Generator Grounding
IEEE San Francisco
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ipc™

Quick primer

- Power resistors aren't color-coded
- Resistors have no polarity
- Know your system before ordering
- Resistors get hot

IEEE Std 32

Time Rating and Permissible Temperature Rise for Neutral Grounding Resistors

Time Rating (On Time)	Temp Rise (deg C)
Ten Seconds (Short Time)	760^{o}C
One Minute (Short Time)	760^{o}C
Ten Minutes (Short Time)	610^{o}C
Extended Time	610^{o}C
Continuous	385^{o}C

Advantages of Neutral Grounding

- • Greater safety for personnel and equipment
- • Increased service reliability
- • Lower operating and maintenance expense
- • Reduced magnitude voltage transients
- • Simplified ground-fault location

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Guidelines

~~Ungrounded Generator~~

IEEE Std 242-2001 (Buff Book)

12.4 Generator Grounding

Generators are not often operated ungrounded. While this approach greatly limits damage to the machine, it can produce high transient overvoltages during faults and also makes it difficult to locate the fault.

Guidelines

NEMA Std MG 1-2003 Motors and Generators

32.34   Neutral Grounding

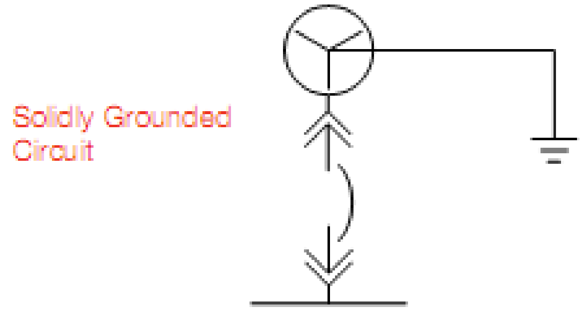
- For safety of personnel and to reduce over-voltages to ground, the generator neutral is often either grounded solidly or grounded through a resistor or reactor.
- The neutral may be grounded through a resistor or reactor with no special considerations required in the generator design or selection unless the generator is to be operated in parallel with other power supplies.
- The neutral of a generator should not be solidly grounded unless the generator has been specifically designed for such operation

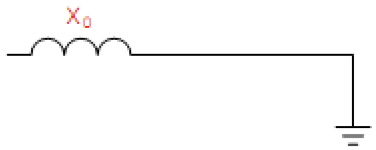
Objectives of Generator Grounding

- Minimize the damage for internal ground faults
- Limit mechanical stress in the generator from external ground faults
- Provide a means of system ground fault detection
- Coordinate with other system/equipment requirements

Solidly Grounded Systems

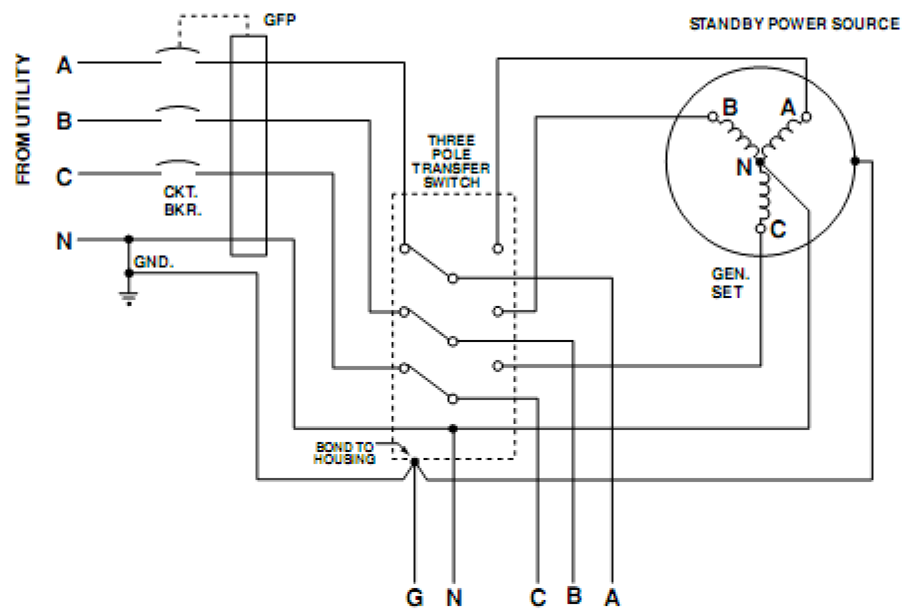
- Best suited for LV 3Ø, 4W systems
- Generator must be rated for use as solidly grounded
- System trips on first fault
- Coordinated relay scheme may be difficult





Three Pole Transfer Switch

- Generator neutral unbonded from case ground
- Single neutral to ground connection
- Not considered separately derived systems



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IEEE Std. 142-1991 (Green Book)

1.8.1 Discussion of Generator Characteristics

- …Unlike the transformer, the three sequence reactances of a generator are not equal. The zero-sequence reactance has the lowest value, and the positive sequence reactance varies as a function of time. *Thus, a generator will usually have higher initial ground-fault current than a three-phase fault current if the generator is solidly grounded. According to NEMA, the generator is required to withstand only the three-phase current level unless it is otherwise specified…*

  A generator can develop a significant third-harmonic voltage when loaded. A solidly grounded neutral and lack of external impedance to third harmonic current will allow flow of this third-harmonic current, whose value may approach rated current. If the winding is designed with a two-thirds pitch, this third-harmonic voltage will be suppressed but zero-sequence impedance will be lowered, increasing the ground-fault current…

  Internal ground faults in solidly grounded generators can produce large fault currents. These currents can damage the laminated core, adding significantly to the time and cost of repair…Both magnitude and duration of these currents should be limited whenever possible.

