

# Atlanta Chapter – IEEE Industry Applications Society

## Electrical Equipment Room Design Considerations

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# Outline

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2. Power Distribution Configurations
3. Selection of Transformer
4. Installation and Location of Transformer
5. Service Entrance Equipment
6. Selection of Circuit Breaker
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9. Maximum Impedance in a Ground Return Loop to Operate an Overcurrent Protective Device
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# Outline

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13. Power Distribution Systems with Multiple Sources
14. Modified Differential Ground Fault (MDGF) Protection Systems
15. Designing a MDGF Protection System
16. Reported Ground Fault Losses

# 1. Definitions

## System Configuration

- The *system configuration* of any Power Distribution System is based strictly on how the secondary windings of the Power Class Transformer, or generator, *supplying* the Service Entrance Main or loads, are configured. (This includes whether or not the windings are referenced to earth.)
- The system configuration is **not** based on how any specific load or equipment is connected to a particular power distribution system.

# 1. Definitions

## Ground Fault Protection System

- *A designed, coordinated, functional, and properly installed system* that provides protection from electrical faults or short circuit conditions that result from any unintentional, electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.

# 1. Definitions

## Ground Fault Protection of Equipment (Per Article 100 in the 2005 NEC)

- “A system intended to provide protection of equipment from damaging line-to-ground fault currents by operating to cause a disconnecting means to open all ungrounded conductors of the faulted circuit. This protection is provided at current levels less than those required to protect conductors from damage through the operation of a supply circuit overcurrent device.”

# 1. Definitions

## Effective Ground-Fault Current Path (per Article 250-2 in the 2005 NEC)

- “An intentionally constructed, permanent, low-impedance electrically conductive path designed and intended to carry current under ground-fault conditions from the point of a ground fault on a wiring system to the electrical supply source and that facilitates the operation of the overcurrent protective device or ground fault detectors on high-impedance grounded systems.”

# 1. Definitions

## Ground Fault

(per Article 250-2 in the 2005 NEC)

- “An unintentional, electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally non-current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.”



