I-GARD

Unparalleled Protection

Technical Webinar Series 2021

“Hybrid Grounding of Generators”

Presented by: **Sergio Panetta**

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November 10th, 2021

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Why HHRG?

(Hybrid High-Resistance Grounding)

ISO 9000

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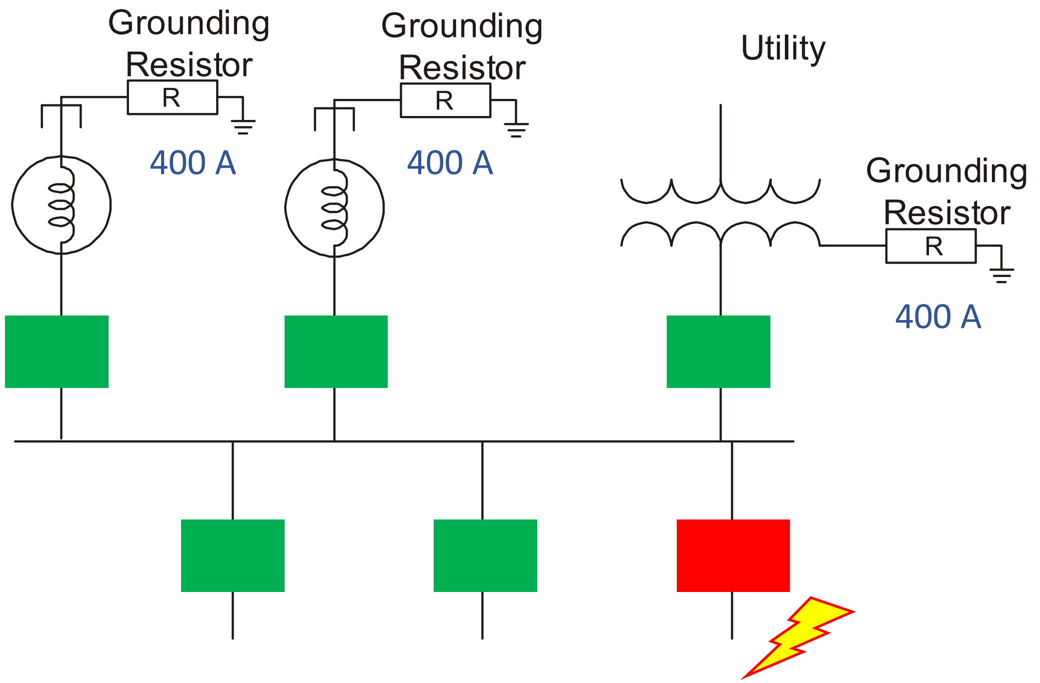
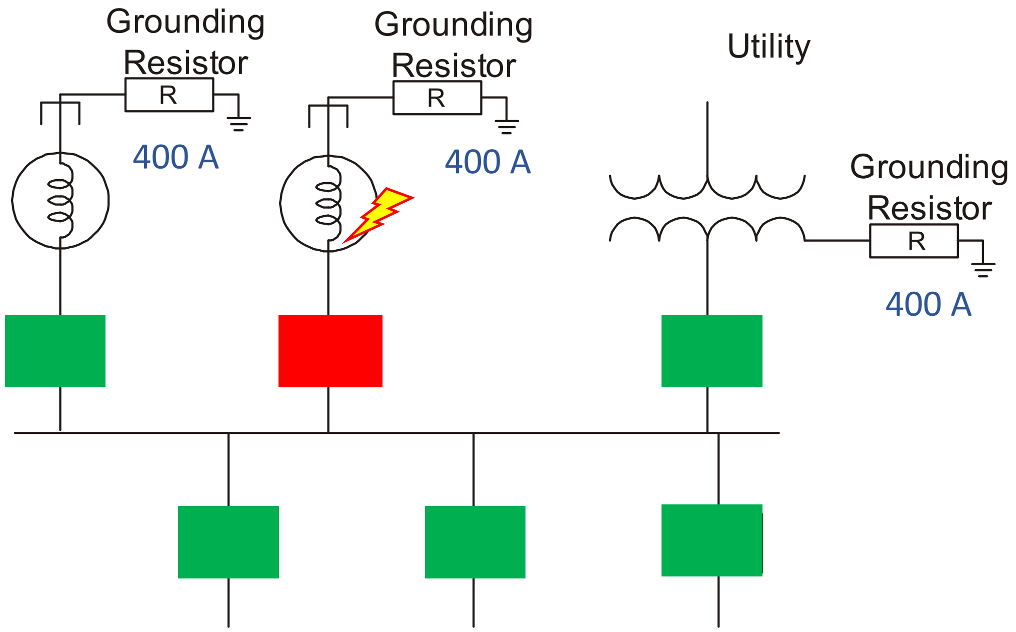
Damage to Generator