Generator Impedance Example

	60 Hz 1800 rpm — Standby					
Frame/# of brgs	691/2	692/2	693/2	695/1	696/1	697/1
Volts	480	480	480	480	480	480
Arrgt. Number	144-1748	166-2664	144-1754	166-2680	166-2692	166-2698
Ratings						
130° C Rise						
ekW	900	1000	1100	1250	1400	1500
kVA	1125	1250	1375	1563	1750	1875
Motor Starting Capability at 30% Voltage Dip	2100	2050	2477	3018	3222	2661
Pitch	0.7142	0.7142	0.7222	0.7333	0.6666	0.7333
Efficiency (%) 100%	94.4	94.4	95	95.4	95.7	95.8
Efficiency (%) 75%	94.8	94.9	95.4	95.7	96.0	96.1
Efficiency (%) 50%	94.7	94.9	95.2	95.5	95.8	96.0

Reactances (per unit)						
Subtransient-Direct Axis X"d	0.1723	0.1988	0.179	0.1662	0.1783	0.2346
Subtransient Quadrature Axis X"q	0.2027	0.233	0.2174	0.2027	0.2209	0.292
Transient Saturated X'd	0.2492	0.2833	0.2583	0.2405	0.2529	0.3273
Synchronous Direct Axis Xd	3.522	3.89	3.6277	3.4137	3.4743	4.4266
Syncrhonous Quadrature Axis Xq	1.7443	1.9287	1.7979	1.6941	1.7266	2.2033
Negative Sequence X2	0.1875	0.2159	0.1982	0.1845	0.1996	0.2633
Zero Sequence Xo	0.0328	0.0367	0.0413	0.0482	0.004	0.0681

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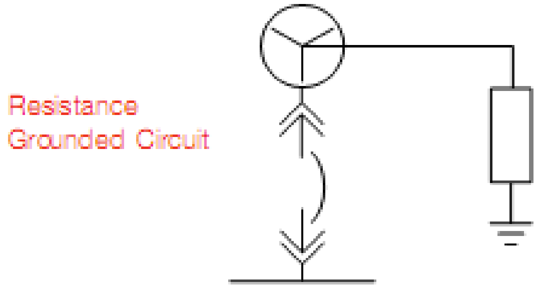
Resistance Grounding

High Resistance

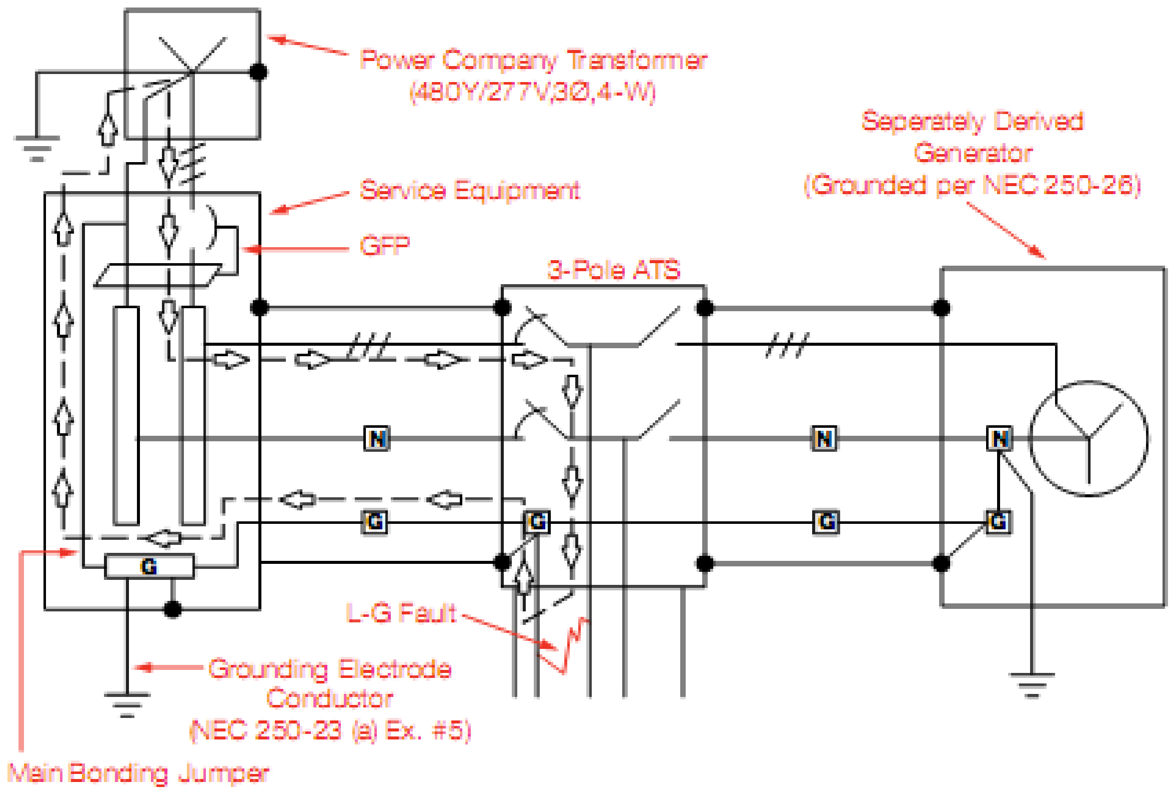
- More often at LV than MV
- Less than 10 amps continuously
- Avoid shutdowns
- Least damage