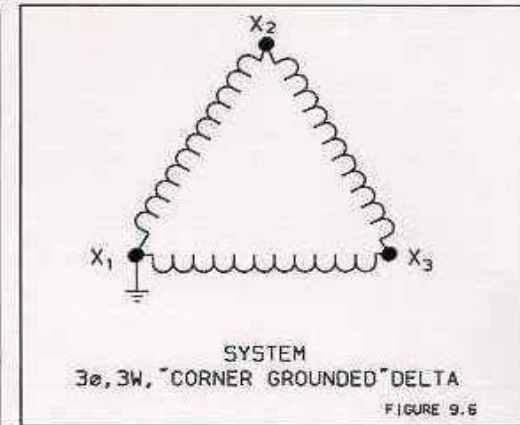
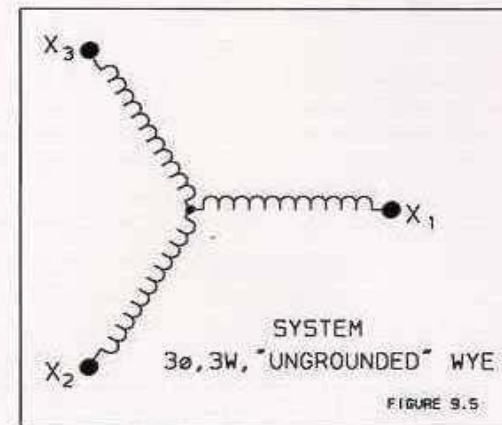
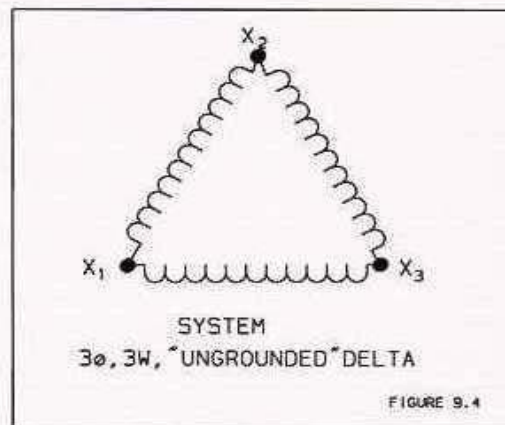
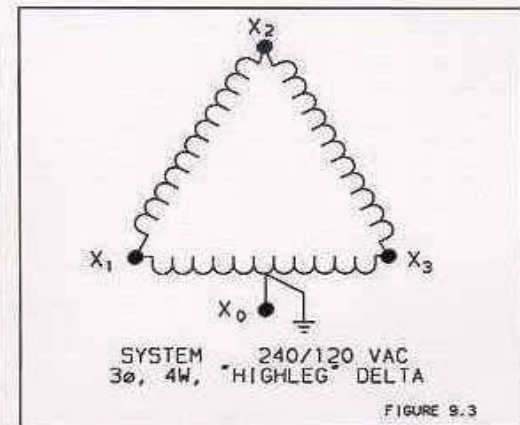
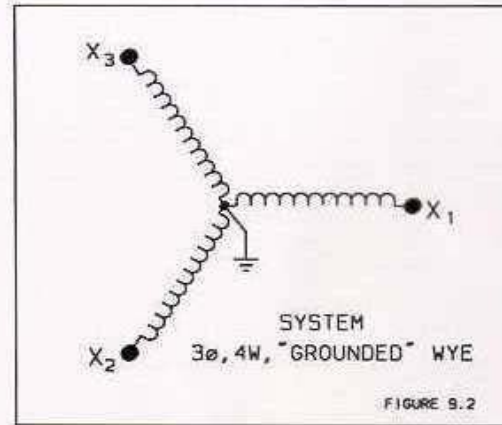
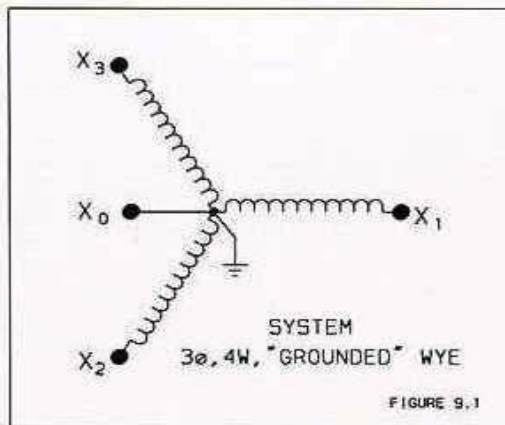
# 1. Definitions

## Ground Fault Current Path

(per Article 250-2 in the 2005 NEC)

- “An electrically conductive path from the point of a ground fault on a wiring system through normally non–current-carrying conductors, equipment, or the earth to the electrical supply source.”

## 2. Power Distribution Configurations



Figures 9.1, 9.2, 9.3, 9.4, 9.5, and 9.6

### 3. The Selection of the Power Class Transformer to Install

- Dry Type
  - Air/Dry
  - Cast Resin
- Liquid Filled
  - Mineral Oil (flammable, marketed or perceived bio hazard)
  - Silicone (non-flammable)
  - Bio [Corn Oil] (flammable, but not a marketed or perceived bio hazard )
- Gas Type

## 4. The Location and Installation of the Power Class Transformer

- Outdoors
  - Enclosure Types Relative to Environment
  - Accessibility
  - Camouflage to Meet Local Requirements
  - Hazardous Locations
  - Protection for and from people
  - Required Markings
  - Security
- Indoors
  - To Vault or Not To Vault
  - Fire Ratings of Location
  - Rating of NEMA Environment
  - Environmental Considerations
  - Cooling Ability
  - Accessibility
  - Security

## 5. Service Entrance Equipment

- Switchboards (UL 891)
  - The UL 891 Standard applies to switchboards nominally rated at 600 V or less and intended for use in accordance with the Canadian Electrical Code, Part 1 (CE Code, Part 1), the National Electrical Code (NEC), ANSI/NFPA 70, and the Mexican Standard for Electrical Installations (Utility), NOM-001-SEDE.
  - The term switchboard is intended to refer to a dead-front switchboards only.
  - Not associated with the following switchboard types:
    - Preset and dimmer control (theater)
    - Live front, railway control, or electrification
    - Constructions intended only for receiving motor control center units.
  - Covers switchboards for use on circuits having available rms symmetrical short-circuit currents of not more than 200 000 A.

