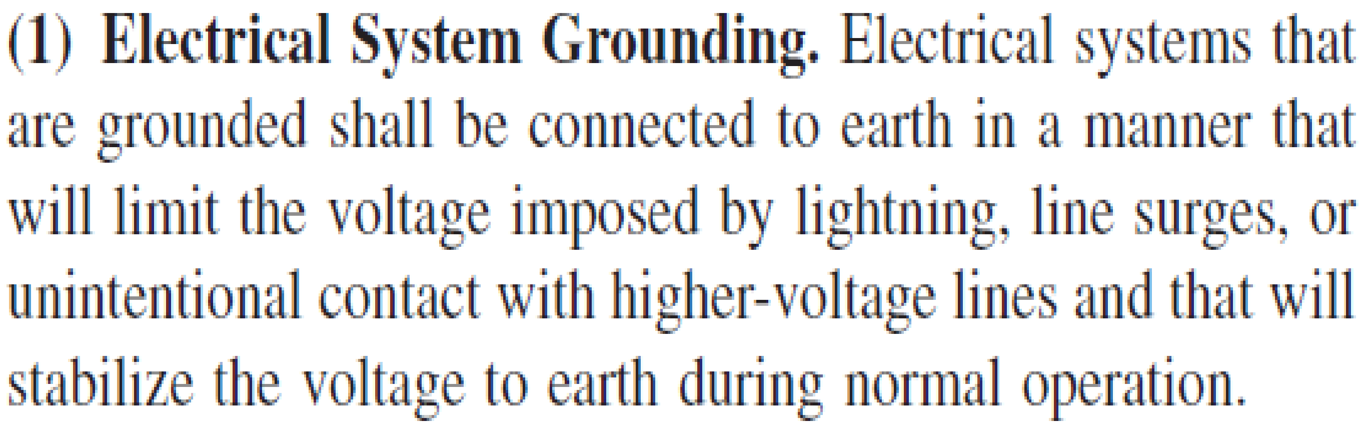
Grounding Systems

I GARD
Unparalleled Protection

Why System Ground?

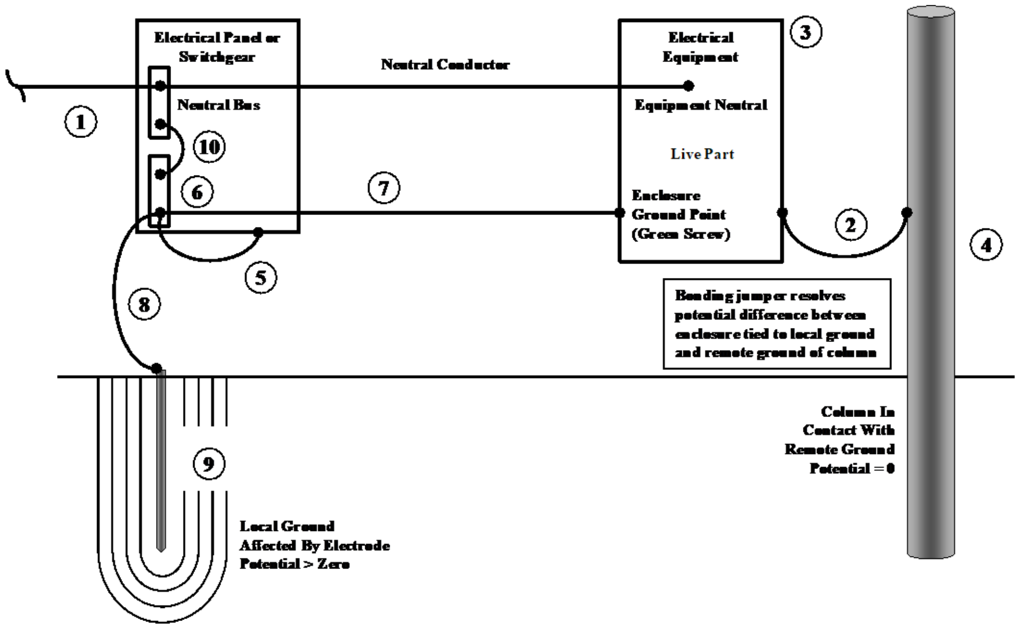
250.4 (A)



(1) **Electrical System Grounding.** Electrical systems that are grounded shall be connected to earth in a manner that will limit the voltage imposed by lightning, line surges, or unintentional contact with higher-voltage lines and that will stabilize the voltage to earth during normal operation.

iGARD

Unparalleled Protection



	NEC	IEC	CEC
1	Grounded Conductor	Protective Earth Neutral (PEN)	Grounded Conductor
2	Bonding Conductor or Jumper	Bonding Jumper	Bonding Conductor
3	Conductive Electrical Equipment Enclosure	Exposed Conductive Parts	Non-Current carrying metal parts
4	Building Steel, Metal Fence, Metal Pipe	Extraneous Conductive Part	Building Steel, Metal Fence, Metal Pipe
5	Equipment Bonding Jumper	Equipment Boning Jumper	Bonding Conductor
6	Ground Bus	Earthing Bus	Ground Bus
7	Equipment Grounding Conductor(EGC)	Protective Earth Conductor(PE)	Grounding Conductor
8	Grounding Electrode Conductor (GEC)	Earthing Electrode Conductor	Grounding Conductor
9	Grounding Electrode	Earth Electrode	Grounding Electrode
10	Main Bonding Jumper	Main Bonding Jumper	Grounding Conductor

IEC V NEC

IEC Terminology

- IT
- TN
- TT

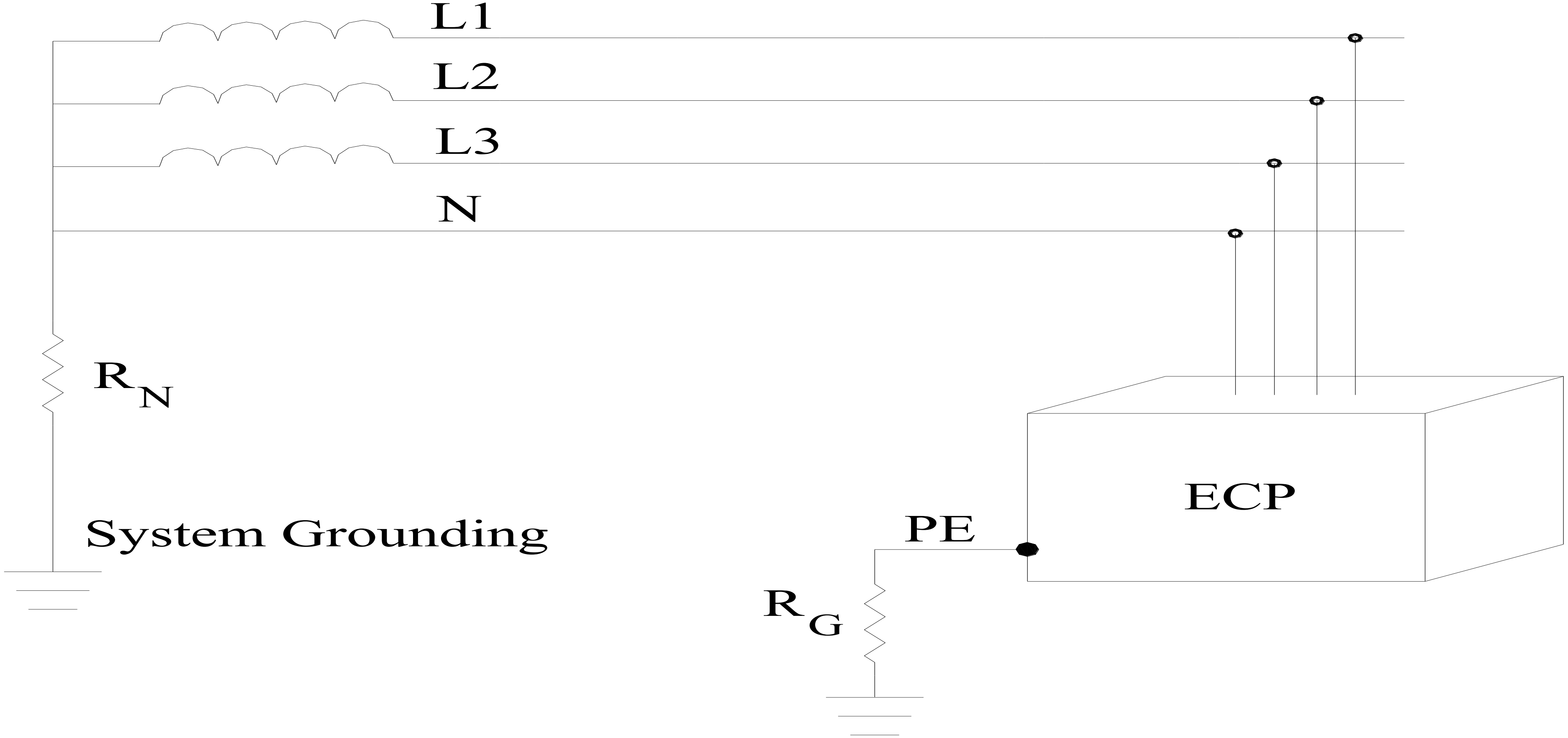
NA EC Terminology

- Ungrounded
- Solidly Grounded
- Impedance grounded
- Hybrid High Resistance grounded