Low Resistance

- More often at MV than LV
- Less than 1000 amps for ten seconds
- Safely shutdown
- Less damage than solidly grounded

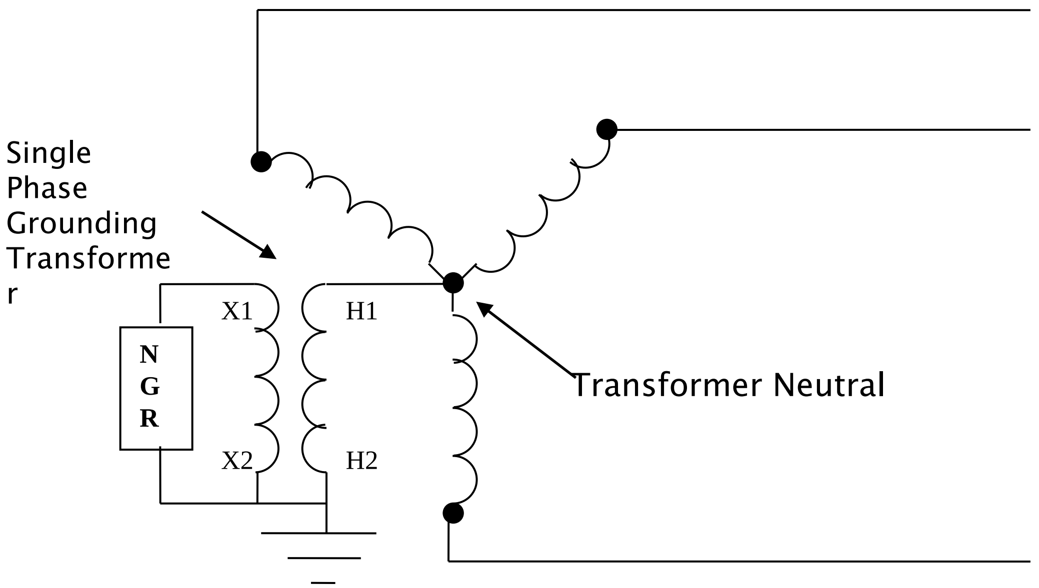


Four Pole Transfer Switch



- Allows multiple layers of GFP, different grounding methods, multiple generators

MV HRG Schematics



Medium Voltage Wye (Four-Wire) Connected Neutral Grounding Resistor

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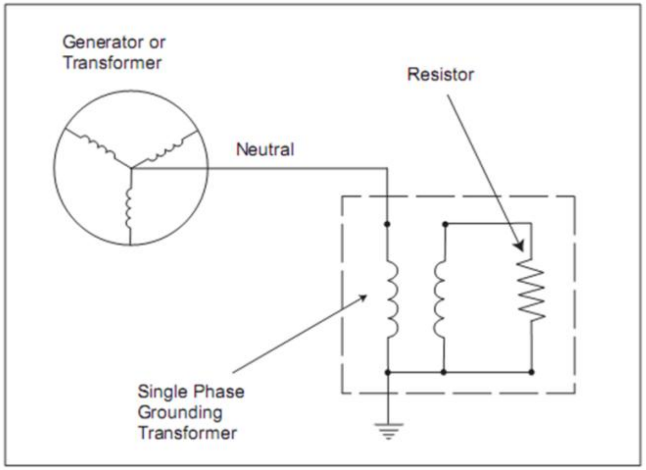
Single Phase GTR

- Usually paired with resistor to give HRG at MV
- Using line to neutral rated resistor not size/cost efficient
- Current normally less than 15A
- Voltage equal to system line to neutral voltage
- Secondary typically 240 V



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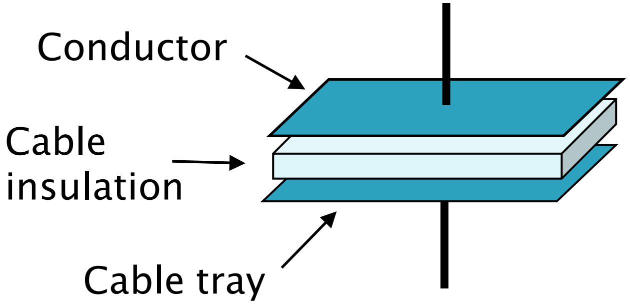
System Capacitance