## 5. Service Entrance Equipment

- Switchboards (UL 891) continued
  - Traditionally have less bus clearances than switchgear.
  - Bussing is rarely insulated (unless specified and paid for).
  - The spaces between all distribution circuit breakers are not usually compartmentalized.
  - Employs a greater use of barriers within a section versus compartments.
  - There are barriers between sections.
  - Circuit Breakers employed within a switchboard section can be molded case, insulated case, or a power type.
  - Instantaneous trip functions on molded case and insulated case circuit breakers employed within a switchboard assembly are not generally ANSI rated for higher short time withstand capability
  - Can possibly be accessible from only one side.

## 5. Service Entrance Equipment

- Switchgear (UL 1558)
  - Covers metal-enclosed low-voltage power circuit breaker switchgear assemblies containing but not limited to such devices as low-voltage power circuit breakers, other interrupting devices, switches, control, instrumentation and metering, protective and regulating equipment.
  - Covers power equipment intended for use in ordinary locations in accordance with the National Electrical Code.
  - UL 1558 requirements are intended to supplement and be used in conjunction with the Standard for Metal-Enclosed Low Voltage Power Circuit Breaker Switchgear, ANSI C37.20.1, and the Standard for Conformance Testing of Metal-Enclosed Low-Voltage AC Power Circuit Breaker Switchgear Assemblies, ANSI C37.51.
  - Covers equipment rated 600 Vac or less nominal, 635 Vac maximum.

## 5. Service Entrance Equipment

- Switchgear (UL 1558) continued
  - For use on circuits having available rms symmetrical short-circuit currents of not more than 200 000 A.
  - Switchgear is 30 cycle rated and can be installed without instantaneous overcurrent protection to assist in selectivity.
  - Traditionally switchgear has more bus clearances
  - Insulated bussing is commonly employed as a standard
  - Compartmentalized cubicles versus barriers between sections
  - Circuit breakers employed are by definition (ANSI standards) classified as power class circuit breakers having a higher short time withstand capability than switchboards.
  - Switchgear is front and rear accessible.



## 6. Selection of MCCB Circuit Breakers as Overcurrent Protective Devices

- Molded Case Circuit Breakers (MCCB)
  - Thermal – Magnetic
    - » Low Voltage Applications up to 600Vac
    - » Typical Current Ratings are from 5A to 2000A
    - » Originally designed for overload and phase-to-phase short circuit protection
    - » If intended to provide ground fault protection, these type circuit breakers must be employed on a circuit with an effective low impedance, ground fault current return path
    - » Mechanism is totally sealed
    - » Mainly require manual operations
    - » Not designed or intended to be serviceable
    - » Typically bolted onto or plugged into bus
    - » Should be installed with equipment turned off
    - » A ground fault module can be installed on some devices
    - » Most are only 80% rated. 100% rating is optional
    - » Same size and ampere rating of same circuit breakers are manufactured with various short circuit ratings. (Knowing the available short circuit current available at point of connections is imperative!)
  - MICROLOGIC or Electronic Trip Units
    - » Offers a combination of LSIG function to the specifier or user
    - » Provides for improved time/current or fault coordination function

## 6. Selection of ICCB Circuit Breakers as Overcurrent Protective Devices

- Insulated Case Circuit Breakers (ICCB)
  - Generally are only UL Rated and not ANSI Rated
  - Low Voltage Applications up to 600Vac
  - Typical Current Ratings are from 400A to 4000A
  - They provide limited internal access to replacement of specific parts
  - Can be fixed mounted directly onto bus or manufactured as a draw-out type within a specifically designed cubicle
  - Can be fitted at the factory with multiple auxiliary functions
    - Multiple Auxiliary Contacts
    - Shunt Trip and Shunt Close Coils
    - LSIG Trip Alarms
    - Electric Motor Operator
  - Most are only 80% rated, 100% rating is optional
  - Ampere rating of circuit breakers can be manufactured with various short circuit ratings. (Knowing the available short circuit current available at point of connections is imperative)
  - MICROLOGIC or Electronic Trip Units
  - Offers a combination of LSIG functions to the specifier or user
  - Provides for improved time/current or fault coordination function

