Grounding for Industrial Systems

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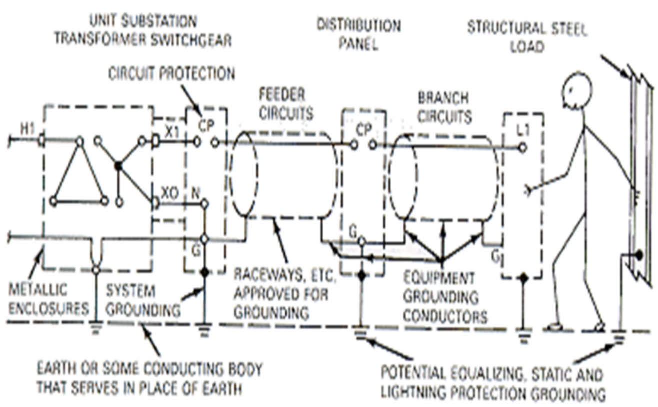
System Failures on Industrial Power Systems

Failure Mode	Percentage of Failures
Line to Ground	**98%**
Phase to Phase	< 1.5%
*Three Phase	< 0.5%

**Most three phase faults are man-made: i.e. accidents caused by improper operating procedure.*

What is a Ground Fault?

- Contact between ground and an energized conductor
- Unleashes large amount of electrical energy
- Dangerous to equipment and people



Z10 Safety Controls

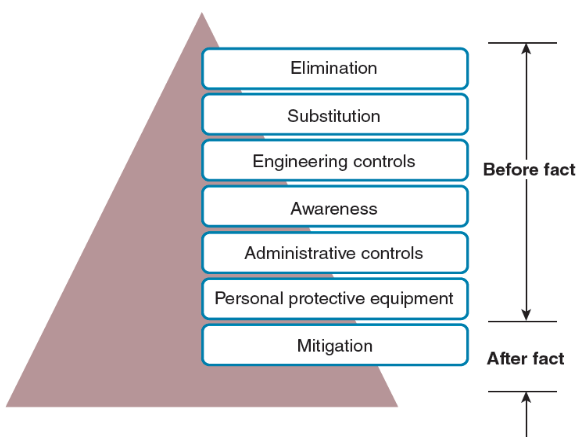


EXHIBIT P.2

Hierarchy of health and safety controls.

Risk Register pre PPE

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Fr =frequency
Pr =Likelihood
Se = Severity
Av = avoidance

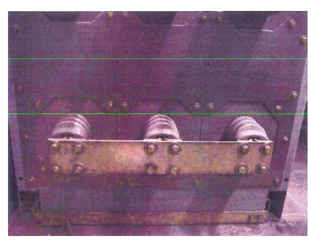
COMMENTARY TABLE F.1 *Risk Register (Based on Table F.2.5)*

		Severity	Probability of Occurrence of Harm, Po = (Fr + Pr + Av)				Risk Score (R)
Scenario No.	Hazard	Se (Table F.2.3)	Fr (Table F.2.4.1)	Pr (Table F.2.4.2)	Av (Table F.2.4.3)	Total	Se × Po

LVMCC
- Troubleshoot fail to start
- Replace starter or CPT (de-engerize, pull bucket, work hot with barriers)
- Utilize spare Bottom entry/ top entry
- Replace breaker
- Replace bucket
- Incomer work

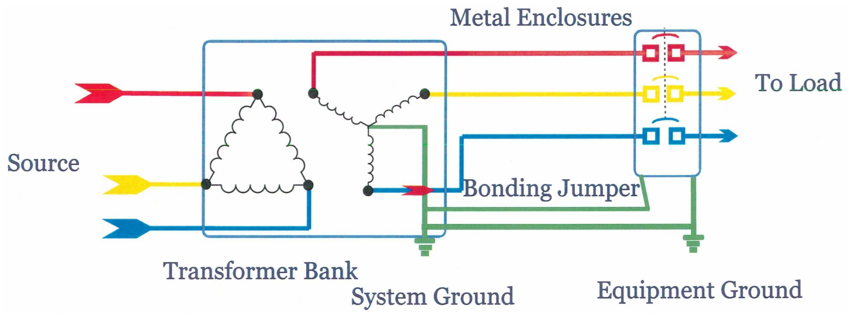
Two Types of Faults

Bolted Faults
- Solid connection between two phases or phase and ground resulting in high fault current.
- Stresses are well contained so fault creates less destruction.



Arc Faults
- Usually caused by insulation breakdown, creating an arc between two phases or phase to ground.
- Intense energy is not well contained, and can be very destructive.

Grounding Definition

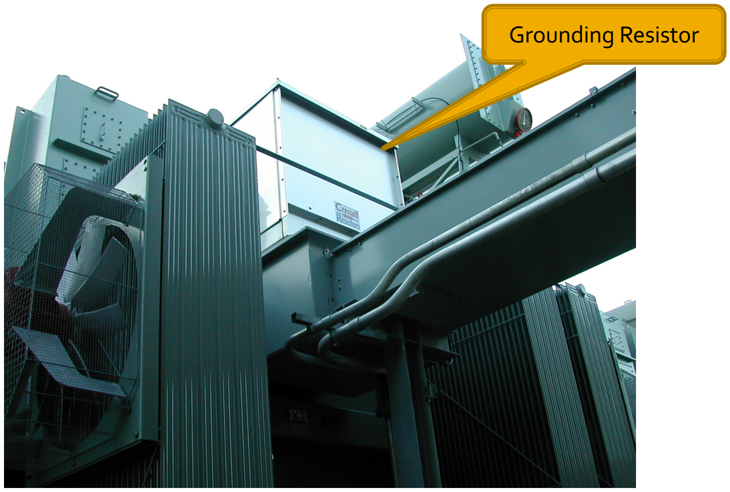


grounding –

- continuous conductive path to the system ground point
- sufficient ampacity to carry ground fault current,
- impedance low enough to limit the voltage rise above ground
- and to facilitate the operation of the protective devices in the circuit.