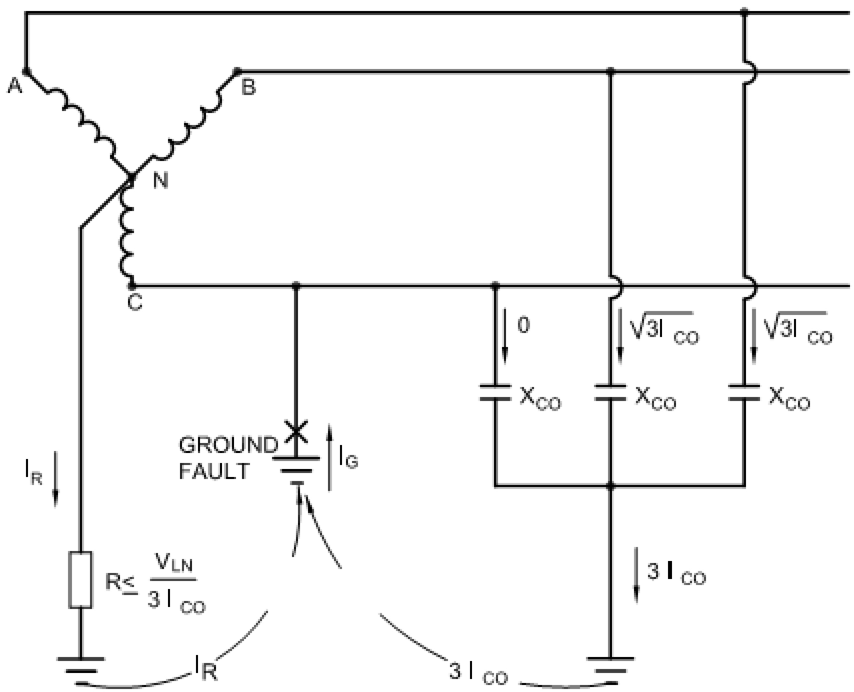
A capacitor is an electrical device that can store energy in the electric field between a pair of closely spaced conductors

(Thank you, Wikipedia)



- Capacitance re-charges during an arcing fault, creating a larger overvoltage
- Overvoltage stresses insulation, leading to further faults

Importance of Charging Current



In ungrounded systems, a voltage is held on the system capacitance after a fault. In an arcing or intermittent fault, this can lead to a significant voltage build-up.

In a high resistance grounded system, the resistance must be low enough to allow the system capacitance to discharge relatively quickly.

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System Charging Current

Only discharges if $R_o < X_{co}$, so $I_r > I_{xco}$
(per IEEE142-1991 1.4.3)

- That is, *resistor current* must be greater than *capacitive charging current*.
- 'Rule of thumb' numbers 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

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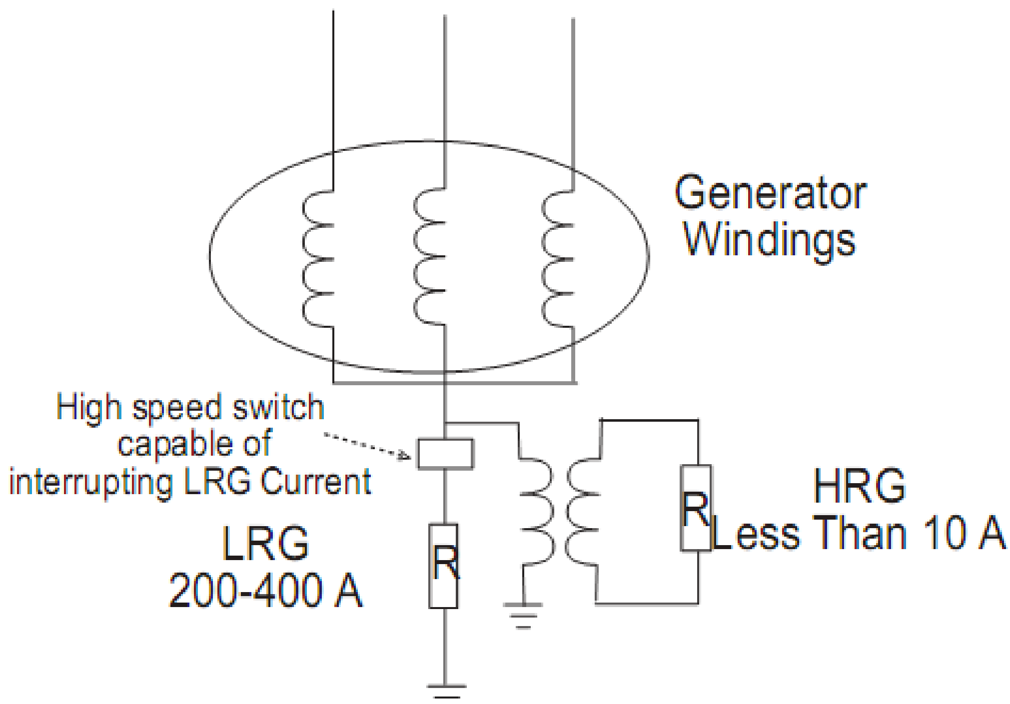
Chosing resistor setting

