GARD

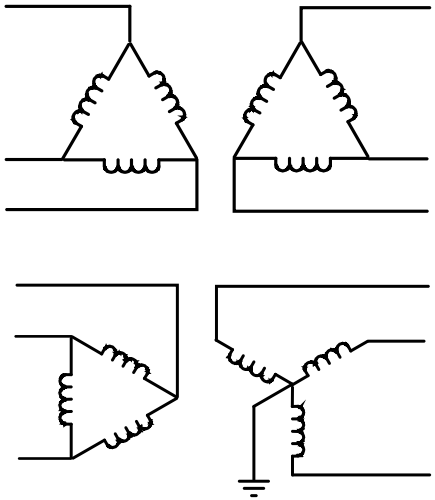
Unparalleled Protection

The Effects of System Grounding and Probability of Arc flash Reduction

Ajit Bapat, P.Eng

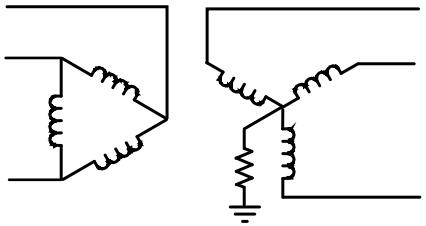
Power System Grounding Methods

- Ungrounded

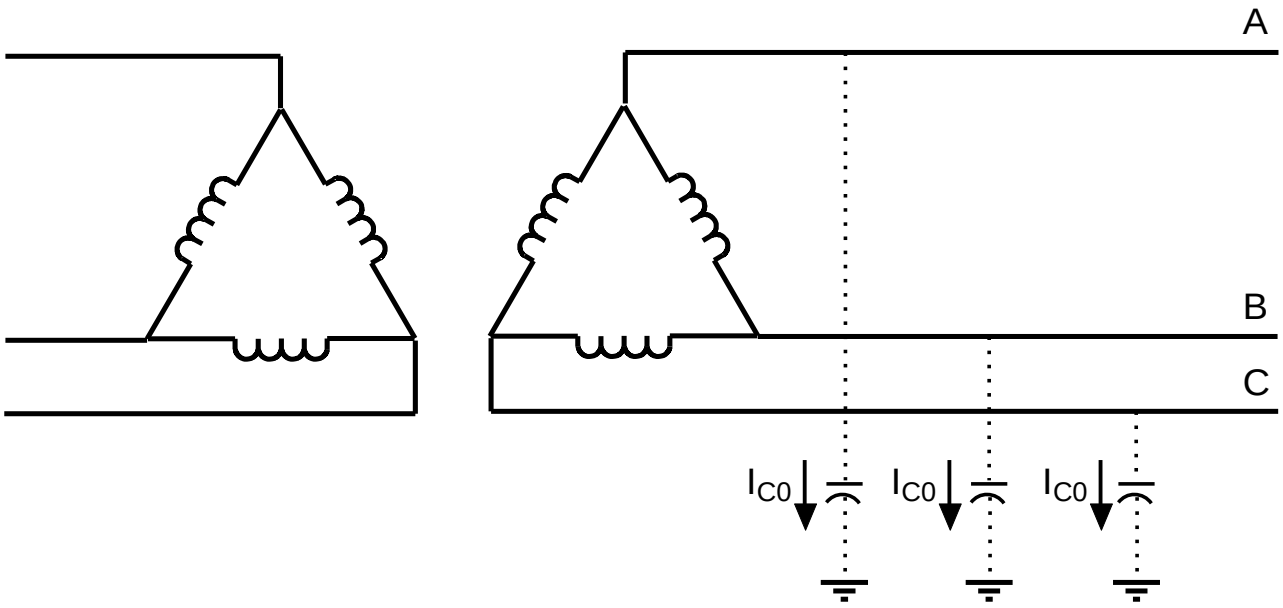


- Solidly Grounded
  Corner Delta Grounded System
  Mid Phase Grounded System

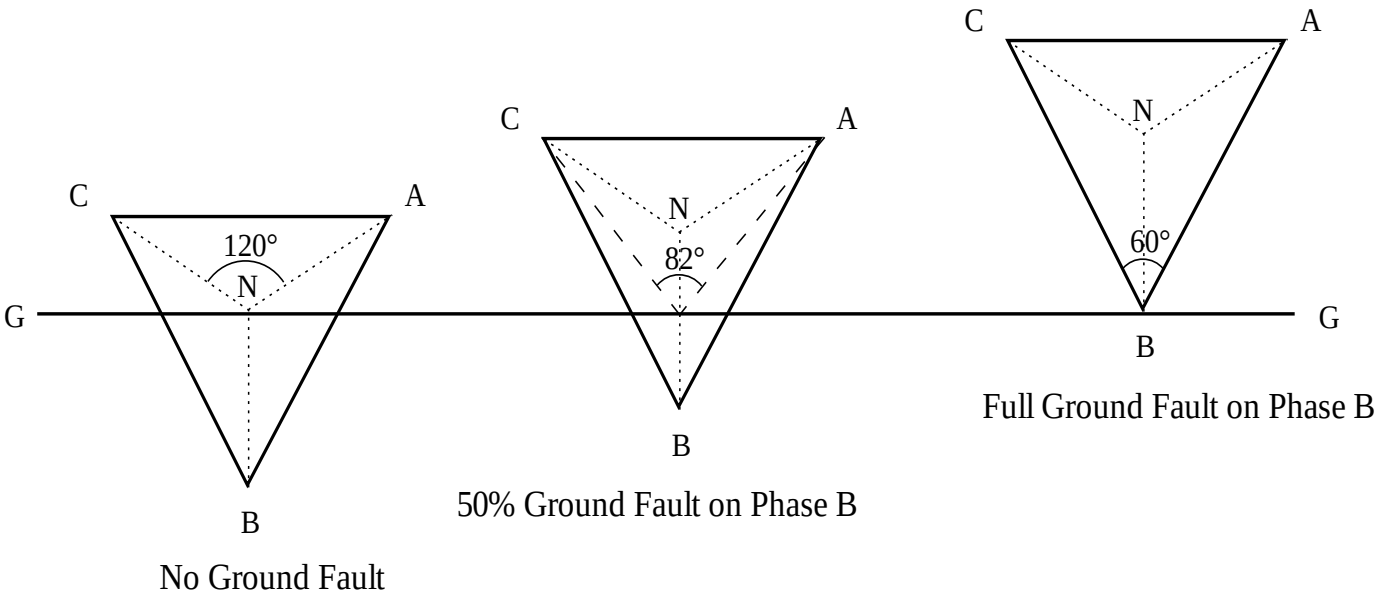
- Resistance Grounded



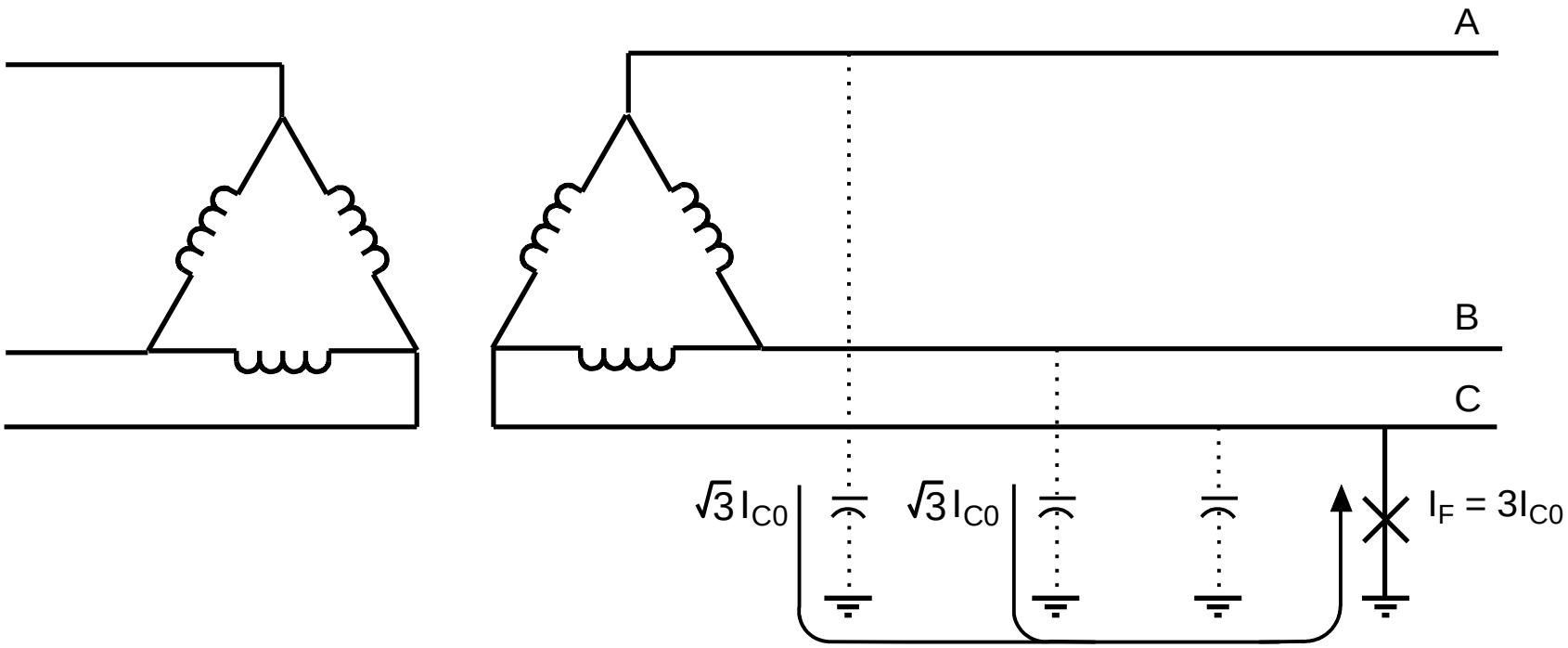
Capacitive Charging Current in Ungrounded System