Grounding Definitions

System Grounding



System Grounding Methods

- Ungrounded
- Solidly Grounded
- Impedance Grounded
  - Low Resistance Grounded
  - High Resistance Grounded
  - Reactance Grounded

Ungrounded System

Ungrounded Systems

- No intentional connection to earth ground
- Weakly grounded through system capacitance to ground
- First fault typically 1 -2 amps
- Severe line to ground transient overvoltages

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Ungrounded Systems

- Seldom used on new systems
- Still relatively common in existing industrial systems
  - Low voltage systems (< 600 V)
  - Medium voltage systems (2.4 - 15 kV)

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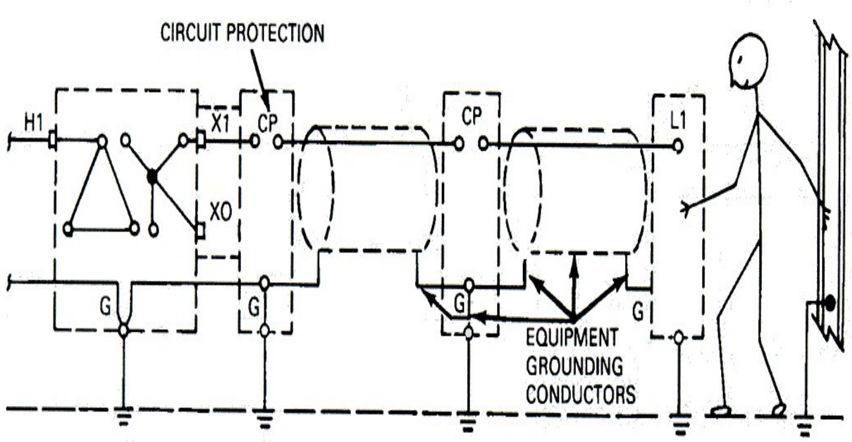
Ungrounded System



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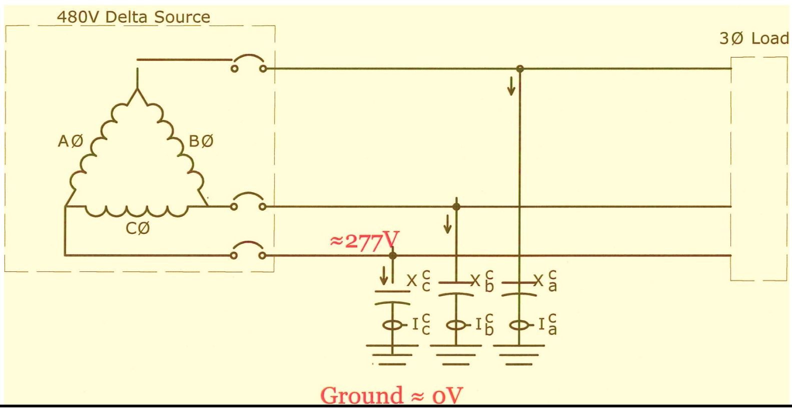
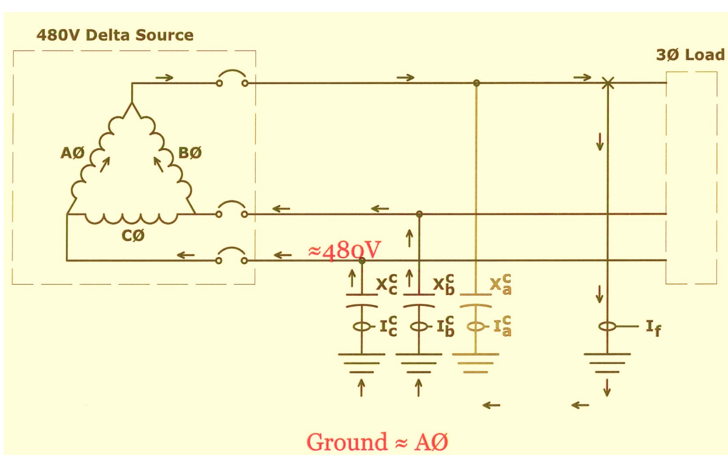
Ungrounded Systems

- Unintentionally grounded through <u>system</u> capacitance
  - Such as cables, transformers, motors, surge suppressors, etc.



Ground Faults

- Ground fault current distribution (minimal current)



Locating Ground Faults

- Good Luck!
  - No direct return to source, only way is through system capacitance.

- Use over-voltage
  - Indicator light and relay method to indicate ground fault.
  - De-energize one feeder at a time.
    - ✓ Very time consuming and dangerous!
      - Unknown ground fault may be on system for long period of time.
      - May de-energize vital equipment trying to find fault.

Solidly Grounded Systems

Solidly Grounded Systems

- Connected to earth ground with no intentional additional impedance in circuit
- Arc fault danger zone and flash hazard large
- Ground fault current close to phase current levels
- Minimal transient overvoltage with faults
- Modern MCCB provide ground fault protection at the motor starter level

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Solidly Grounded

- Almost universally used on high voltage systems (> 72 kV)
- Commonly used on utility distribution systems up to 34.5 kV

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Solidly Grounded

- Commonly used on low voltage (<600 V) commercial, institutional, and residential systems
- Sometimes used on low voltage (<600 V) industrial systems

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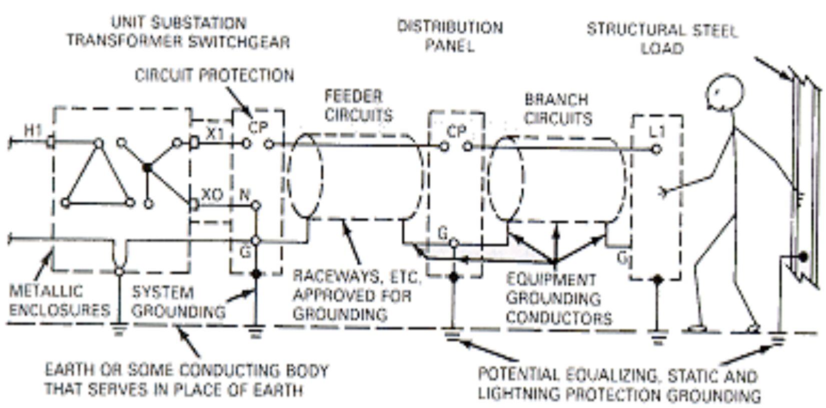
Solidly Grounded System



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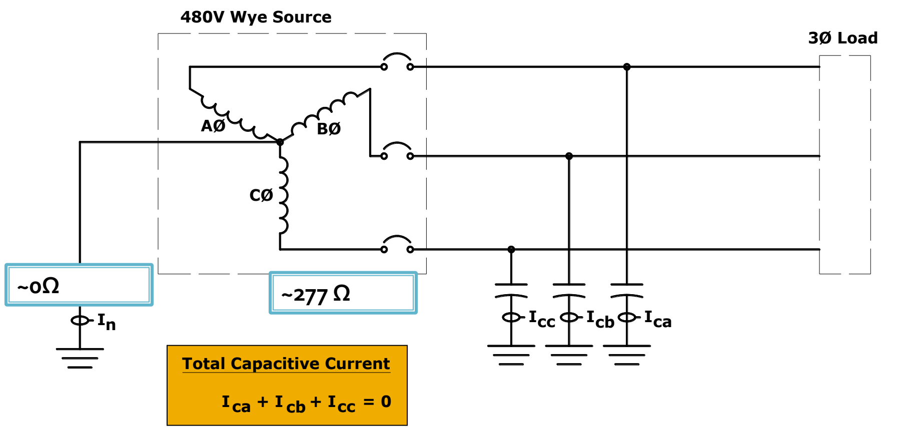
Solidly Grounded Systems