I GARD

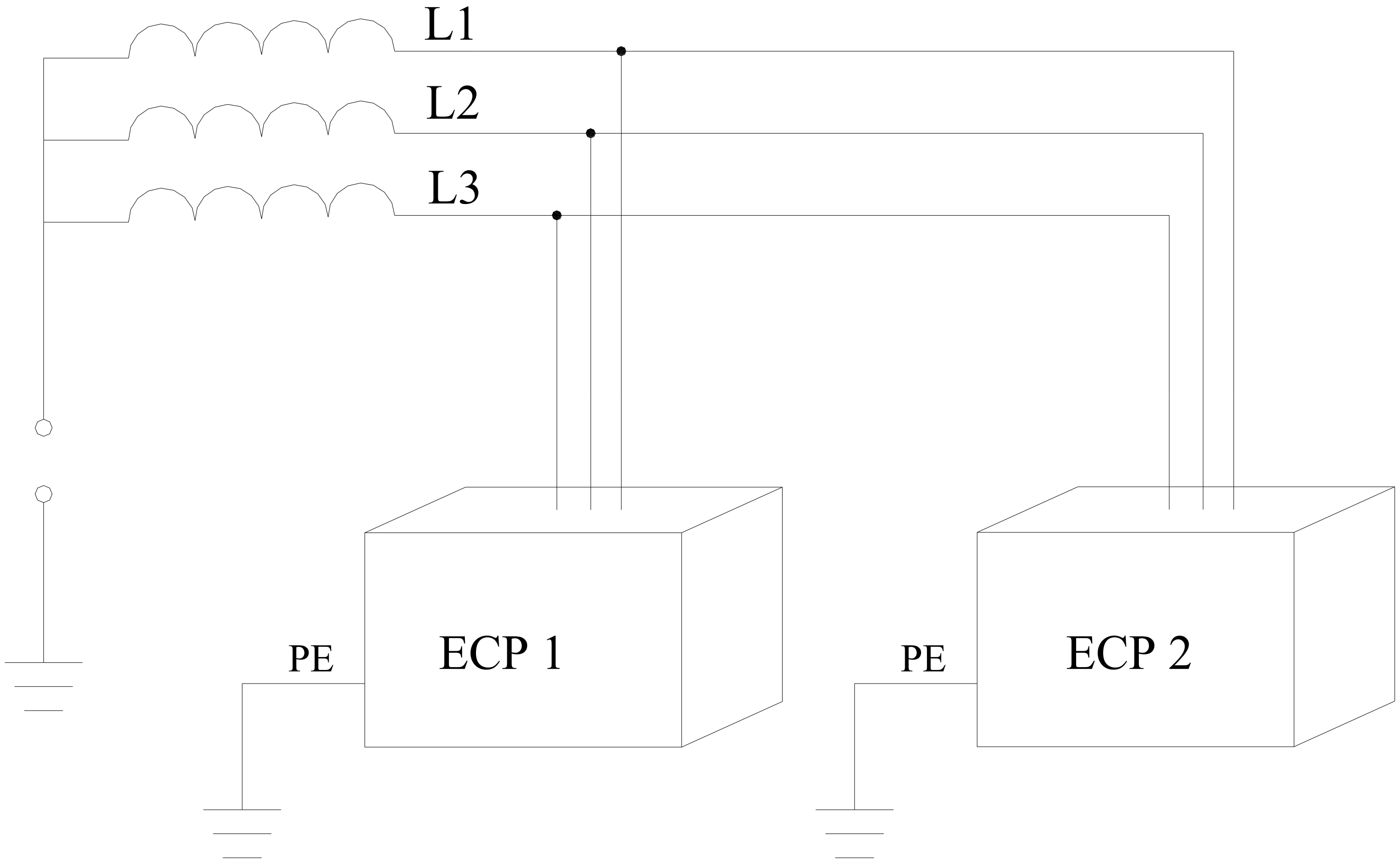
Unparalleled Protection

IEC TT System

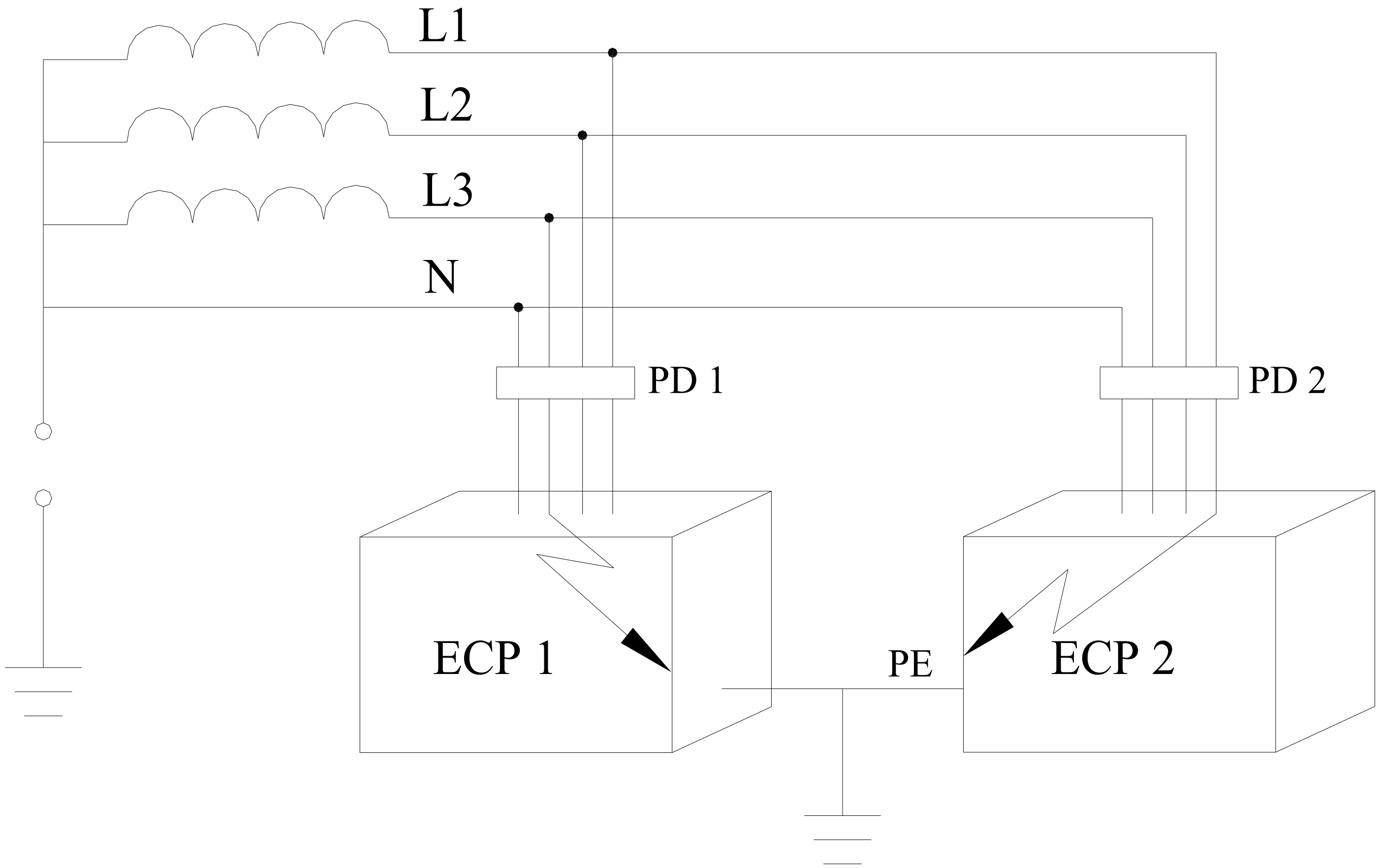


Unparalleled Protection

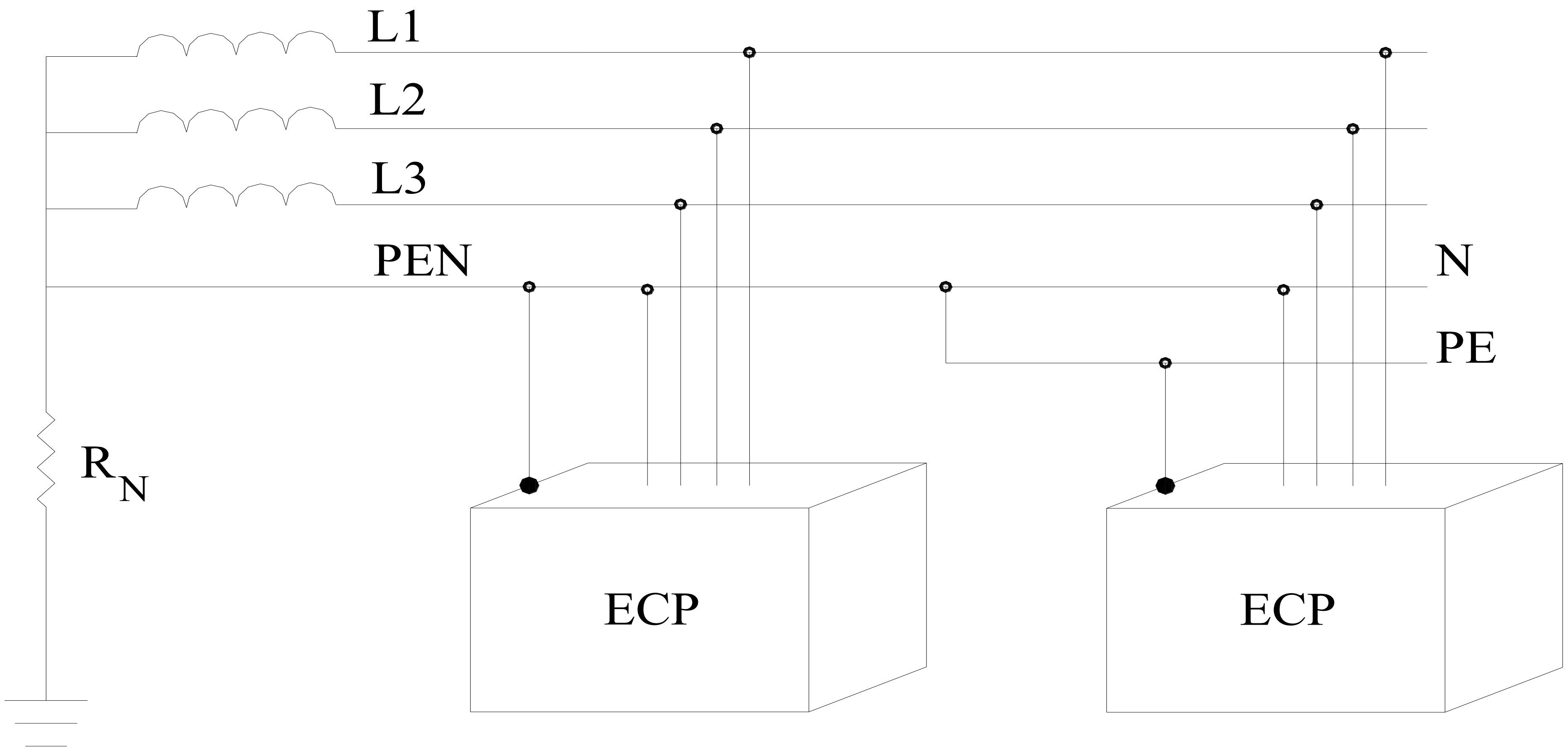
IEC IT System



IEC IT System

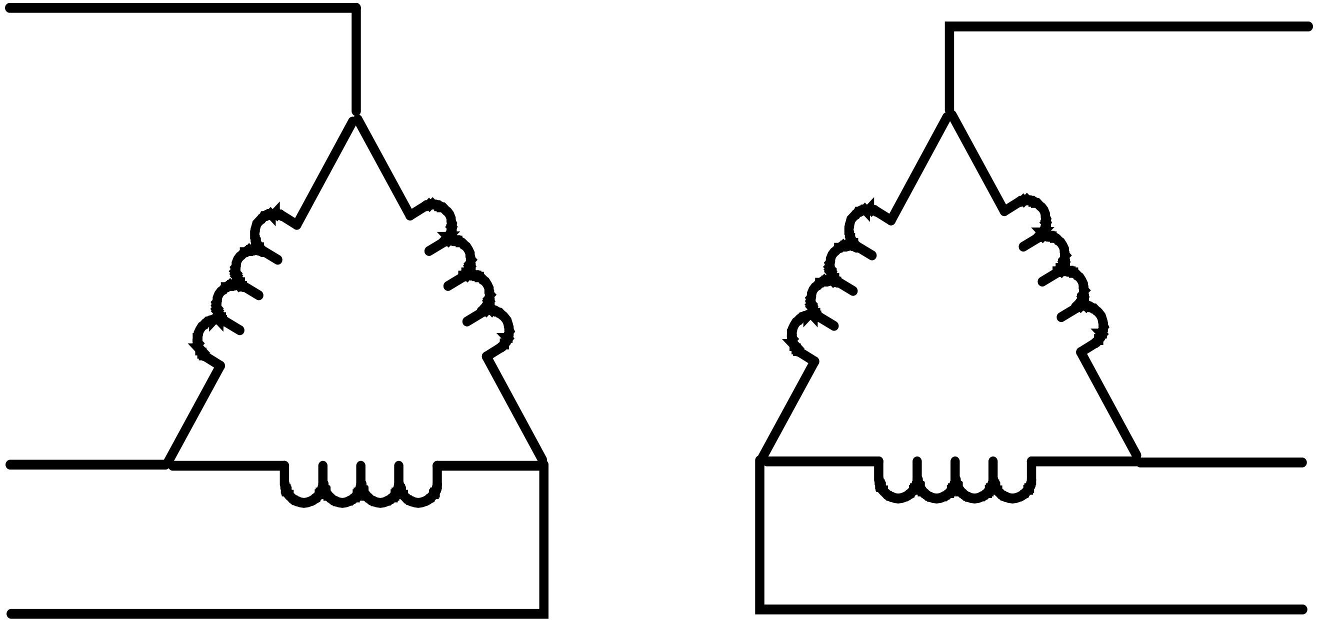


IEC TN System



Unparalleled Protection

Ungrounded System



Ungrounded System

- Ungrounded: Method used to ground first power systems
  - Very large transient over-voltage conditions may exist.
    - Insulation not rated, therefore, hazard to personnel and equipment.
  - Very difficult to locate ground fault.
    - Good chance of second ground fault on a different phase due to prolonged ground fault.

I-GARD
Unparalleled Protection

Ungrounded System

- **IEEE Std 3003.1-2019**
- Recommended Practice for System Grounding of Industrail and Commercial Power Systems

- 4.2. Various detection schemes are used to detect the presence of a single line-to-ground fault. The simplest scheme employs three light bulbs rated for line-to-line voltage, each connected between line voltage and ground. Under normal operation, the three bulbs are illuminated with low equal intensity.

Ungrounded System

- **IEEE Std 141-1993 (Red Book)**
- Recommended Practice for Electric Power Distribution for Industrial Plants

- 7.2.1 Accumulated operating experience indicates that, in general purpose industrial power distribution systems, **the over-voltage incidents associated with ungrounded operation reduce the useful life of insulation** so that electric current and machine failures occur more frequently than they do on grounded power systems.

iGARD

Unparalleled Protection

Ungrounded System

- **IEEE Std 3003.1 -2019**
  - Recommended Practice for System Grounding of Industrial and Commercial Power Systems

- 4.2. Various detection schemes are used to detect the presence of a single line-to-ground fault. The simplest scheme employs three light bulbs rated for line-to-line voltage, each connected between line voltage and ground. Under normal operation, the three bulbs are illuminated with low equal intensity.

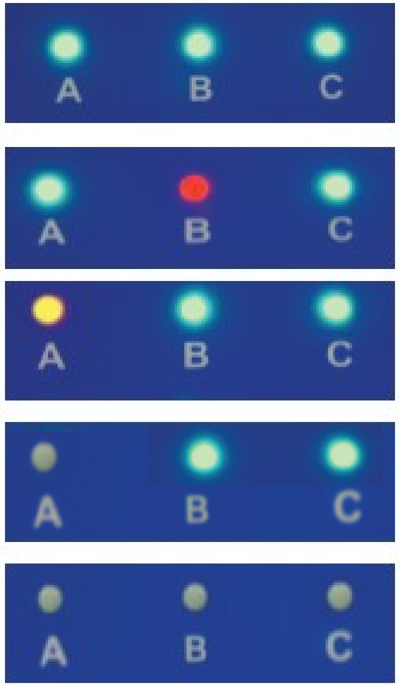
Ungrounded System

- NEC 250.21 (B) **Ground Detectors.** Ground detectors shall be installed in accordance with 250.21(B)(1) and (B)(2).
- (1) Ungrounded ac systems as permitted in 250.21(A)(1) through (A)(4) operating at not less than 120 volts and at 1000 volts or less shall have ground detectors installed on the system.
- (2) The ground detection sensing equipment shall be connected as close as practicable to where the system receives its supply.