Ground Fault on Ungrounded Systems



System Charging Current $3I_{C0}$



Ungrounded Systems

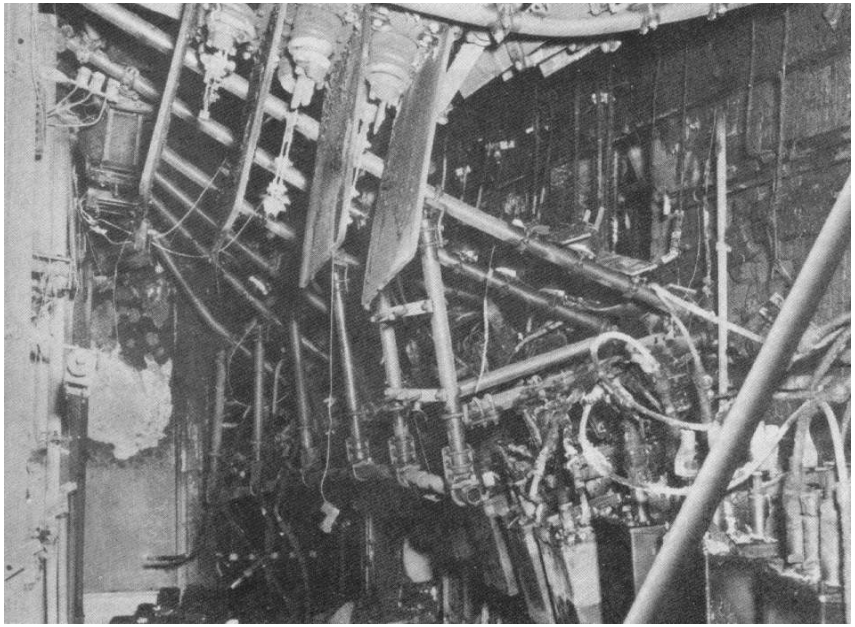
- Negligible fault current and no tripping on first ground fault
- Difficult to locate ground faults
- 5-6 times transient voltage escalation on intermittent, sputtering arcing ground faults due to DC voltage buildup across the stray capacitance to ground