## 6. Selection of PCB Circuit Breakers as Overcurrent Protective Devices

- Power Circuit Breakers (PCB)
  - ANSI Rated and not UL Rated
  - Low Voltage Applications up to 600Vac
  - Typical Current Ratings are from 800A to 6000A
  - They provide internal access to inspection, maintenance, and replacement specific parts
  - Manufactured as draw-out type construction with isolated compartment or cubicle
  - Can be fitted at the factory with multiple auxiliary functions
    - Multiple Auxiliary Contacts
    - Shunt Trip and Shunt Close Coils
    - LSIG Trip Alarms
    - Electric Motor Operator
  - 100% rated
  - Tested and rated to a higher level of initial or asymmetrical short circuit current
  - More robustly constructed than ICCBs
  - Intended for longer use life and more open and close operations
  - MICROLOGIC or Electronic Trip Units with LSIG functions are standard
  - Has higher initial cost.

## 7. Electrical Room Construction (New)

- Electrical room accessibility by at least two portals (Based on the placement and orientation of equipment, more exits may be required by local AHJs)
- Cooling and humidity requirements for equipment
- Ventilation requirement for a specific equipment room
- Minimal space between physical structures and other electrical equipment
- Accessibility of equipment for maintenance and servicing
- Emergency accessibility requirements
- Security accessibility and requirements
- EPO installation and their locations
- To sprinkle or not to sprinkle. [The on going conflicts and turf wars between local AHJs (fire marshal, electrical inspector, building inspector) concerning the routing of steam and water pipe above electrical equipment and the requirements for a sprinkler system over electrical equipment.] NEMA 1 or NEMA 3R equipment??
- Are service or load conductors rated for application and environmental conditions?
- Are dissimilar circuit breakers being employed in multiple ended power distribution equipment (Multiple Sources)?
- Need for Differential Ground Fault Protection?

## 7. Electrical Room Construction (New) - continued

- Conflicts between the architecture and electrical engineer of record concerning available/needed space for all electrical equipment rooms.
- Dual use spaces (Electrical Equipment Room and Storage Area)
- Fire alarms
- Security Cameras and their location
- Is all electrical equipment effectively bonded and grounded?
- Effective lighting within electrical rooms or closets.
- Equipment installation requirements and guidelines provided by the electrical equipment manufacturer
- Operations and Maintenance Manuals provided by the electrical equipment manufacturer
- Startup and Testing requirements
- Lock Out / Tag Out Requirements
- Danger and Warning Labels (Inform and Warn Requirements)

## 7. Electrical Room Construction (New) - continued

- The need for a house keeping pad under the equipment.
- Locations within a specific building or facilities for the placement of service equipment, distribution equipment, power panels, motor control centers, ATS Units, battery banks, UPS Units, onsite generators, etc.....
- Requirements for any house keeping pad constructed (material composition and necessary height)
- Flooding concerns from either external and internal sources
- Structural and seismic requirements for the electrical room
- Structural and bracing requirements for the electrical equipment enclosures
- Structural and bracing requirements for overhead busways, busducts, and conduits
- Need for floor drains or sump pumps in electrical rooms
- Critter protection
- Internal heater and humidity controls
- Will any local employees have access to water hoses???













**Photo 8. Inspector examining electrical equipment.**



**Photo 10. Workman is properly protected and inspector is shown in the flash hazard boundary in front of the switchboard with no personal protective equipment. If this equipment is energized, what is wrong with this picture?**



**Photo 11. Workman is properly protected and inspector is shown in the flash hazard boundary in front of the motor control center. If this equipment is energized, what is wrong with this picture?**











## 8. Electrical Room Construction (New to Existing Equipment – Additional Considerations)

- Bringing existing Service Equipment into compliance to current electrical Codes
- Additions of multiple power sources from another transformer or generator
- Dissimilar power or service equipment are rarely compatible (**BIG RED FLAGS**)
- Are all power sources effectively bonded together via a low impedance path
- Complex technical issues to resolve because of incompatible ground fault protection systems



## 9. Maximum Impedance in a Ground Return Loop to Operate an Overcurrent Protective Device

Fuse Size in Amperes Value "a"	Circuit Breaker Ampere Rating Value "b"	Maximum %Z in Ground Return Loop*	* (480/1.732)/ 3A (or) 1.5b
5A	10A	18.48 OHMS	
10A	20A	9.23 OHMS	
15A	30A	6.12 OHMS	
20A	40A	4.62 OHMS	
30A	60A	3.08 OHMS	
40A	80A	2.31 OHMS	
50A	100A	1.75 OHMS	
75A	150A	1.23 OHMS	
100A	200A	0.924 OHMS	

