probability, but sustained arcing can occur. 480-, 600-volt systems—high probability; in the order of 1.0.
Rms current③ for sustained single-phase line-to-ground arcing fault, in percent of bolted line-to-ground fault values.	Based on 140 volt arc and 375 volt restrike voltages— 208 V—* 480 V—* 600 V—*
Shock hazard, phase-to-ground, for (a) No ground fault (b) Ground fault on phase conductor.	(a) Phase-to-neutral voltage from each phase to ground. (b) Varies; maximum would be approximately line-to-line voltage on two phases.

Advantages in Relation to:

Control of transient and steady-state overvoltages from neutral to ground.	The low-reactance grounded neutral system effectively controls to safe levels the overvoltages generated in the power system by resonant capacitive-inductive circuits, static charges, and restriking ground faults. It may not control overvoltages arising from physical contact with certain higher voltage systems.
Automatic tripping by phase and/or ground overcurrent devices for the first ground fault.	System is designed to provide automatic tripping by ground overcurrent devices for the first ground fault. The phase overcurrent devices may also operate, depending on their ratings, relative to the reactance-limited fault current. To many power system operators, fast tripping on ground faults, which limits fault damage and prevents equipment burndown, is advantageous to system service reliability.
Ease of discrimination between an arcing line-to-line or line-to-ground fault and normal system load current.	Usual levels of arcing faults will cause tripping of phase devices. Use of zero-sequence type relaying will permit prompt discrimination between low-level ground faults and normal load currents. Line-to-line arcing faults usually involve ground quickly. Thus ground relays minimize the possibility of arcing-fault burndown.
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Less than line-to-neutral voltage appears on contactor coil. Motor start is not likely.
Difficulty of locating the first line-to-ground fault.	Generally not difficult. Fault is usually self-isolating via phase overcurrent device operation, but ground fault relaying is recommended to isolate low level faults on high current circuits. Noise, smoke, and flash during fault aid in pinpointing the fault site.
Cost of system maintenance.	Probably somewhat higher than for solid neutral grounding, because insulation may be subjected to higher than normal voltage stresses for certain fault conditions.

For footnotes see Page 33.

* Calculations not completed.



Disadvantages in Relation to:

Probability of sustained arcing for line-to-ground fault on single-phase circuit extension (no escalation).	208-volt systems—small probability.* 480-, 600-volt systems—high probability; in the order of 1.0.
Probability of escalation of single-phase arcing line-to-ground fault, into line-to-line or three-phase arcing fault (in bare bus system).	High probability, in the order of 1.0, particularly for 480- and 600-volt systems.
Shock hazard, phase-to-ground, resulting from fault-path contact with a higher voltage system.	May be as high as normal line-to-neutral voltage, approximately, on the higher voltage system.
Safety hazard, for ground faults in directly connected control circuits using line-to-line rated voltage contactor coils.	Pushing "start" button with ground fault in control circuit may permit line-to-ground fault current to flow through push button, causing momentary personnel hazard until the protective device operates. A motor already running may not drop out when the "stop" button is pressed, or protective contacts on energized equipment may be bypassed by an accidental ground, preventing equipment shutdown if safety limits are exceeded.
Effect of delayed removal of line-to-ground fault on system (no escalation).	Continuing presence of ground fault may result in equipment burndown and delayed restoration of service.
Flash hazard to personnel, arising from accidental line-to-ground fault (no escalation).	Severe flash hazard for ground fault on any phase.

Typical Area of Application

The low-reactance method of system grounding is not very often used. It is basically designed for systems where the limited mechanical or electrical capability of equipment requires reducing ground-fault current. In particular it is applied to local generators at 600 volts or less to limit the ground fault current contribution of the generator to a value no greater than the bolted three-phase fault-contribution value.

General Remarks

To avoid transient overvoltages the low reactance neutral grounding method must not reduce ground fault current below 25 percent of the three-phase fault value. This is generally higher than the minimum fault current desired in a resistance grounded system and reactance grounding is therefore not usually considered an alternative to resistance grounding.

This type of system grounding may interfere with normal four-wire system operation if the ground fault current is limited to a value much below 100 percent of three-phase fault current.

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* Not to be construed as being dependably self-extinguishing.

FOOTNOTES

①On a line-to-neutral basis, X_T = reactance of source generator or transformer, X_S = low voltage distribution system reactance, X_N = reactance of grounding reactor, and R_N = resistance of grounding resistor. X_{CO} = system line-to-ground capacitive reactance, including surge capacitors, if present.