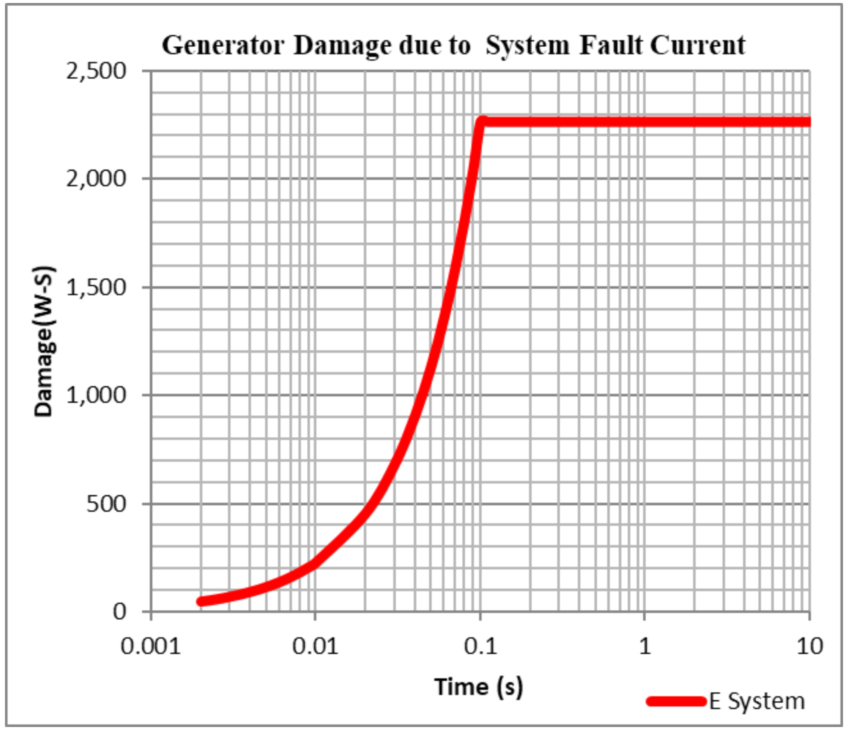
Through Faults



Damage to Generator

Due to contribution of external grounding

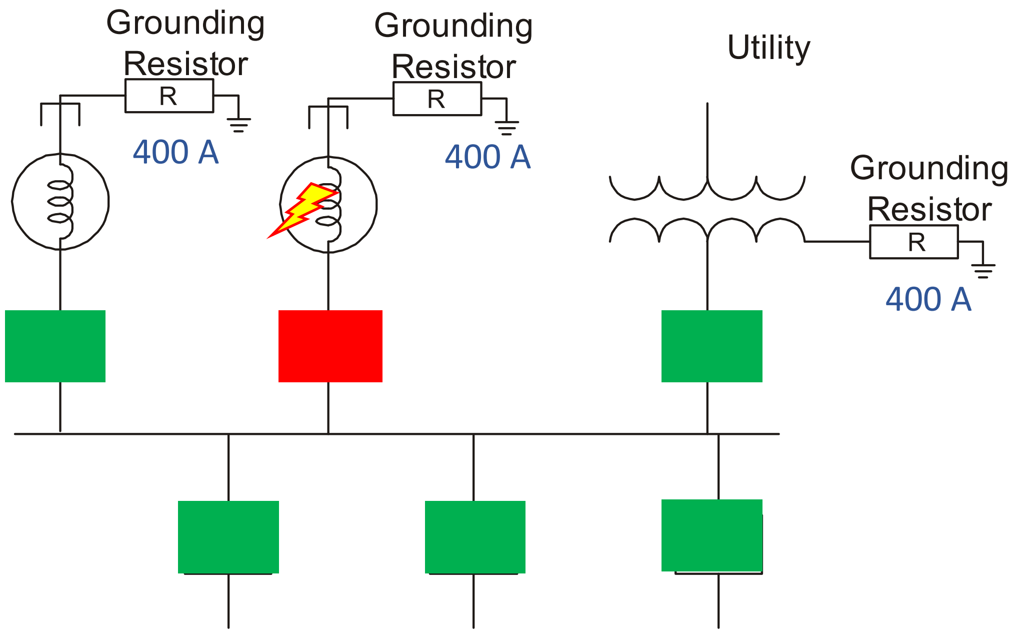


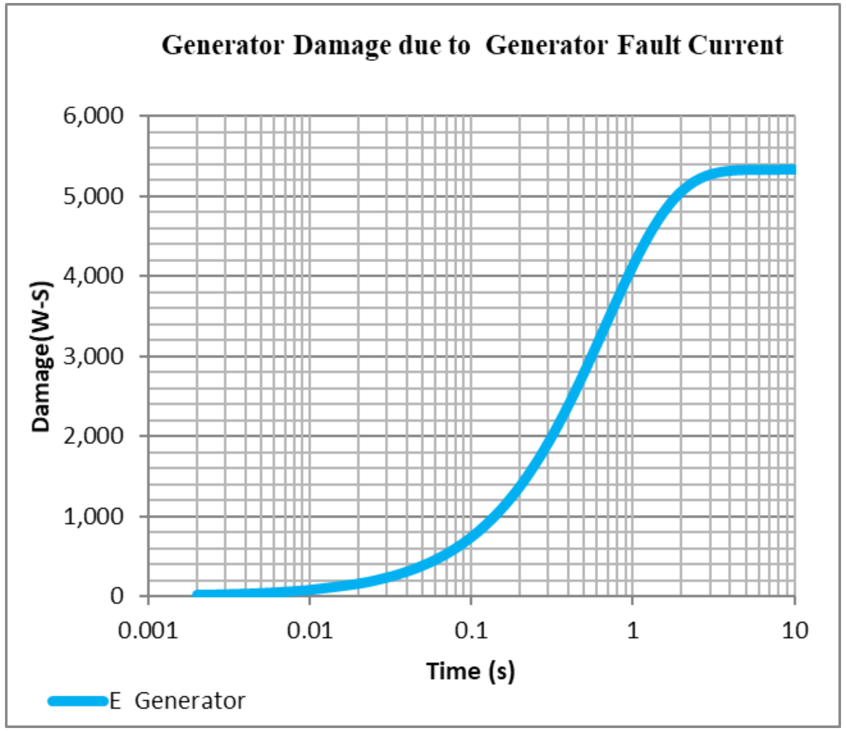


$$E = \int i^k dt$$

Damage to Generator

Due to internal grounding





$$E = \int (Ie^{-t/\tau})^k dt$$

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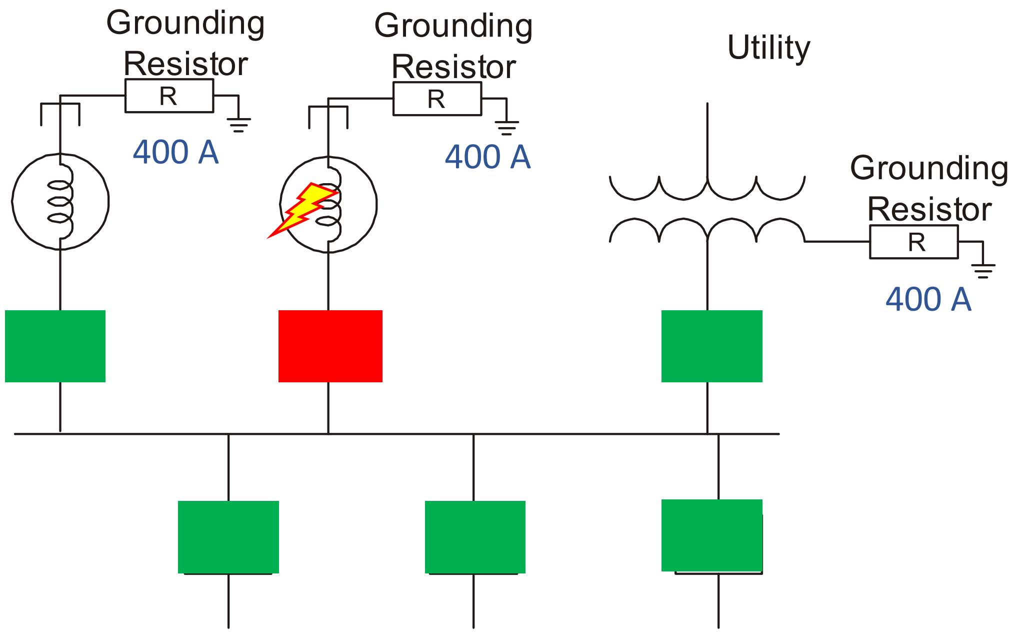
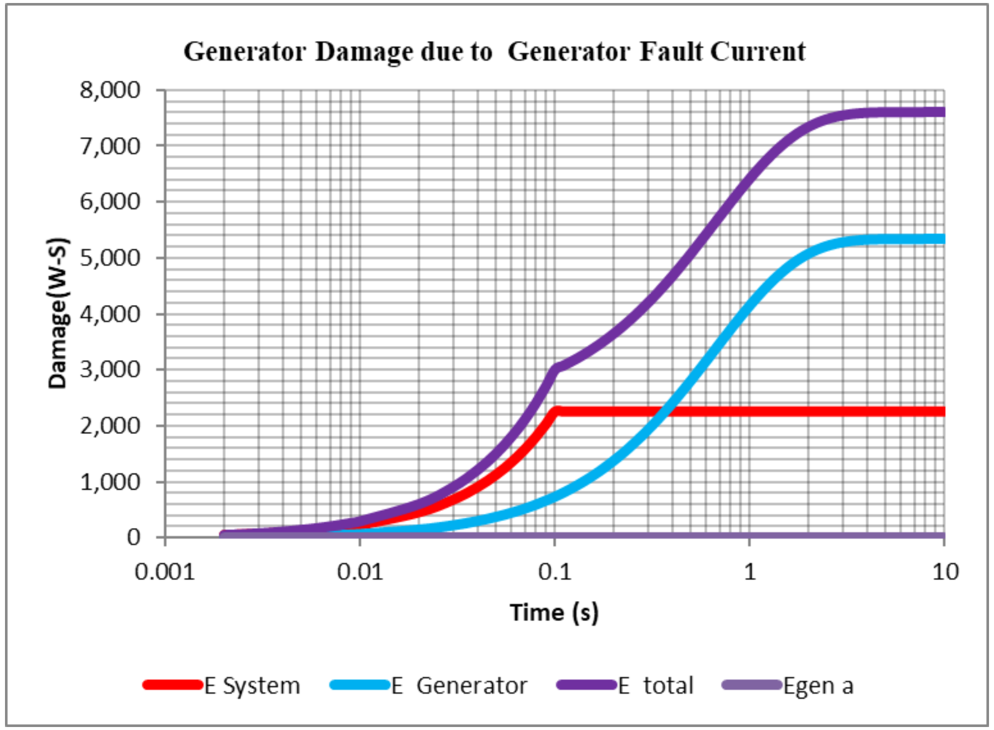
Damage to Generator
Due to contribution of external grounding





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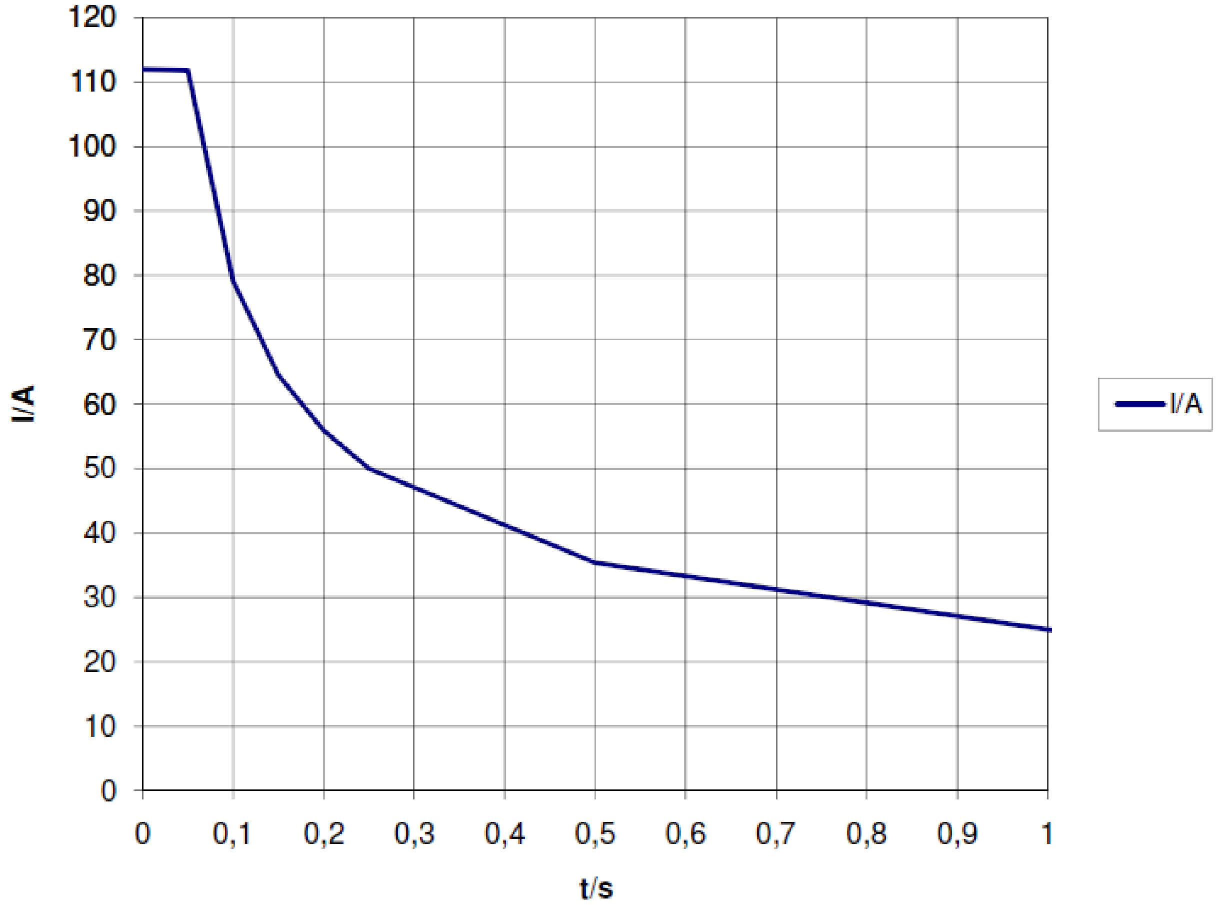
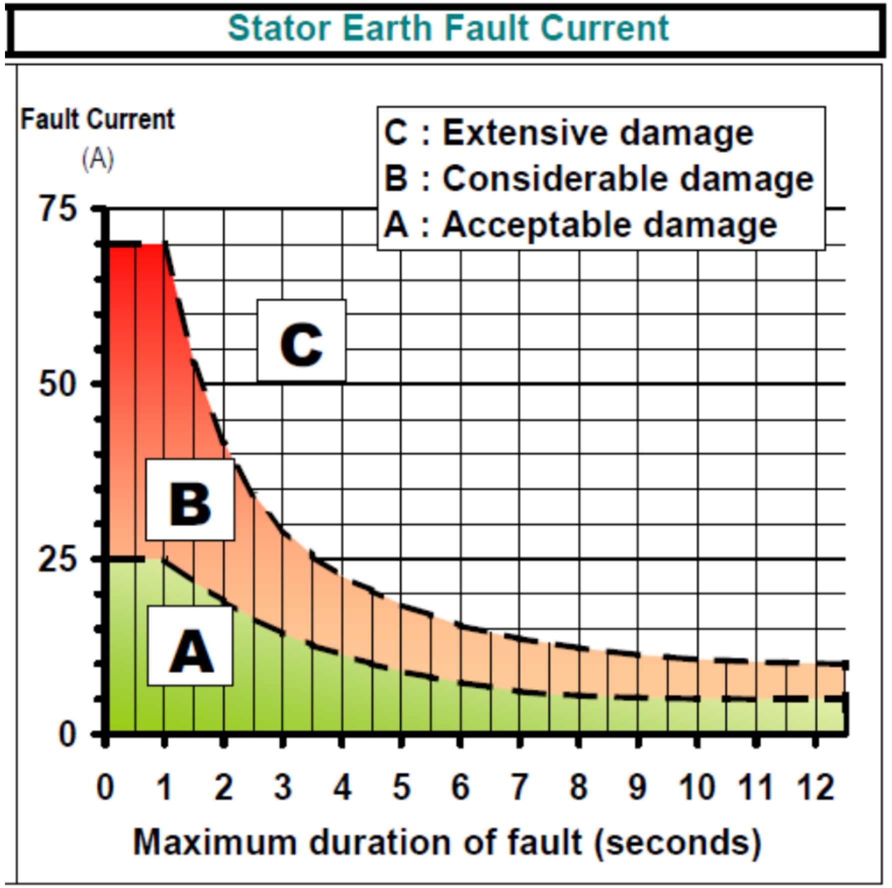
Stator Fault Winding Damage Curve