## 9. Maximum Impedance in a Ground Return Loop to Operate an Overcurrent Protective Device

Fuse Size in Amperes Value "a"	Circuit Breaker Ampere Rating Value "b"	Maximum %Z in Ground Return Loop*	* (480/1.732)/ 3A (or) 1.5b
125A	250A	0.739 OHMS	
150A	300A	0.616 OHMS	
175A	350A	0.528 OHMS	
200A	400A	0.462 OHMS	
250A	500A	0.370 OHMS	
300A	600A	0.308 OHMS	
400A	800A	0.231 OHMS	
500A	1000A	0.185 OHMS	
600A	1200A	0.154 OHMS	

## 9. Maximum Impedance in a Ground Return Loop to Operate an Overcurrent Protective Device

Fuse Size in Amperes Value "a"	Circuit Breaker Ampere Rating Value "b"	Maximum %Z in Ground Return Loop*	* (480/1.732)/ 3A (or) 1.5b
800A	1600A	0.116 OHMS	
1000A	2000A	0.093 OHMS	
	2500A	0.074 OHMS	
1500A	3000A	0.062 OHMS	
2000A	4000A	0.047 OHMS	

## 10. 2005 NEC Requirements

### **Ground-Fault Protection of Equipment** (per Article 230-95 in the 2005 NEC)

- “Ground-fault protection of equipment shall be provided for solidly grounded wye electrical services of more than 150 volts to ground but not exceeding 600 volts phase-to-phase for each service disconnect rated 1000 amperes or more. The grounded conductor for the solidly grounded wye system shall be connected directly to ground without inserting any resistor or impedance device.
- The rating of the service disconnect shall be considered to be the rating of the largest fuse that can be installed or the highest continuous current trip setting for which the actual overcurrent device installed in a circuit breaker is rated or can be adjusted.”

## 10. 2005 NEC Requirements

### **Setting for Ground-Fault Protection**

(per Article 230-95(A) in the 2005 NEC)

- “The ground-fault protection system shall operate to cause the service disconnect to open all ungrounded conductors of the faulted circuit. The maximum setting of the ground-fault protection shall be 1200 amperes, and the maximum time delay shall be one second for ground-fault currents equal to or greater than 3000 amperes.”

# 10. 2005 NEC Requirements

## Ground-Fault Protection of Equipment

(NECH Commentary for Article 230-95(A) in the 2005 NEC)

- “The maximum setting for ground-fault sensors is 1200 amperes. There is no minimum, but it should be noted that settings at low levels increase the likelihood of unwanted shutdowns. The requirements of 230.95 place a restriction on fault currents greater than 3000 amperes and limit the duration of the fault to not more than 1 second. This restriction minimizes the amount of damage done by an arcing fault, which is directly proportional to the time the arcing fault is allowed to burn.
- Care should be taken to ensure that interconnecting multiple supply systems does not negate proper sensing by the ground-fault protection equipment. A careful engineering study must be made to ensure that fault currents do not take parallel paths to the supply system, thereby bypassing the ground-fault detection device. See 215.10, 240.13, 517.17, and 705.32 for further information on ground-fault protection of equipment.”

# 10. 2005 NEC Requirements

## Testing the Ground-Fault Protection

### System (per Article 230-95(C) in the 2005 NEC)

- “The ground-fault protection system shall be performance tested when first installed on site. The test shall be conducted in accordance with instructions that shall be provided with the equipment. A written record of this test shall be made and shall be available to the authority having jurisdiction.”
- (The requirement for ground-fault protection system performance testing is a result of numerous reports of ground-fault protection systems that were improperly wired and could not or did not perform the function for which they were intended. This Code and qualified testing laboratories require a set of performance testing instructions to be supplied with the equipment. Evaluation and listing of the instructions fall under the jurisdiction of those best qualified to make such judgments, the qualified electrical testing laboratory (see 90.7). If listed equipment is not installed in accordance with the instructions provided, the installation does not comply with 110.3(B).)