②In the application of solid dielectric insulated wire and cable in electrical power systems the requirements for thermo-plastic conductor insulations are given in IPCEA (Insulated Power Cable Engineers Association) Standards publication No. S-61-402 (Second Edition), which is also identified as NEMA Standards publication No. WC-5-1968. A section of Part 3 of this Standard discusses cable insulation thicknesses as follows.

"The selection of the cable insulation level to be used in a particular installation shall be made on the basis of the applicable phase to phase voltage and the general system category as outlined below:

> 100 Percent Level—Cables in this category may be applied where the system is provided with relay protection such that ground faults will be cleared as rapidly as possible, but in any case within 1 minute. While these cables are applicable to the great majority of cable installations which are on grounded systems, they may be used also on other systems for which the application of cables is acceptable provided the above clearing requirements are met in completely de-energizing the faulted section.
>
> 133 Percent Level—This insulation level corresponds to that formerly designated for ungrounded systems. Cables in this category may be applied in situations where the clearing time requirements of the 100 percent level category cannot be met, and yet there is adequate assurance that the faulted section will be de-energized in a time not exceeding 1 hour. Also they may be used when additional insulation strength over the 100 percent level category is desirable.
>
> 173 Percent Level—Cables in this category should be applied on systems where the time required to de-energize a grounded section is indefinite. Their use is recommended also for resonant grounded systems. Consult the manufacturer for insulation thicknesses."

The foregoing material indicates that when the time required to de-energize a grounded section of a power system is indefinite, the use of a 173 percent level of thermoplastic conductor insulation is required by the IPCEA-NEMA Standard. High-resistance neutral grounded low-voltage systems, on which system ground faults may be permitted to exist for periods in excess of one hour, would be included in the "173 percent" category of the Standard; so also would ungrounded and resonant grounded systems.

Since the insulation requirements for solidly grounded neutral systems are fulfilled by a 100 percent insulation level, it is apparent that equipment and circuit conductor costs may be higher when ungrounded or high resistance neutral grounded systems are used and ground faults are unremoved for more than an hour. Furthermore, in these instances the user of high-resistance and ungrounded systems may find that wire and cable warranties are dependent on the use of 173 percent insulation levels for equipment and circuits.

With regard to systems operating at 600 volts and less, it may be observed that the National Electrical Code has a single insulation wall thickness for all 600-volt thermoplastic insulation applications and the NEC thickness is essentially the same as the IPCEA-NEMA Standard 100 percent level.

③These values are of interest to establish minimum sensitivity requirements for relaying. Even greater sensitivities are desirable to account for situations where the current is suppressed to lower values. The percentage figures in the tables are the calculated theoretical values for the system, arc and restrike voltages indicated. Actual fault current values may be greater or less than those calculated, because of differences in driving voltage, arc voltage and/or restrike voltage, and because of the influence of physical factors not included in the theoretical calculations.

④The low current value at 208 volts results from the relatively high arc voltage and restrike voltage used in the calculation. Experimental data and field reports indicate that arcing faults of much higher current value may be produced in 208-volt systems. The use of lower arc and restrike voltage values in the calculation would increase the calculated 208-volt current value.

⑤All grounded systems require a grounding electrode and grounding electrode conductor as basic equipment for grounding the system.

⑥A "delta" system is one in which the neutral is not available. New systems should use wye-connected source, with the neutral brought out.

⑦While low-resistance and reactance-grounded systems may meet most of the NEC 250–51 requirements for "Effective Grounding", they do not provide the limitation of voltage from phase-to-ground and from grounded conductor (neutral) to ground which are commonly expected of "grounded" systems. Therefore such impedance-grounded systems have not been indicated as suitable for serving single-phase load circuits with one-side grounded or four-wire, three-phase circuits.

⑧Use of recommended practices in the primary and secondary systems, such as 400 amp grounding at 13.8 kV and 1000 amp or higher at 600 volts and below, will avoid excessive overvoltage in the secondary system when physical contact with the primary system occurs. In such cases the secondary phase-to-ground voltages will not exceed those present during a line-to-ground fault in the secondary system. A high voltage-low voltage crossover will result in dangerous overvoltage on the low-voltage system if the high-voltage system is solidly grounded. 13.8 kV utility systems are frequently solidly grounded, and all higher voltage systems are almost always solidly grounded.