Unparalleled Protection

I-Gard VIA

Other Voltage Indicators



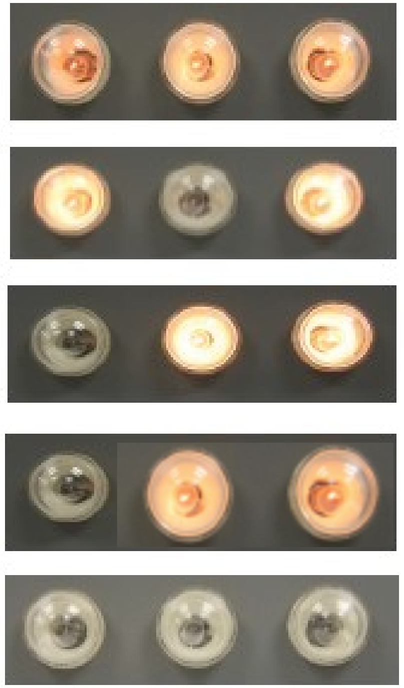
Healthy

Ground Fault

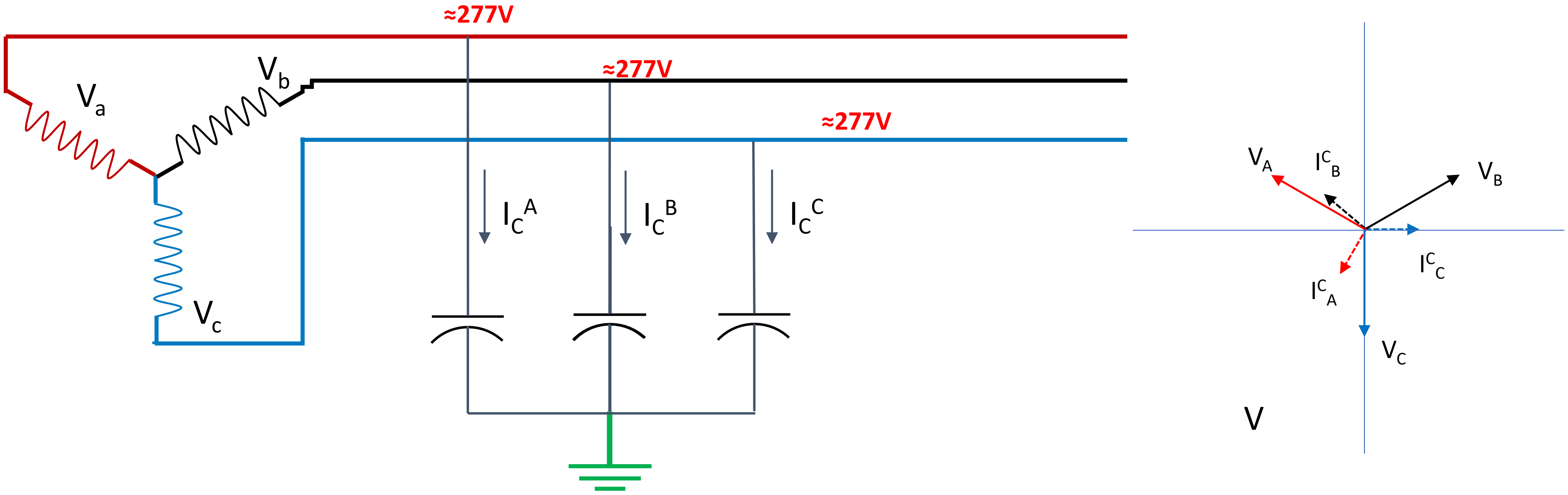
Partial Ground Fault

Bulb blown

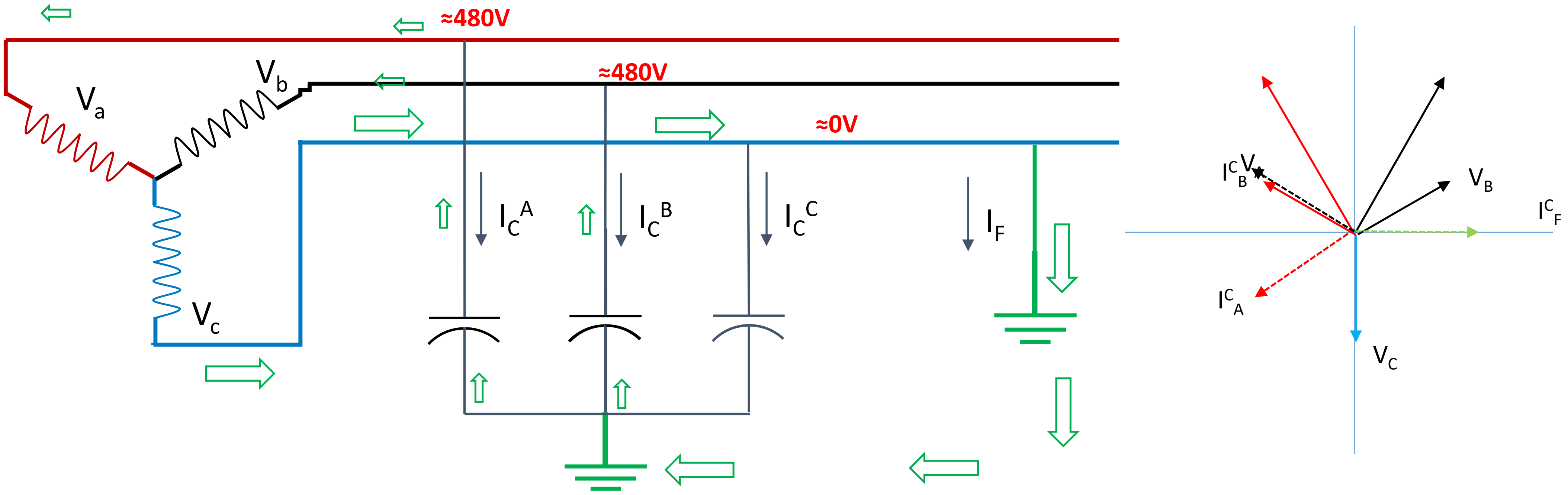
More than one fuse is blown



Ungrounded System



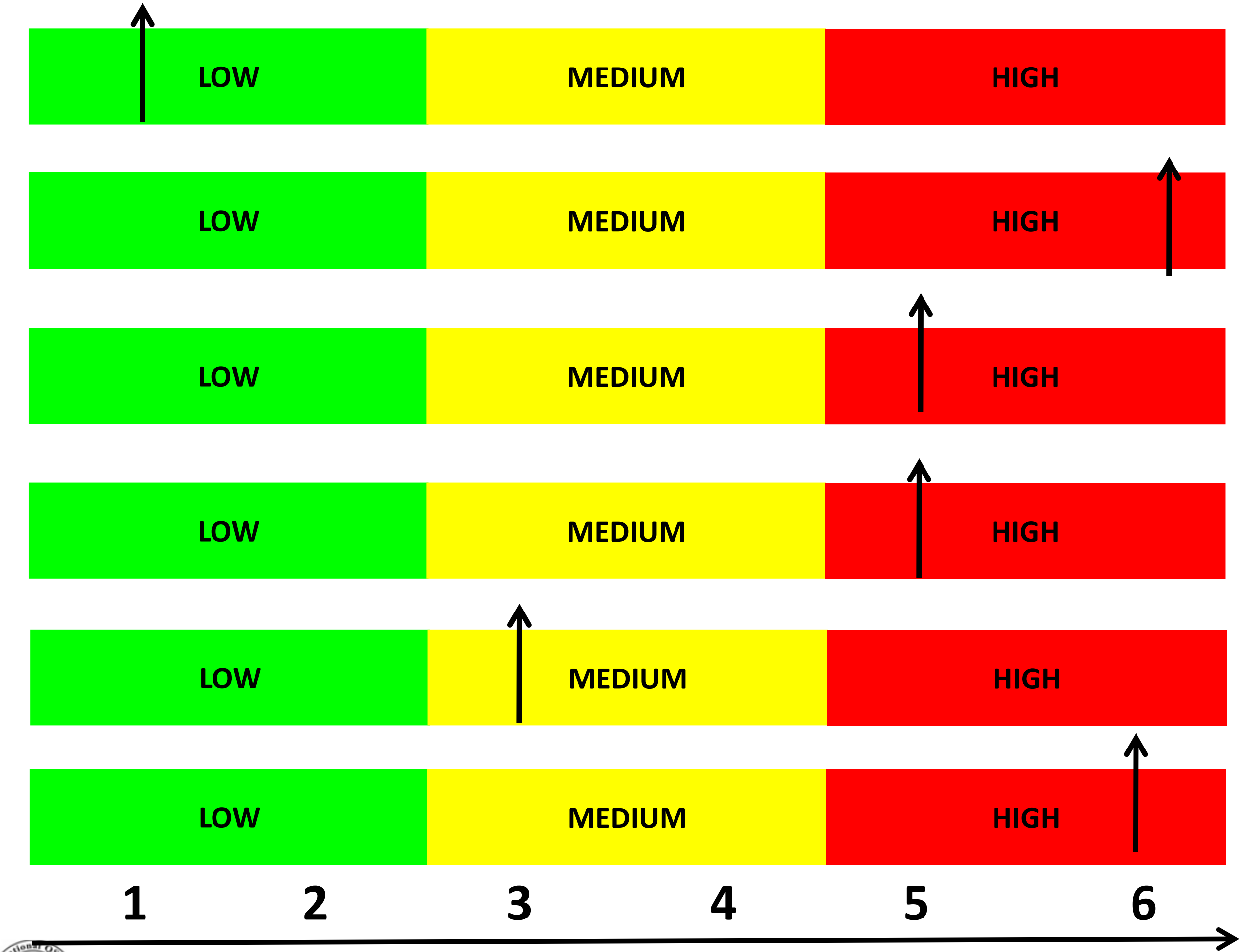
Ungrounded System



GARD

Unparalleled Protection

Ungrounded System



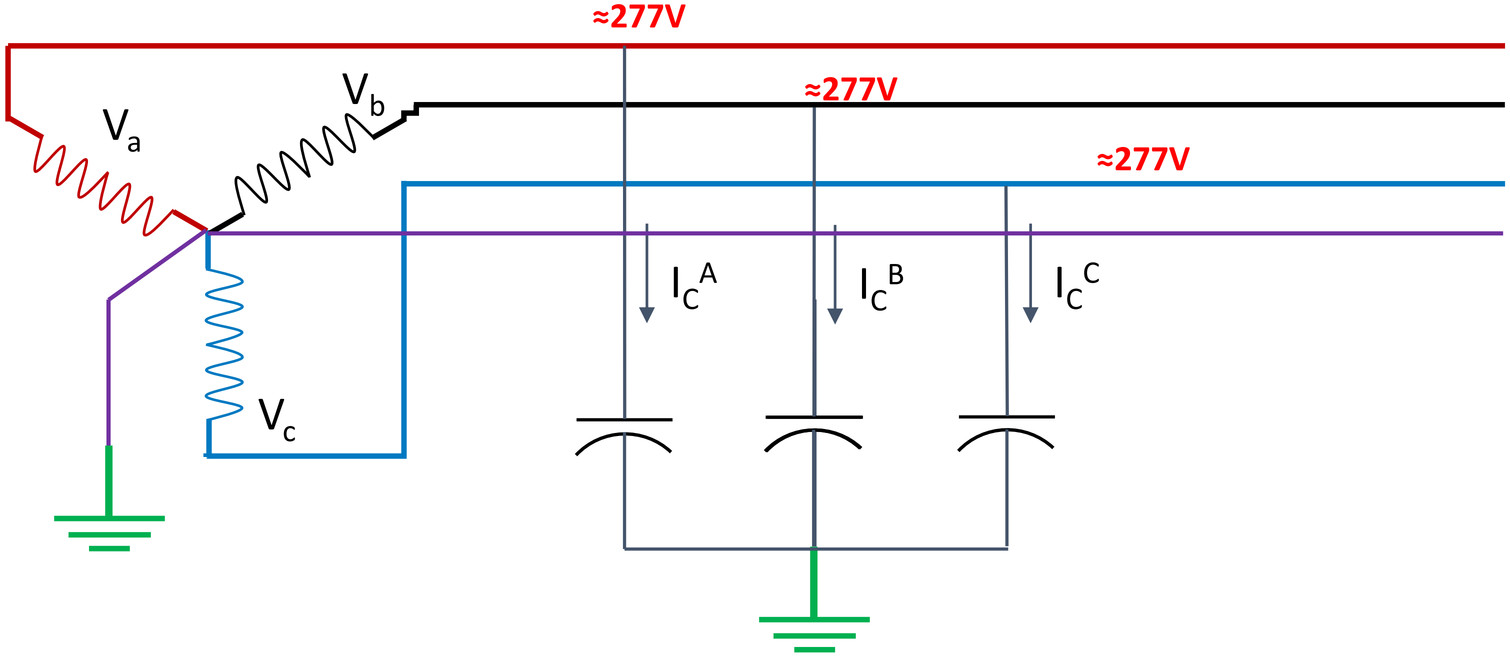
1	**Unscheduled Process Interruptions on first ground fault. Typically $7,000 to $30,000 per hour**
6	**Unable to locate the first ground fault in a timely manner**
5	**Loss of Critical Process due to power interruption (second ground fault)**
5	**Capital Equipment Damage – NFPA Average $45,000.**
3	**Arc Flash Hazard – frequency / probability**
6	**Arc Flash Hazard – magnitude of destructive arc**
26	

Solidly Grounded

- **IEEE Std 3003.1 -2019**
  - Recommended Practice for System Grounding of Industrail and Commercial Power Systems

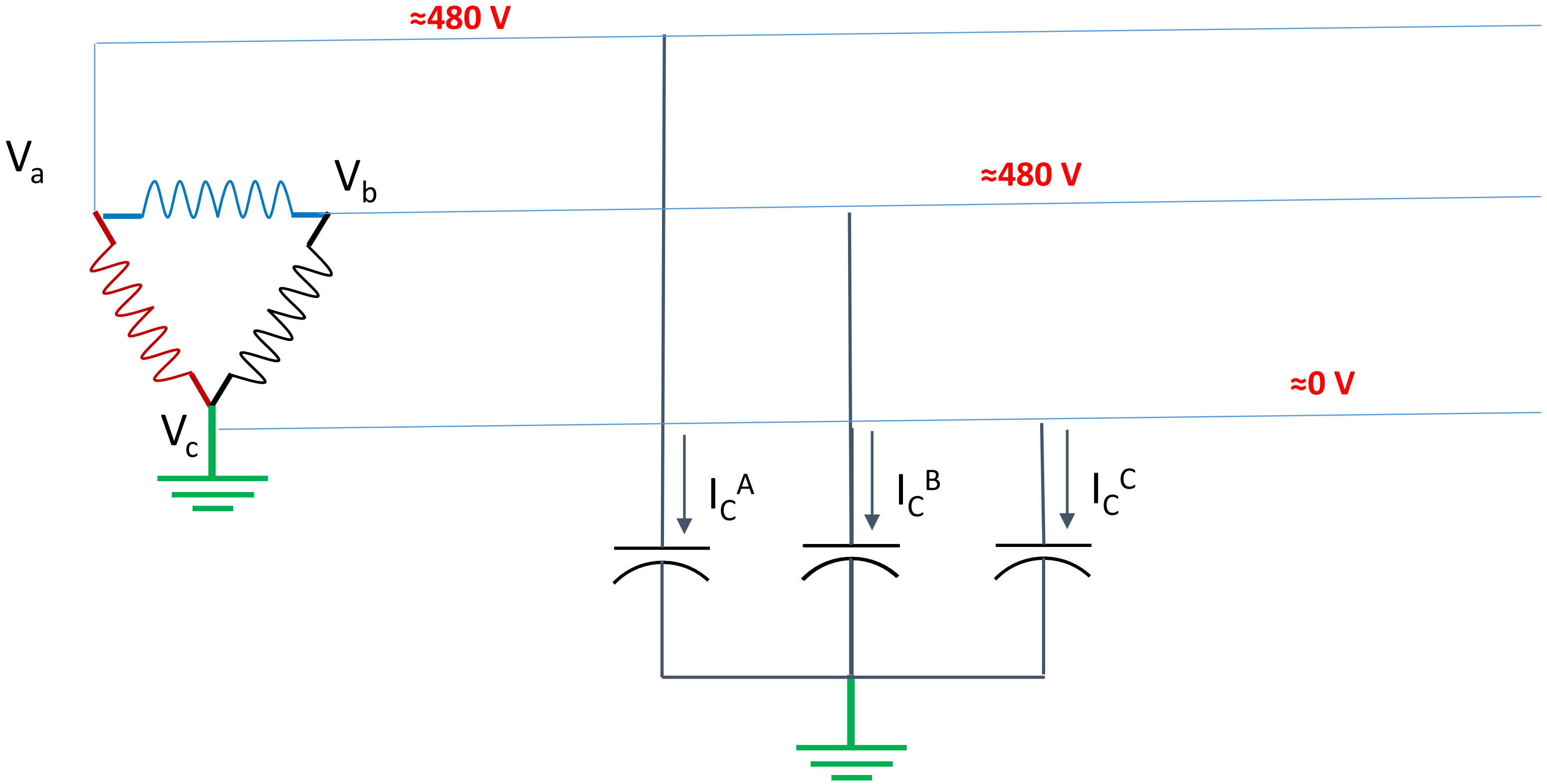
- 4.6. Solid grounding refers to the connection of a system conductor, usually the neutral of a generator, power transformer, or grounding transformer directly to ground, without any intentional intervening impedance. Two examples of solidly grounded systems are shown in Figure 20. Acknowledging the impedance of the source and the unintentional impedance in the connection to ground leads to reference of these systems as effectively grounded.

Solidly Grounded



I GARD

Unparalleled Protection

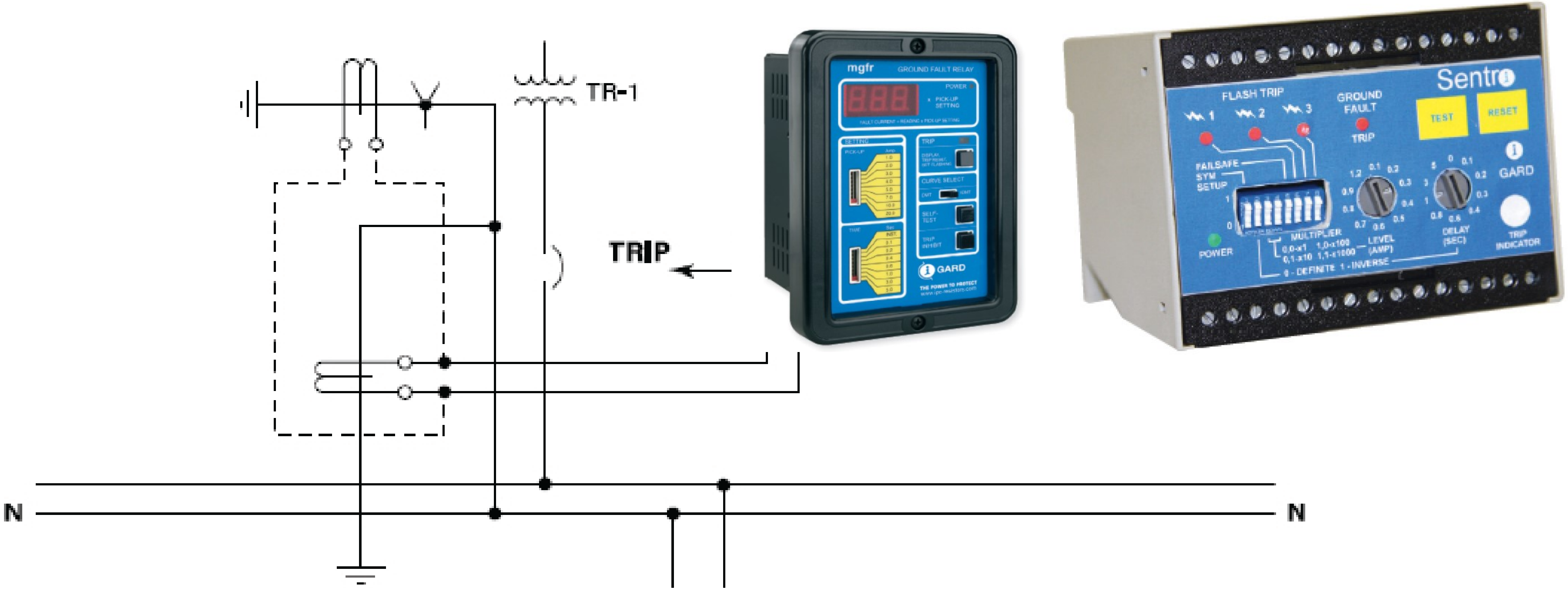


Solidly Grounded

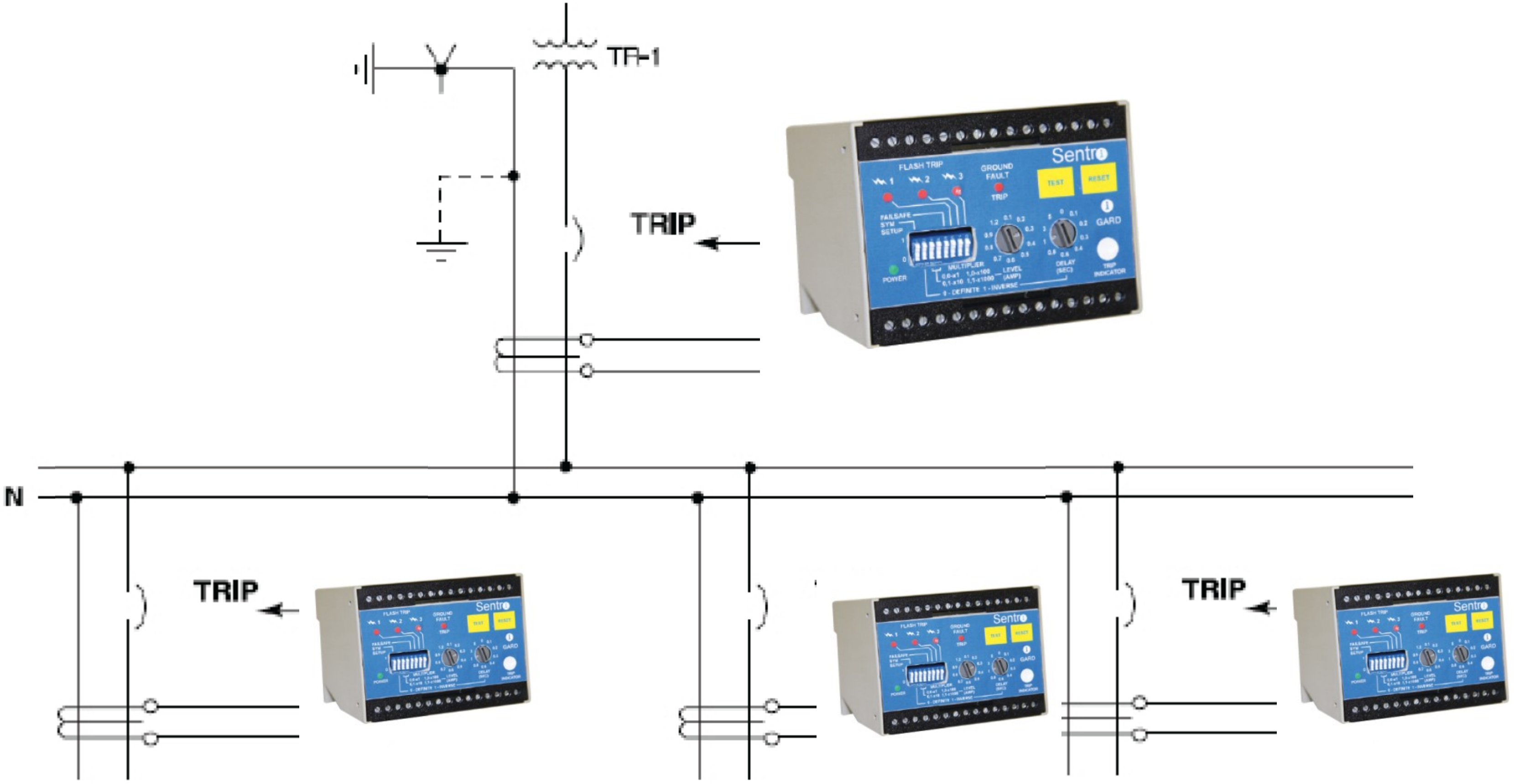
- **230.95 Ground-Fault Protection of Equipment.**
  - Ground-fault protection of equipment shall be provided for solidly grounded wye electric services of more than 150 volts to ground but not exceeding 1000 volts phase-to-phase for each service disconnect rated 1000 amperes or more. The grounded conductor for the solidly grounded wye system shall be connected directly to ground through a grounding electrode system, as specified in 250.50, 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.