## 10. 2005 NEC Requirements

### **Effective Ground-Fault Current Path**

(per Article 250-4(A)(5) in the 2005 NEC)

- “Electrical equipment and wiring and other electrically conductive material likely to become energized shall be installed in a manner that creates a permanent, low-impedance circuit facilitating the operation of the overcurrent device or ground detector for high-impedance grounded systems. **It shall be capable of safely carrying the maximum ground-fault current likely to be imposed on it from any point on the wiring system where a ground fault may occur to the electrical supply source.** The earth shall not be considered as an effective ground-fault current path.”



# 11. Ground Fault Sensing

- There are three basic types of sensor arrangement used to sense abnormal current flow in a Zero Sequence Relaying Scheme. They are;
  - A. Zero Sequence Sensing – Where one sensor is employed to surround all phase conductors and neutral conductor.
  - B. Modified Zero Sequence Sensing – Where one sensor is employed to surround all phase conductors and a separate sensor surrounding the neutral sensor.
  - C. Residual Sequence Sensing – Where one sensor surrounds each phase conductor and neutral conductor.

## 12. Zero Sequence Sensing vs. Residual Sequence Sensing

### Zero Sequence Sensing

- Current sensors or current transformer are **external** to disconnecting device
- Usually associated with a separate and **externally mounted** Ground Fault Relay
- No internal relationship to disconnect to be operated. All GFP components are **externally mounted**.
- Disconnect requires a shunt trip coil
- **Requires a separate and reliable source of control power. (Weakest Link)**