⑨The zero value at 208 volts results from the high restrike voltage used in the calculation. The use of a considerably lower restrike voltage would permit the calculation of a non-zero rms current value.

PRINCIPAL METHODS OF LOW-VOLTAGE SYSTEM GROUNDING

The preceding material makes no recommendations for the application of specific system grounding methods, because this is dependent upon the particular system involved. As the introductory comments indicate, the "sales and/or application engineer is best qualified to consult with the customer and advise him on the choice of grounding method for his specific conditions and objectives."

From a practical viewpoint, however, it should be recognized that two methods of system grounding — the solidly grounded neutral and the high-resistance grounded neutral (with or without tracing pulse) methods—are those which are most frequently applied. Very often, the choice of a method of grounding comes down to a selection between these two methods. For that reason, it is appropriate to re-emphasize certain ideas and provide additional information regarding these particular grounding techniques, to aid in the selection process. Furthermore, the table on page 38 provides a useful quick reference for comparing the main features of these two grounding methods with one another and with the ungrounded system.

SOLIDLY GROUNDED NEUTRAL SYSTEM

This system has the neutral point directly grounded through an adequate ground connection in which no impedance has been inserted intentionally. By proper selection and setting of its circuit protective devices, the solidly grounded neutral system is intended to provide automatic disconnection of faulty circuits on the occurrence of line-to-ground or line-to-line faults. Most often, in conventional practice, this automatic segregation of defective circuits is provided by the phase overcurrent devices. More and more, however, it is being recognized that this type of system may justify supplementary ground fault relaying to detect and remove low-level arcing faults to ground which, if unremoved, could cause extensive burndown of equipment. No instances are known of such burndowns having occurred on solidly grounded neutral systems equipped with sensitive ground fault relaying.

An important feature of the solidly grounded neutral system is that it has essentially zero shock hazard on the neutral conductor during a line-to-ground fault, and is thus satisfactory for serving four-wire three-phase distribution systems with line-to-neutral connected loads.

Application Area

The solidly grounded neutral system has been applied most satisfactorily in general industrial and commercial power distribution systems (including those serving "critical" loads) where one or more of the following characteristics prevail:

1. Four-wire three-phase power service is required.
2. Automatic tripping for isolation and removal of ground faults is desirable and acceptable.
3. Maximum possible system insulation life is to be secured through effective control of transient and steady-state overvoltages.
4. Competent operating and maintenance personnel are not continuously available for tracing ground faults and scheduling their removal from the system with minimum deliberate delay.
5. There is an unusual possibility of a high voltage-low voltage crossover.

Requirements for Securing Maximum Benefits

To secure the maximum in benefits from the use of a solidly grounded neutral system, the following items are essential:

1. Proper equipment grounding conductors installed to insure adequate ground fault current for tripping.
2. Properly set and maintained phase overcurrent protective devices.
3. Properly set and maintained ground fault protective devices where this requirement is not served by the phase devices.
4. Observance of the limitations of single-pole interrupters. (See GER-2253, "Application Limitations of Single-pole Interrupters in Polyphase Industrial and Commercial Building Power Systems," R. H. Kaufmann.)

The observance of the limitations of single-pole interrupters is necessary to prevent an undesirable reduction in fault current level during arcing line-to-ground or line-to-line fault conditions. Preventing such a reduction helps to assure prompt removal of these faults by ground- or phase-overcurrent protective devices.

HIGH - RESISTANCE GROUNDED NEUTRAL SYSTEM

The neutral point of this system is connected to ground through an impedance, the principal element of which is resistance. Although an official definition is lacking, it is to be understood here that "high resistance grounding" implies the use of a neutral resistor which limits the resistor current during a bolted line-to-ground fault to not less than ($3I_{co}$), the total system charging current ($3E_{LN}/X_{co}$). Furthermore, in a well-designed high-resistance grounded system the resistor current under ground fault conditions will not be greatly in excess of the total system capacitive charging current to ground with the result that the total maximum current in a solid fault to ground will be approximately $\sqrt{2}$ times the neutral resistor current. Only very rarely, on systems having a great many surge capacitors, will the total ground fault current exceed 5 amperes when the neutral resistor is chosen as indicated; in general, the total fault current will be less than one ampere.