- Chose fault current higher than capacitive charging current
- Ex. If charging current is determined to be 1.9 A, chose at least 3 A of fault current

Hybrid Grounding



- Low resistance grounding overcomes capacitive charging current
- After generator is isolated the LRG is removed, limiting fault current to 5 A

Ground Fault Detection

- Source Ground – monitors current flow in system grounding conductor connected between neutral and ground
- Zero Sequence – detects vector unbalance of current sum in each phase
- Residual Connected – uses multiple CT’s and relays, indicating any leakage to ground

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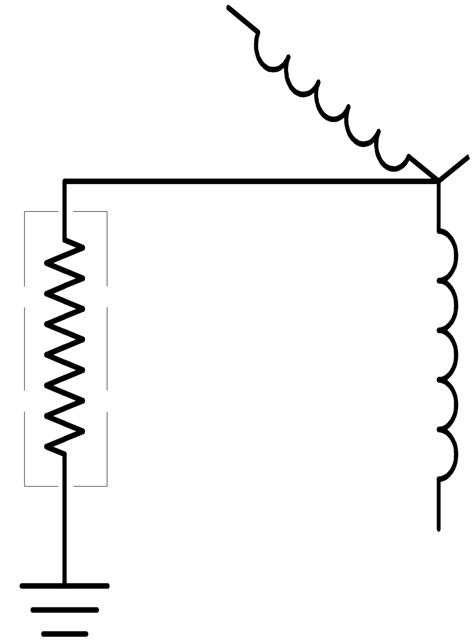
Excessive Neutral Current

- Neutral current includes ground fault current and harmonics/noise
- Cumulative current may be sufficient to alarm/trip



- Use filter/tuned relay to avoid nuisance alarms

$$I_{total} = I_{fault} + I_{3rd} + I_{5th} + I_{7th} \cdots$$

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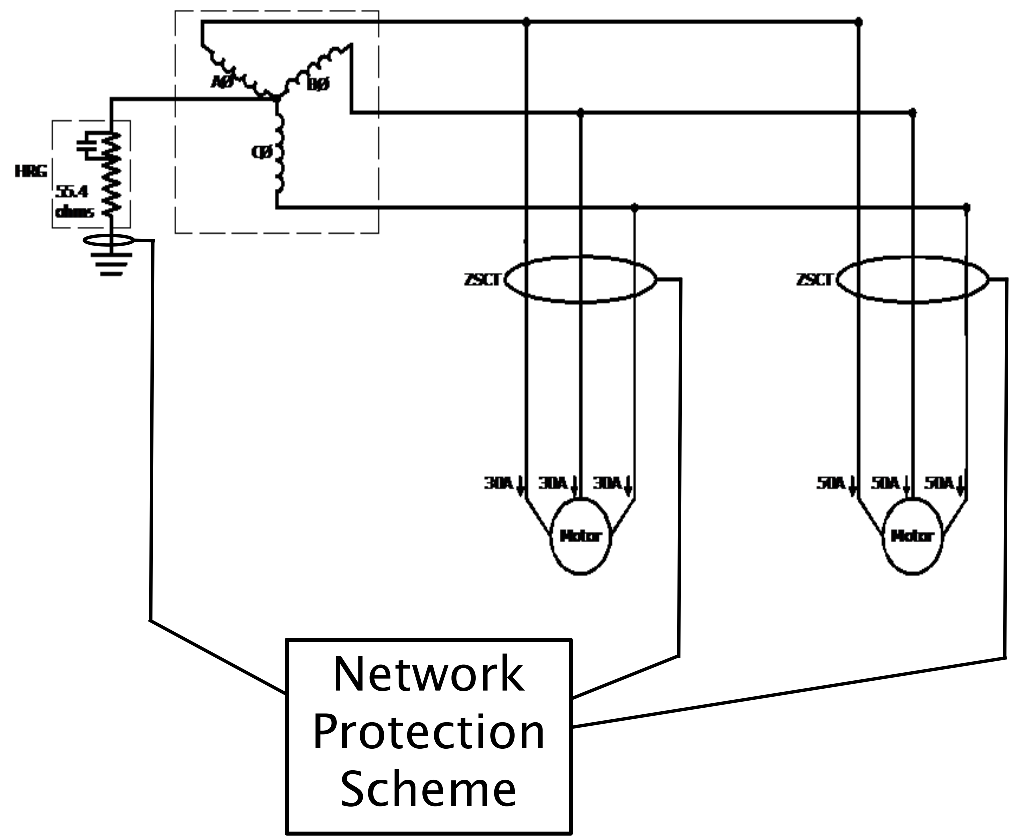
Communication with Feeder relays