Manufacturer 1



Stator Fault Winding Damage Curve
Manufacturer 2



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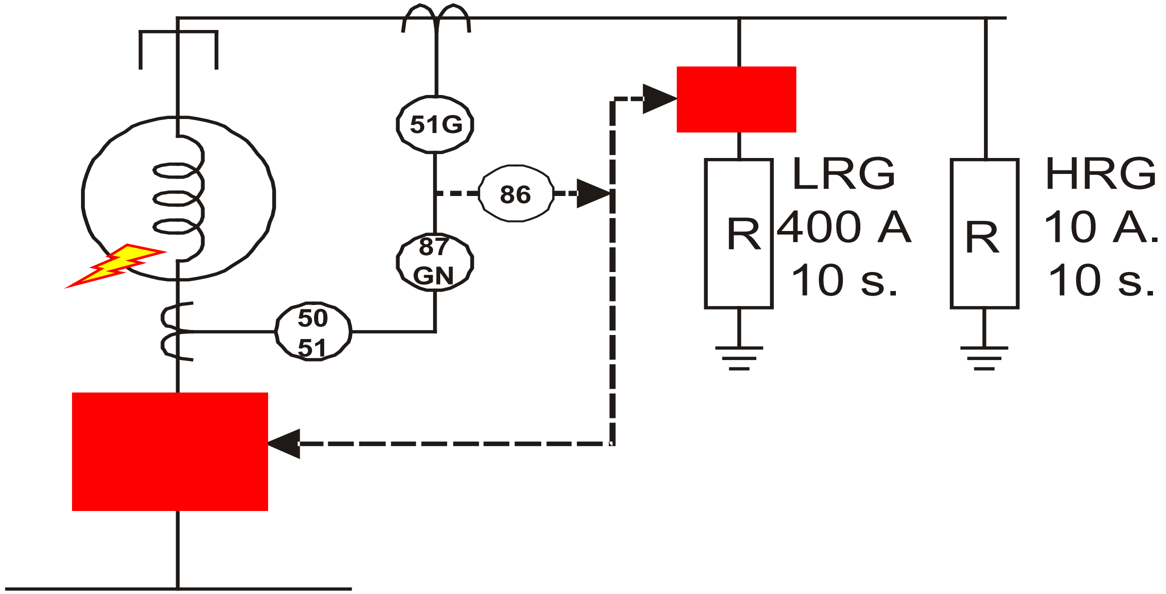
Damage to Generator



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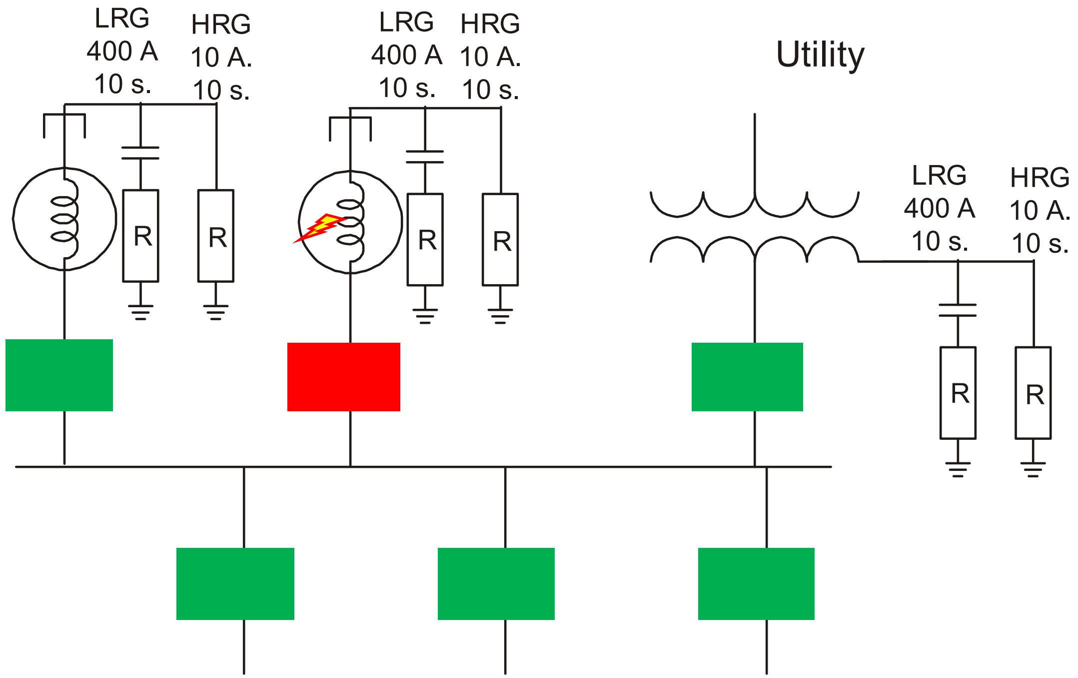
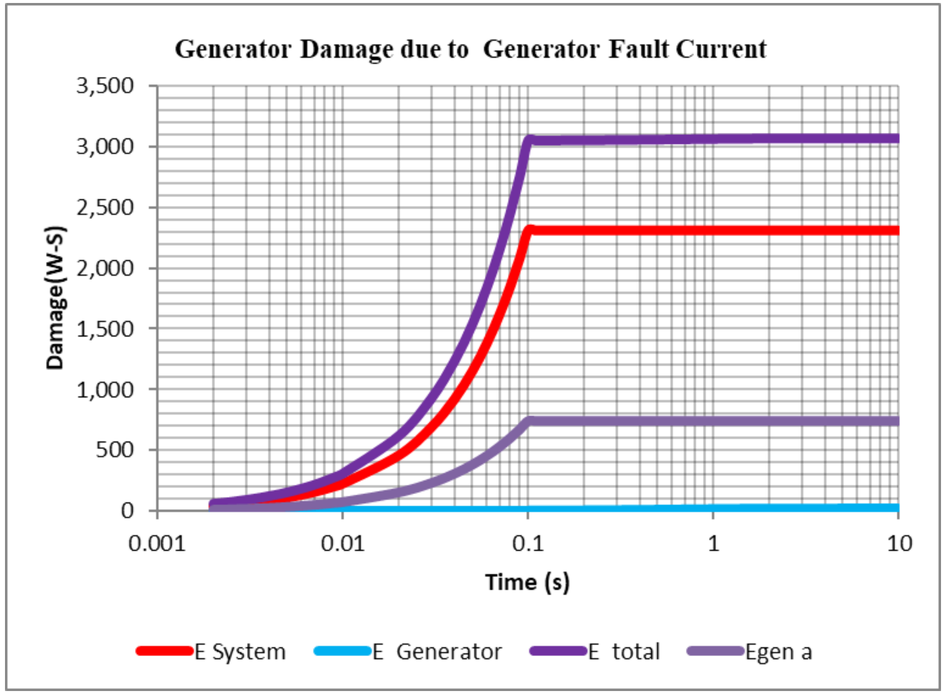
Damage to Generator