- Intentionally grounded through ground wire



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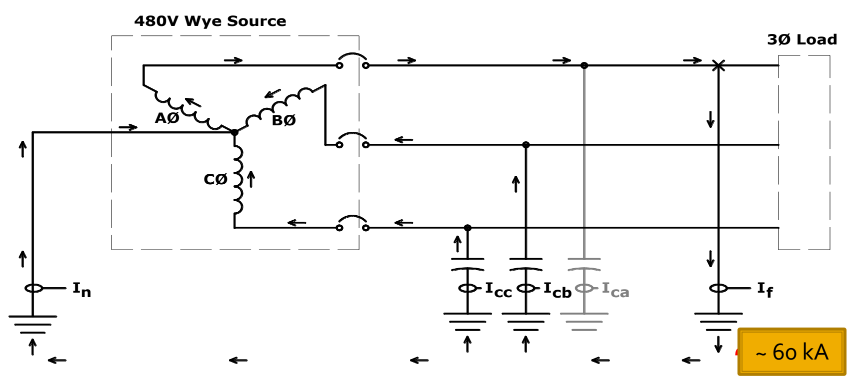
Quick Calc /Bolted Ground Faults

- Ground fault current distribution on AΦ



Estimated Total Fault Current

$$I_f = \left(\frac{1}{Z_{pu}}\right) * I_{fla} + (I_{cb} + I_{cc}) = \sim I_n$$

~0A (3A)

Example (2500kVA, 480V, Z = 5%)

$$I_n = I_f = \left(\frac{1}{0.05}\right) * 3000A = \sim 60{,}000A$$

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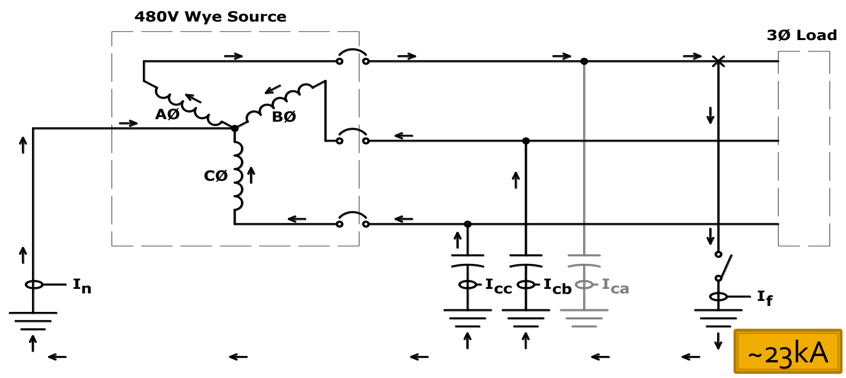
Quick Calc / Arcing Ground Faults

- Ground fault current distribution on AΦ



Estimated Total Fault Current

$$I_f = \left(\frac{1}{Z_{pu}}\right) * I_{fla} * .38 + (I_{cb} + I_{cc}) = \sim I_n$$

~0A (3A)

Example (2500kVA, 480V, Z = 5%)

$$I_n = I_f = \left(\frac{1}{0.05}\right) * 3000A * .38 = \sim 23kA$$

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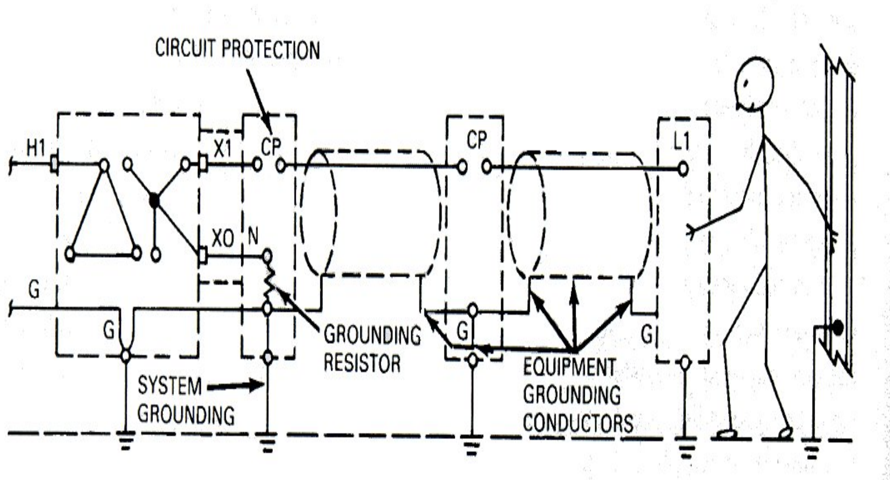
Resistance Grounded Systems

Resistance Grounded System



Resistor Ratings for Low Resistance Ground

- Voltage rating is system line-to-neutral voltage
- *Resistors available for all common system voltages up to 13,800V*
- Current ratings available for medium voltage systems are from 25A to 2000A
- *Choose resistor current based on system configuration and relaying*

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Resistor Ratings for Low Resistance Ground

- Time ratings available are 10 seconds, 60 seconds, and extended time
- *Most installations take either 10s or 60s rating.*
- *Choose based on system ground fault clearing time.*
- *Extended time ratings rarely used; for special conditions where resistor will be energized for 10 minutes or more.*

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Resistor Construction Low Resistance Ground

- Typically for outdoor use
- Resistor elements are usually stainless steel
  Check material against ambient atmosphere to prevent possible corrosion damage
- Temperature rise may be 760°C
  Resistor must be well ventilated and must be kept away from combustible material

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Resistor Construction Low Resistance Ground

- Frame of resistor is often connected to middle of resistor element
- *Under fault conditions, frame is energized at 1/2 line-to-ground voltage*
- *Frame must be insulated from ground*
- *Frame must be inaccessible to personnel*

Duty Rating for NGR's

IEEE Std 32

Time Rating and Permissible Temperature Rise for Neutral Grounding Resistors

Time Rating (On Time)	Temp Rise (deg C)
10 sec	760
1 min	760
10 min	610
Continuous	385

Duration Must Be Coordinated With Protective Relay Scheme

Resister Material

- Resistance increases as resistor heats up
- Cheaper stainless steel alloys may produce undesirable results

Resistance change per degree C	
Nickel Chromium	0.01%
18SR/1JR SS	0.02 – 0.04%
304SS	0.22%