- Faulted feeder has one phase ~ 0 V
- Zero Sequence CT detects fault current

- Integration of HRG (via Ethernet or RS-485) allows for selective tripping



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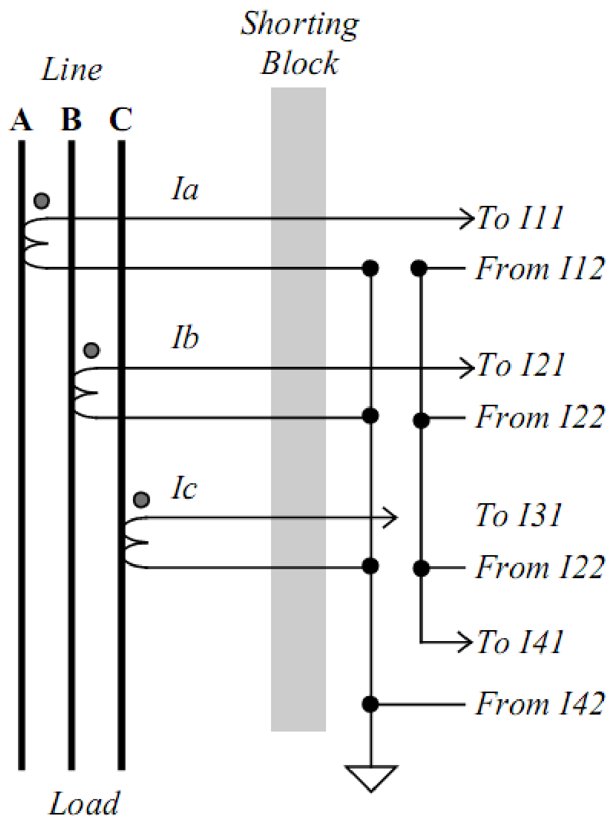
Alternative for Residual Current



- Less sensitive than ZSCT
- Less costly than ZSCT
- Effective for feeder identification

Paralleled Generators

- Easy if all generators are same design and pitch, always operated at equal loading and are not switched with three pole transfer switch

IEEE Std. 142-1991 (Green Book)
1.7.3 Paralleled Generators in an Isolated System

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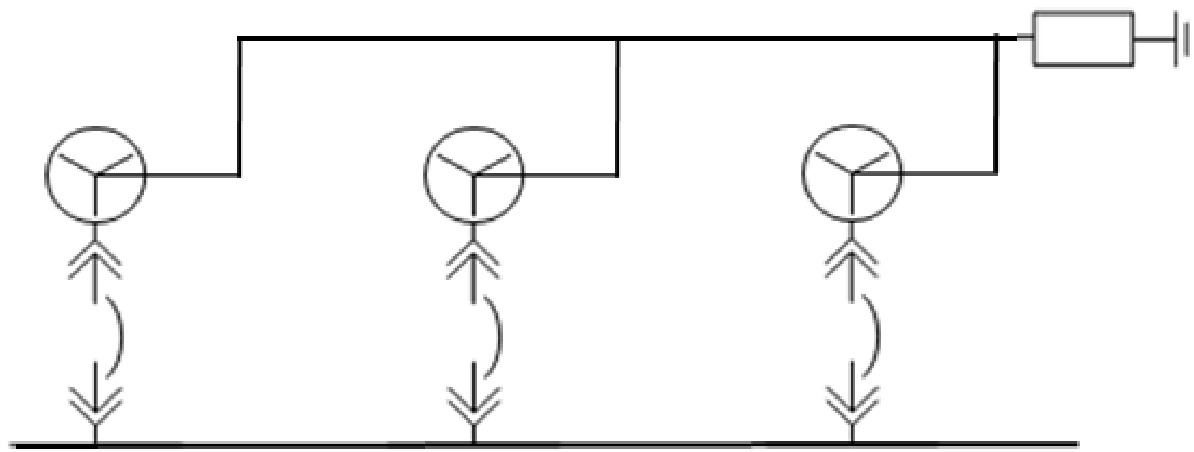
Common Grounding Path



- Collecting neutrals and solidly grounding them collectively creates a path for excessive 3rd harmonic current
- Collecting neutrals through a single grounding resistor may exceed the continuous duty of the resistor

Contribution of Ground Conductor

AWG Stranded Copper Wire Resistance				
Size	Diameter		Resistance @ 77ºF	
AWG	inch	mm	ohm/1000'	ohm/km
18	0.0465	1.182	6.5227	21.400
14	0.0740	1.880	2.5756	8.450
12	0.0933	2.371	1.6215	5.320
10	0.1177	2.989	1.0180	3.340
8	0.1484	3.770	0.6401	2.100
6	0.1871	4.753	0.4023	1.320
4	0.2360	5.994	0.2533	0.831
0	0.3752	9.530	0.1003	0.329

NEC 250.36

In no case shall the ground system conductor be smaller than 8 AWG copper or 6 AWG aluminum or copper-clad aluminum.