The high resistance grounded system generally is designed so that automatic segregation of the faulty circuit does **not** take place on the occurrence of the first ground fault. Thus when a ground fault occurs there is no immediate interruption of service, and loads on the faulty circuit are continued in operation. This is often a desirable operating characteristic for certain critical loads to permit an orderly shutdown and/or to avoid the severe financial penalty arising from loss of production or from contingent equipment damage following an unscheduled outage. It is imperative to get the first ground fault removed from high-resistance grounded systems as quickly as possible, however, because while the initial ground fault remains on, the occurrence of another ground fault will result in flash hazard to personnel and possibly in the shutdown of two circuits, instead of only one. Thus, the continued presence of a ground fault constitutes a substantial peril both to personnel and to system service continuity. Furthermore, in equipment with multi-turn coils turn-to-turn failure may follow, with possibly greater resultant damage than if the system were soldily grounded.

For the foregoing reasons any purchaser choosing a high-resistance grounded system should be alerted to the need for ground fault detection and alarm equipment, continuously available equipment and personnel for tracing and locating ground faults with the system energized, and operating instructions that require the removal of such faults with all the urgency that conditions permit.

Furthermore, the user should be aware of the requirements of the IPCEA-NEMA Standard for thermoplastic insulated conductors, as discussed in footnote ② on page 33.

Application Area

The high-resistance grounded neutral system has been applied with the most favorable results in industrial systems—particularly in the process-type industries—where one or more of the following characteristics are prevalent:

1. Automatic tripping on the first ground fault is not desirable or acceptable.
2. The minimizing of ground-fault flash hazard for personnel is an objective.
3. A substantial reduction in the risk of equipment burndown arising from ground faults is desired.
4. Competent operating and maintenance personnel are available for promptly tracing ground faults and scheduling their removal with minimum deliberate delay.
5. 4-wire 3-phase service is **not** required.
6. Control of system transient overvoltages is required, but the avoidance of certain possible steady-state overvoltage conditions is of secondary importance to avoiding automatic tripping on the first ground fault.

Requirements for Securing Maximum Benefits

The attainment of maximum benefits from the use of the high-resistance grounded neutral system is dependent on the following:

1. The selection of a grounding resistor to provide a resistor ground-fault current only slightly greater than the line-to-ground system charging current ($3E_{LN}/X_{co}$).
   This means the total ground fault current will be approximately $\sqrt{2}$ times the system charging current.
2. The application of procedures and fault-tracing equipment for quick detection, location, and removal of ground faults.*
3. The proper setting and maintenance of phase-overcurrent devices.
4. Consideration of the use of ground overcurrent protective devices for backup protection.
5. The installation of proper equipment grounding conductors.
6. The observance of the limitations of single-pole interrupters. (See GER-2253, "Application Limitations of Single-pole Interrupters in Polyphase Industrial and Commercial Building Power Systems," R. H. Kaufmann.)

The limitations of single-pole interrupters should be observed to avoid a reduction in fault current level during line-to-line fault conditions and during the existence of sequential-occurrence line-to-ground faults at different locations. This procedure facilitates the prompt removal of such faults by ground- or phase-overcurrent protective devices acting upon three-phase interrupters.

Evaluation of These Alternative Grounding Methods

There are many possible criteria against which to measure the suitability of a particular method of system grounding. While nontechnical factors, such as the need to minimize the disorderly shutdown of certain critical loads, may be the predominant influence in the choice of a grounding method, it is appropriate to weigh other factors in the process of making a decision. Among these other factors the following are particularly important:

1. Control of Overvoltages.
   The sources of overvoltage which may occur on a power distribution system are many. Inasmuch as the method of system grounding may be effective in relieving such overvoltages, the most significant are (see Industrial Power Systems Data Book, Section .22):
   A. Physical contact with a higher voltage system.
   B. Resonance in series inductive-capacitive circuits.
   C. Repetitive restrike (intermittent ground faults).
   D. Autotransformer connections.