Common Options

- Enclosure rating
- Enclosure finish
- Current transformer
- Potential transformer
- Disconnect switch
- Entrance/exit bushings
- Elevating stand
- Seismic rating
- Hazardous area classification
- Third party certification

15kV System Design

- 400A Resistance grounded wye connected system
- Greatly reduce fault energy for ground faults
- Table assumes 25MVA 7% transformer with .3 sec clearing time

	watt sec	Cal/CM2
Solid grounded 15kA fault	107,000 MW-sec	151
Resistance grounded 400A Limit	2.8MW-sec	4

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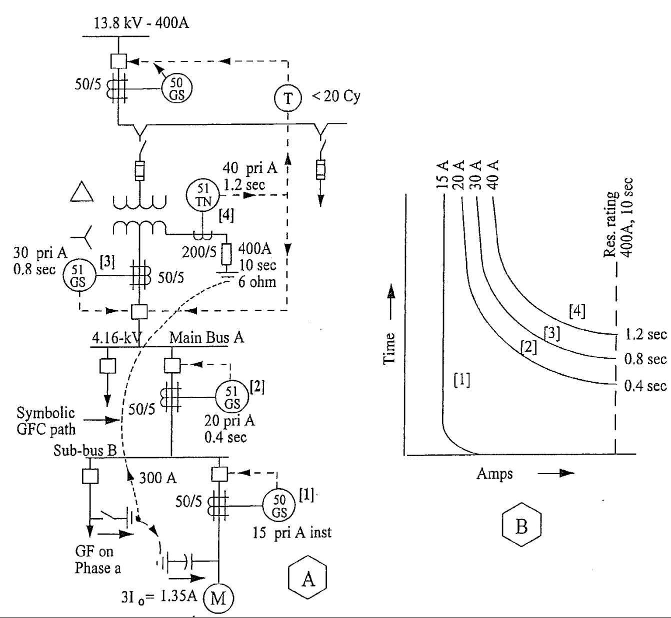
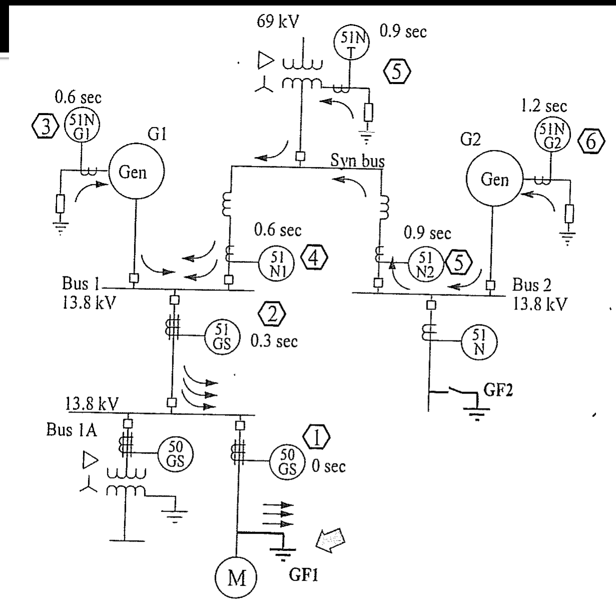
400 Amp Ground fault protection



Multiple Grounds

- Additive nature of magnitude



High Resistance Grounded Systems

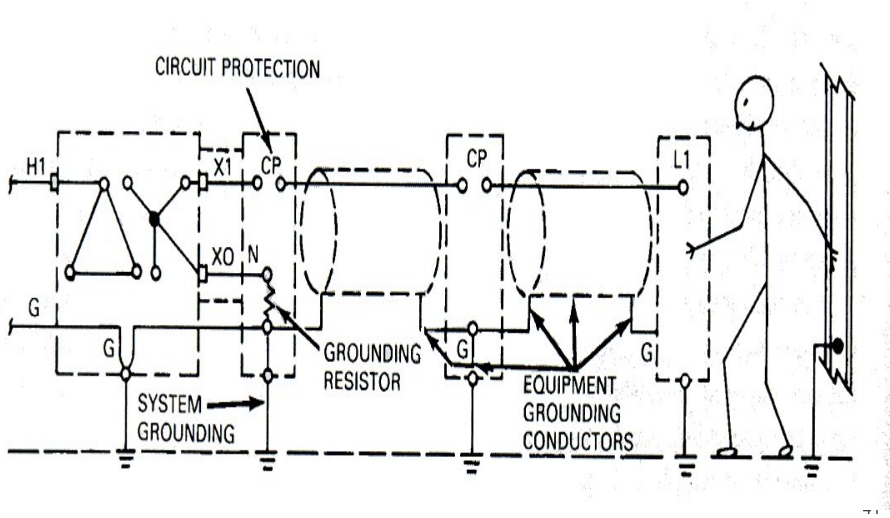
High Resistance Ground

- Commonly used on low voltage systems in industrial plants
- Becoming popular on advanced medium voltage systems in industrial plants
- Used by utilities for large generators

High Resistance Grounding

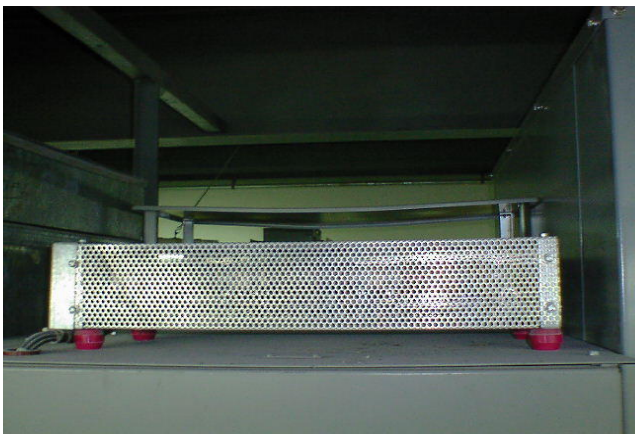
- Connected to earth ground through a high resistance
- Limits ground fault current to a few amperes (1-10 A is common)
- Protective schemes alarm only
- To be effective, $R_0 > X_{C0}$ and $R_0 < 2X_0$