Due to contribution of external grounding





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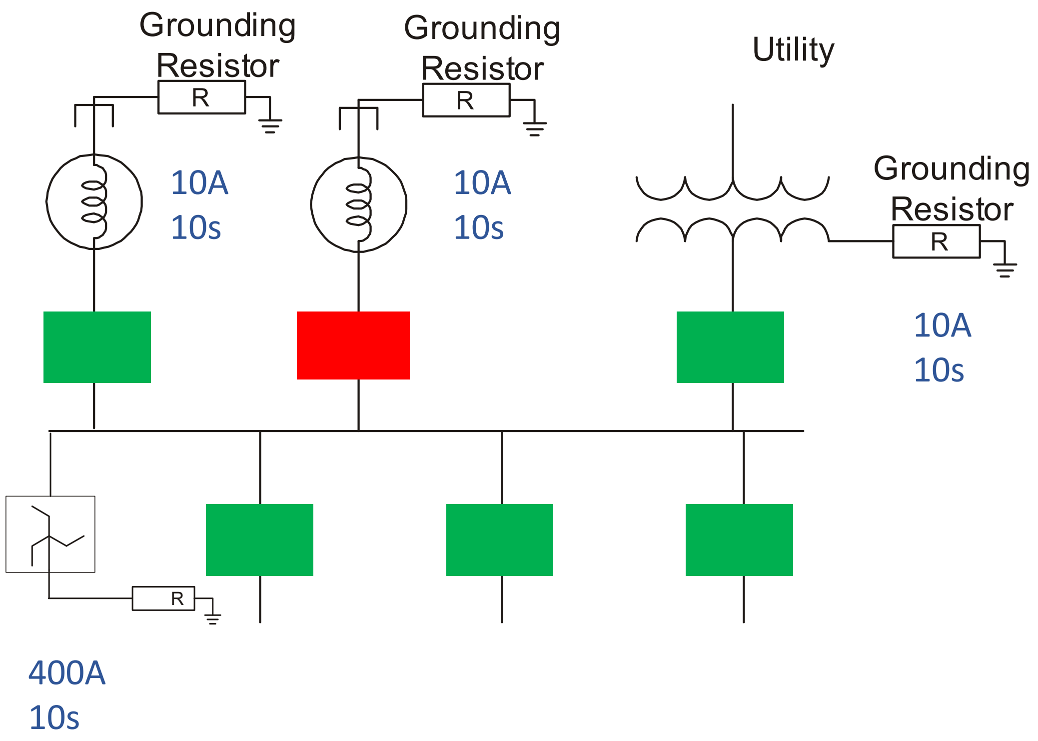
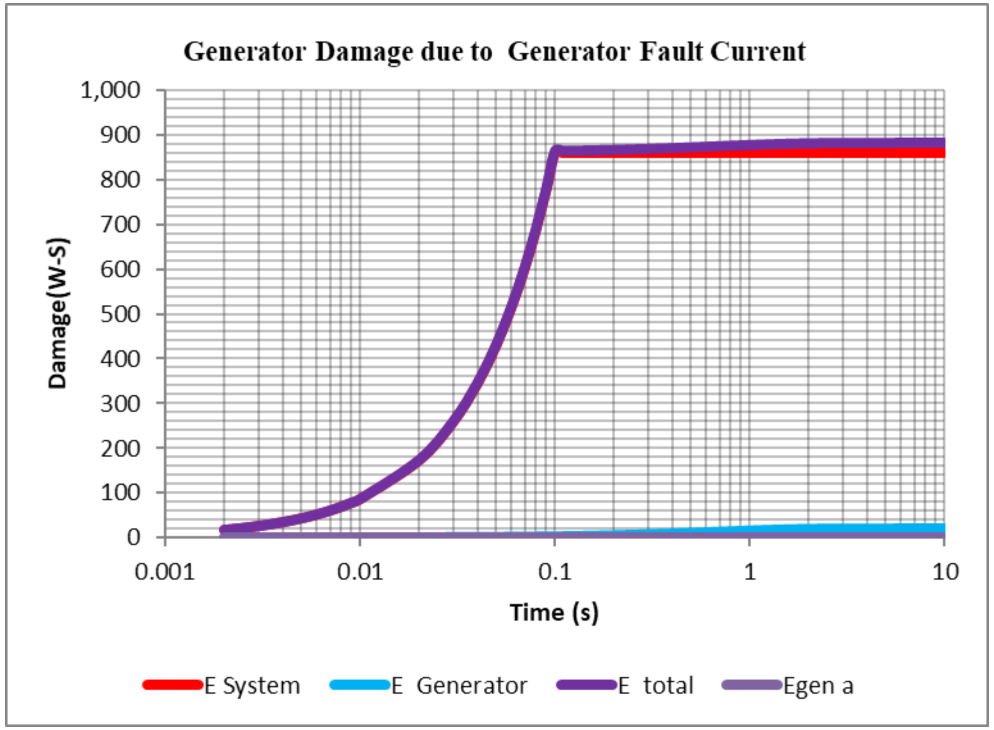
Damage to Generator

Due to contribution of external grounding





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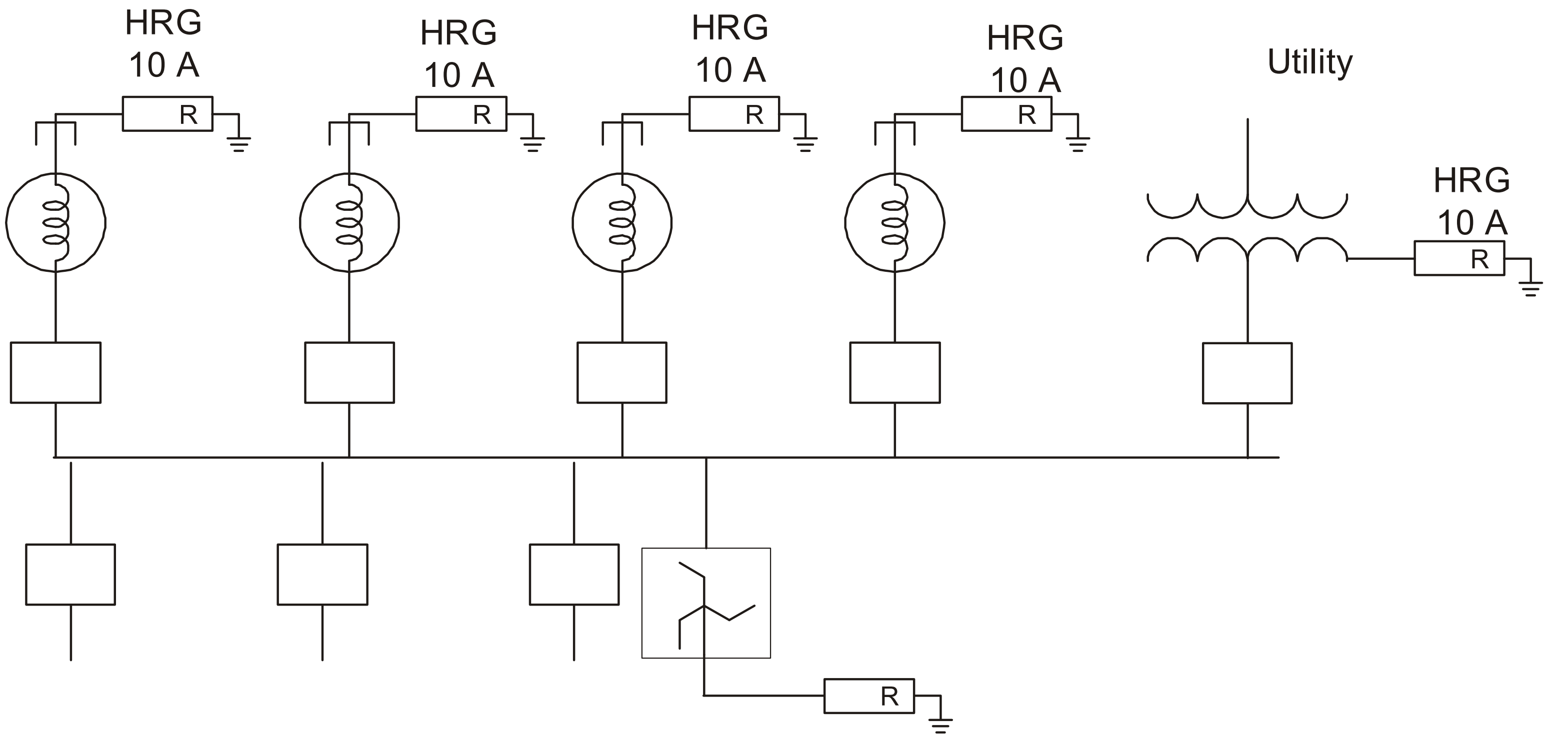
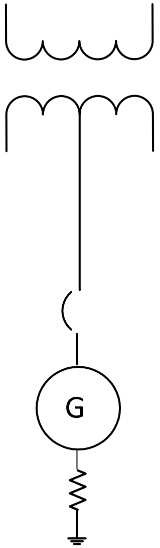
Calculating Charging Current

For Bus connected generators and HHRG



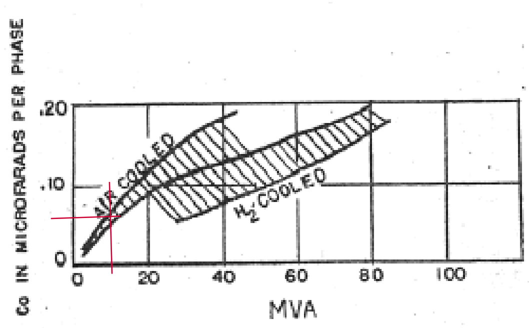
Calculating Charging Current

For unit connected generators and HHRG

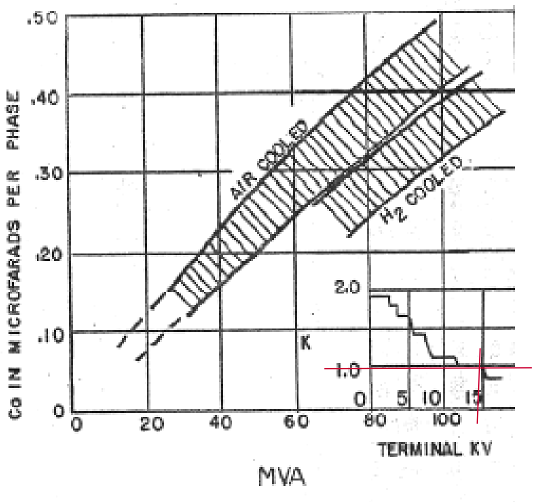


3 set of 500 kcmil
250 feet

10 MVA Gen
13.8 kV



a) For 3600 RPM machines

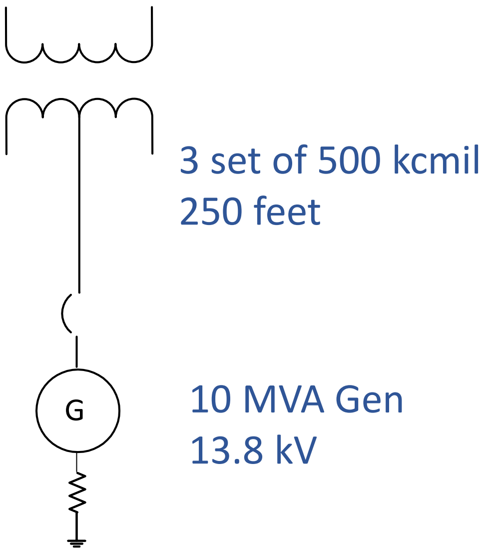


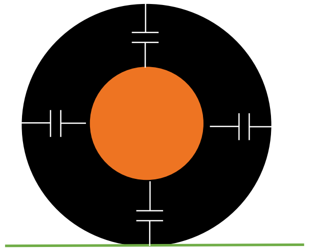
b) For 1800 RPM machines

Gen , 0.05 μF/ϕ
Terminal voltage 1

Calculating Charging Current

For unit connected generators and HHRG





Gen , 0.05 μF/ϕ

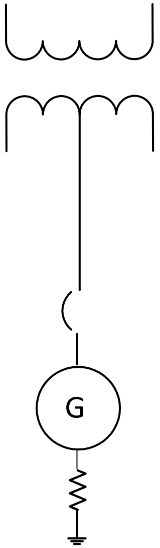
Terminal voltage 1

Cables 0.0929μF/kFt/ϕ

Total 0.05 + 3*250'*0.0929/1000 = 0. 07μF

Calculating Charging Current

For unit connected generators and HHRG



3 set of 500 kcmil
250 feet

10 MVA Gen
13.8 kV

Gen 0.05 μF/ϕ

Terminal voltage 1

Cables 0.0929μF/kFt/ϕ

Total 0.05 + 3*250’*0.0929/1000 = 0. 07μF

$$Z = \frac{1}{2\pi f C} = 22162\ \Omega/\phi$$

$$I = \frac{V}{Z} = 13800/22162 = 0.62$$

$$3I_{C0} = 1.86\ A$$

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5 kV Systems
Why the delineation?