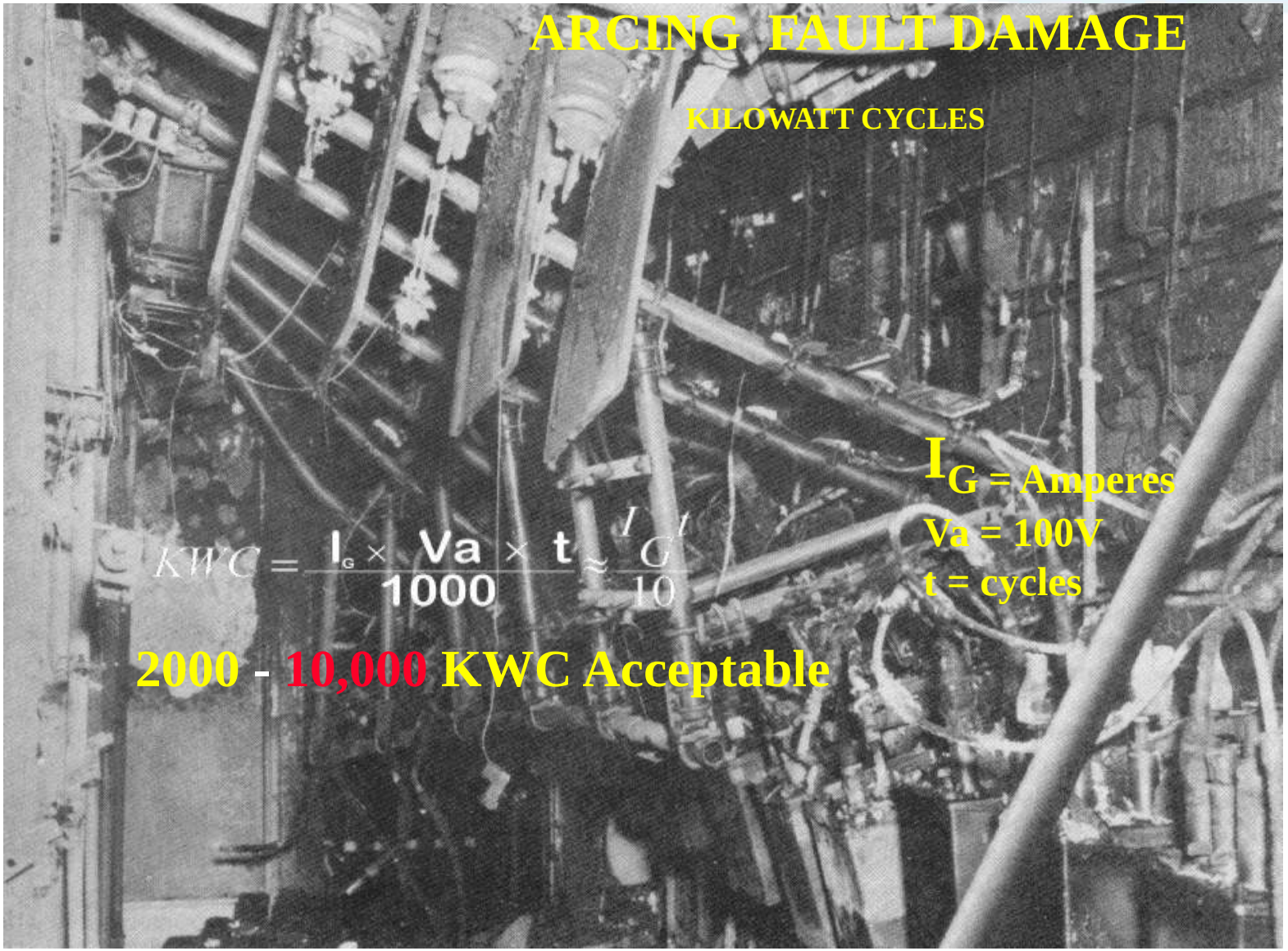
Solidly Grounded Systems

- Eliminates transient overvoltage problem
- Permits line-to-neutral loads (lighting, heating cables)
- Ground faults easy to locate, but cause unscheduled service interruption
- Danger from arcing ground faults , fault current could be less than half of short circuit current level. Potential Arc Flash Hazard
- Since 1970’s, ground fault protection mandatory for solidly grounded 600V services rated 1000A and higher by the CEC and the NEC

Arcing Ground Faults

- Sustained arcing faults can release intense heat and mechanical energy causing severe damage and injury
- Fault current can be 50% of Isc or substantially less




ARCING FAULT DAMAGE
KILOWATT CYCLES
$KWC = \frac{I_G \times Va \times t}{1000} \approx \frac{I_G t}{10}$
I_G = Amperes
Va = 100V
t = cycles
2000 - 10,000 KWC Acceptable

Arcing Ground Fault Damage

A) 100 Kilowatt Cycles
The location of the fault is identifiable by close inspection - there will be spit marks on the metal and some smoke marks.

B) 2000 Kilowatt Cycles
If there is no damage then the equipment can usually be restored by painting smoke marks and repairing punctures in the insulation.

C) 6000 Kilowatt Cycles
Minimal amount of damage results, but fault may more easily be located.

D) 10,000 Kilowatt Cycles
The fault will probably be contained by the metal enclosure.

E) 20,000 Kilowatt Cycles
The fault will probably burn through a single thickness enclosure and spread to other section of the equipment

F) Over 20,000 Kilowatt Cycles
Considerable destruction in proportion to the let-through energy

IEEE – Arcing Faults

- IEEE Std 242-2001
  Recommended Practice for the Protection and Coordination of Industrial and Commercial Power Systems 8.2.2
  One disadvantage of the solidly grounded 480 V system involves the high magnitude of destructive, arcing ground-fault currents that can occur.