Resistance Grounded System



Pictures of HRG System

- Resistor – Mounted on top of Swgr



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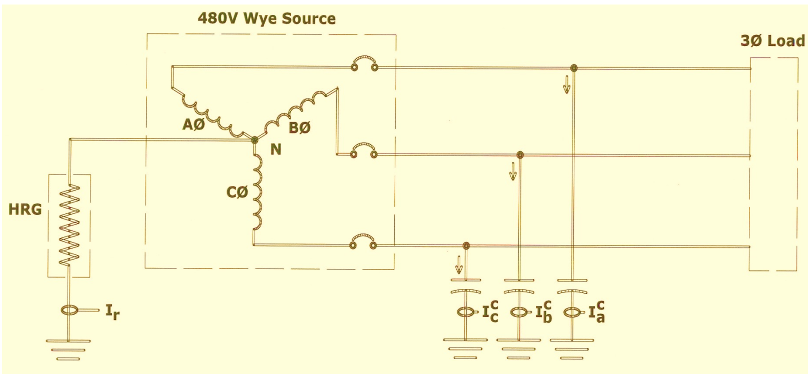
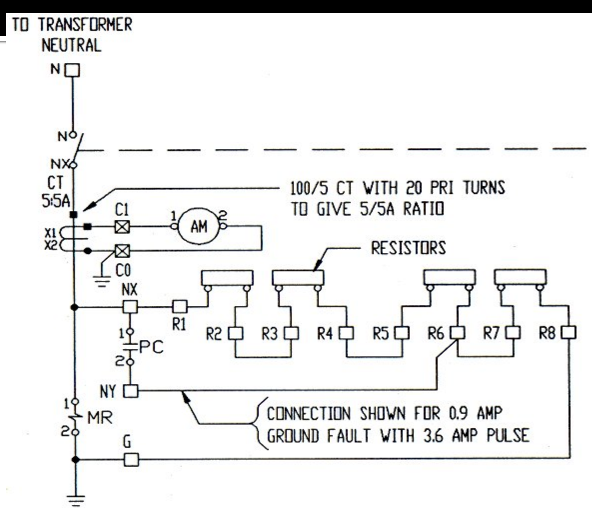
High Resistance Grounding

Intentionally grounded through neutral resistor



Low Voltage



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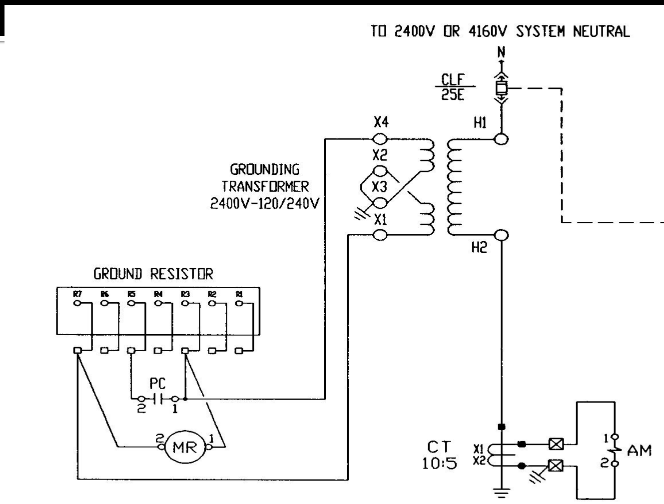
Medium Voltage HRG



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Resistor Current Rating

- Setting must be higher than charging current
- Current rating for low voltage systems is typically from 0.9A to 3.6A
- Current rating for medium voltage systems is typically from 2A to 7A or from 5A to 20A at primary voltage

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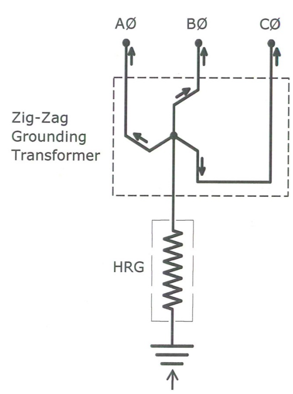
High Resistance Grounding

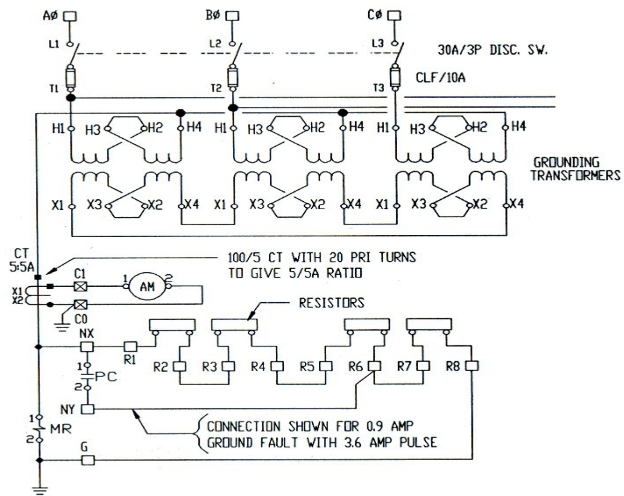
- Advantages
  - Eliminates overvoltage transients
  - Allows faulted circuit to continue operation
- Disadvantages
  - Potential for nuisance alarming
  - Maintenance personnel may ignore first fault

What if no neutral exists?

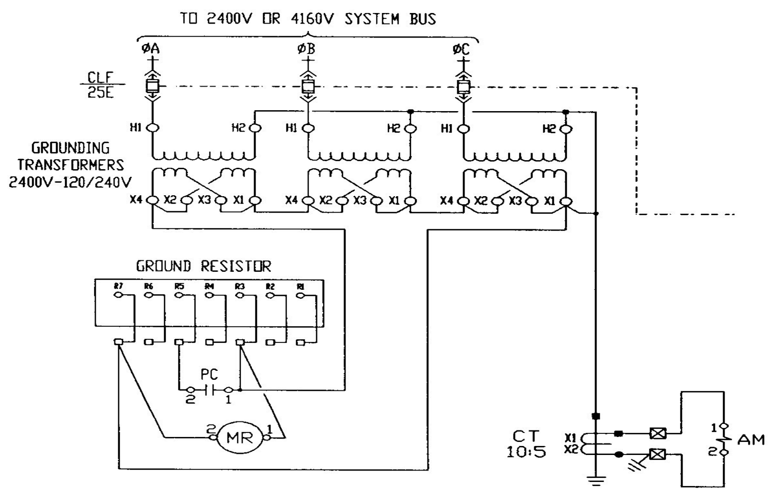
- Can HRG be used on Delta connected systems?
  - A grounding transformer is installed (either a zig-zag or a wye-delta) from all three phases to create an artificial neutral for grounding purposes only.



