Eaton Presentation On Power System Grounding – Generator Grounding - Winding Pitch Factors, Hybrid Grounding

IEEE Nashville

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Characteristics of Different Power System Grounding techniques: Fact & Fiction

By

David Shipp Cutler-Hammer

Frank Angelini Cutler-Hammer

Power System Grounding Abstract

- Most Misunderstood Element of Power System design

Introduction

- History
- Solidly Grounded
- Ungrounded

Present Practice

- Industrial / Commercial
- NEC Art. 250-1 Scope
- Grounded to Limit Voltages due to;
  - Lightning
  - line Surges
  - Unintentional Contact with Higher Voltages
  - Stabilize V_{LG} During Normal Operation

NEC Article 250-5

- (b) AC Systems 50V-1000V - Shall be Grounded
  - $V_{LG} \leq 150V$
  - 3 phase/4 wire
  - 3 phase/4 wire Delta

NEC Article 250-5

- (b) Continued
  - Exception 5 High Impedance Grounded Shall be Permitted
  - Qualified Maintenance Personnel Only
  - Service Continuity Required
  - V_{L-N} Loads Not Served

NEC Article 250-5

- [c] AC Systems ≥ 1KV
  - Where Such Systems Are Grounded, They Shall Comply With Article 250

Definitions (IEEE "Green Book")

- Ungrounded System
- Grounded System
- Grounded Solidly
- Resistance Grounded
- Effectively Grounded