- IEEE Std 141-1993
  Recommended Practice for Electric Power Distribution for Industrial Plants 7.2.4

  In solidly grounded system Line to ground fault has the highest probability of occurrence and has the highest probability of escalating into a phase-to-phase or three-phase arcing fault, particularly for the 480 and 600 V systems. The danger of sustained arcing for phase-to-ground fault…is also high for the 480 and 600 V systems, and low or near zero for the 208 V system.

Testing done for IEEE 1584 demonstrates that migration of arc from Line to ground to line to line only takes 8-10 ms

Arc Mitigation – Total System Approach

Step 1
Reduce Hazard Frequency

Step 2
Pre- hazard warning - take preventative action

Step 3
Impact Mitigation

Use Methods to Reduce Hazards

- NFPA 70E section 130.2 FPN No.3 states “Proven designs such as arc-resistant switchgear,…high-resistance grounding and current limitation….are techniques available to reduce the hazard of the system”

- CSA Z462 “Proven designs such as arc-resistant switchgear, remote racking (insertion or removal), remote opening and closing of switching devices, high-resistance grounding of low-voltage and 5 kV (nominal) systems, current limitation, and specification of a covered bus within equipment are techniques available to reduce the hazard of the system”.

Safety Related Requirements in 70E - Informative Annex O

0.2.2 Design Considerations

Design should facilitate the ability to eliminate hazard or reduce risk by:

- Reducing likely hood
- Reducing Magnitude and Severity
- Enabling achievement of an electrically safe work condition

0.2.4 Incident Energy Reduction Methods

(2) Arc Flash Relay

(3) High resistance Grounding

Arc Flash Protection and Mitigation by Design

- High Resistance Grounding

Line to ground faults are most likely faults and HRG limits the fault current so that no arc flash hazard exists

- Arc Flash Protection tripping

For phase to phase faults where arcing is initiated fast detection and tripping will reduce the arc energy and thus reduce the hazard risk category

Arc Flash Protection

- Applied for Low and Medium Voltage systems
- Used in LV switchboards and LV switchgear as well as Metalclad and Metalenclosed circuit breaker switchgear
- Fast acting tripping system uses circuit breakers to trip and isolate.

I-Gard Arc-i-tec

- Arc Flash Mitigation > detection in 1 millisecond
- Reduction of Arc Flash energy by fast detection and tripping. Minimizes total clearing time.
- Reliability – Ensures fastest possible reaction time with out nuisance tripping. Combines light sensing and overcurrent protection

I-Gard Components

- Main Module: Provides control power, displays alarms, provides outputs and takes 20 inputs
- Current sensing module: 5A or 1A sec CT adjustable sensitivity
- Arc Flash Module: Detects Flash, adjustable sensitivity, 10 optical sensors per module, 16 modules can be connected in a series chain
- Optical sensor: Mounts in the switchgear compartment
- Optical fibre: Connects optical sensor directly to Arc Flash module < 100 m
- Communication cable: Twisted pair shielded (blue cable) identifies the sensor that detected the fault.