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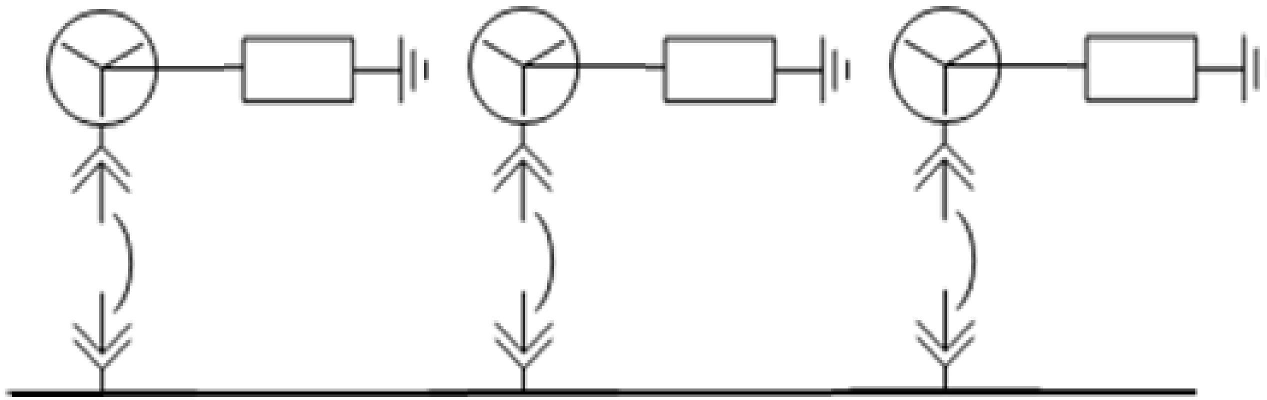
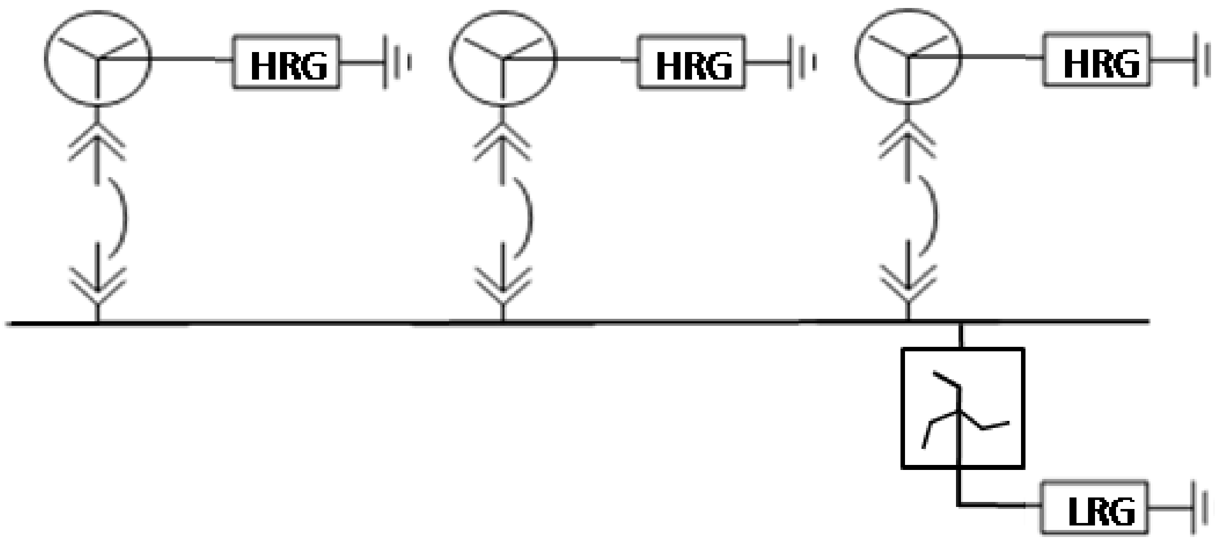
Separate Grounding Paths



- Separately grounding prevents circulating 3rd harmonic current
- Must have means of disconnecting neutral if generator is being serviced
- Multiple NGR's has cumulative effect on ground fault current

Distributed Hybrid Grounding



- A neutral deriving transformer holds the fault current on the main bus to a consistent current rating
- Each generator is protected against internal faults by HRG

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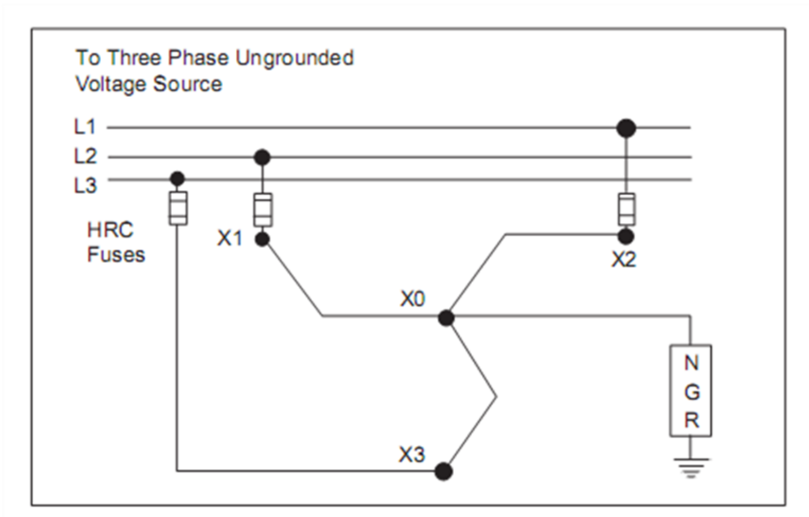
Neutral Deriving Transformer