Unparalleled Protection

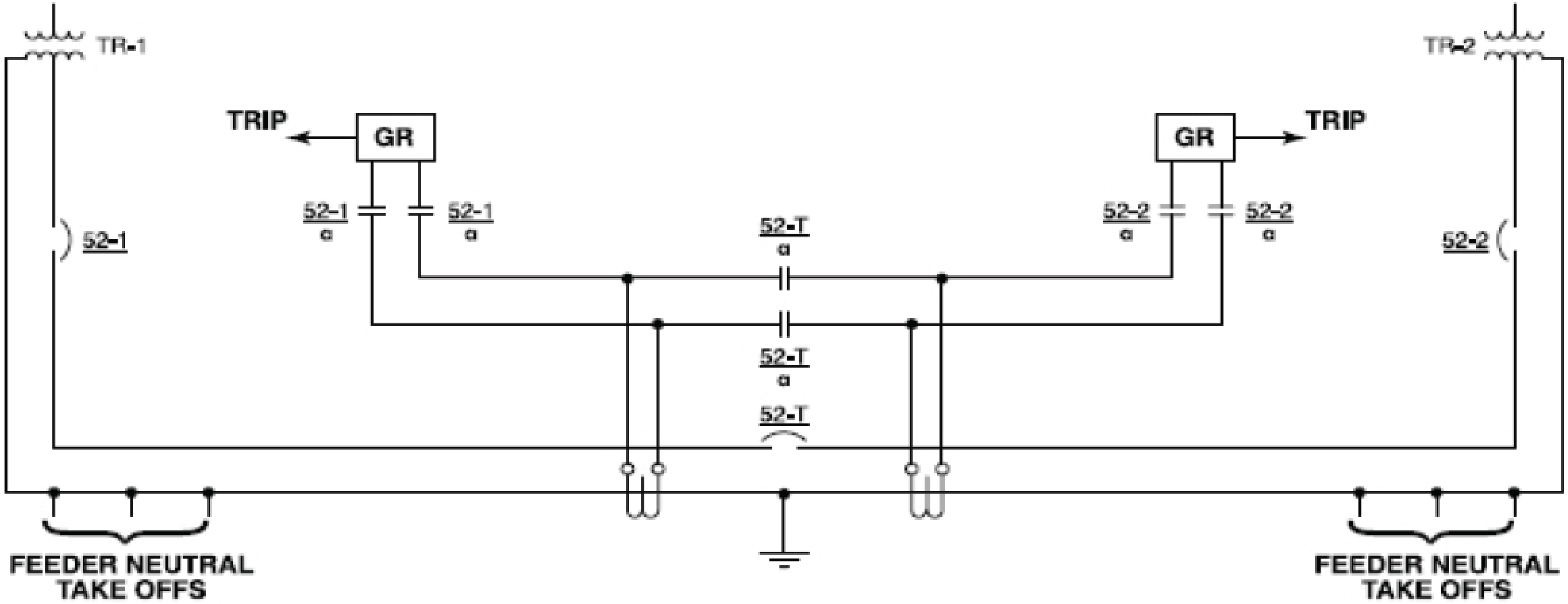
Solidly Grounded



Solidly Grounded

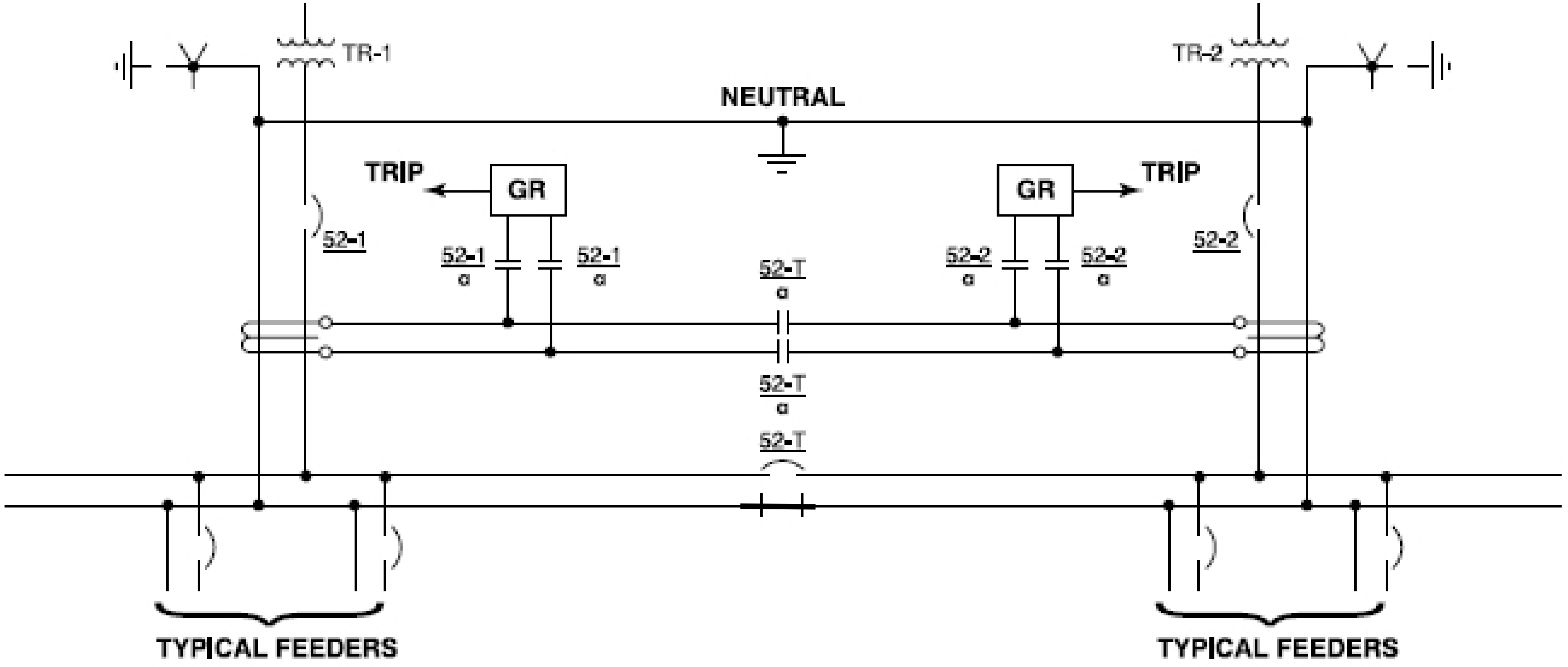


Solidly Grounded



Unparalleled Protection

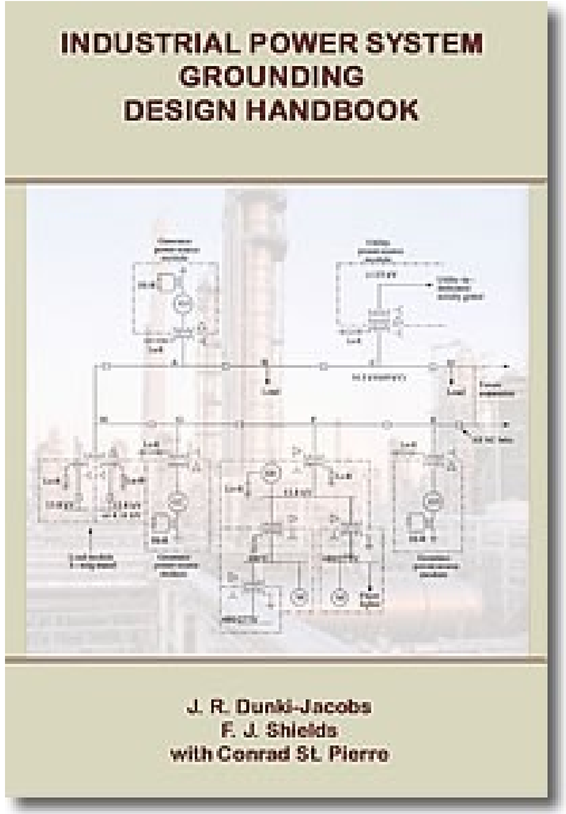
Solidly Grounded



Solidly Grounded

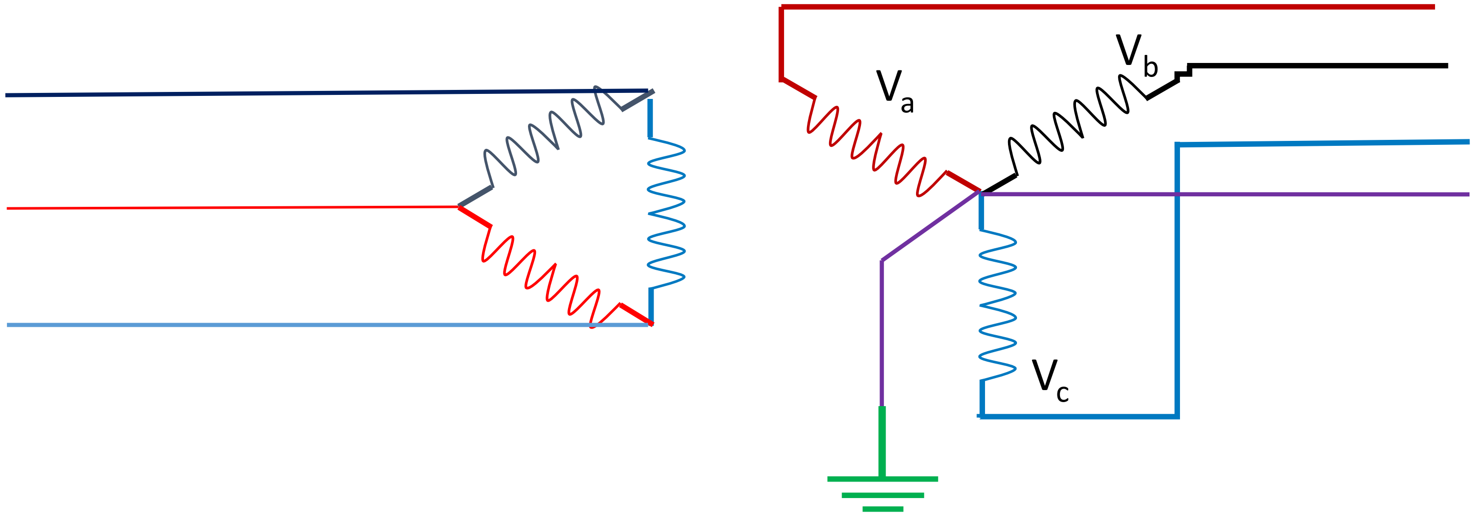
According to Industrial Power System Grounding Design Handbook - 95% of all electrical faults are phase to ground faults.

Solidly grounded systems are most susceptible to arc flash incidences



INDUSTRIAL POWER SYSTEM
GROUNDING
DESIGN HANDBOOK

J. R. Dunki-Jacobs
F. J. Shields
with Conrad St. Pierre



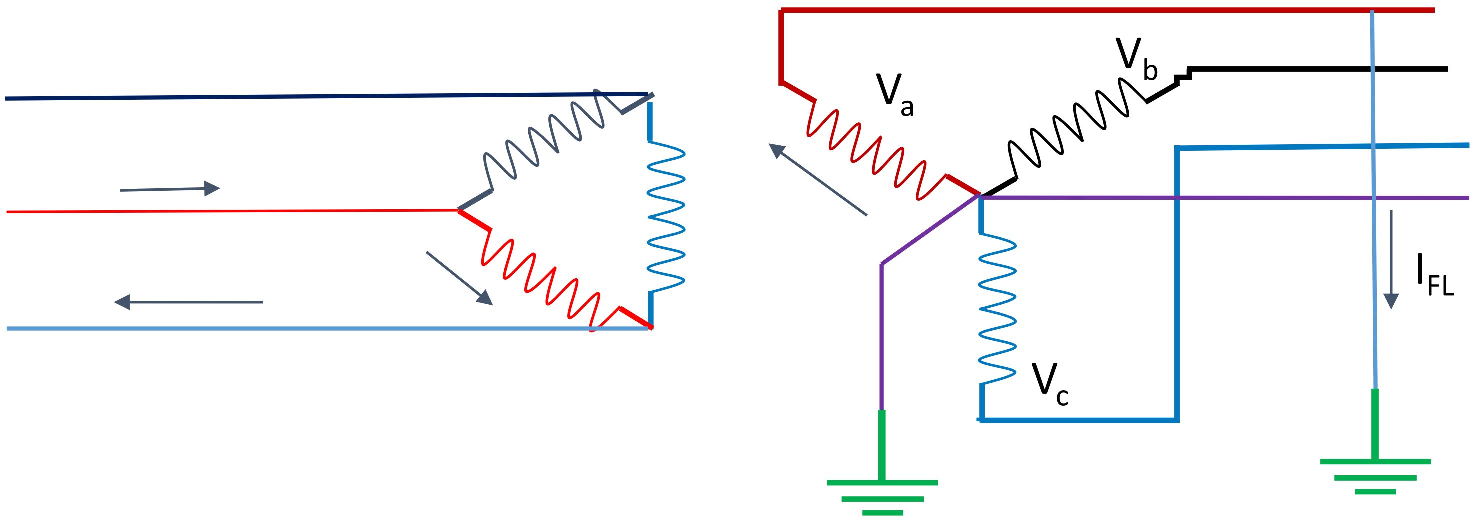
2500 kVA 13.8kV Primary/
480 V secondary

$$I_{FL} = \frac{2500}{(\sqrt{3})*.48}=3007\text{ A}$$

GARD

Unparalleled Protection

Solidly Grounded



2500 kVA 13.8kV Primary/
480 V secondary

5% Z

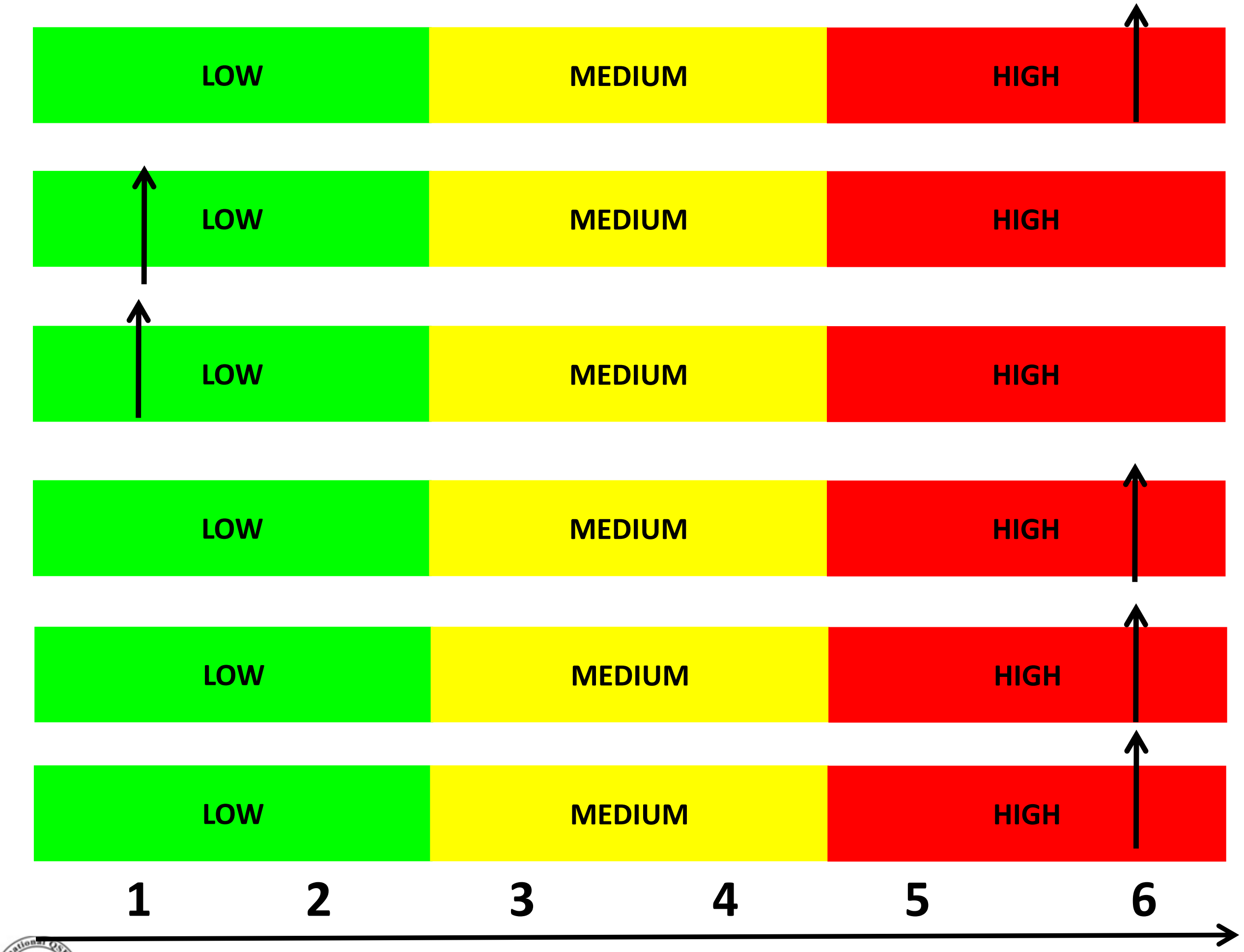
$I_{FL} = \frac{1}{.05+0.02}$=14.29

I_{FL} =14.29*3007= 43kA

$I_{PRI} = 43 * \frac{480}{(\sqrt{3})*13800}$=863 A

I_{FL} =43 *480/= 43kA

Solidly Grounded

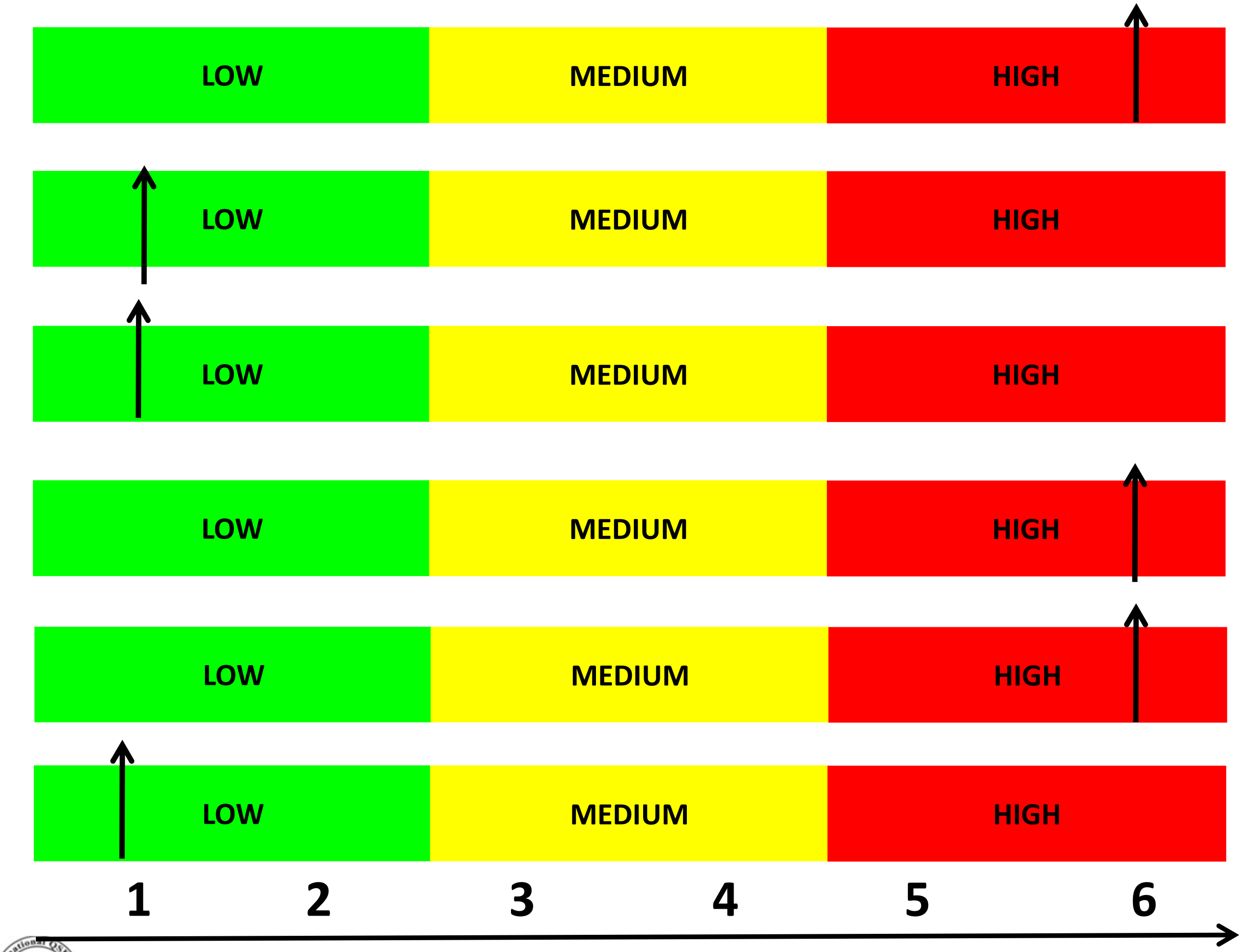


6	**Unscheduled Process Interruptions on first ground fault. Typically $7,000 to $30,000 per hour**
1	**Unable to locate the first ground fault in a timely manner**
1	**Loss of Critical Process due to power interruption (second ground fault)**
6	**Capital Equipment Damage – NFPA Average $45,000.**
6	**Arc Flash Hazard – frequency / probability**
6	**Arc Flash Hazard – magnitude of destructive arc**
26	