   The solidly grounded neutral system effectively controls to safe levels the overvoltages which tend to be impressed on or self-generated in the power system by the above situations. The high-resistance grounded system, on the other hand, is able to effectively control to acceptable levels only the overvoltages in categories B. and C. above. Overvoltages arising from physical contact with higher voltage systems, from faults in systems interconnected with an ungrounded autotransformer, or from autotransformer extended winding failures, are not satisfactorily controlled by the high-resistance grounded system.
2. Shock Hazard.
   Serious, perhaps lethal, electrical shock caused by accidental contact with energized phase conductors is a hazard common to almost all power distribution systems, grounded as well as ungrounded. Since the human body presents a relatively high impedance fault-to-ground, only extremely sensitive ground fault detection, coupled with very rapid fault isolation and near-perfect dependability, can significantly improve the present incidence of injuries or deaths attributable to such contacts. Unfortunately, detector-interrupter combinations of the required sensitivity and speed are presently applicable only in the smallest of power systems—as in residential or pool-side service—and are not currently practical in industrial and commercial power systems. Thus avoidance of injury or death from shock in these systems is essentially a matter of avoiding working on energized equipment, the observance of safe work habits, the proper maintenance and repair of equipment, and the installation of an adequate grounding network. Despite these measures, however, accidental contact with energized conductors or with the frames or enclosures of faulted equipment or circuits improperly grounded will continue to occur. For these reasons, comment on the difference between solidly grounded neutral and high-resistance grounded neutral systems under such conditions is appropriate.
   In the absence of a circuit fault to ground, the solidly grounded neutral and the high-resistance

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*See GER-2375 "High-resistance Grounding of . . . delta systems with ground-fault alarm and traceable signal to fault," F. K. Fox, H. J. Grotts, C. H. Tipton.

grounded neutral systems both present direct-contact shock hazard; line-to-neutral voltage exists from each phase to ground, and the neutral point is at essentially ground (zero) potential.

In the presence of a solid line-to-ground fault, normal line-to-neutral voltage continues to be present on two of the three-phase conductors to ground in the solidly grounded system, while in the high-resistance grounded system essentially normal line-to-line voltage appears on two of the phase conductors (to ground) for the duration of the fault, thus increasing the shock potential on these phases. Of greater importance, however, is the fact that the neutral conductor of the solidly grounded neutral system remains at essentially ground potential during the line-to-ground fault interval, while in the resistance-grounded system the neutral point assumes a potential above ground approximately equal to the value of the normal line-to-neutral voltage. Stated another way, the ground fault current flow in the neutral resistor elevates the neutral point above ground potential by about the normal line-to-neutral voltage value. It is essentially for this reason that the resistance-grounded system is not satisfactory for general four-wire power distribution, since the neutral conductor during line-to-ground faults would be energized to about normal line-to-neutral voltage. On four-wire systems, line-to-neutral connected loads are served by single-pole interrupters, the disconnection of which in a resistance grounded system would not prevent the appearance of hazardous shock potential between the "white" wire and ground during line-to-ground faults. Thus the safety of electricians working on supposedly de-energized circuits would be jeopardized during line-to-ground faults in four-wire systems served from resistance-grounded sources, unless two-pole interrupters were used to serve the line-to-neutral connected loads. This, however, would be a costly change from present practices and requirements.

In the presence of an adequate equipment grounding network, the shock potential presented by the frame of an equipment or device having an internal line-to-ground fault is less in the high-resistance grounded system than in the solidly grounded neutral system. In either case, however, the shock potential is low. Under the same fault conditions, but in the absence of an adequate equipment grounding network, no difference in shock hazard exists between the two systems described.

3. Flash Hazard.

Whenever a phase-to-phase or phase-to-ground fault takes the form of a flashover through air (an arcing fault) the release of energy in the fault may cause the violent generation of hot gases and arc plasma, accompanied by incandescent metallic vapors. The site of the fault, when a relatively high fault current flows—say, a thousand amperes or more—becomes a flaming eruption with considerable blasting and burning effect. Such a fiery explosion represents an extreme peril to persons working at or near the fault location, and may realistically be referred to as a **flash hazard.**

In the solidly grounded neutral system it is possible for several thousand amperes to flow during a line-to-ground arcing fault. Obviously, the flash hazard associated with such a fault would be severe. With high current flow in the arc there is a strong probability that instantaneous overcurrent protective devices will promptly remove the fault. If the arcing fault current occurs at reduced levels the flash hazard, though still serious, will be correspondingly reduced in severity. Under these restricted flow conditions supplementary ground fault relaying may be required to detect and extinguish the fault, at least on the larger circuits.

The extent of the flash hazard in solidly grounded neutral systems clearly is of sufficient degree, at its best, to make it a safety requirement that equipment and circuits be worked upon only when de-energized, thus eliminating the risk of fault initiation. The voltage hazard always present in energized systems also imposes this same requirement.