- Creates a neutral point in a 3 wire system
- Rated for system voltage, expected current and duty cycle
- Two methods to establish a neutral

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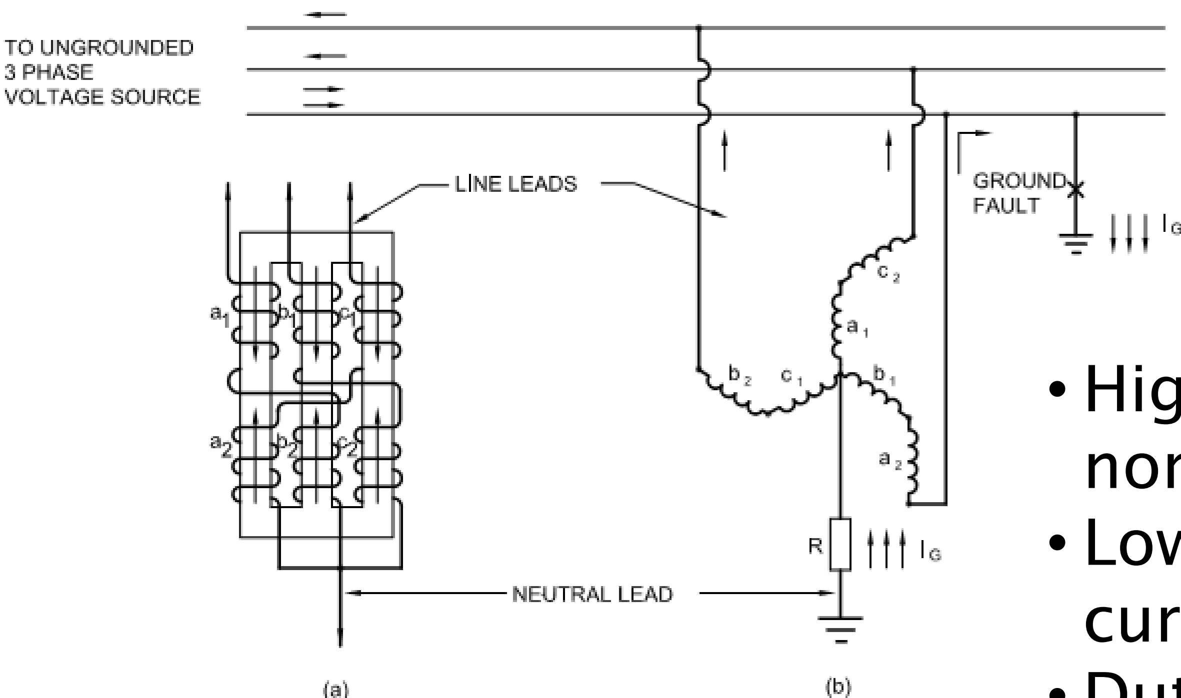
Zig-Zag Transformer



- High impedance to normal phase currents
- Low impedance to fault current
- Duty cycle same as resistor

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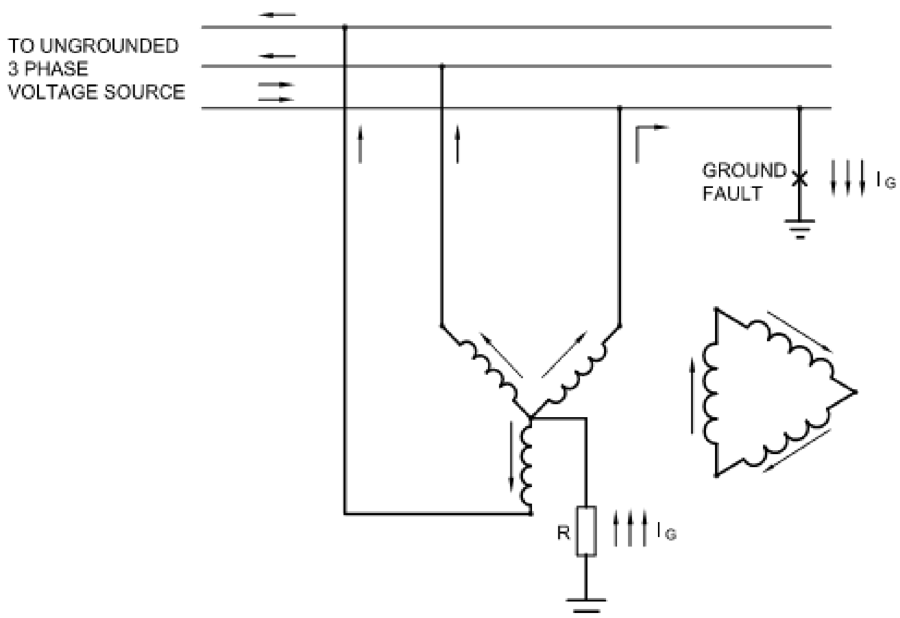
Wye Delta Grounding Transformer



- Uses 3 industrial control transformers
- Connect to create neutral
- Low voltage resistor

Recommendation

- Solidly ground only at LV when generator permits, loads are non-critical and primarily single phase
- HRG at LV
- LRG at MV or where charging current is excessive