What Comprises a Ground System? Figure 1

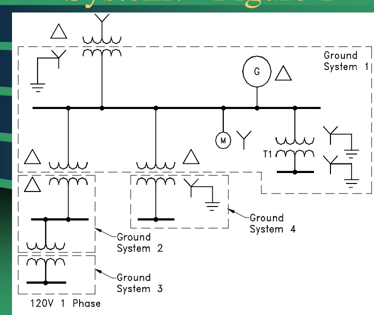


Figure 2: Ground Fault on an Ungrounded System

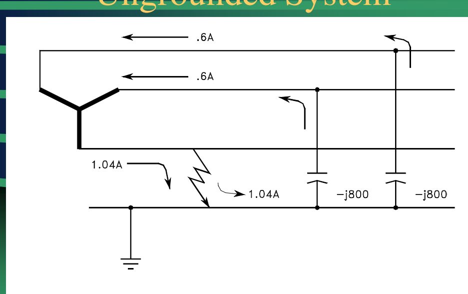


Figure 3: Voltages During Ground Fault on an Ungrounded System

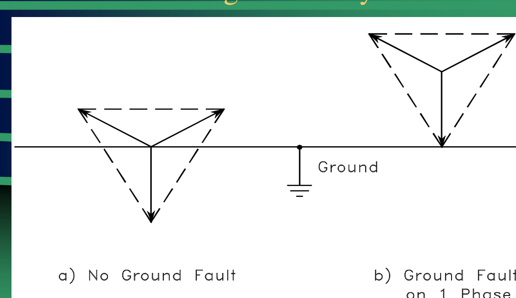


Figure 4: Ground Fault on a Solidly Grounded System

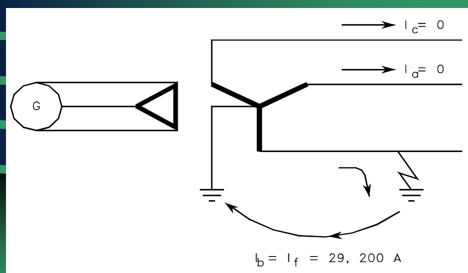


Figure 5: Voltage Profiles for Solidly Grounded System

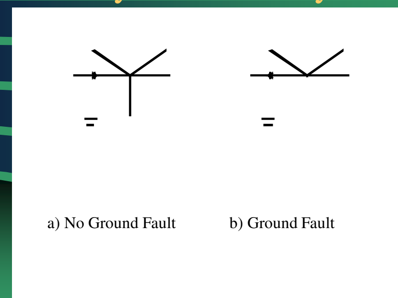


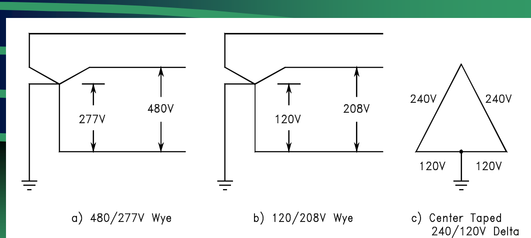
Table I
Solid Grounded vs. Ungrounded

	System Grounded	System Ungrounded
Voltage		
Phase A to Phase C	480	480
Phase A to Phase B	$480/\sqrt{3}$	480
Phase C to Phase B	$480/\sqrt{3}$	480
Phase A to Ground	$480/\sqrt{3}$	480
Phase B to Ground	0	0
Phase C to Ground	$480/\sqrt{3}$	480
Fault Current - Amperes		
Phase B	29,200	1.04
Phase C	0	.6
Phase A	0	.6

To Ground the System or Not to Ground

- V_{LN} Loads Served?
- Service Continuity Importance?

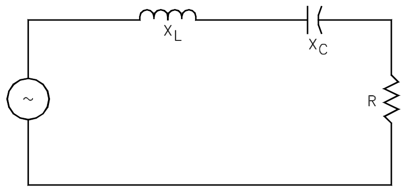
Solidly-Grounded Systems Figure 6:(Industrial/Commercial)



Ungrounded Systems

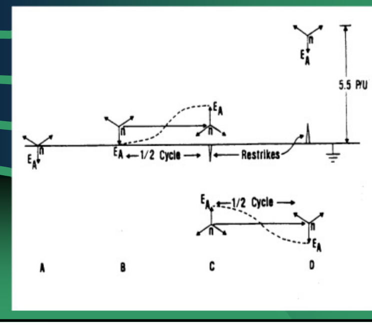
- Multiple Ground Faults
- Resonant Conditions
- Transient Overvoltages

Figure 7: Series Resonant Circuit



$$I_F = \frac{E}{R + j(X_L - X_C)} = \frac{E}{R + j0} = \frac{E}{R}$$

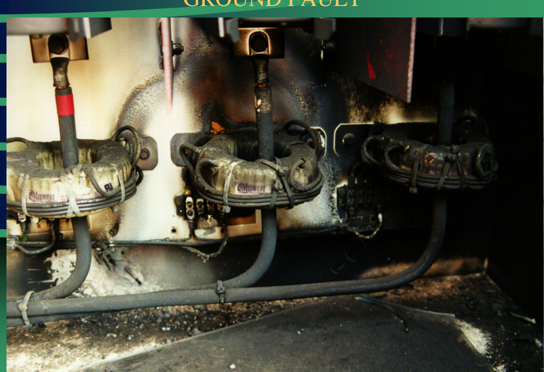
Fig. 8: Transient Overvoltage from Restriking Ground Fault