The high-resistance grounded system is not free from flash hazard and warrants similar rules regarding working on energized equipment. The flash hazard in this type system on the occurrence of a first **ground** fault, however, is minimal, provided escalation does not occur. The restriction in current flow is so great that limited energy is released in the arc. Also, the arc itself is difficult to sustain. Little flash and spark are produced and the tendency, at the point of contact between conductor and ground, is for the arc to extinguish or for a slight "tack" welding action to be produced.

The serious flash hazard situation in high-resistance grounded systems occurs when a line-to-ground fault escalates into a line-to-line fault, or when the fault occurs as a line-to-line or double line-to-ground fault. The latter two events may be brought about, respectively, through an electrician's error or from the occurrence of a **second** ground fault on the system. The flash hazard from a line-to-line fault is a danger associated with the solidly grounded neutral system also, but the occurrence of a double line-to-ground fault is a peril associated largely with the high-resistance grounded system. In a line-to-line arcing fault on a high-resistance grounded system the flash hazard may be as great as for a line-to-ground fault on a solidly grounded neutral system. Thus the resistance grounded system is not secure from very serious flash hazard. This is one reason that application of this type of system grounding should be bolstered by ground-fault indicating and tracing equipment, and by the requirement that ground faults be removed as promptly as operations permit.

4. Detection of Arcing Faults.

The need for rapid detection and removal of arcing faults in low-voltage systems has been well covered in the technical literature in the past few years. Fundamentally, the objective is to control arc burning damage to an acceptable degree and avoid or minimize equipment burndowns. The use of sensitive zero-sequence type relaying may permit prompt detection and subsequent removal of arcing faults, especially in the solidly grounded neutral system. This kind of system commonly includes ground itself in the fault circuit, even though the fault may be initiated line-to-line. With sensitive ground fault relays, even low-level arcing faults may be quickly detected and removed before extensive damage is incurred at the fault site. Thus the solidly grounded neutral system provides an effective **basis** for protection against destructive arcing fault burndowns.

In the high-resistance grounded system little if any threat of burndown is presented by a single fault to ground, provided it is not left on for prolonged periods. Line-to-line arcing faults, however, will cause severe equipment damage if not removed within a few cycles. When the arcing fault current is relatively high, the conventional phase overcurrent devices will function to detect and remove the faults. Under certain conditions, however, the rms current value associated with an arcing line-to-line fault may be so low as not to operate conventional phase overcurrent devices, or to operate them only after a prolonged interval; then burndown may occur. This is possible, for instance, when single-pole interrupter operation has only partially disconnected the faulty circuit, when a double line-to-ground fault on separate circuits introduces substantial impedance into the fault circuit or when the arc resistance lowers the current. In the double line-to-ground fault case sensitive ground fault relays can detect and remove one or both faults provided they are on different circuits. If the low level arcing fault involves only one circuit, however, on either a line-to-line or double line-to-ground basis, ground fault relaying will be ineffective and burndown can occur unless the fault current level increases sufficiently to operate the phase overcurrent devices. Such escalation is not certain and thus, in contrast to the solidly grounded neutral system, the high-resistance grounded system does not provide a simple, economical means to assure detection and removal of low-level arcing faults regardless of where they occur. Also, the high-resistance grounded system does not offer as good rotating machine protection as solid grounding **with ground fault relaying,** since ground faults are not quickly detected and removed, and may burn into turn-to-turn faults creating greater damage to the machine. This compromise in rotating machine protection is inbuilt in the "non-interruptible" design concept of high resistance neutral grounding.

Summary Remarks

There is, obviously, no single method of system grounding which will prove to be most satisfactory in all possible situations. Each application problem must be resolved on the basis of its individual requirements and constraints, leading usually to a compromise choice in which something is gained at the expense of something else. The solidly grounded neutral system with ground fault relaying will provide acceptable performance. In other instances, the high-resistance grounded neutral system with tracing pulse may have user preference. For each of these system grounding methods the typical application areas are suggested in preceding paragraphs, while concluding statements may be made as follows:

Solid Neutral Grounding

The solidly grounded neutral system provides transient overvoltage control and a means for automatic easy detection and selective isolation of system faults, as well as the possibility of good rotating machine protection. To secure greater benefits from its use, however, and to improve personnel safety and system service reliability, this type of system grounding may require the use of supplementary ground fault relaying.