- NFPA 70 E Annex O 2.3

(7) High-resistance grounding. A great majority of electrical faults are of the phase-to-ground type. High-resistance grounding will insert an impedance in the ground return path and will typically limit the fault current to 10 amperes and below (at 5 kV nominal or below), leaving insufficient fault energy and thereby helping reduce the arc flash hazard level. High-resistance grounding will not affect arc flash energy for line-to-line or line-to-line-to-line arcs.

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3.11.10 (C)

(C) Thickness of Insulation for Shielded Insulated Conductors.

Thickness of insulation for shielded solid dielectric insulated conductors rated 2001 volts to 35,000 volts shall comply with Table 311.10(C) and 311.10(C)(1) through (C)(3).

Insulation Level	Time for Ground Fault	
100%	<1 Minute	
133%	<1 Hour	
173%	<Days	

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5 kV v 5000 V

Table 311.10(C) Thickness of Insulation for Shielded Solid Dielectric Insulated Conductors Rated 2001 Volts to 35,000 Volts

Conductor Size (AWG or kcmil)	2001–5000 Volts		5001–8000 Volts						8001–15,000 Volts						15,001–25,000 Volts			
	100 Percent Insulation Level		100 Percent Insulation Level		133 Percent Insulation Level		173 Percent Insulation Level		100 Percent Insulation Level		133 Percent Insulation Level		173 Percent Insulation Level		100 Percent Insulation Level		133 Percent Insulation Level	
	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils	mm	mils
8	2.29	90	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6–4	2.29	90	2.92	115	3.56	140	4.45	175	—	—	—	—	—	—	—	—	—	—
2	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	—	—	—	—
1	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	6.60	260	8.13	320
1/0–2000	2.29	90	2.92	115	3.56	140	4.45	175	4.45	175	5.59	220	6.60	260	6.60	260	8.13	320

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MV Generators

Medium Voltage Generators are not designed to withstand full fault current during a single phase to ground fault, that is the reason that the preferred method of grounding is:

- Low Impedances
- High Impedances

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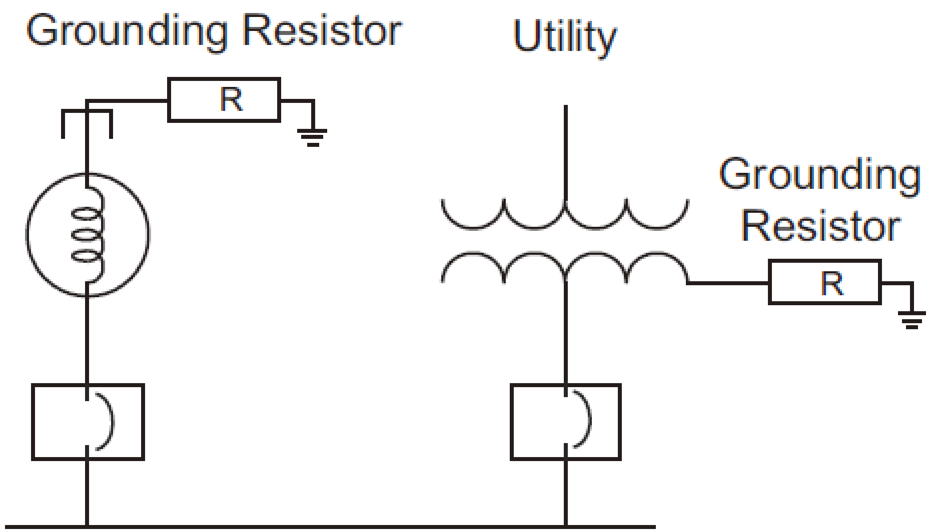
Grounding Methods

1. Low Impedance Grounded

- The resistor typically limits GF currents from 200 to 800 A for a short duration.
- Fault current is selected to minimize the damage and to enable selective coordination of the protection system
- This method is used when the charging current of the facility is > 10A
- The protection system cannot detect a Ground Fault of less than 5A



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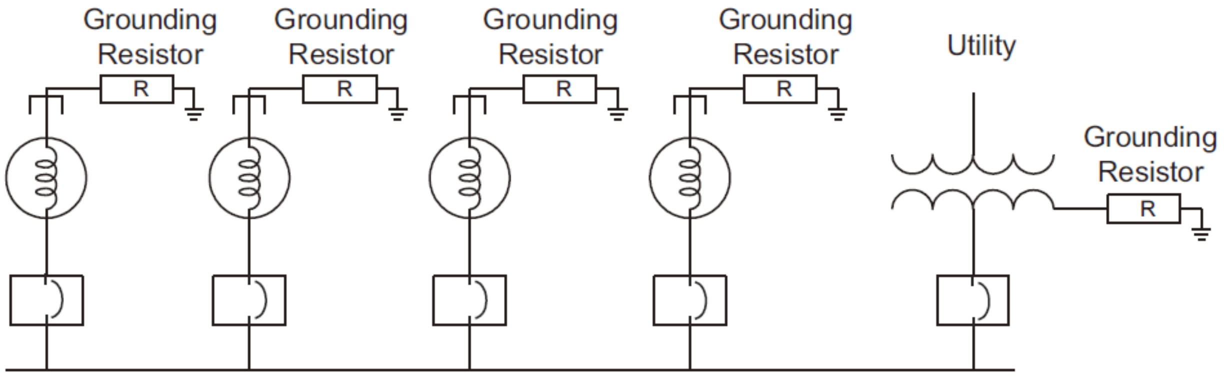
Grounding Methods
1. Low Impedance Grounded



ADVANTAGES

This method minimizes:

- Damage at the point of fault
- Shock hazards caused by stray currents
- Thermal and mechanical stress on equipment
- Control Transient Over voltages

DISADVANTAGES

- When a GF occurs within the stator winding of the generator it will not be removed (even though the generator breaker has opened)
- The generator will continue to supply current to the fault and this will damage the generator itself (due to duration not the magnitude of the fault).
- As more generators are connected, the advantages quickly diminish

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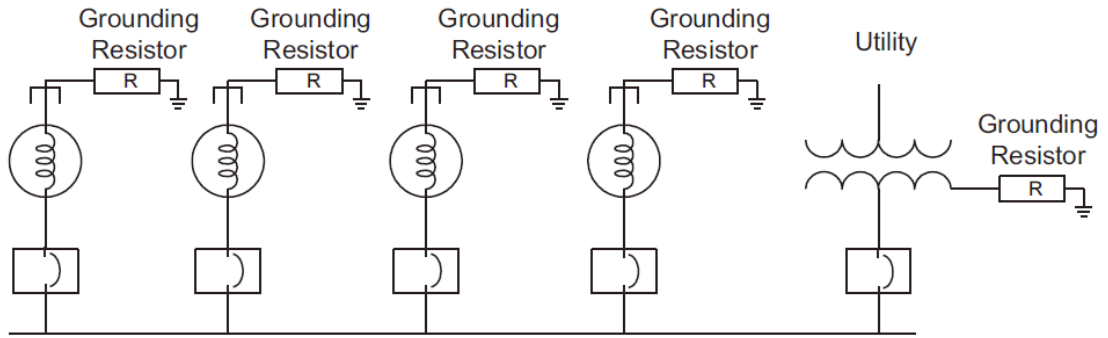
Grounding Methods

Multiple Point Grounded

- Each generator is grounded through its own grounding resistor
- There is no risk of leaving the generator ungrounded neither safety hazard when servicing a generator.

DISADVANTAGES

- If the fault occurs in the stator windings, the fault current will not be interrupted and it will have a severe damage in the stator windings.
- This will happen even if the circuit breaker of the generator has opened.



Multiple Point Grounded System

Grounding Methods

2. High Impedance Grounded

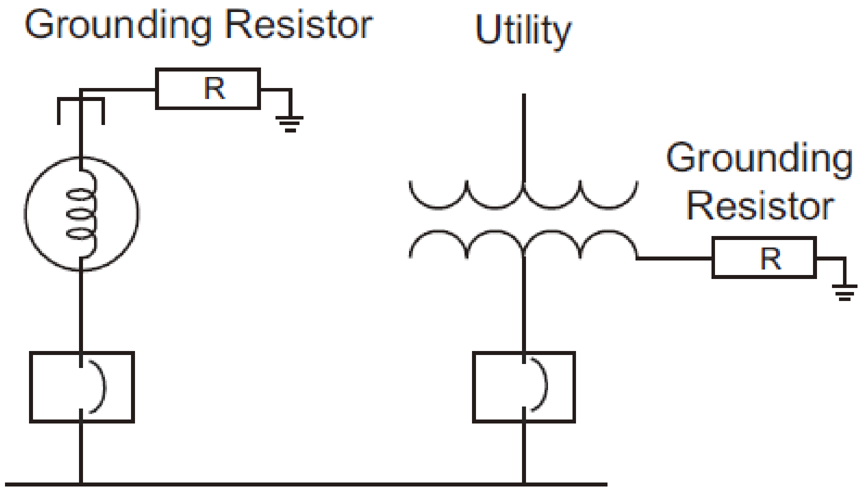
- Fault current is selected to be equal to or greater than the system capacitive charging current
- The resistor typically limits Ground Fault currents to a low value for an extended duration.