GARD

Unparalleled Protection

Solidly Grounded/ w mitigation



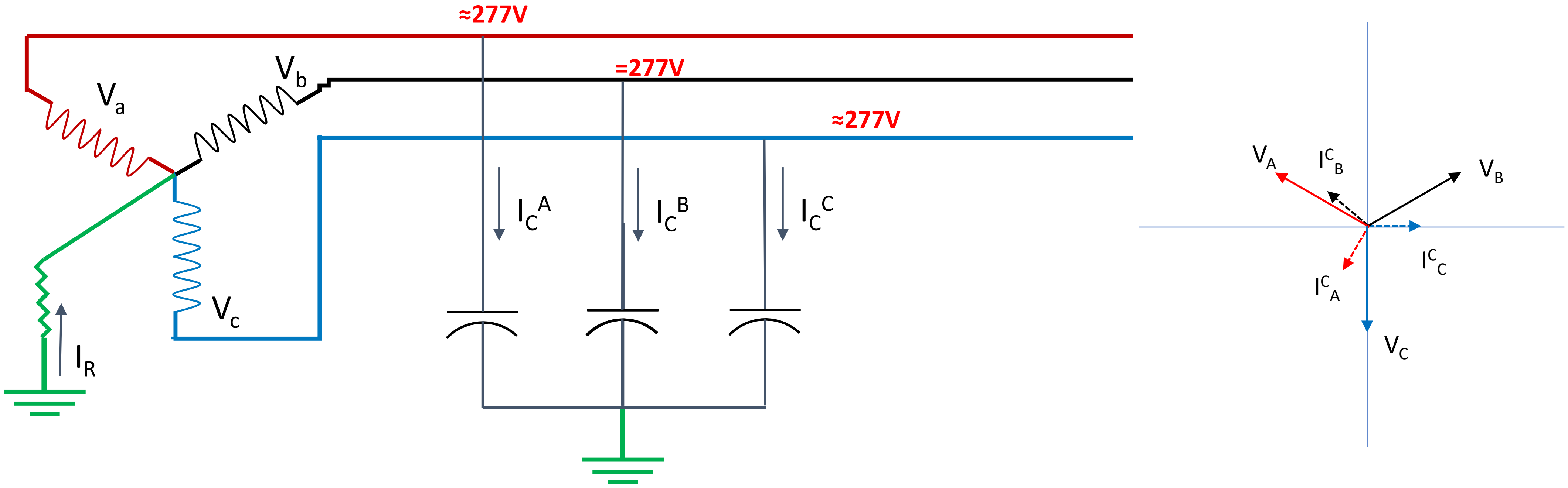
6	**Unscheduled Process Interruptions on first ground fault. Typically $7,000 to $30,000 per hour**
1	**Unable to locate the first ground fault in a timely manner**
1	**Loss of Critical Process due to power interruption (second ground fault)**
6	**Capital Equipment Damage – NFPA Average $45,000.**
6	**Arc Flash Hazard – frequency / probability**
1	**Arc Flash Hazard – magnitude of destructive arc**
21	

Resistance Grounded

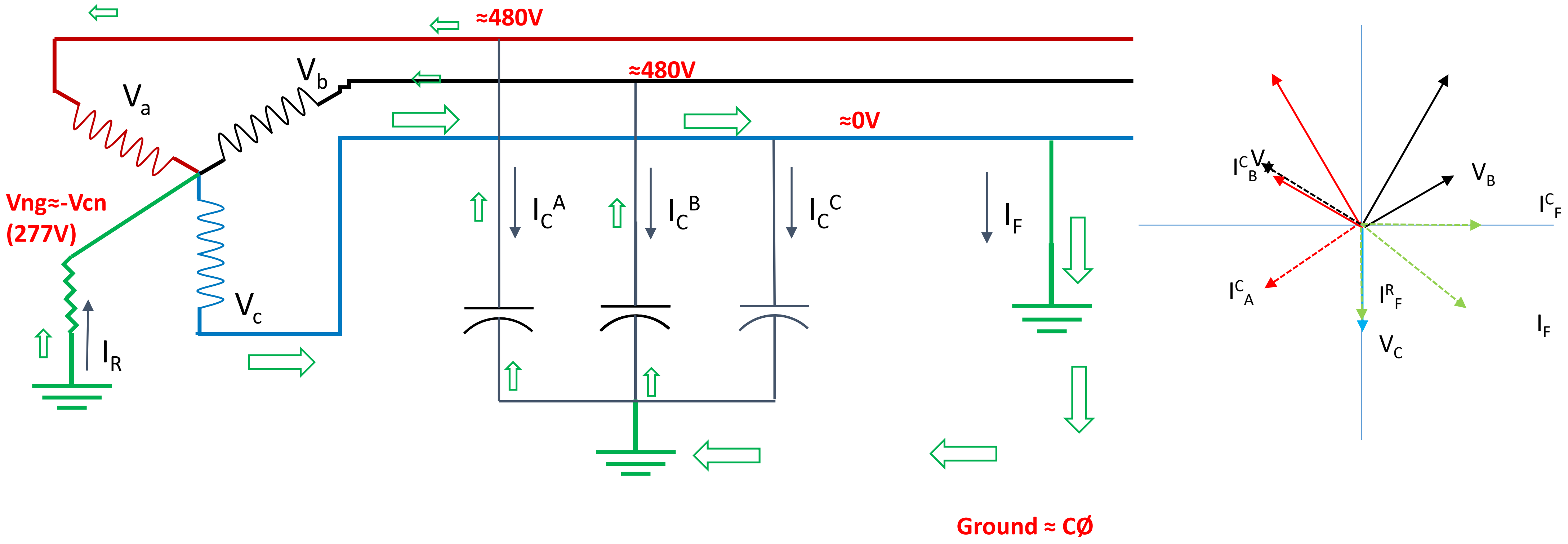
- **IEEE Std 3003.1 -2019**
  - Recommended Practice for System Grounding of Industrail and Commercial Power Systems

- 4.3. In a resistance-grounded system, the neutral of the transformer or generator is connected to ground through a resistor. A typical resistance-grounded neutral system is shown in Figure 11. As commonly installed, the resistance has a considerably higher ohmic magnitude than the system reactance at the resistor location. Consequently, the line-to-ground-fault current is primarily limited by the resistor itself.

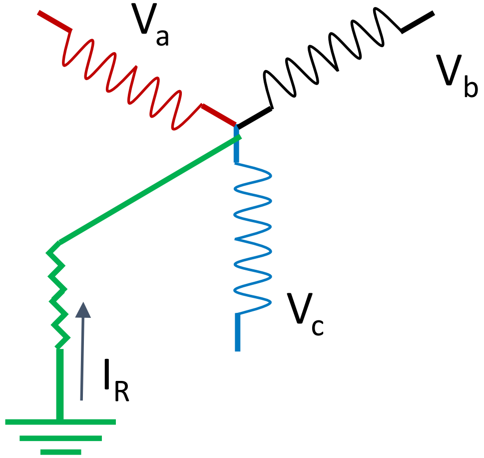
Resistance Grounded



Resistance Grounded



Resistance Grounded



Voltage (v)	Charging current (A)	NGR (OHMS)	HRG/LRG
480	2	55	HRG
4160	15	160	HRG
4160	25	6	LRG

Resistance Grounded

- NEC 250.36 **High-Impedance Grounded Neutral Systems.**
- Highimpedance grounded neutral systems in which a grounding impedance, usually a resistor, limits the ground-fault current to a low value shall be permitted for 3-phase ac systems of 480 volts to 1000 volts if all the following conditions are met:
- (1) The conditions of maintenance and supervision ensure that only qualified persons service the installation.
- (2) Ground detectors are installed on the system.
- (3) Line-to-neutral loads are not served.

Resistance Grounded

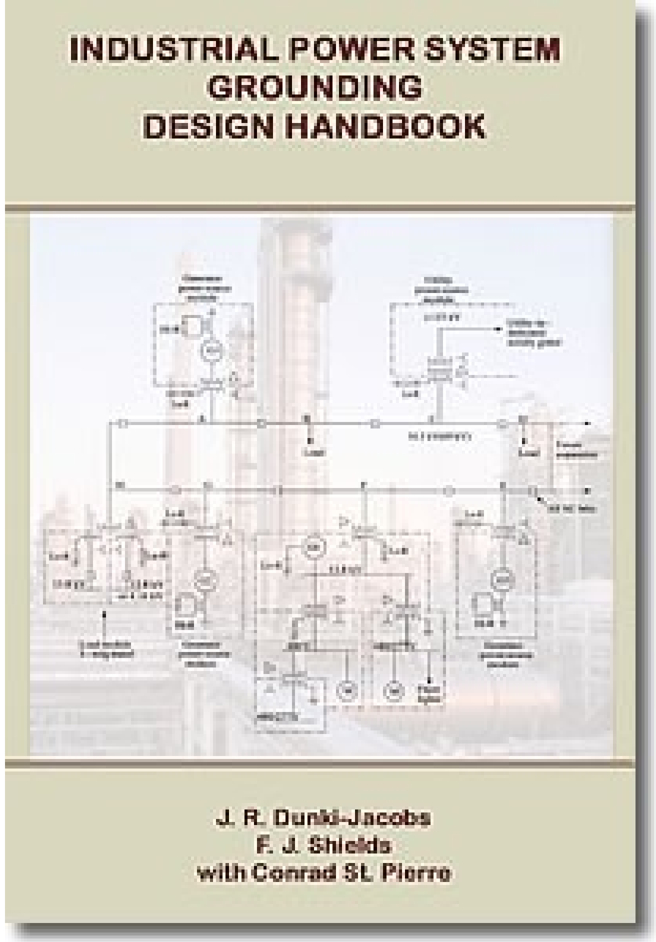
- NEC 250.186 **Impedance Grounded Neutral Systems.**
- Impedance grounded neutral systems in which a grounding impedance, usually a resistor, limits the ground-fault current shall be permitted where all of the following conditions are met:
- (1) The conditions of maintenance and supervision ensure that only qualified persons service the installation.
- (2) Ground detectors are installed on the system.
- (3) Line-to-neutral loads are not served.

Resistance Grounded

How Does HRG reduce Arc Flash?

95% of all electrical faults are phase to ground faults.

By limiting the fault current to a low level, 10 amps or less, there is insufficient current for the arc to re-strike and it self-extinguishes.

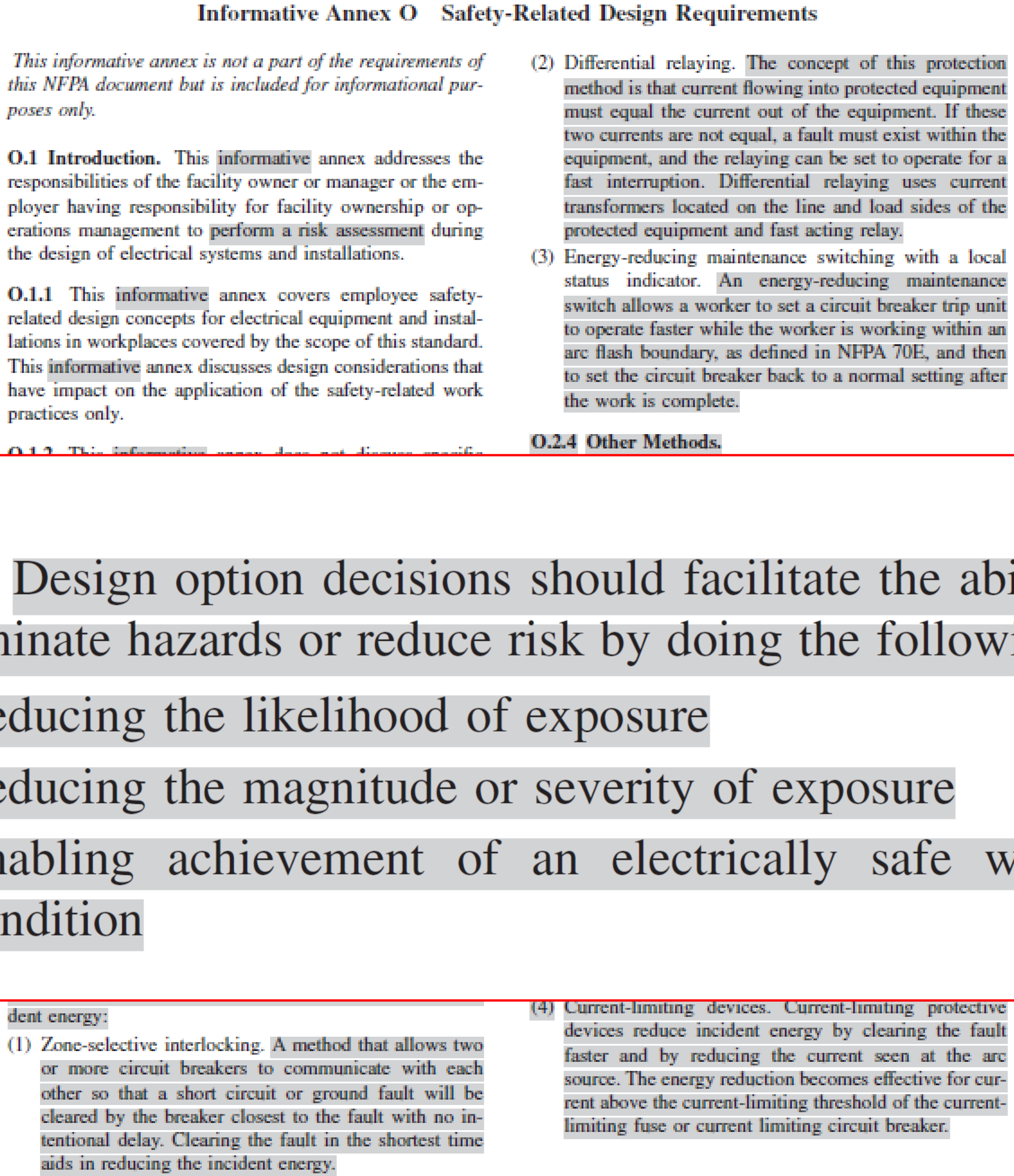


INDUSTRIAL POWER SYSTEM
GROUNDING
DESIGN HANDBOOK

J. R. Dunki-Jacobs
F. J. Shields
with Conrad St. Pierre

GARD

Unparalleled Protection



Informative Annex O Safety-Related Design Requirements

This informative annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

O.1 Introduction. This informative annex addresses the responsibilities of the facility owner or manager or the employer having responsibility for facility ownership or operations management to perform a risk assessment during the design of electrical systems and installations.

O.1.1 This informative annex covers employee safety-related design concepts for electrical equipment and installations in workplaces covered by the scope of this standard. This informative annex discusses design considerations that have impact on the application of the safety-related work practices only.

O.1.2 This informative annex does not discuss specific

dent energy:

(1) Zone-selective interlocking. A method that allows two or more circuit breakers to communicate with each other so that a short circuit or ground fault will be cleared by the breaker closest to the fault with no intentional delay. Clearing the fault in the shortest time aids in reducing the incident energy.

(2) Differential relaying. The concept of this protection method is that current flowing into protected equipment must equal the current out of the equipment. If these two currents are not equal, a fault must exist within the equipment, and the relaying can be set to operate for a fast interruption. Differential relaying uses current transformers located on the line and load sides of the protected equipment and fast acting relay.