Arc-i-tec


LATCHING TRIP INDICATOR
ARC-i-TEC
ARC FLASH PROTECTION RELAY
GARD
www.i-gard.com
TRIP
ERROR
POWER
PROG
TEST
RESET

Arc Detection and Mitigation
Optical Arc Detection

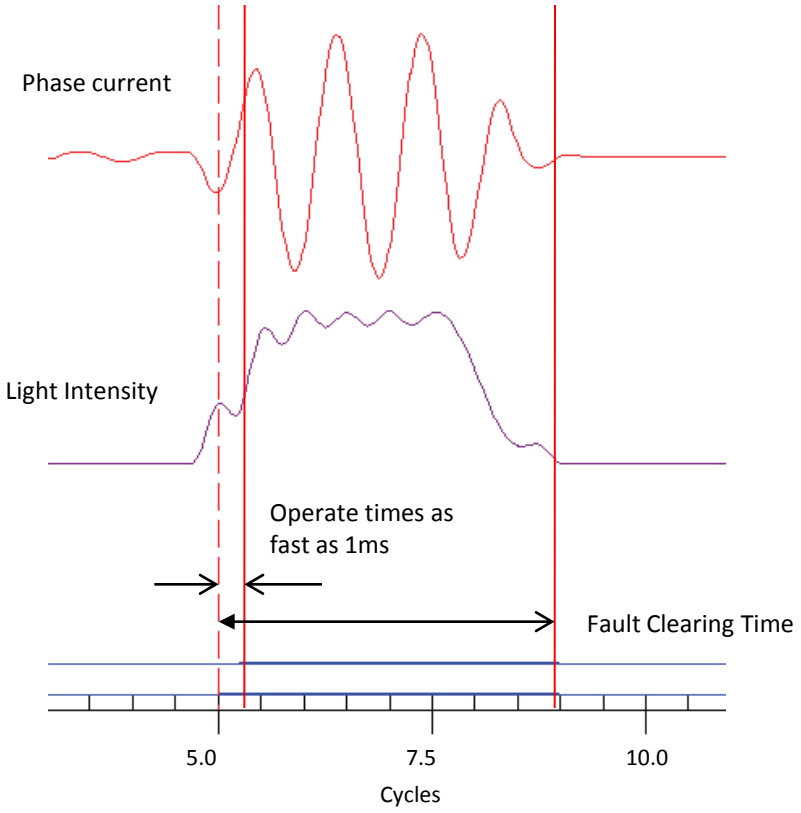
Improved Safety –

Reduction of arc-flash energy with fast detection and tripping, under 1 ms.

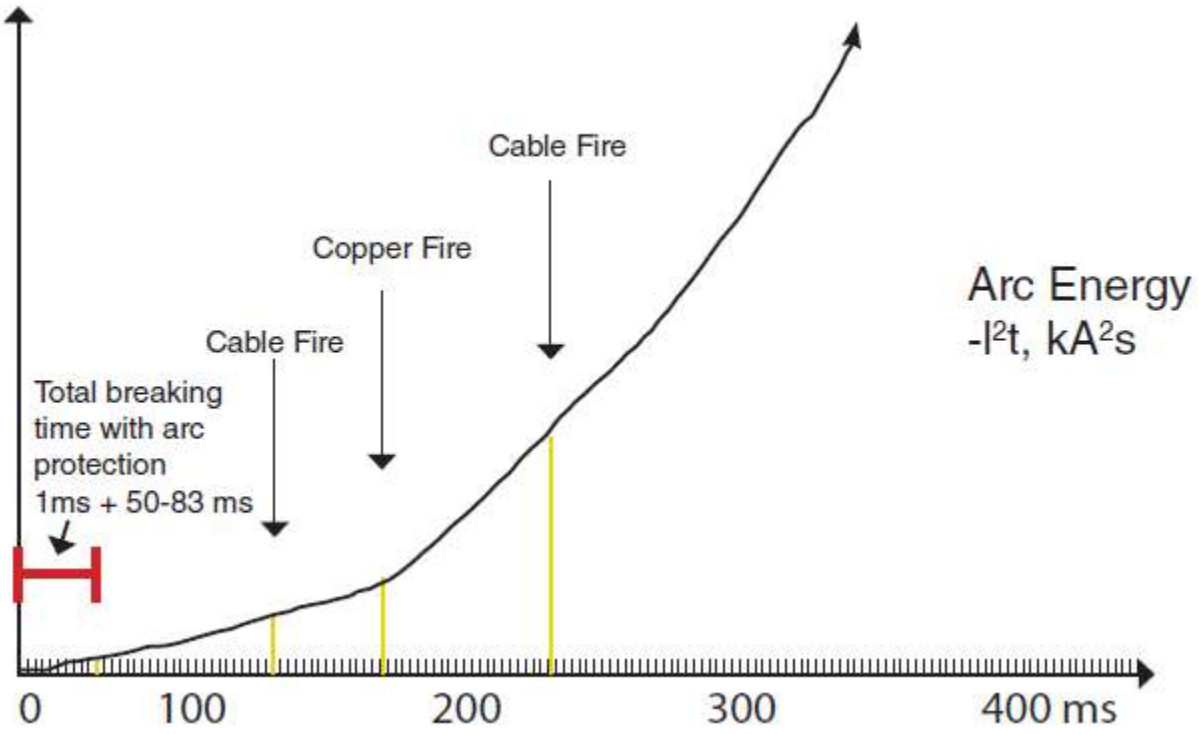
Reacting at the speed of light minimizes the total fault-clearing time.