ADVANTAGES

- The Minimal fault current at the point of fault
- Continuity of operation
- Reduction of transient overvoltages
- Ability to find the Ground Fault location without power interruption

DISADVANTAGES

- As the charging current increases in large distribution network, more generators are placed online, High Impedance Grounded may not be the ideal solution



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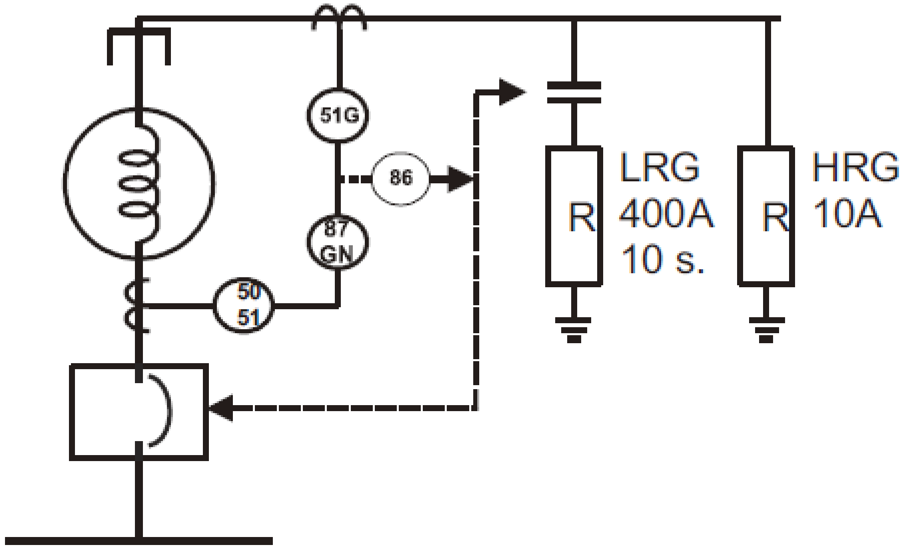
Grounding Methods

3. Hybrid Grounding

A combination of Low Impedance and High Impedance is the optimal solution, because:

- The generator will be grounded through a Low Impedance and a High Impedance device
- The system would effectively be Low Impedance for all Ground Faults
- If the fault is a *Ground Fault within the generator*, the system will revert to a High Impedance Grounded, minimizing the damage
- The Ground Fault current will be limited to the sum of the Low Impedance and High Impedance systems (410 A in figure)



ADVANTAGES

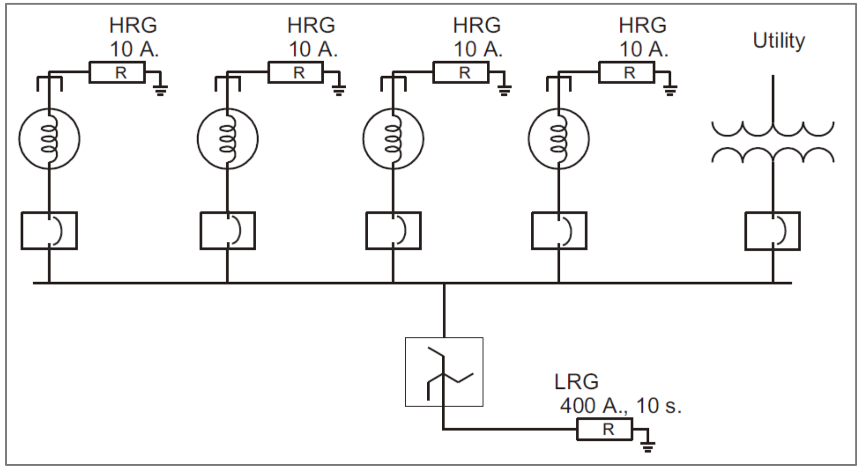
- All the Ground Faults will have selective coordination (benefits from Low Impedance)
- Minimal damage at the point of fault
- The generator will never be left in an ungrounded state
- The stator winding will be protected

Grounding Methods

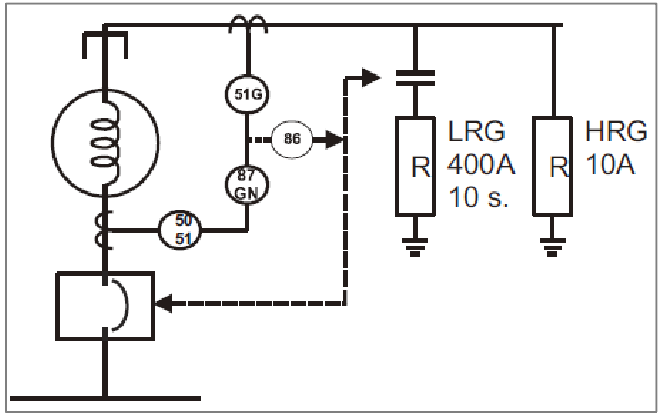
Variation of a Hybrid Grounded System

An additional scenario is when multiple units are placed on line, the system need to be reconfigured in order to keep all the benefits of a Hybrid Grounded system and for avoiding extremely high Ground Fault currents:

- The maximum ground fault will be in the order of magnitude of 400 A, regardless of how many sources are connected to the system
- GF will be isolated by the closest breaker by selective coordination



- GF within the stator will be isolated by the differential scheme, minimizing the damage to the stator



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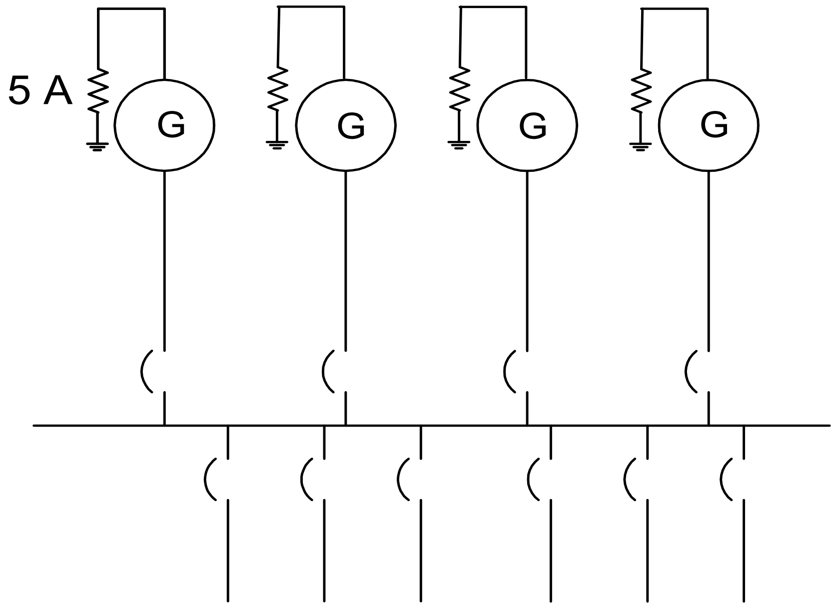
Low Voltage Application



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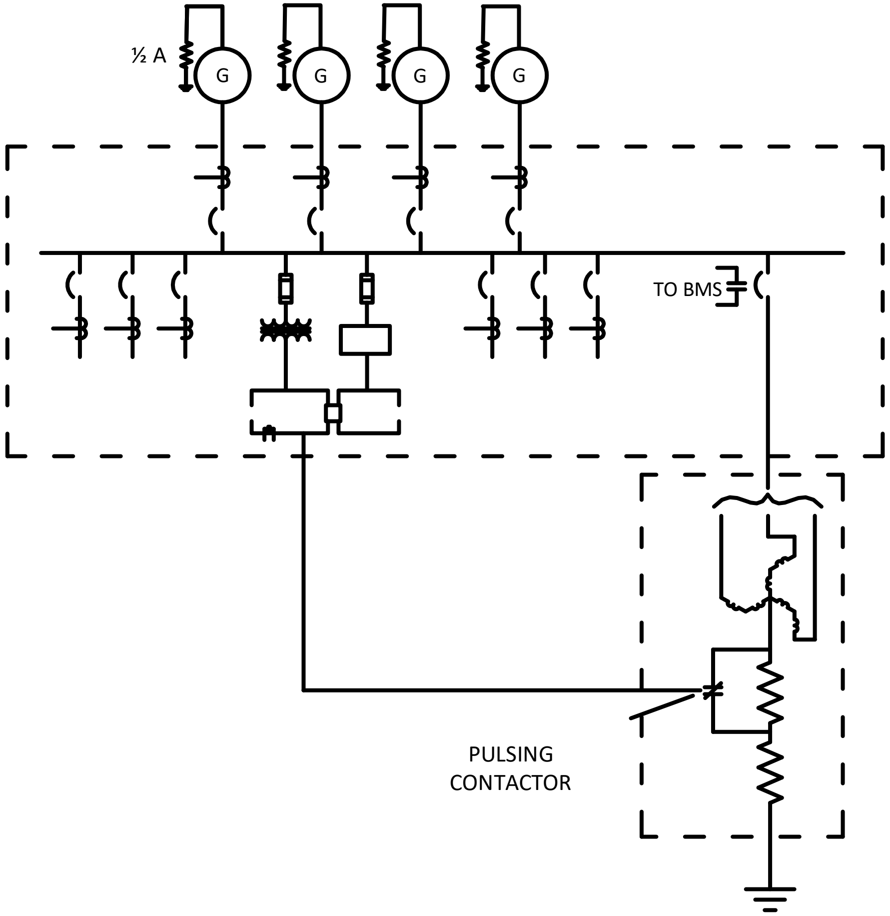
Low Voltage Application