## 12. Zero Sequence Sensing vs. Residual Sequence Sensing

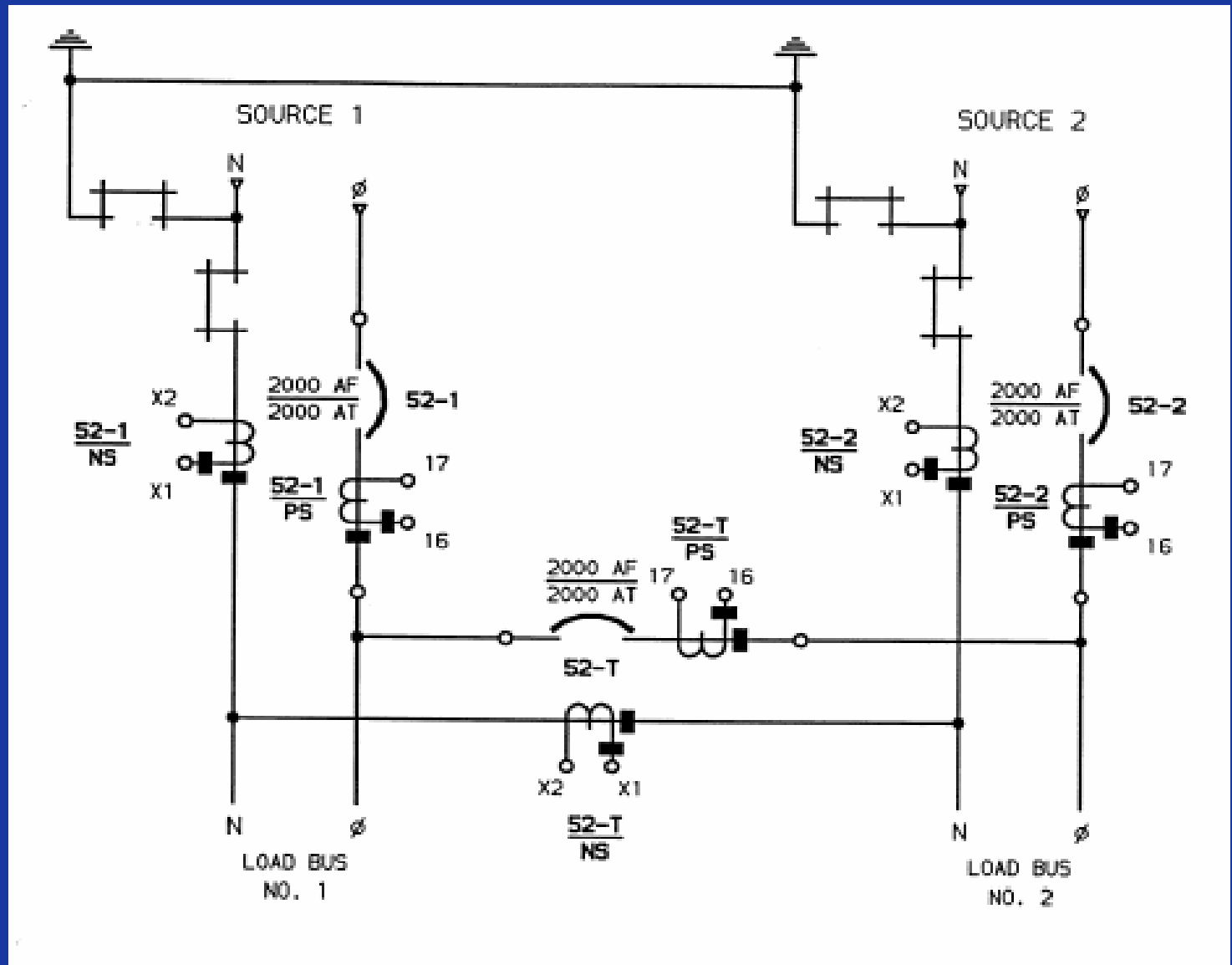
### Residual Sequence Sensing

- Phase sensors are usually internal to protective device to be operated.
- Ground fault relaying is usually performed internal to protective device or circuit breaker to be operated.
- No external control power supply required. Protective device or circuit breaker is “self-powered”.
- Self powered residual sequence sensing GFP is referred to as *Integral Ground Fault Protection*.

# 13. Power Distribution Systems with Multiple Sources

- Two or more sources of power connected to the switchboard or switchgear.
- Separate Main Circuits Breakers
- Tie Circuit Breakers
- Separate Load Busses
- Neutral Bus associated with each power source are interconnected together.
- Multiple neutral-to-ground bonds via the connection of multiple System Bond Jumpers and Main Bonding Jumpers (MBJ).
- The interconnection of multiple grounding conductors on the line side of the main circuit breakers can function as a parallel neutral bus.
- Multiple current paths for imbalanced neutral currents and ground fault currents to flow.

# 13. Power Distribution Systems with Multiple Sources



## 14. Modified Differential Ground Fault (MDGF) Protection Systems

- The purpose of a MDGF Protection System is to sense and properly relay all of the phase and neutral currents which circulate through and within a multiple source power distribution system at all times during normal and abnormal conditions.
- The MDGF Protection System prevents nuisance tripping of circuit breakers from the flow of imbalanced currents from imbalanced loads.
- The MDGF Protection System prevents nuisance tripping of circuit breakers from the flow circulating currents in and out of the switchboard or switchgear from closed transition operations.
- The MDGF Protection System opens all of the appropriate circuit breakers closes to the faulted location within a switchboard or switchgear.
- The MDGF Protection System provides for the sectionalization of load busses.

## 15. Designing a MDGF Protection System

Before a MDGF Protection Systems for a multiple sourced switchboard can be configured the following must be evaluated.

- A. Type of circuit breaker?
  - 1. The internal sensors and ground fault relaying are not always configured the same.
- B. Frame size of the circuit breaker?
  - 1. Different frame size breakers often have different C.T. ratios.
  - 2. Different series circuit breakers can have the frame size and C.T. ratios, but different instantaneous C.T. polarities.