Reliability –

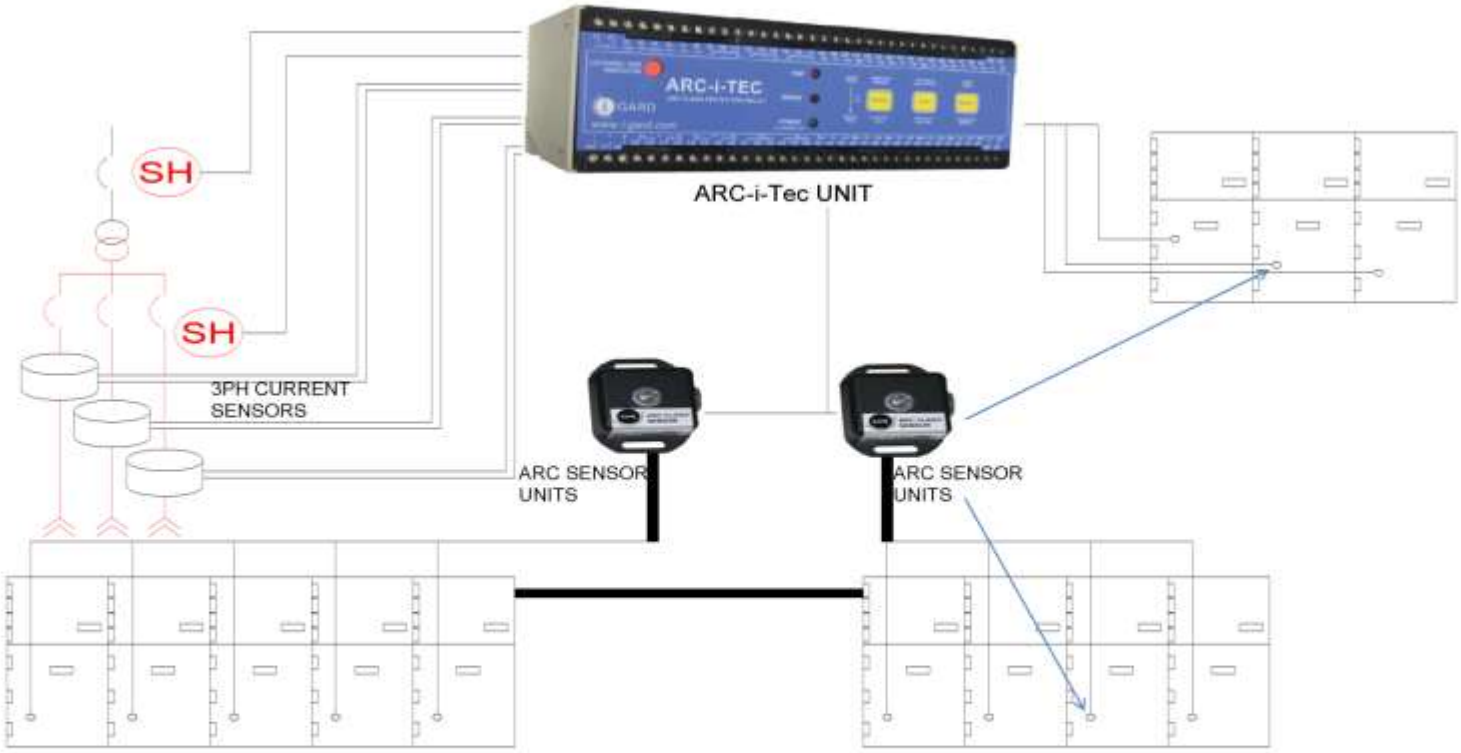
Optional over-current module combines light sensing technology with fast overcurrent protection to ensure the fastest possible reaction time without nuisance tripping.



Fast tripping reduces energy exposure and damage



Arc Detection and Mitigation Current and Light Schematic Arc-i-tec



Arc Detection and Mitigation

Protection Type	Clearance Time	Incident Energy
MCGG Over-Current	3.1 seconds	37 Cal / cm2
MCGG Instantaneous	0.45 seconds	5.4 Cal / cm2
Pressure sensor	0.058 seconds	1.3 Cal / cm2
Optical Arc Detection	0.051 seconds	1.2 Cal / cm2

Assumes circuit breaker interrupting time of 0.05 seconds

Arc Detection and Mitigation

Total Clearing Time is Critical

Reduce the Time,	Reduce the Damage,	Reduce the Incident Energy
-35 ms:	no significant damage to persons or Switchgear, which can often be returned to use after checking the insulation resistances	1.27 Cal /cm2
- 100ms:	small damage, requires cleaning and possibly some minor repair likely	3.23 Cal/cm2
- 500ms:	large damage both for persons and the switchgear, which must be partly replaced.	18.1 Cal/cm2

The arc burning time is the sum of the time to detect the arc and the time to open the correct breaker.