Low Voltage Derived Neutral HRG

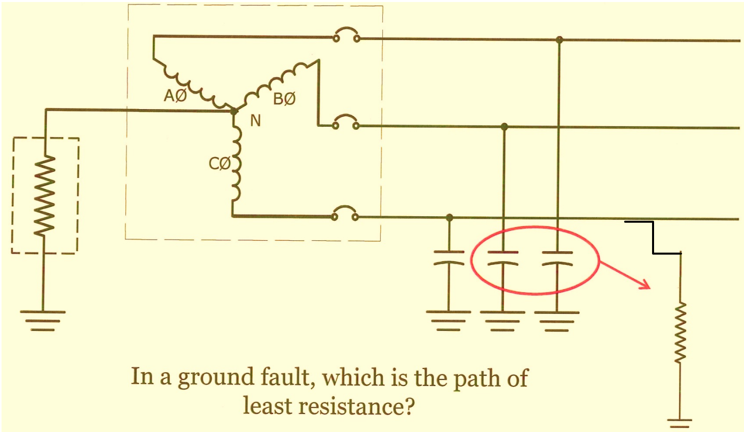


Medium Voltage Derived Neutral



System Capacitance

In a ground fault, which is the path of least resistance?



System Charging Current

- **Only discharges if $R_o < X_{co}$, so $I_r > I_{xco}$**

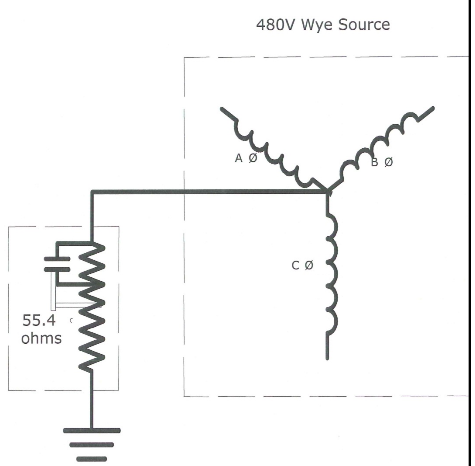
  (per IEEE 142-1991 1.4.3)

  - That is, resistor current must be greater than capacitive charging current.
  - **'Rule of thumb' for 480V system:**

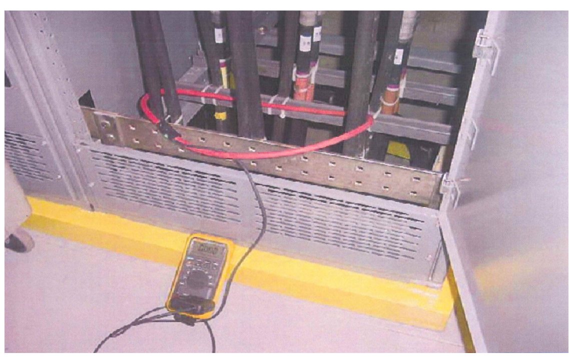
Transformer (kVA)	Charging Current (A)
1000	0.2 -0.6
1500	0.3 -0.9
2000	0.4 -1.2
2500	0.5 -1.5

Fault Location

- Operator controlled contactor connected across half the grounding resistor
- When activated, contactor alternately shorts half the resistor and forces the current to double
- Possible to use ammeter to track the current fluctuation



Ground Fault Location Method

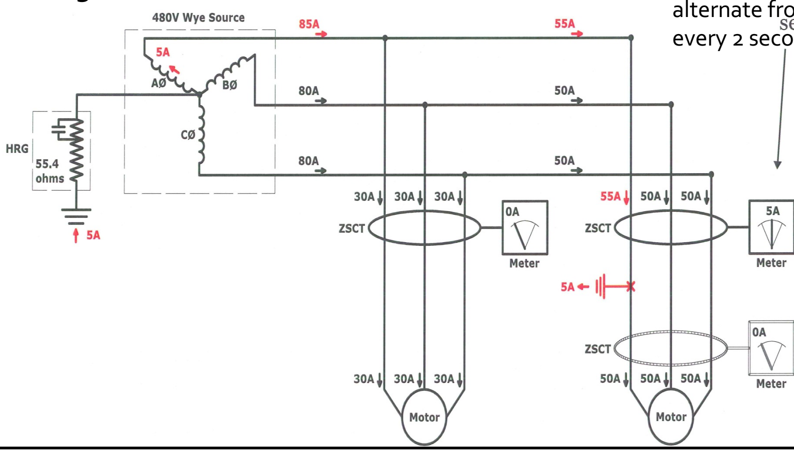


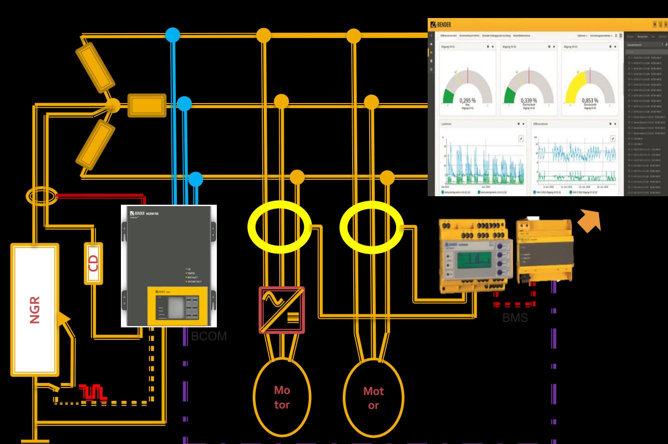
***NOTE:** Tracking a ground fault can only be done on an energized system. Due to the inherent risk of electrocution this should only be performed by trained and competent personnel. Appropriate PPE measures should be taken into consideration as well.*

Fault Location

- Method to quickly locate ground faults

Meter reading will alternate from 5A to 10A every 2 seconds.

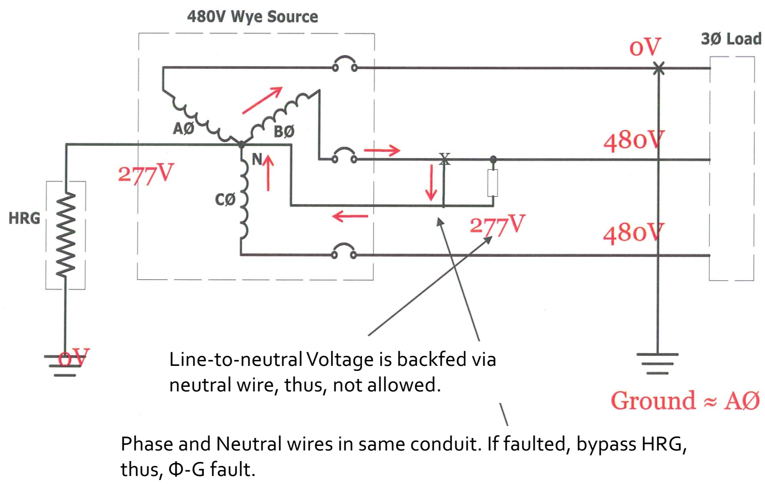




Relaying System can be used to retrofit specific load alarm or tripping

No Single Phase Loads

- No line-to-neutral loads allowed, prevents Hazards.