(3) Energy-reducing maintenance switching with a local status indicator. An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to operate faster while the worker is working within an arc flash boundary, as defined in NFPA 70E, and then to set the circuit breaker back to a normal setting after the work is complete.

O.2.4 Other Methods.

(4) Current-limiting devices. Current-limiting protective devices reduce incident energy by clearing the fault faster and by reducing the current seen at the arc source. The energy reduction becomes effective for current above the current-limiting threshold of the current-limiting fuse or current limiting circuit breaker.

O.2.2 Design option decisions should facilitate the ability to eliminate hazards or reduce risk by doing the following:

(1) Reducing the likelihood of exposure

(2) Reducing the magnitude or severity of exposure

(3) Enabling achievement of an electrically safe work condition

NFPA 70E®

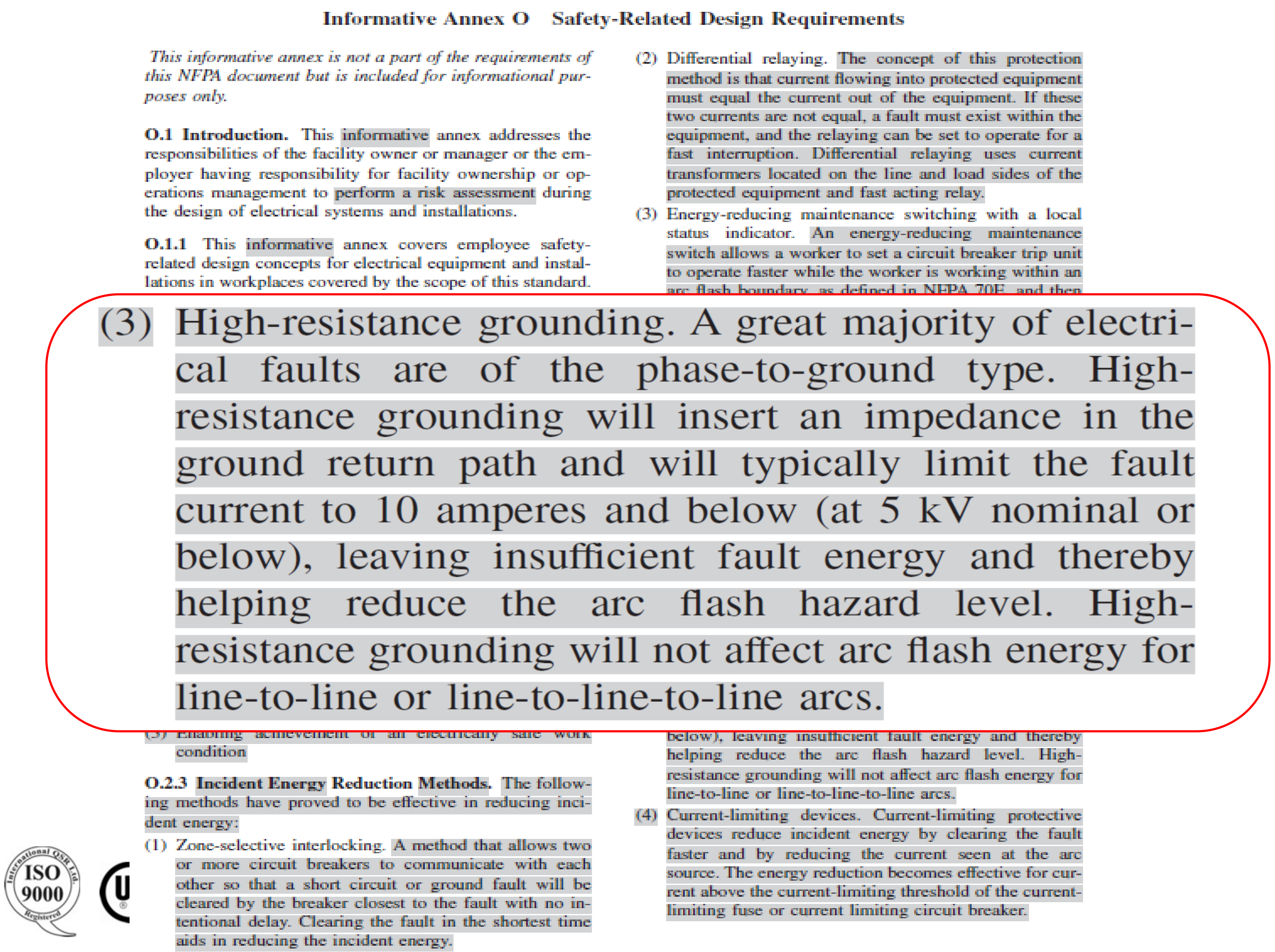
Standard for Electrical Safety in the Workplace®

2018

GARD

Unparalleled Protection

Resistance Grounded



Informative Annex O Safety-Related Design Requirements

This informative annex is not a part of the requirements of this NFPA document but is included for informational purposes only.

O.1 Introduction. This informative annex addresses the responsibilities of the facility owner or manager or the employer having responsibility for facility ownership or operations management to perform a risk assessment during the design of electrical systems and installations.

O.1.1 This informative annex covers employee safety-related design concepts for electrical equipment and installations in workplaces covered by the scope of this standard.

(5) Enabling achievement of an electrically safe work condition

O.2.3 Incident Energy Reduction Methods. The following methods have proved to be effective in reducing incident energy:

(1) Zone-selective interlocking. A method that allows two or more circuit breakers to communicate with each other so that a short circuit or ground fault will be cleared by the breaker closest to the fault with no intentional delay. Clearing the fault in the shortest time aids in reducing the incident energy.

(2) Differential relaying. The concept of this protection method is that current flowing into protected equipment must equal the current out of the equipment. If these two currents are not equal, a fault must exist within the equipment, and the relaying can be set to operate for a fast interruption. Differential relaying uses current transformers located on the line and load sides of the protected equipment and fast acting relay.

(3) Energy-reducing maintenance switching with a local status indicator. An energy-reducing maintenance switch allows a worker to set a circuit breaker trip unit to operate faster while the worker is working within an arc flash boundary, as defined in NFPA 70E, and then

(3) 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.

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.

(4) Current-limiting devices. Current-limiting protective devices reduce incident energy by clearing the fault faster and by reducing the current seen at the arc source. The energy reduction becomes effective for current above the current-limiting threshold of the current-limiting fuse or current limiting circuit breaker.

NFPA 70E®

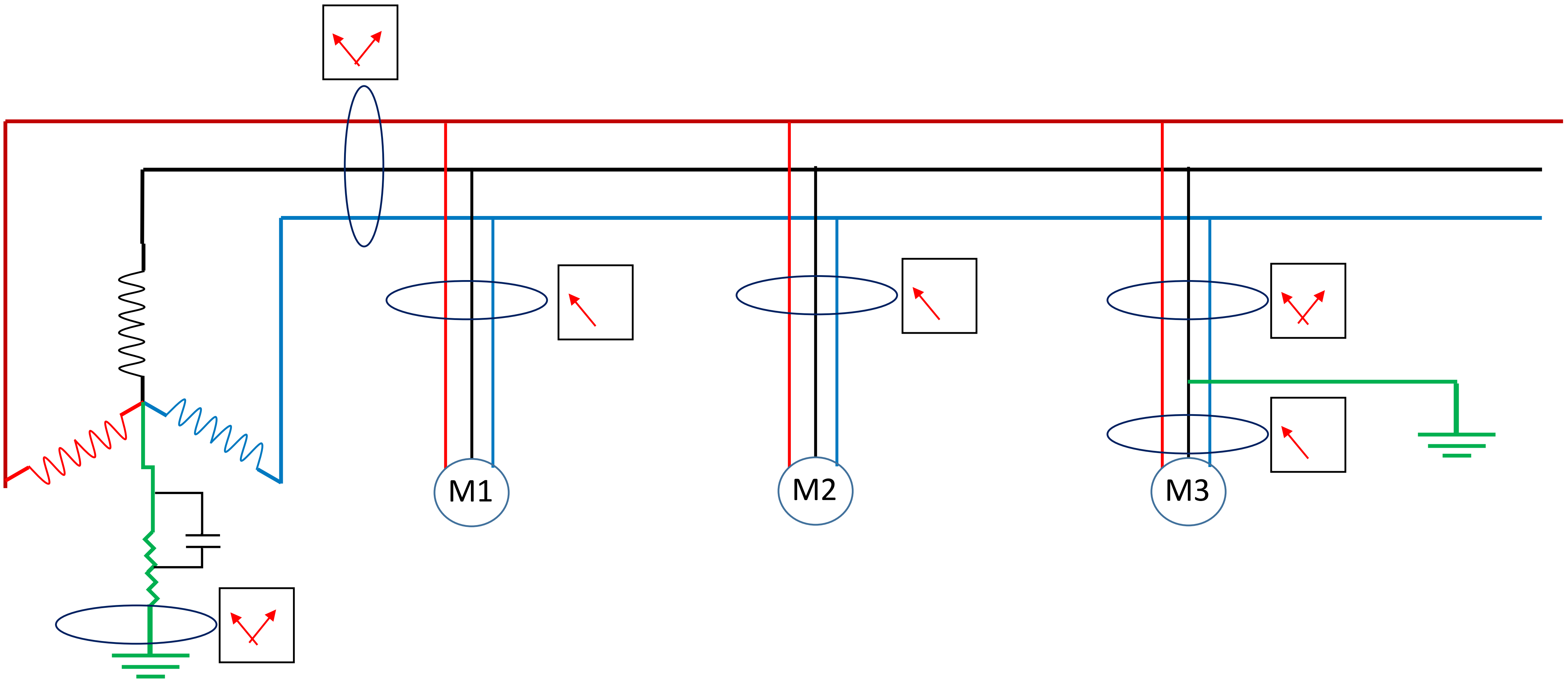
Standard for Electrical Safety in the Workplace®

2018

iGARD

Unparalleled Protection

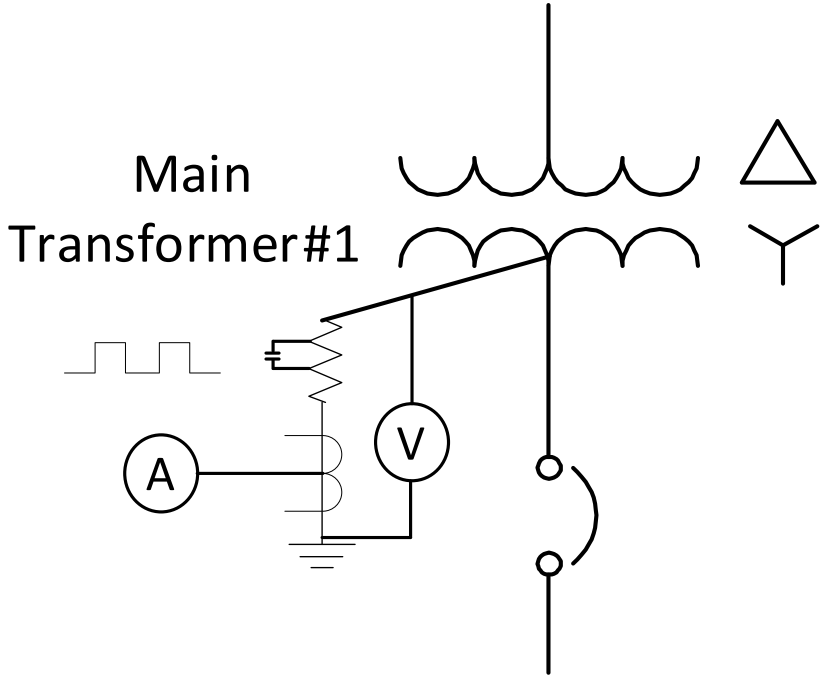
Resistance Grounded



Resistance Grounded

- Minimum Requirements
- Resistor to limit Fault
- Ammeter to measure current
- Voltmeter to measure voltage
- Pulsing Contactor

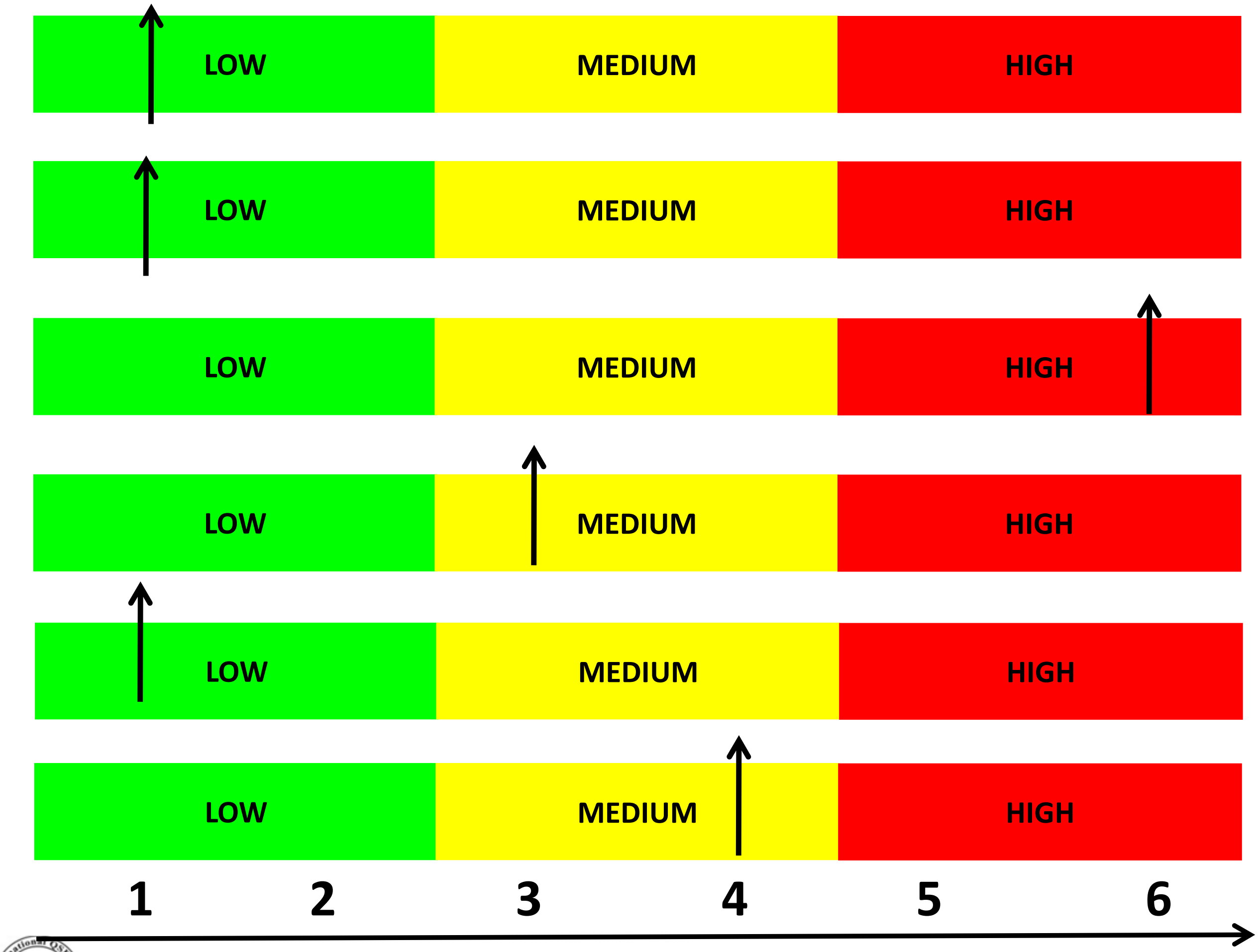
HRG



GARD

Unparalleled Protection

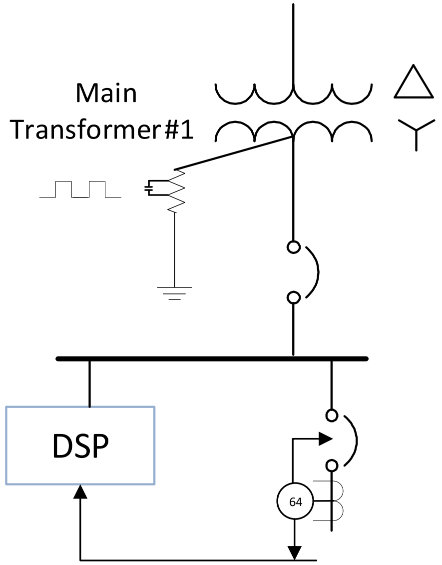
Resistance Grounded (STD HRG)