In the solidly grounded neutral system arcing line-to-ground faults can produce violent local eruption which could result in personnel injuries and severe damage to equipment if not quickly removed. Most line-to-line faults, however, will promptly involve ground and will be removed without significant delay by phase overcurrent devices or supplementary ground fault relays. This method of system grounding is the one most widely used at present in industrial and commercial power distribution, and is required on four-wire systems.

High-resistance Neutral Grounding

High-resistance neutral grounding has frequently been applied in process and similar industries in the belief that delayed tripping of a faulted critical process circuit will improve over-all service continuity by permitting an orderly shutdown under ground fault conditions. The basic objective is to secure control of the self-generated system transient overvoltages while minimizing the possibility of having a service interruption arising from a first ground fault. Since the prolonged existence of a ground fault increases the probability of a second ground fault shutting down two circuits simultaneously, it is advisable to complement this grounding method with ground detection and alarm devices and fault-tracing equipment, to help in securing maximum benefits from this type of grounding.

Rapid removal of the initial ground fault by system operators may also influence the selection of conductor thermoplastic insulation thicknesses, as indicated in footnote ② on page 33.

High resistance neutral grounding, on a first ground fault, avoids the arc blast and minimizes the fault damage associated with arcing line-to-ground faults. Such faults, however, may escalate into line-to-line faults or, if unremoved, may be compounded by a similar fault on another phase, with subsequent arc damage quite like that with a solidly grounded neutral system. Furthermore, unremoved ground faults continue to produce some damage at the fault point and may eventually escalate to more serious character. On equipment with multi-turn coils, such as motors, such unremoved faults may cause eventual turn-to-turn failures and consequent severe damage (turn-to-turn currents are not limited by the grounding resistor).

This method of neutral grounding is not satisfactory for general four-wire service, since the elevation in voltage of the neutral conductor during any line-to-ground fault may result in a severe shock hazard to personnel. To minimize this would require the use of two-pole interrupters on single-phase circuits. Even then, there might be other problems in the safe use of portable tools or appliances. The high resistance method of system grounding is, however, gaining increased acceptance on three-wire systems with plant operators in process and other industries who are desirous of securing control of transient overvoltage while avoiding a disorderly shutdown of electrical equipment and/or the presence of a severe flash hazard on the occurrence of a first ground fault.

PRINCIPAL CHARACTERISTICS OF MAJOR METHODS OF GROUNDING LOW-VOLTAGE SYSTEMS

PRINCIPAL CHARACTERISTICS OF MAJOR METHODS OF GROUNDING LOW-VOLTAGE SYSTEMS

System Property	Type of System Grounding		
	Solid *	High Resistance **	Ungrounded
Immediate Shutdown of Faulty Circuit on Occurrence of First Ground Fault	Yes	No	No
Control of Transient Overvoltages Due to Arcing Ground Faults	Yes	Yes	No
Control of Impressed or Self-generated Steady-state Overvoltages	Yes	No	No
Flash Hazard to Personnel During Ground Fault (No Escalation of Fault)	Severe	Essentially zero	Essentially zero
Arcing Fault Damage to Equipment During Ground Fault (No Escalation)	May be severe unless fault is promptly removed	Usually minor unless fault removal is so prolonged as to cause fault escalation	Usually minor but transient overvoltages may cause fault escalation or multiple insulation failures
Shock Hazard, Unfaulted Phases to Ground, During Ground Fault	Line-to-neutral voltage	Approximately line-to-line voltage	May be several times line-to-neutral voltage
Shock Hazard, Equipment Frame to Ground During Solid Internal Line-to-Ground Fault	Moderate	Minimum	Small
Detection of Arcing Faults	L-L or L-G arcing faults readily detected, esp. with ground fault relaying	Ground detectors and fault locating equipment required for L-G arcing faults. L-L faults readily detected by phase overcurrent devices unless fault current is severely limited	Ground detectors and fault locating equipment required for L-G arcing faults. Transient overvoltages may meanwhile cause additional insulation breakdowns. L-L faults readily detected by phase overcurrent devices unless fault current is severely limited
Suitable for Four-wire, Three-phase Service	Yes	No	No

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* For optimum results, use of solid grounding method should include sensitive ground fault relaying.

**For optimum results, use of high resistance grounding method should include equipment and procedures for alarming, tracing and removing the ground fault promptly.

NOTES

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