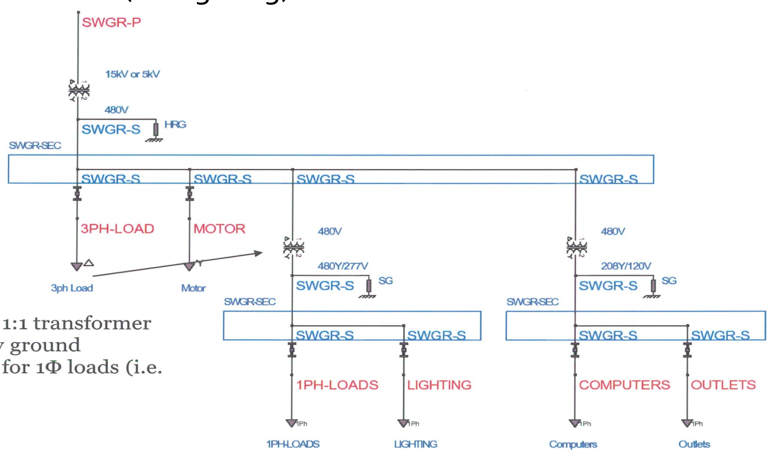


Design Considerations with HRG Systems

- Very few potential hazards with HRG, however…
  - Elevated Voltages
  - Trained Personnel
  - Cables, TVSSs, VFDs Insulation
- Line-to-Neutral Loads
  - Isolation transformers
- Loss of Ground
  - System becomes Ungrounded or Solidly Grounded introducing more Hazards

Resolve Line to Neutral Loads

- Add small 1:1 transformer and solidly ground secondary for 1Φloads (i.e. lighting).



Add small 1:1 transformer and solidly ground secondary for 1Φ loads (i.e. lighting).

High Resistance Ground

- Surge protection must be rated based on line to ground potential rise
- High frequencies can appear as nuisance alarms
- Ground fault may be left on system for an extended time

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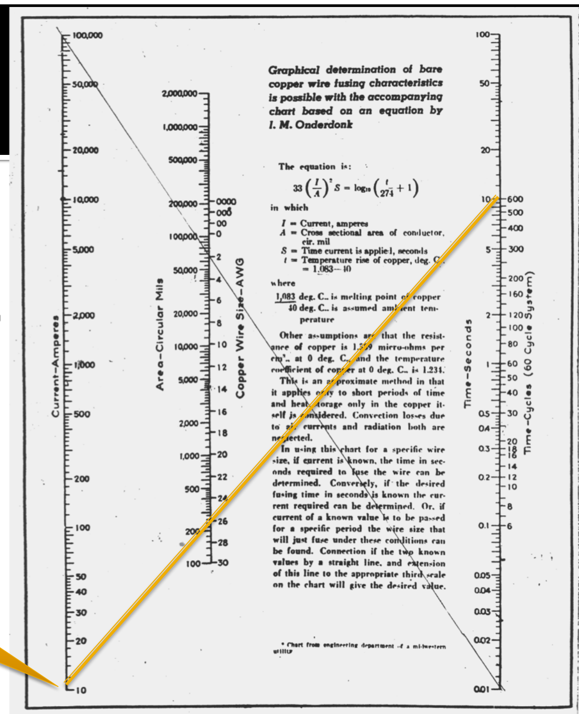
Why HRG

Time to melt copper at 10 amps



10 amps

Retrofitting High Resistance Grounding

	LV	MV
Solidly Grounded	•Insert resistor in Xo •Use isolation transformers to support line to neutral loads	•Insert transformer and resistor at Xo •Install zero sequence ct's and meters •Surge arrestors •Cable voltage rating •Grounded Neutral Cap Bank
Un-Grounded	•Derive neutral	•Derive neutral •Install zero sequence meters

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Why Convert

- Trips Vs alarm - impact on Operations
- Limit damage due to faults
- Eliminate propagation to 3 phase
- Reduced Arc Flash zones for 90% of all faults
- Control of Voltage transients

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Evidence of Multiple Arcs

- Multiple arc paths
- Arc can move from columnar arc to diffuse arc and back
- Arcs will wink out when they can not be sustained
- Ground current involved at system Xo if solidly grounded

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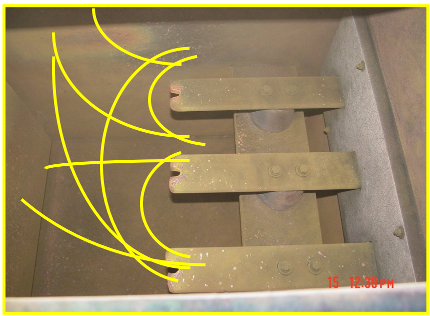
Bar conductors and the available arc paths



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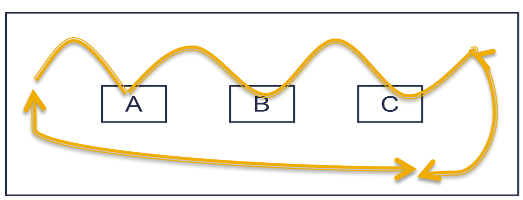
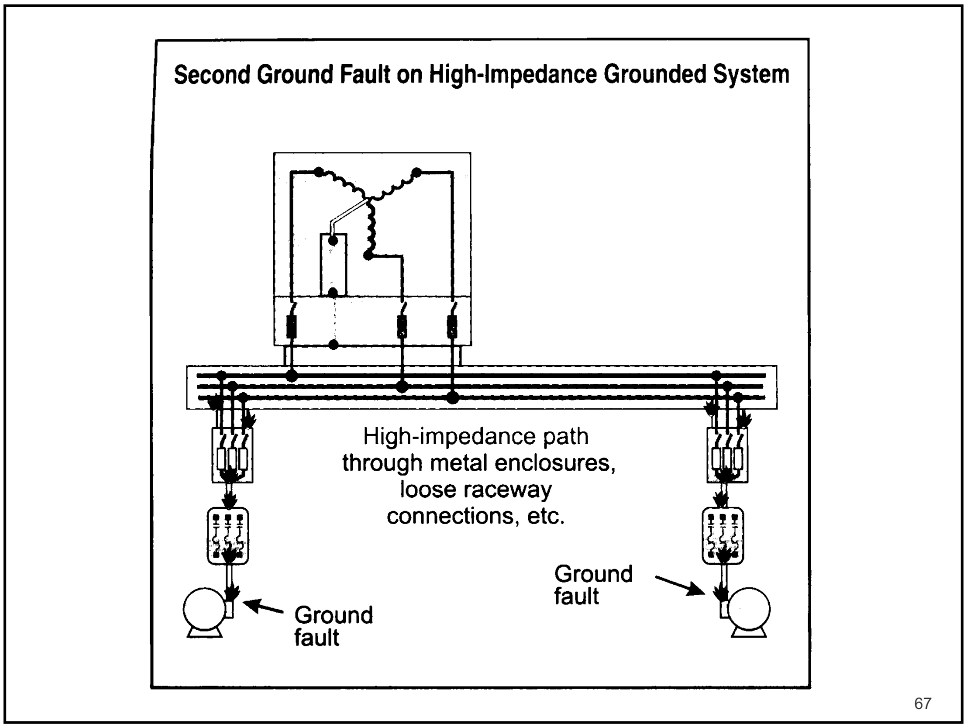
Arc Physics Low Voltage Equipment