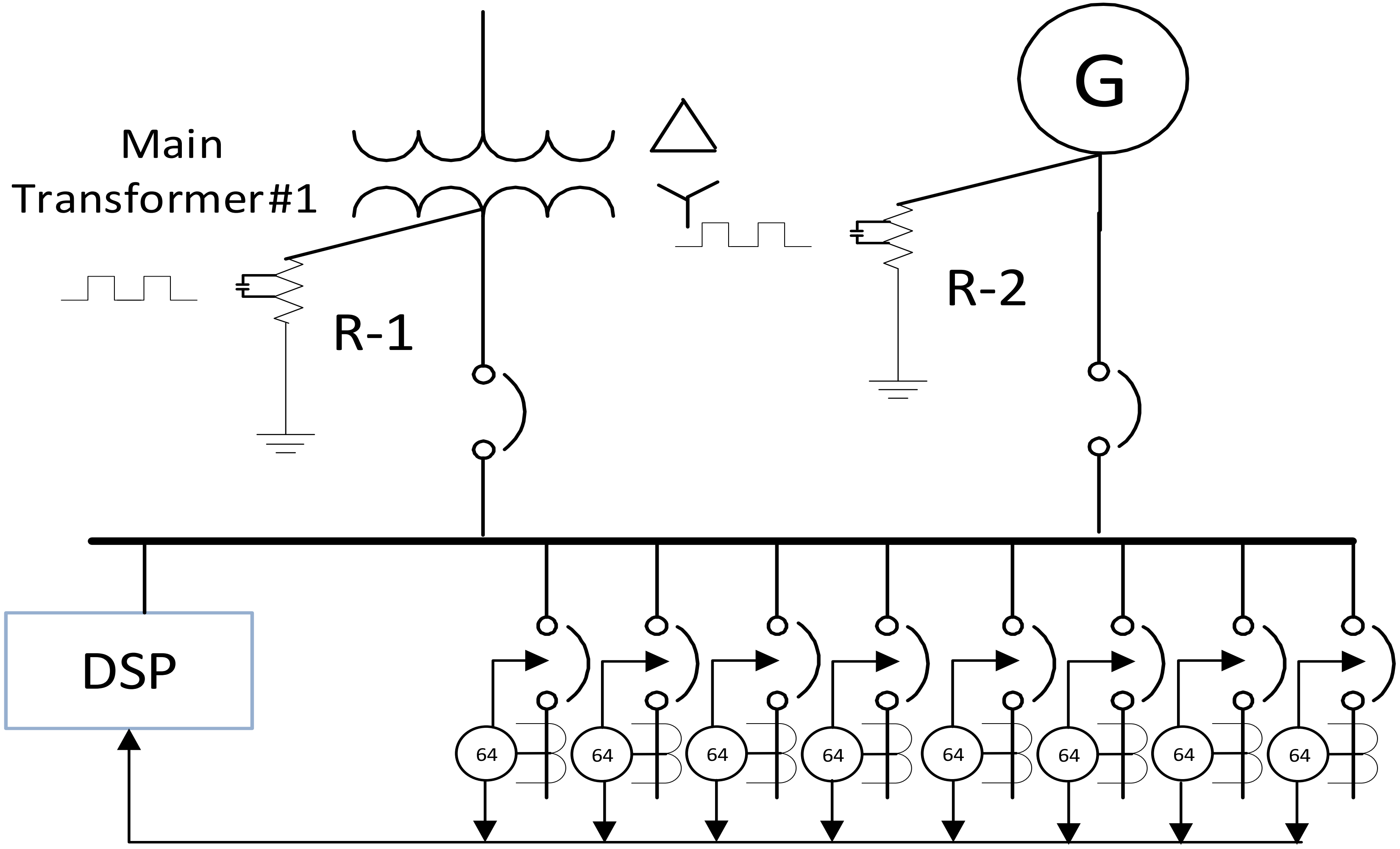
1	**Unscheduled Process Interruptions on first ground fault. Typically $7,000 to $30,000 per hour**
1	**Unable to locate the first ground fault in a timely manner**
6	**Loss of Critical Process due to power interruption (second ground fault)**
3	**Capital Equipment Damage – NFPA Average $45,000.**
1	**Arc Flash Hazard – frequency / probability**
4	**Arc Flash Hazard – magnitude of destructive arc**
16	

Resistance Grounded (SMART HRG)

- Minimum Requirements
- Resistor to limit Fault
- Pulsing Contactor
- Option for resistor monitoring
- Feeder Indication
- Easier fault location
- SIFT/ adjustable timer
- Arc Flash Monitor



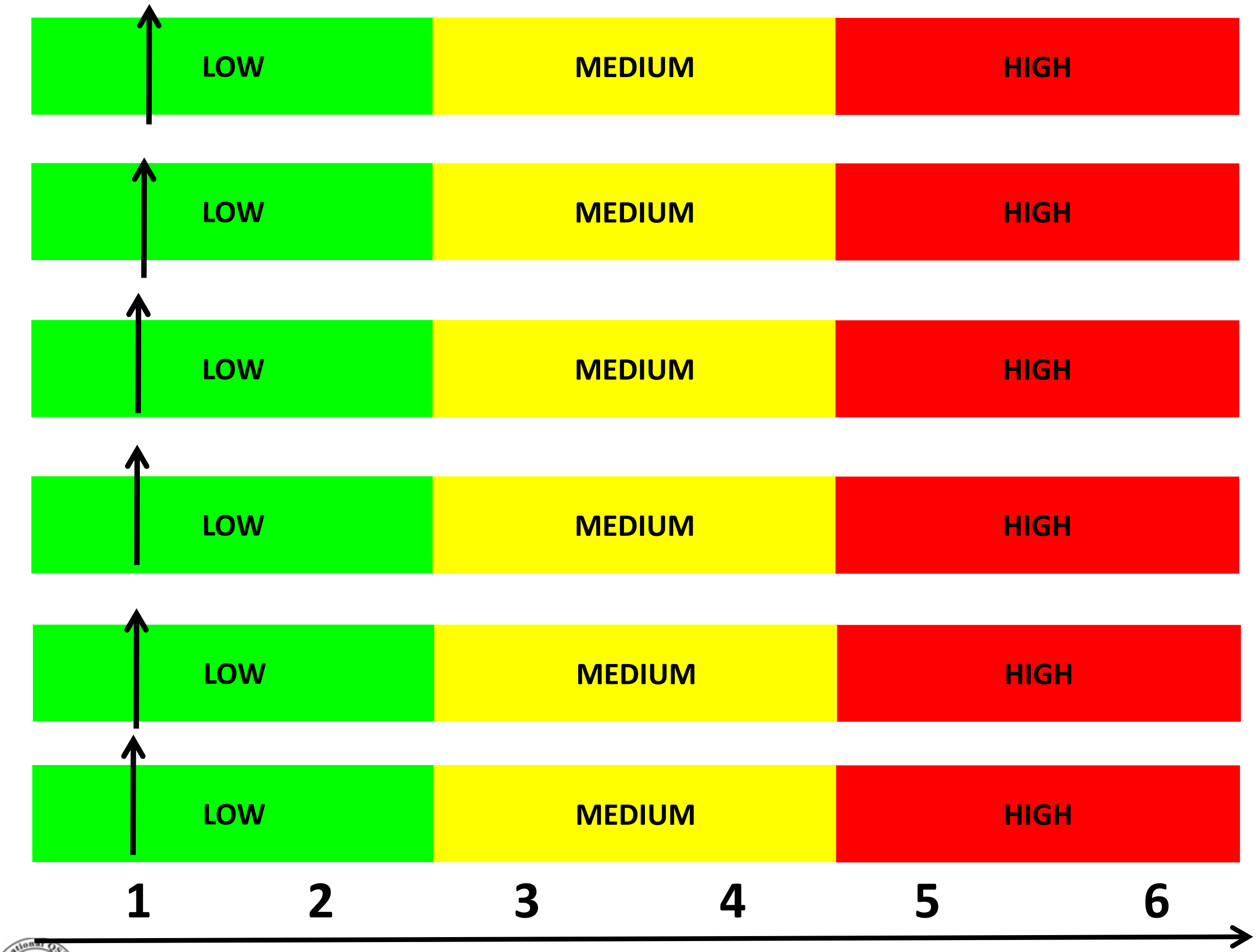
Resistance Grounded



GARD

Unparalleled Protection

Resistance Grounded



1	**Unscheduled Process Interruptions on first ground fault. Typically $7,000 to $30,000 per hour**
1	**Unable to locate the first ground fault in a timely manner**
1	**Loss of Critical Process due to power interruption (second ground fault)**
1	**Capital Equipment Damage – NFPA Average $45,000.**
1	**Arc Flash Hazard – frequency / probability**
1	**Arc Flash Hazard – magnitude of destructive arc**
6	

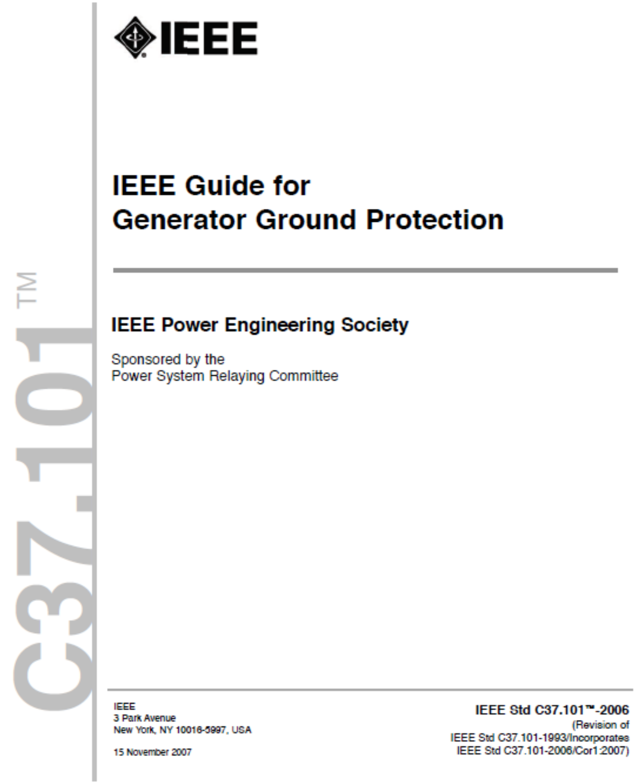
GARD

Unparalleled Protection

HHRG

Reliability and Safety Impact	Ungrounded	Solidly Grounded	High Resistance Grounded	Smart SENTINEL HRG	Smart SENTINEl HRG c/w ADM Module
Process continuity under ground fault condition	✓	✗	✓	✓	✓
Control transient over-voltages	✗	✓	✓	✓	✓
Ability to locate ground fault	✗	✓	✓	✓	✓
Process continuity of critical process with second ground fault	✗	✗	✗	✓	✓
Arc Flash Mitigation for safety	✗	✗	✗	✗	✓

HHRG



C37.101™

IEEE

IEEE Guide for
Generator Ground Protection

IEEE Power Engineering Society

Sponsored by the
Power System Relaying Committee

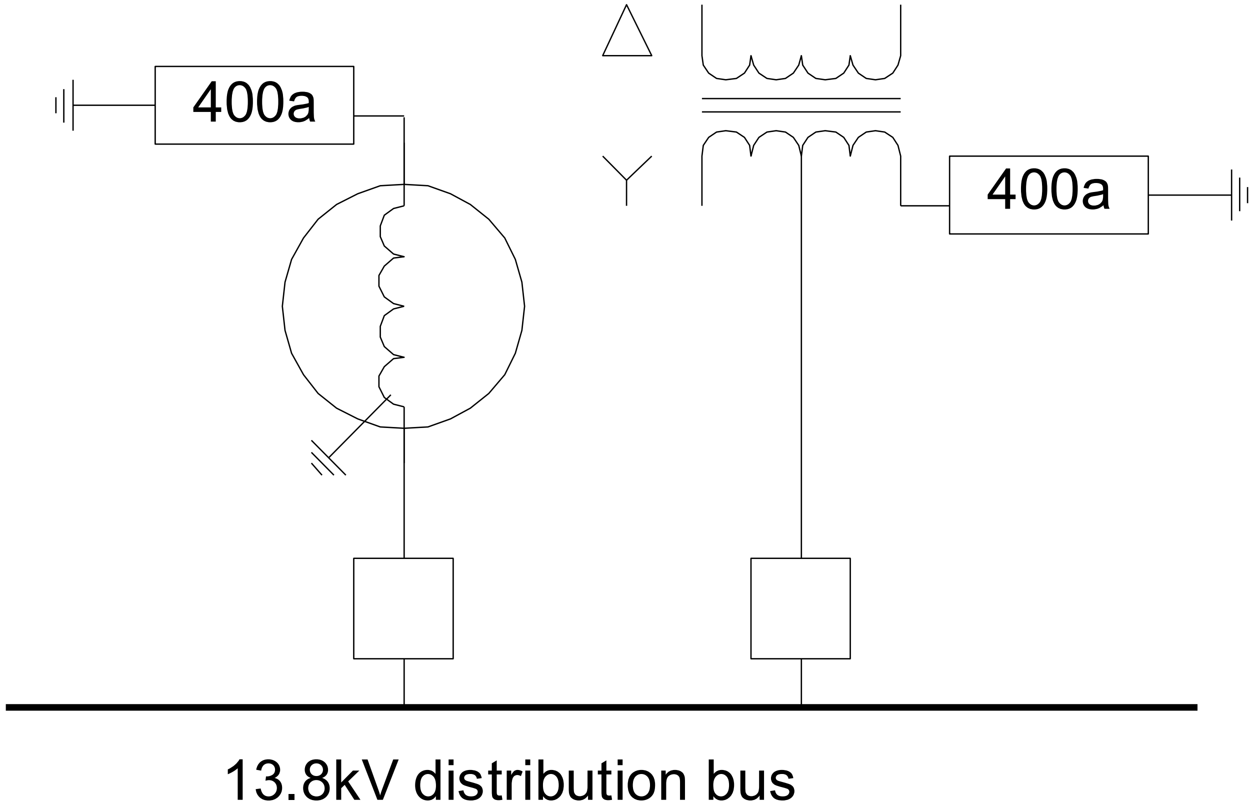
IEEE
3 Park Avenue
New York, NY 10016-5997, USA

15 November 2007

IEEE Std C37.101™-2006
(Revision of
IEEE Std C37.101-1993/Incorporates
IEEE Std C37.101-2006/Cor1:2007)

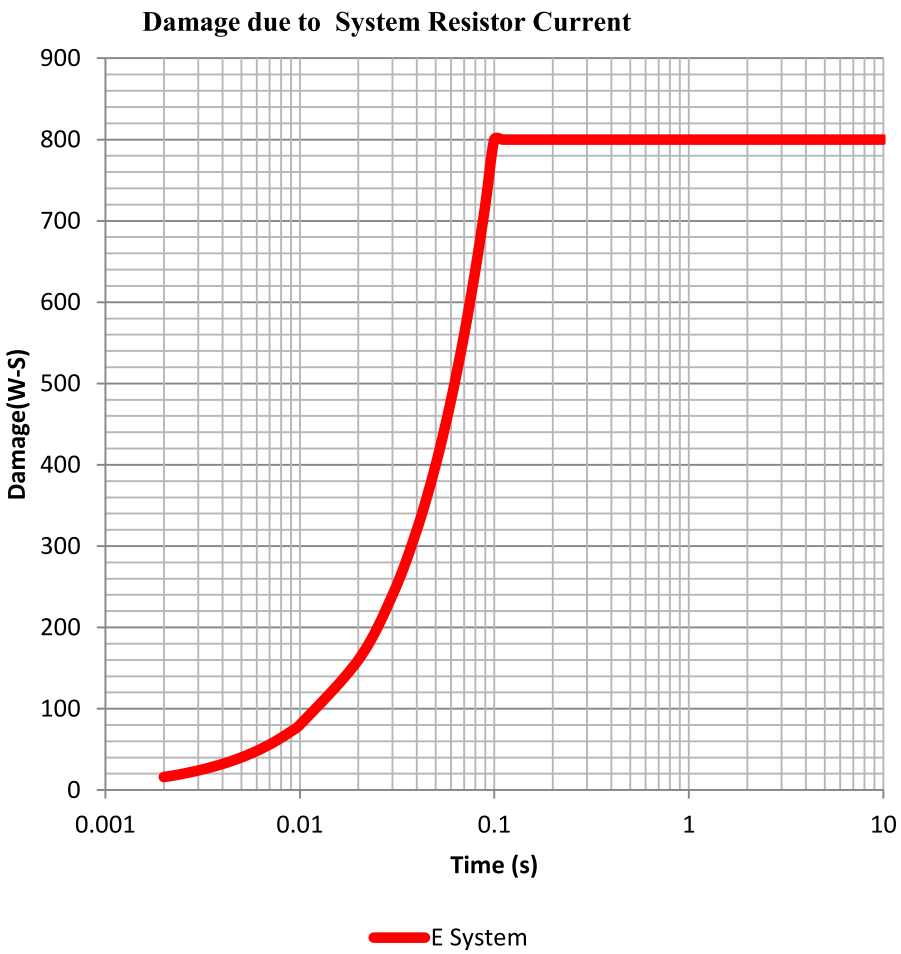
PART 1 : FIG.6-TYPICAL GENERATOR GROUND FAULT

[Author = Powell]