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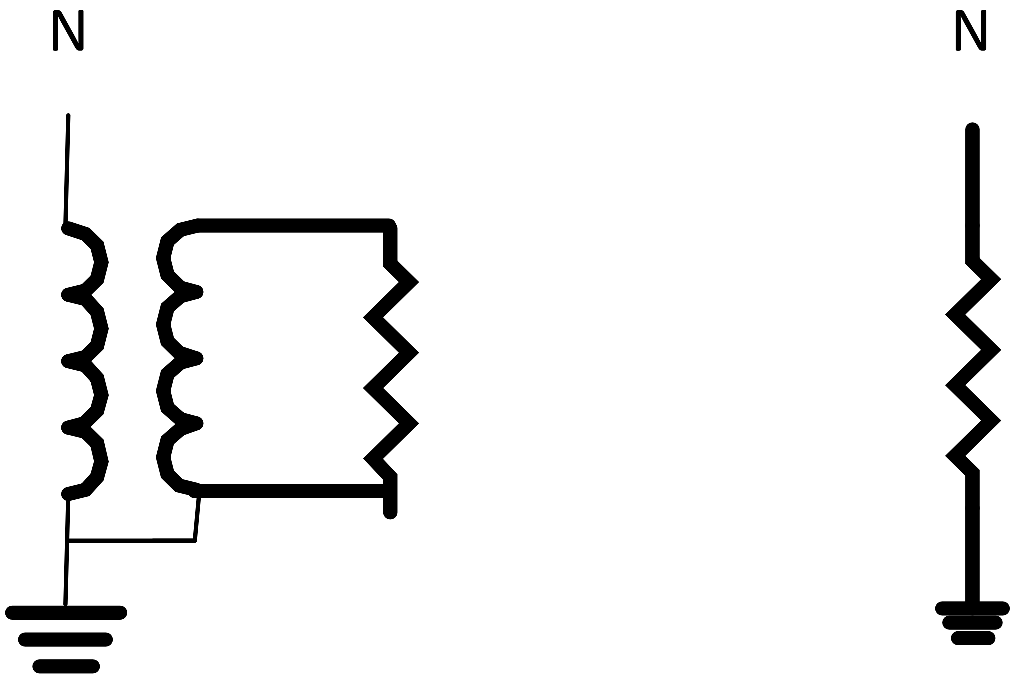
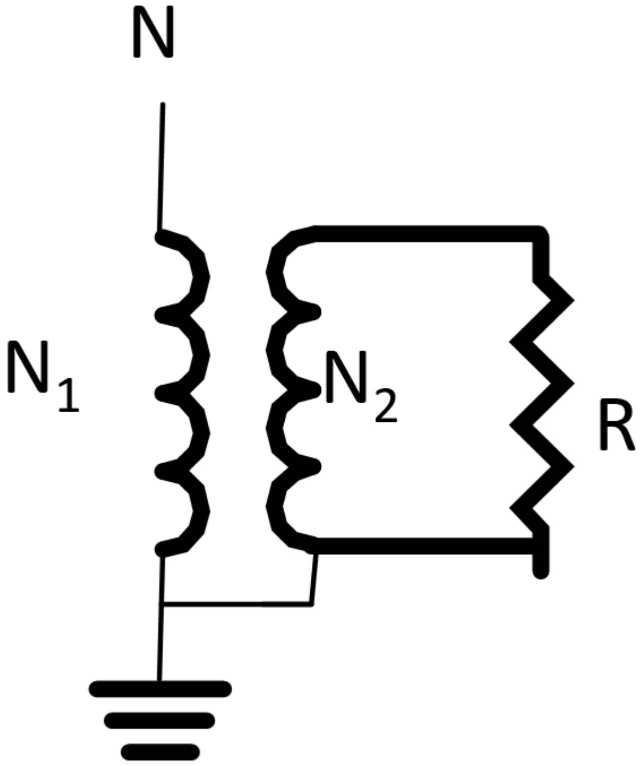
Resistor Sizing



Resistor Sizing

$$R = \frac{V_N}{I}$$

Resistor Sizing



$$R = \left(\frac{N_1}{N_2}\right)^2 \frac{V_N}{I}$$

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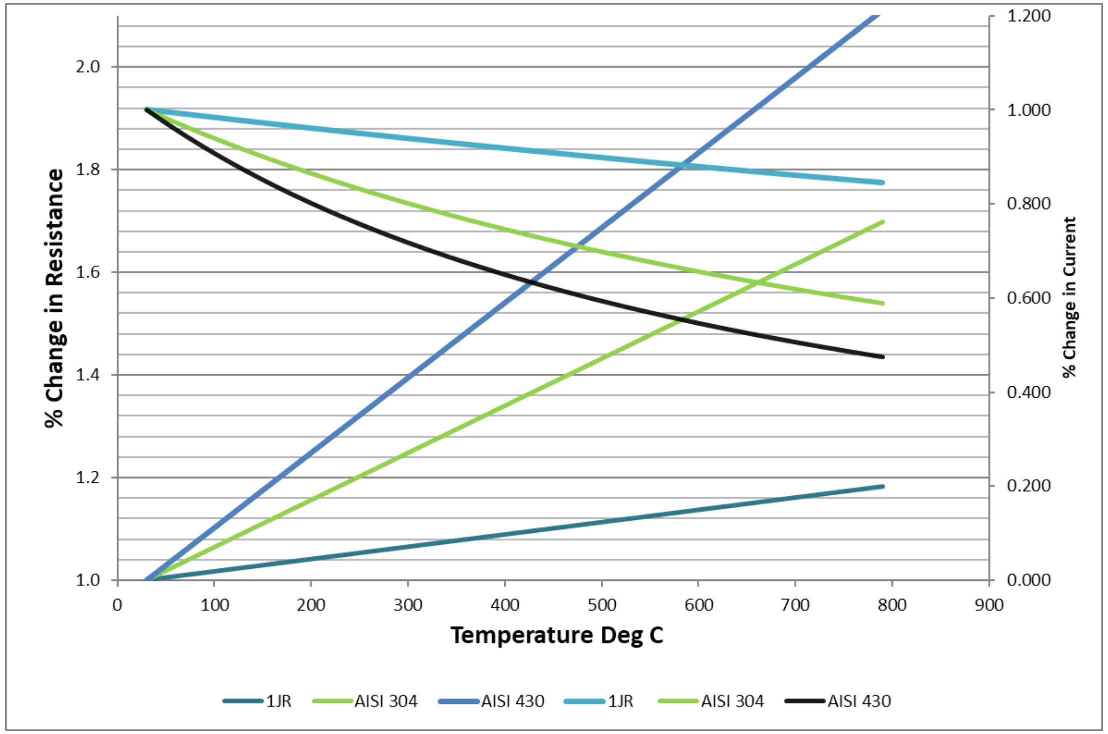
Resistor Sizing
Temperature Coefficient of Resistance



MATERIAL	Temperature Coefficient of Resistance α (1/°c)
1 JR	0.000241
AISI 304	0.00092
AISI 430	0.00146

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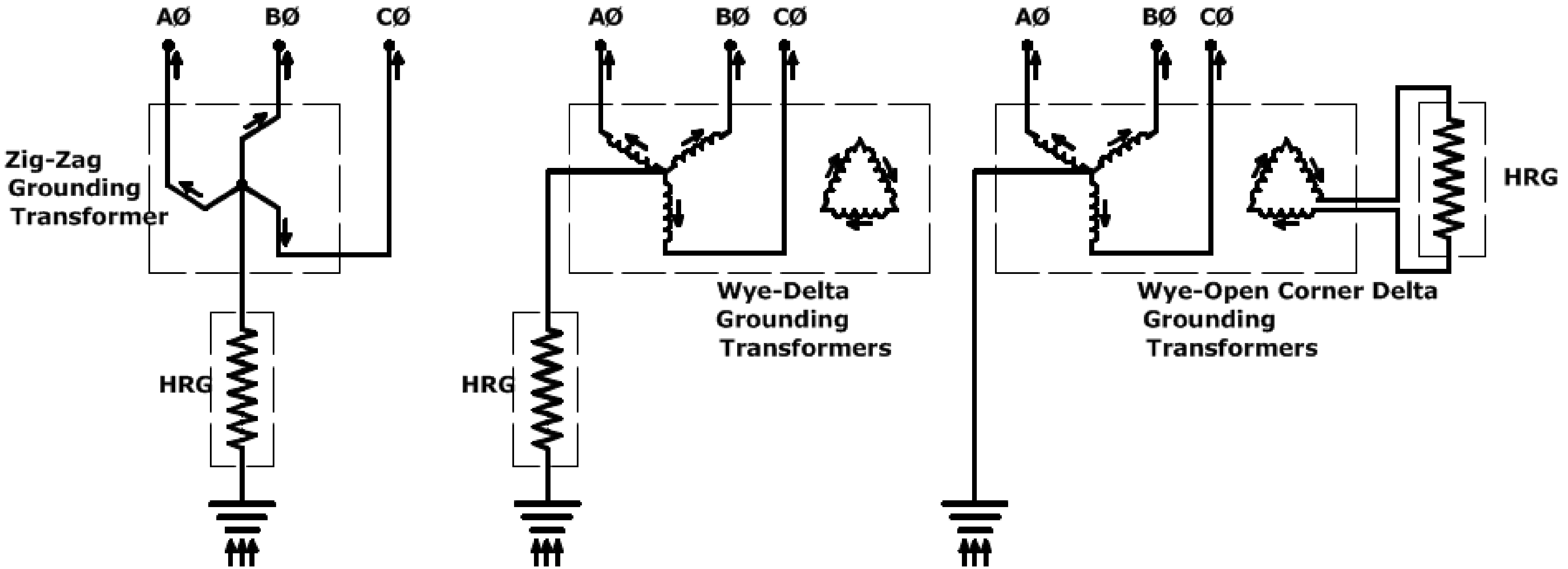
Limiting Ground Faults