THREE PHASE FAULT INVOLVING - "A TO B" - "B TO C" & "A TO C THROUGH STRUCTURAL STEEL"



Benefits of Grounding

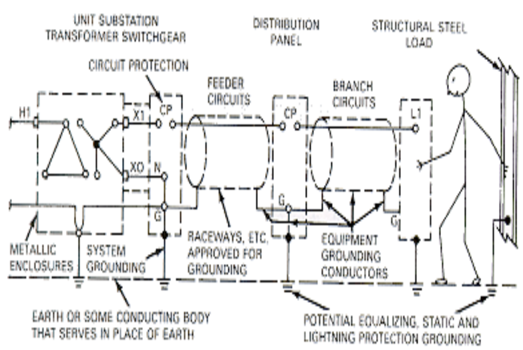
Productivity Impact		Ungrounded System	Solidly Grounded System	Low Resistance Grounded System	High Resistance Grounded System
		System Type			
Equipment Damage	Overvoltages	Severe	None	Limited	Limited
	Overcurrent - Damage at point of fault	Unknown	Severe	Minimal	None
	Maintenance Costs	High	Reasonable	Reasonable	Low
Downtime	Continuous Operation with Ground Fault	Possible but not recommended	Not possible	Not possible	Ideal
	Relay Co-ordination (Appropriate Equipment Tripped, Ease of fault location)	Difficult	Difficult	Good	Excellent
Personnel	Safety to Personnel	Poor	Good	Good	Excellent

Objectives of Equipment Grounding

- To reduced shock hazard to personnel
- To provide adequate current carrying capability (impedance and duration) to handle ground fault current w/o fire or hazard
- To provide a low-impedance return path for ground fault current to ensure operation of overcurrent device

Risk of a Poor Grounding System

- Panel is 20 Ω to ground
- Transformer ground
  = 10 Ω to ground
- No ground return path
- Ig=Ground Fault

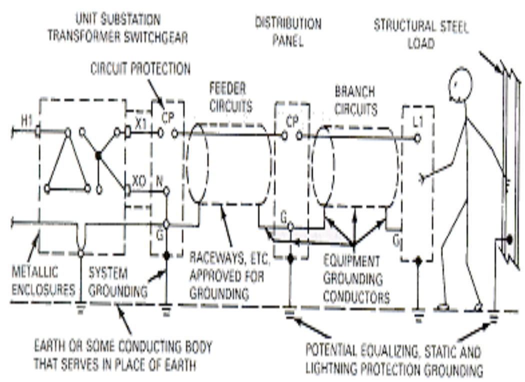


$$Ig = \frac{\text{Volts}}{\text{R of the ground path}} = \frac{277\text{Vac}}{20\ \Omega + 10\ \Omega} = 9.233\text{A}$$

Panel touch potential with 9.23Amps of fault current

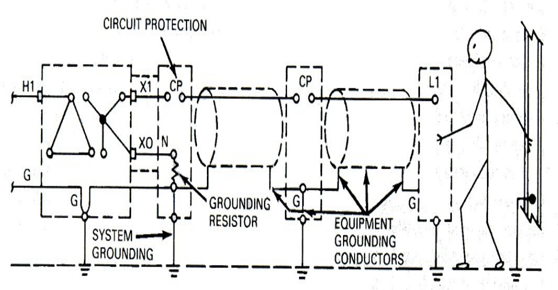
- V=IgR
- V=(9.233A)(20 Ω)
- V= 184Vac

- If a good return path - 0 volts across panel



HRG Grounding System

- HRG is roughly 75 Ω R
- Panel is 20 Ω to ground
- Transformer ground = 10 Ω to ground
- No ground return path
- Ig=Ground Fault

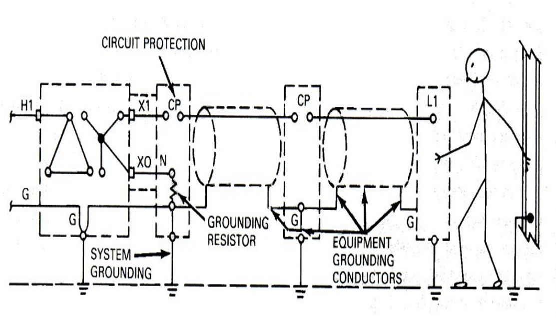


$$I_g = \frac{\text{Volts}}{\text{R of the ground path}} = \frac{277\text{Vac}}{75\ \Omega + 20\ \Omega + 10\ \Omega} = 2.6\text{A}$$

HRG Grounding System

- V=IgR
- V=(2.6A)(20 Ω)
- V= 52Vac
- If good path

20 & 10 ohms can approach
5 ohms and touch volts
Approaches les than 10
volts



Specific Susceptibility

- Physiological Effects of Electric Current
  - As current increases, the following effects occur
    - ✓ 1 mA: threshold of perception
    - ✓ 1 to 6 mA: let-go current –unpleasant but can be released
    - ✓ 9 –25 mA: pain and hard to release; may require secondary treatment
    - ✓ 60 –100 mA: highly dangerous; ventricle fibrillation, stoppage of cardio-pulmonary system; immediate treatment required
- Fibrillation Current is the Criterion on Which Analysis is Based

Current vs. Time

- Alternate Analysis
  - Biegelmier's Curve
- Summary
  - Eat, drink, survive shocks better

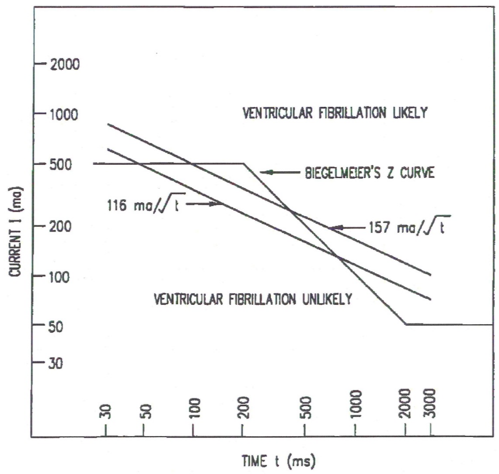


Figure 5—Body current versus time