TVSS Failure Due to Arcing Ground Fault

MOTOR STARTER FAILURE DUE TO ARCING GROUND FAULT

MOTOR STARTER FAILURE DUE TO ARCING GROUND FAULT



SWGR TAP BOX FAILURE DUE TO ARCING GROUND FAULT

ESP MOTOR FAILURE DUE TO ARCING GROUND FAULT

ESP MOTOR WYE POINT FAILURE DUE TO ARCING GROUND FAULT

UNGROUNDED GENERATOR

Arcing Ground Fault – 2 PH to Ground

Ground Fault on L.C. 81

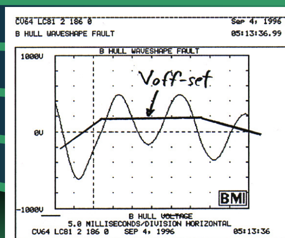


Figure E-34

Ground Fault on L.C. 81

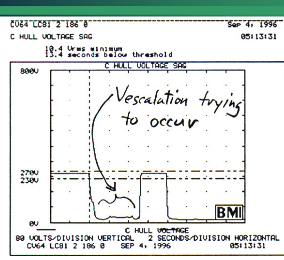


Figure E-37

Ground Fault on L.C. 81

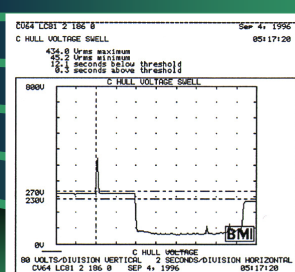


Figure E-3

Figure 9

- Inductance Grounded

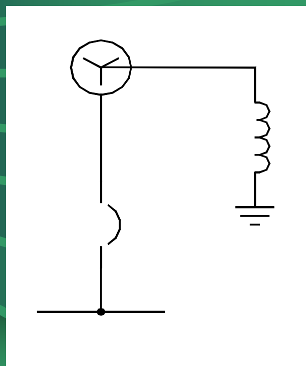


Figure 10: Resistance Grounded

- L.R.-200A to 1000A
- H.R.-Less than 10A

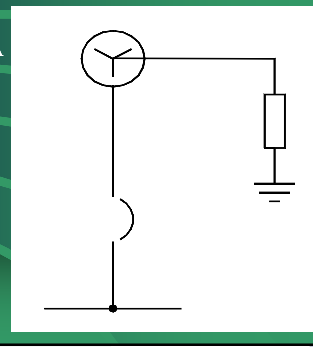


Figure 11: Grounding Transformers

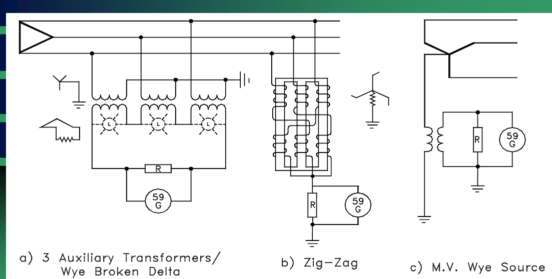


Fig. 12: The Effect of Grounding Impedance on Transient Overvoltages

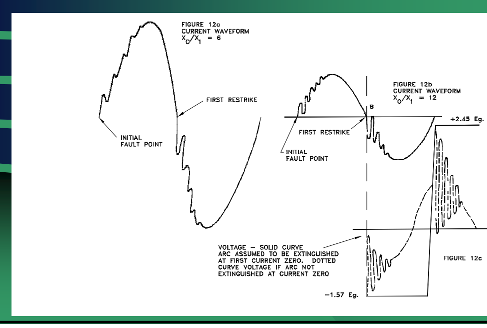


Table II
X_0 / X_1 and R_0 / X_0 for Low Transient Overvoltages

• Ungrounded	• No Ratios Available • Produces High $V_{transients}$
• Solid Grounded	• X_0/X_1 Very Low Unless Wye-Wye
• Reactance Grounded	• $X_0/X_1 \leq 3.0$

Table II
X_0 / X_1 and R_0 / X_0 for Low Transient Overvoltages

• Low Resistance Grounded	• $R_0/X_0 \geq 2.0$ • $X_0/X_1 \leq 20$
• High Resistance	• $I_{0R} \geq I_{0C}$

Other Factors

- Mechanical Stress in Generators
- Selective Relaying
- Surge Protection

Table III:System Characteristics With Various Grounding Methods

	Ungrounded	Essentially solid grounding		Reactance grounding	Ground-fault neutralizer	Resistance Grounding	
		Solid	Low-value reactor	High-value reactor		Low resistance	High resistance
Current for phase-to-ground fault in percent of three-phase fault current	Less than 1%	Varies, may be 100% or greater	Usually designed to produce 60 to 100%	5 to 25%	Nearly zero fault current	5 to 20%	Less than 1%
Transient over-voltages	Very high	Not excessive	Not excessive	Very high	Not excessive	Not excessive	Not excessive
Automatic segregation of faulted zone	No	Yes	Yes	Yes	No	Yes	No
Lightning arresters	Ungrounded neutral type	Grounded-neutral type	Grounded-neutral type if current is 60% or greater	Ungrounded neutral type	Ungrounded neutral type	Ungrounded neutral type	Ungrounded neutral type
Remarks	Not recommended due to over voltages and nonsegregation of fault	Generally used on system (1) 600 volts and below and (2) over 15kV		Not used due to excessive over-voltages	Best suited for high-voltage over-head lines where faults may be self-healing	Generally used on industrial systems of 2.4 to 15kV	Generally used on systems 5kV and below