## 15. Designing a MDGF Protection System

C. How are the circuit breakers supplied with power?

1. Are the circuit breakers top feed?
2. Are the circuit breakers bottom feed?

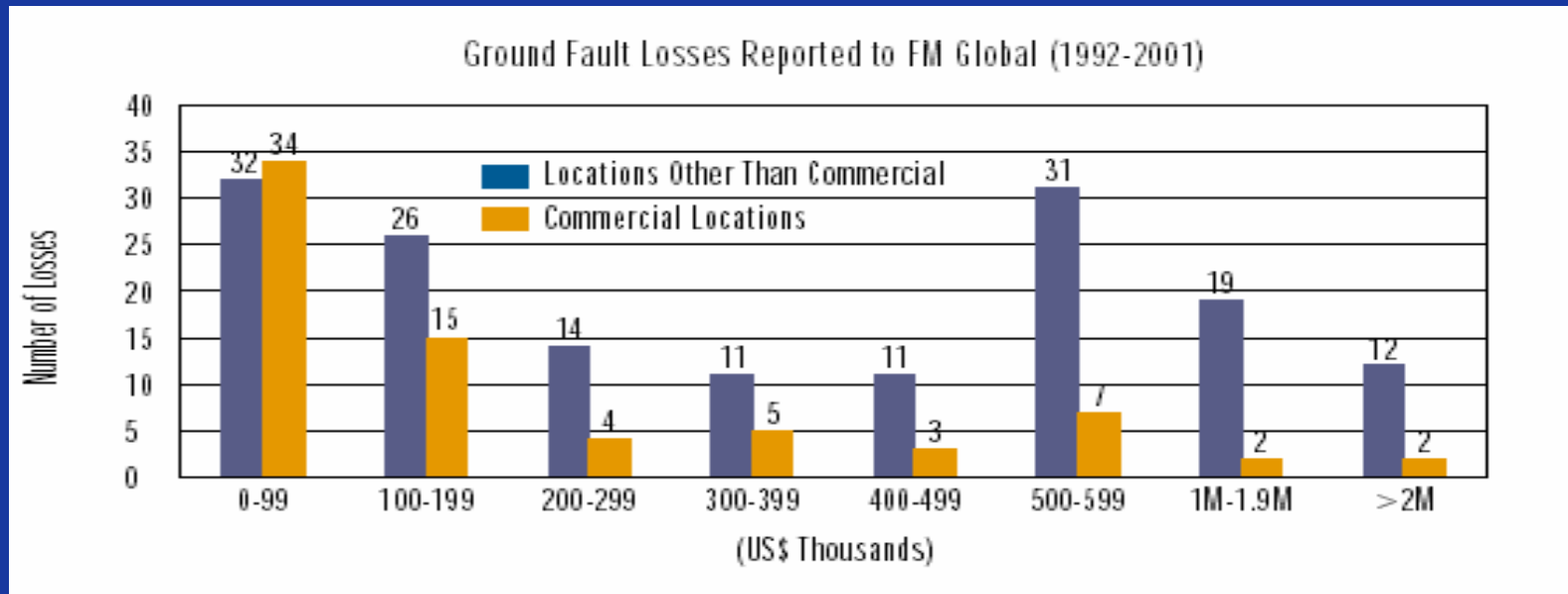
D. Are the circuit breakers “fixed” or “draw out” type?

The MDGF must be maintained when any circuit breaker is open or removed from its cell (drawn out).

E. Is the tie circuit breaker (52T) specified to ground fault protection?

1. “Non-Relayed” Tie Circuit Breaker has no GF Protection
2. “Relayed” Tie Circuit Breaker has GF Protection

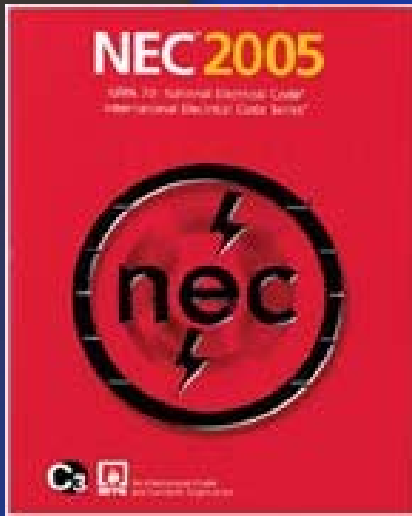
## 16. Reported Ground Fault Losses



One Major Loss (Claim) Every Two Weeks

# Special Notes for Consideration

- Phase-to-ground faults are the most common form of electrical faults. (95% to 98%)
- During any phase-to-ground fault the ground fault return path is 50% of the power circuit.
- Phase-to-ground faults are the most destructive type of electrical faults.
- Contrary to popular belief or some marketing publications, fuses do NOT provide selective coordination from most phase-to-ground faults.
- For a current limiting fuse to limit current as designed and intended a fault must be a “bolted fault”. Current limiting fuses do not coordinate well during high impedance phase-to-ground faults.
- Multiple levels of ground fault protection via MICROLOGIC Circuit Breakers provides the best form of selective coordination from phase-to-ground fault condition.
- Complex ground fault protection systems (MDGF) require a specific level of electrical engineering expertise.



# Code – NEC, NFPA 70

- The NEC is a minimum construction and installation “requirement” document.
- The NEC is NOT a design or performance standard .
- “Minimum requirements” are often insufficient for the construction and installation of mission critical facilities as Data Centers, Communication Centers, Hospitals, Industrial Plants, Military Facilities, Prisons, and Transportation Centers.

# Questions & Answers

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