3 ways

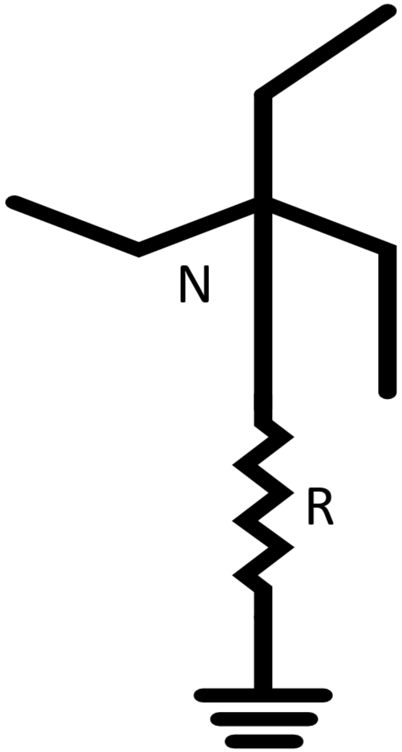


Limiting Ground Faults

Zig-Zag Transformer

$$KVA = V_{lN}\ X\ I_F$$

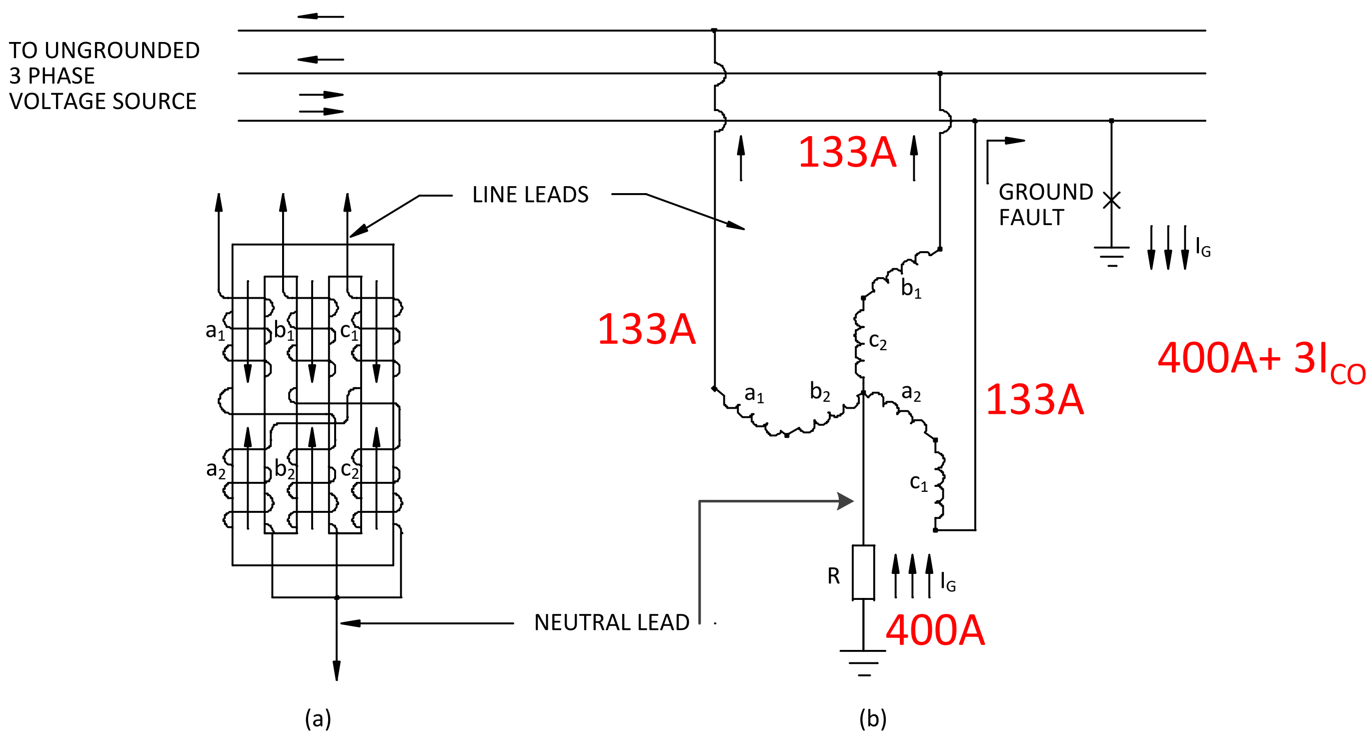
$$= \sqrt{3}\ V_{LL}\ X\ I_L$$



$$R = \frac{V_N}{I}$$

Limiting Ground Faults

Zig-Zag Transformer



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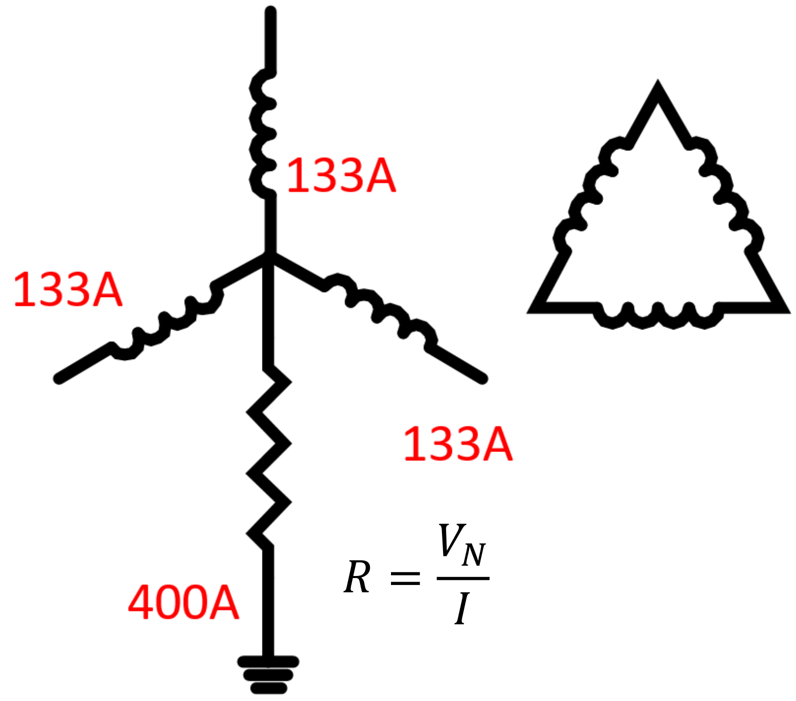
Limiting Ground Faults
Wye-Grounded / Delta



$$R = \frac{V_N}{I}$$

400A+ $3I_{CO}$

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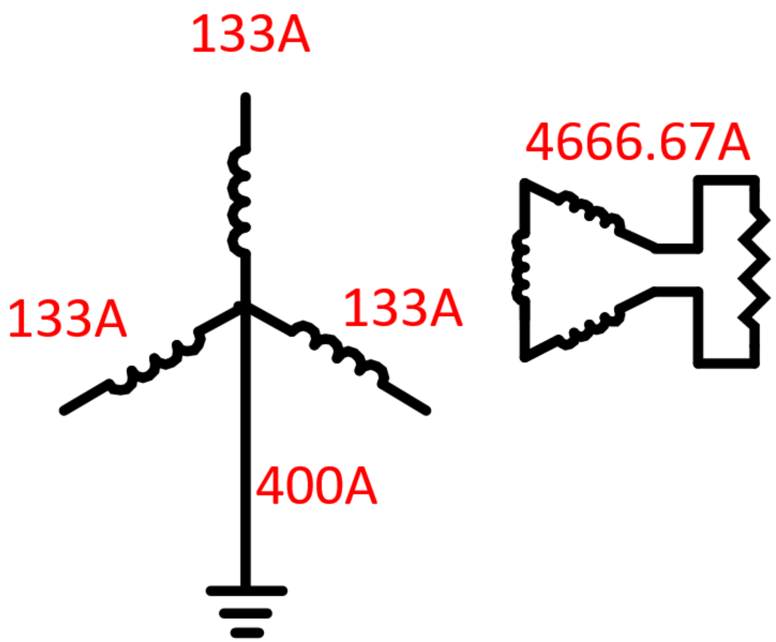
Limiting Ground Faults

Wye-Grounded / Open Corner Delta



4160 V_{LL}

Transformer ratio 4200:120

$R = \frac{V_{open\ delta}}{I_R}$ = 205/4666.67= 0.044Ω

Transformer Power=1.66 MVA

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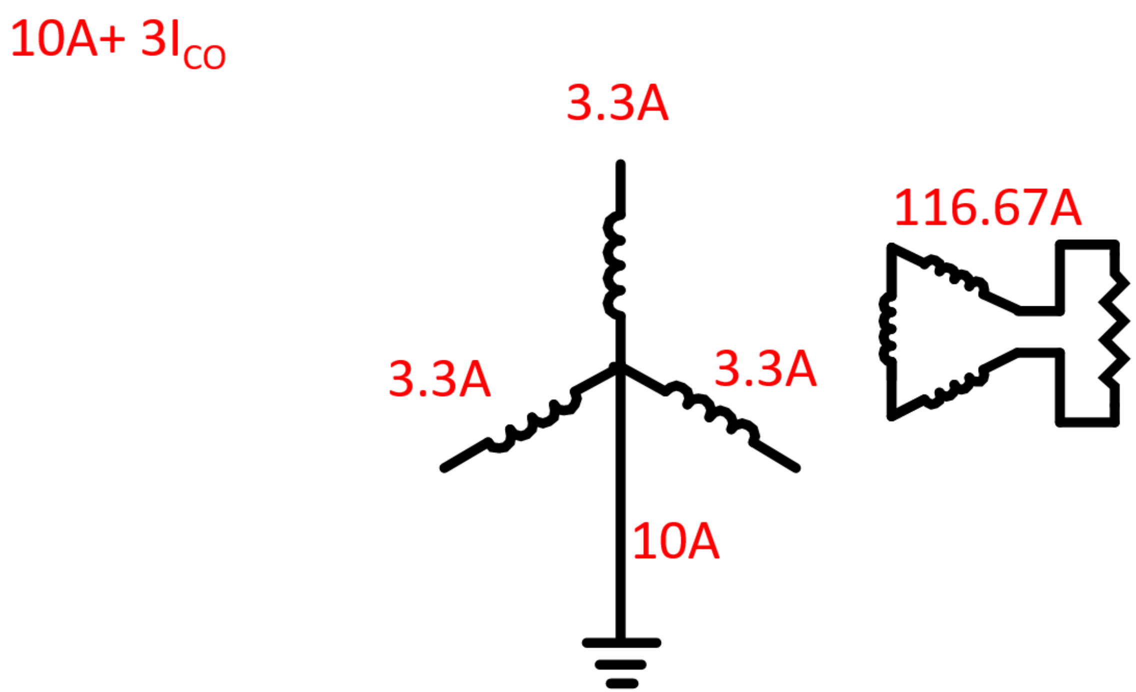
Limiting Ground Faults



4160 V_{LL}

Transformer ratio 4200:120

$R = \frac{V_{open\ delta}}{I_R}$ = 205/116.67= 1.7 Ω

Transformer Power=41.6 kVA

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Q&A session

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Thank you!!!
For attending I-Gard’s webinar series during 2021

We are looking forward to see all of you in 2022!!

If there is a specific topic that you would like to be presented during 2022
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