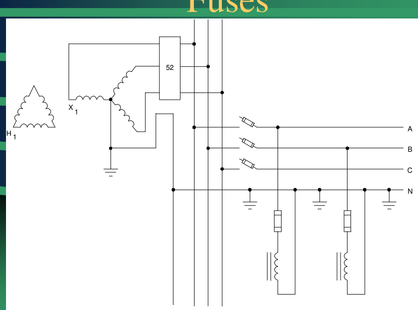
Practicable System Grounding Selections

- L. Voltage ($\leq$ 1000V)
  - Solid
  - H. Resistance
- H. Voltage (>15 KV)
  - Solid
- M. Voltage
  - Solid
    - 3 PH / 4 W
    - Aerial Lines
    - Unshielded Cables

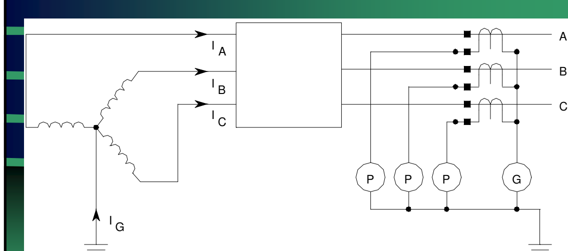
Practicable System Grounding Selections

- Medium Voltage
  - L. Resistance
    - Motors / Generators
    - Shielded Cables
    - No V_{LN} Loads
- Medium Voltage
  - H. Resistance
    - $\leq$ 5 KV-No Tripping
    - > 5 KV - Tripping
    - No V_{LN} Loads

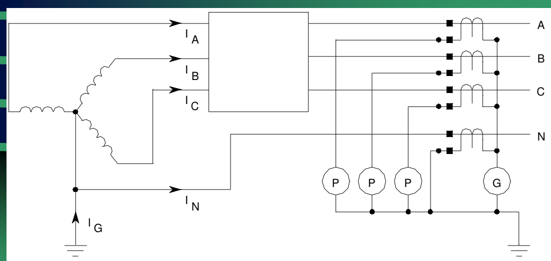
Ground Fault Protection Using Fuses



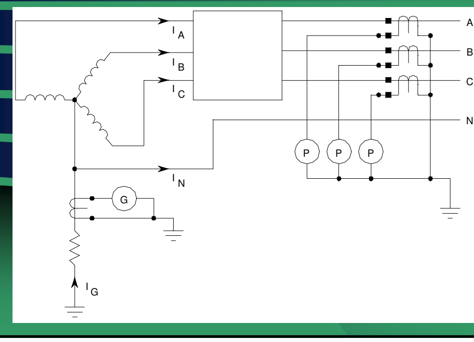
Residual Ground Fault Detection 3 Wire



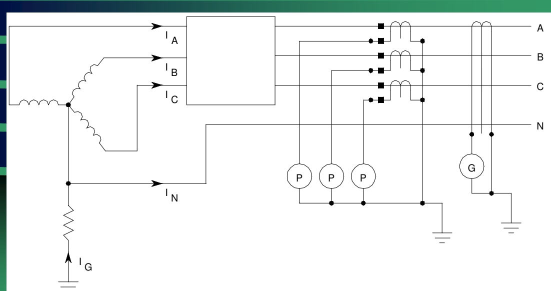
Residual Ground Fault Detection 4 Wire



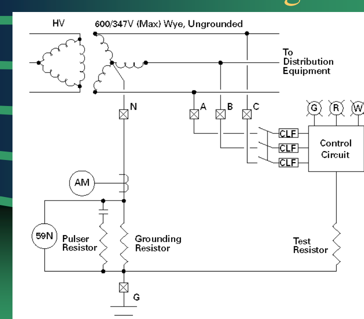
Source Neutral Ground Detection



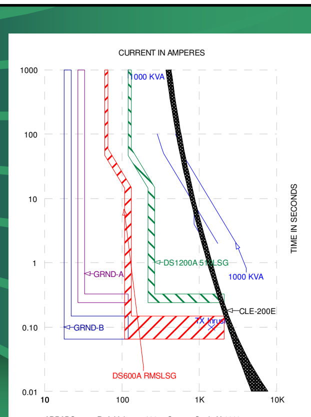
Zero Sequence



H. Resistance / Pulsing Contactor



- NEC Art. 230-95
- L.V. Ground Fault Protection Coordination



Zone Interlocking