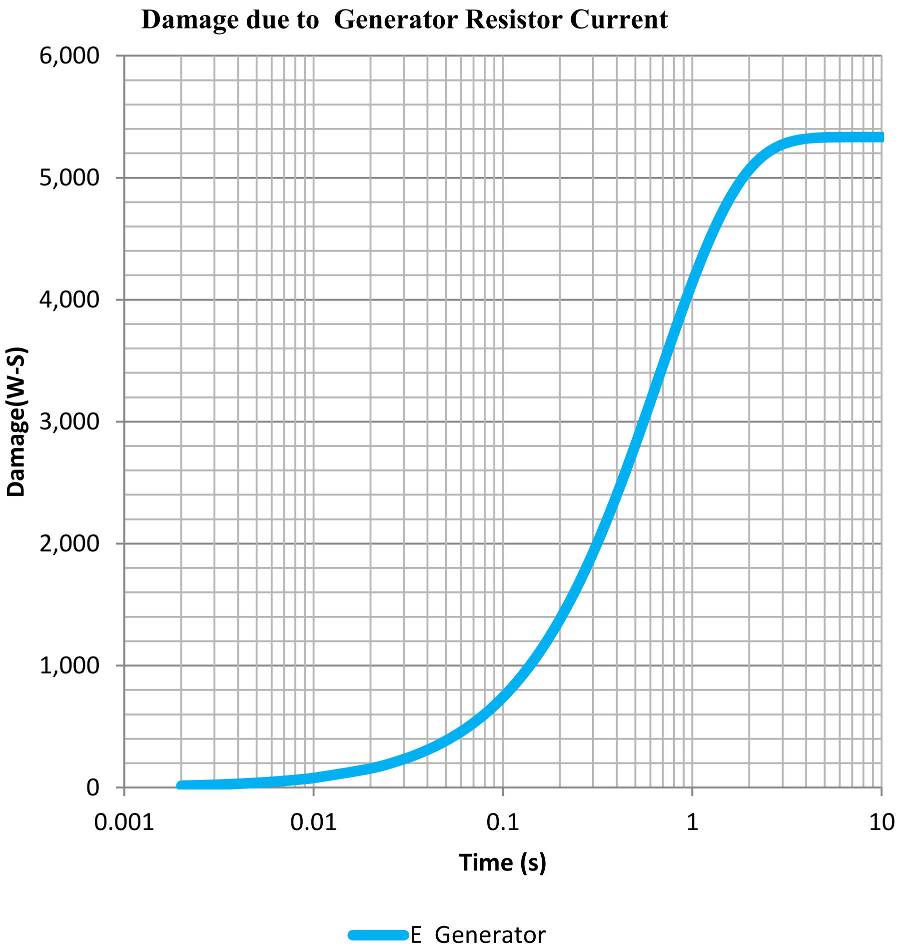
System Damage

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



Generator Damage

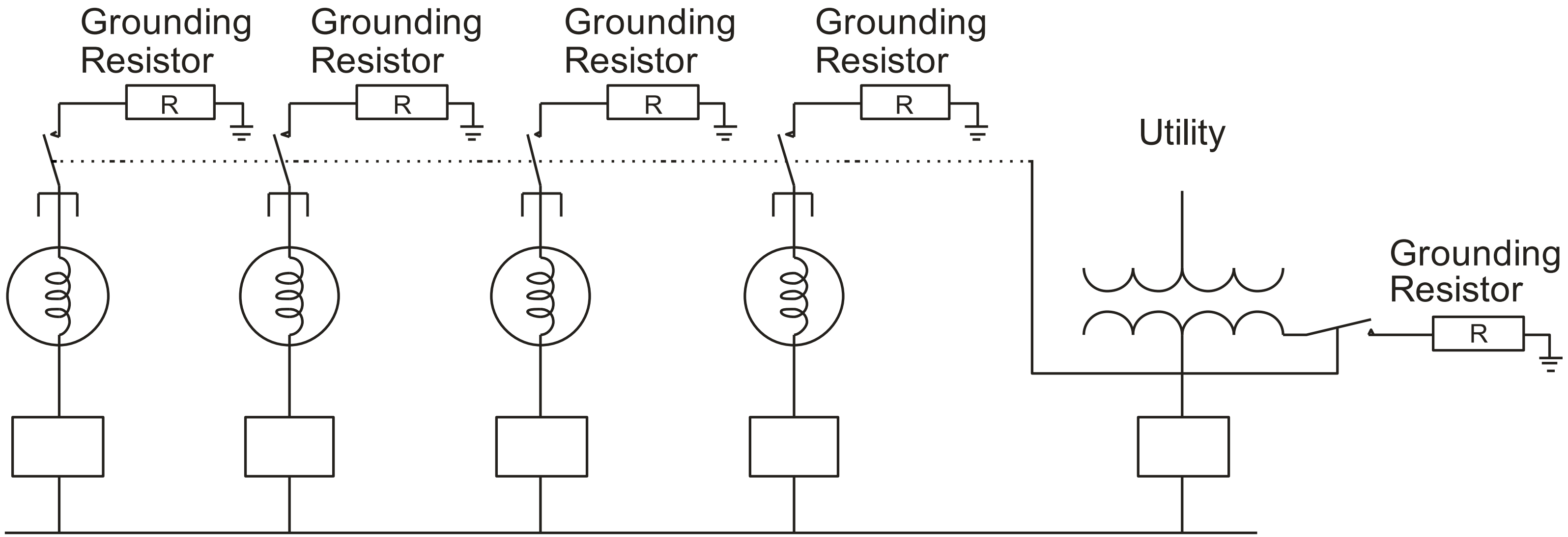
$$E = \int (Ie^{-t/\tau})^k dt$$



GARD
Unparalleled Protection

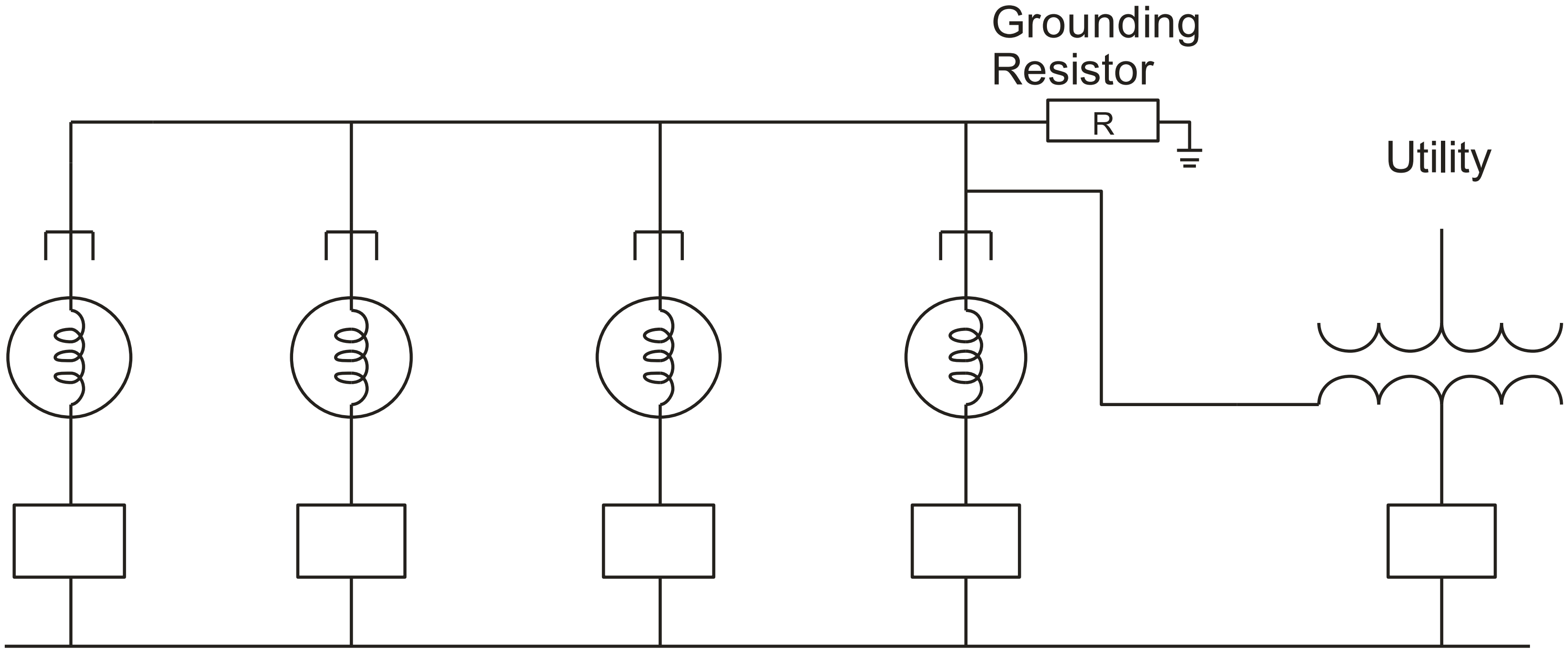
Single point ground switched

- Very complex, switching required, danger of system becoming ungrounded if supply main breaker trips
- NOT Recommended



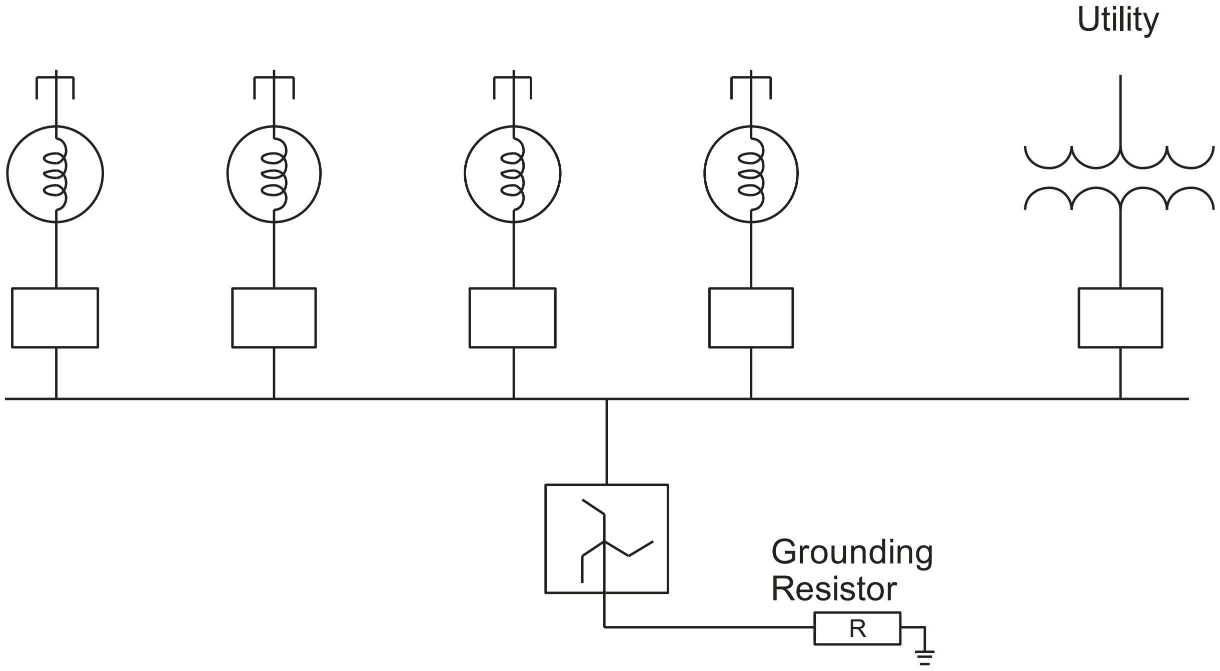
Common neutral low resistance Grounded

- **Circulating currents will flow causing generator de-rating**



Single point ground at the main bus

- Known fault current for L-G faults, independent of number of generators in circuit

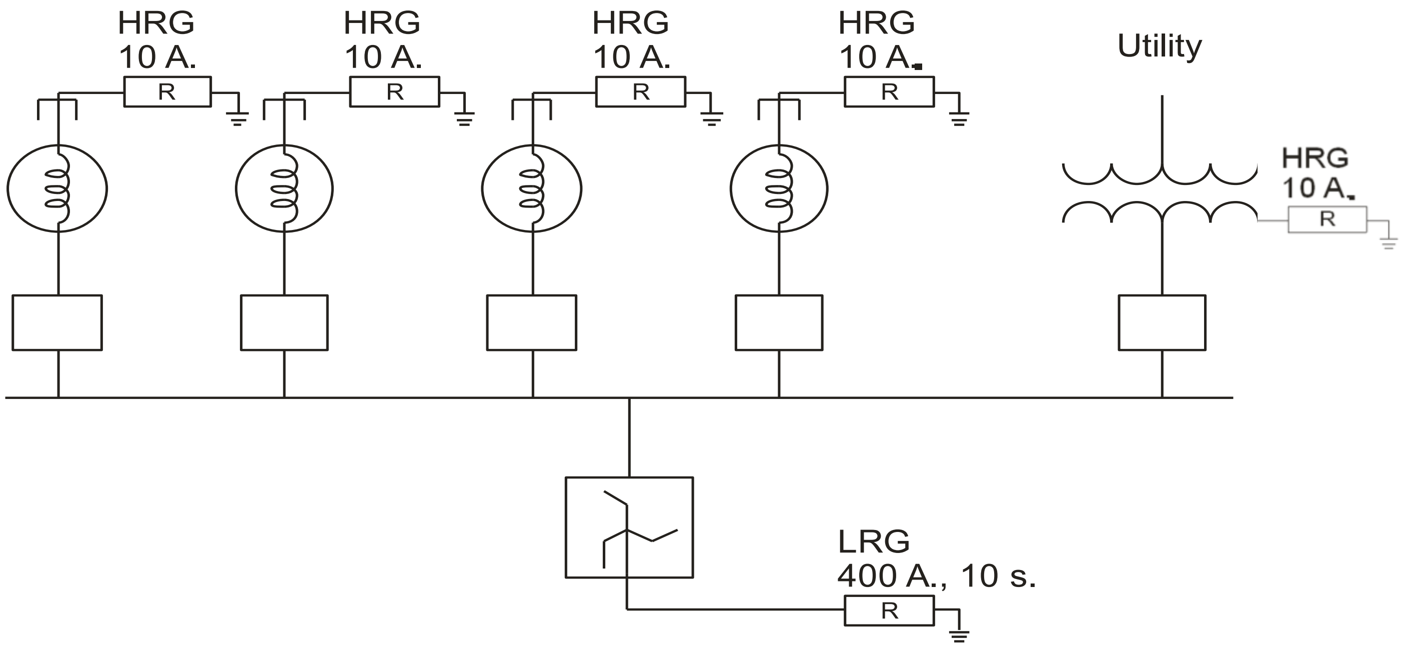


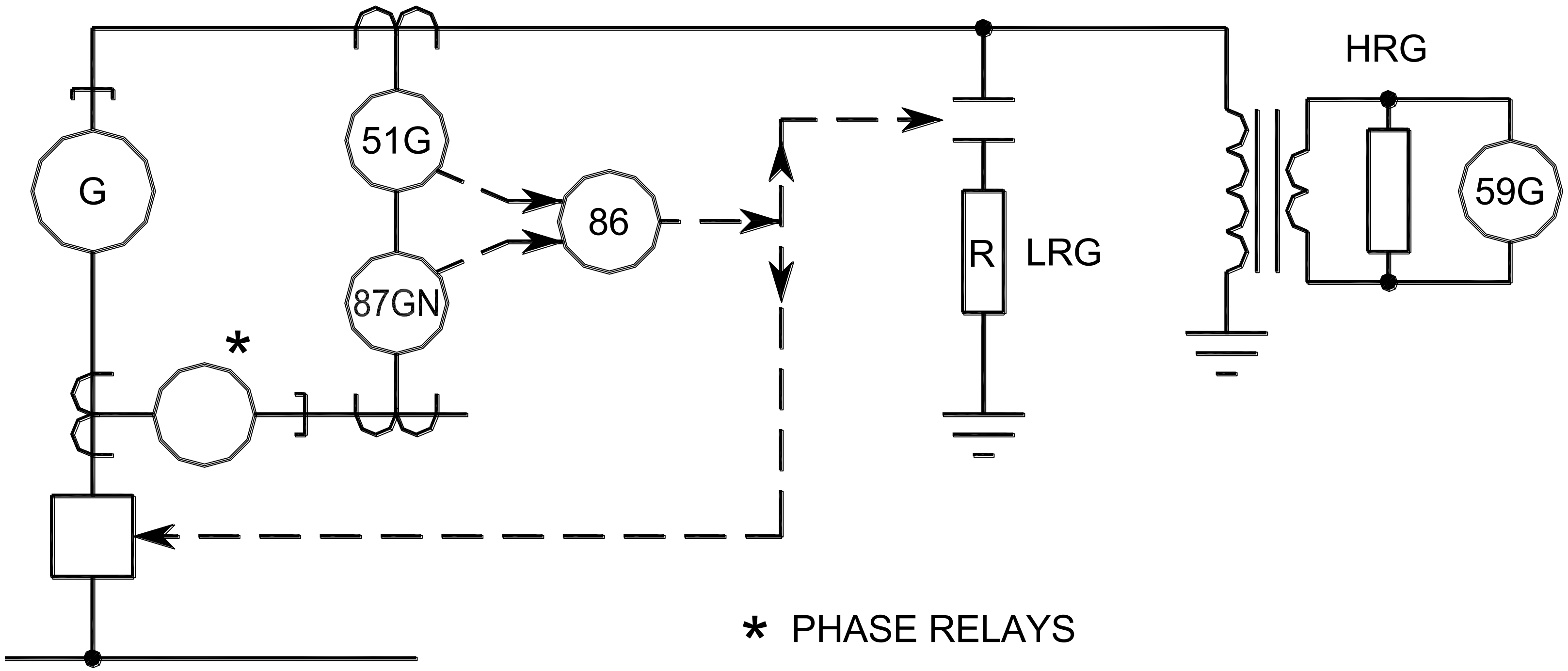
iGARD

Unparalleled Protection

Hybrid grounding of multiple generators

- Reduces generator damage. Sufficient current to overcome 3Ico, selective relaying easy to apply
- HRG can be 5A and LRG can be reduced to suit





* PHASE RELAYS

How to Get in Touch

I-Gard Corporation
Head Office
7686 Bath Rd
Mississauga, Ontario Canada L4T 1L2

Phone: 905.673.1553 Toll Free 1.888.737.4787
Fax: 905.673.8472
E-mail: info@i-gard.com

Our business hours are Monday to Friday 9:00 a.m. to 5:00 p.m. (EST), if during those hours you are not able to call us, simply send us an e-mail or leave us a message.

The following members of our inside sales team will be pleased to assist you:

• General Inquiries	Support@i-gard.com
• Sergio Panetta	spanetta@i-gard.com

www.i-gard.com

GARD

Unparalleled Protection

Questions

www.i-gard.com