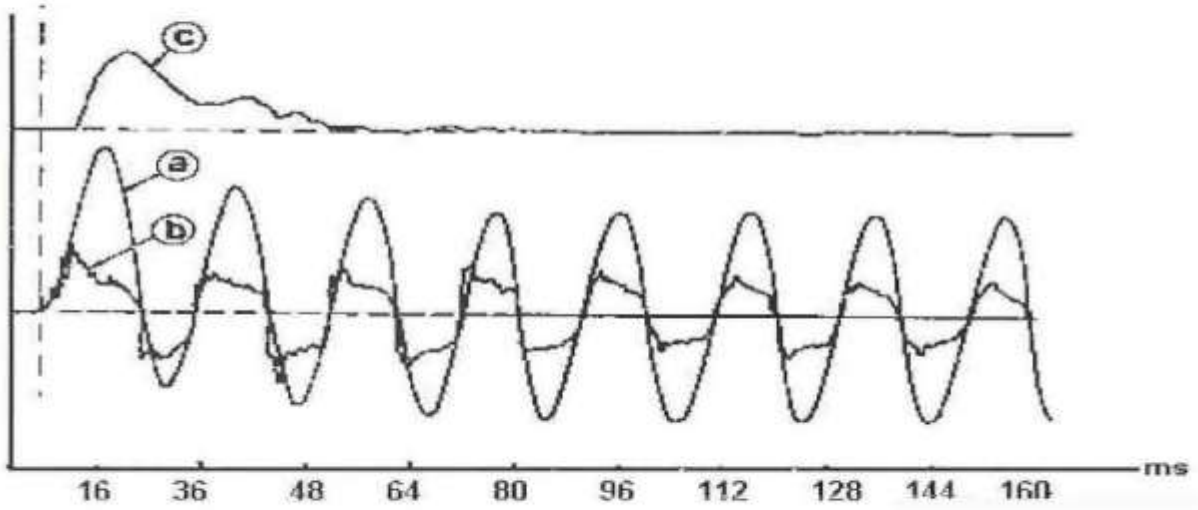
*Based on 50kA maximum bolted fault current on a 480 volt solidly grounded system.

Arc Detection and Mitigation

Arcing is accompanied by radiation in the form of light, sound, heat and electromagnetic waves as well as an associated pressure wave.

Internal Arc

- **The energy developed by the internal arc generates heat and pressure; ex:**



- **a: short circuit current (phase with max asymmetry)**
- **b: arc voltage**
- **c: internal pressure**

Arc Detection and Mitigation

Two Direct Detection Methods

Pressure Arc Detector

- Detecting the pressure wave generated by the arc
- Detection time 8ms

Light Arc Detector

- Detecting the arc flash through optical arc detection
- Detection time 1ms

Pre Hazard Alarm

All US Navy electrical fires over a 20 year period were examined and it was determined that 60% to 80% of all arcing faults originated as inline arcs caused by faulty connections, insulation breakdown, moisture etc

The US Navy in association with John Hopkins University developed an Arc Detection System to predict these faults using Thermal Ionization Detection.

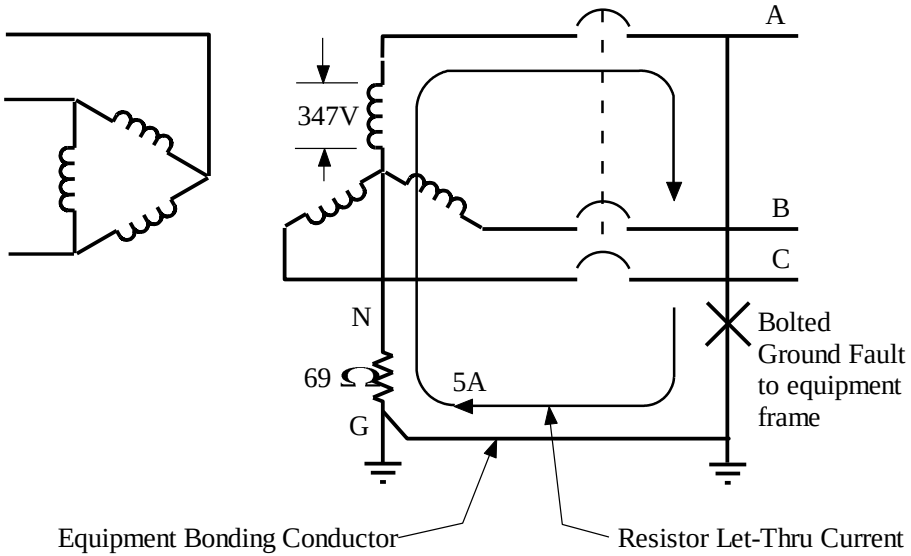
The system combines a conventional smoke detector's radioactive ionization chamber with custom electronics, allowing it to sense pyrolysis products that indicate overheated electrical insulation. The Thermal Ionization Detector is not a direct measurement of the temperature of the hot spot. It is calibrated to infer temperature from the emission of particles from certain types of overheated connections

Resistance Grounding

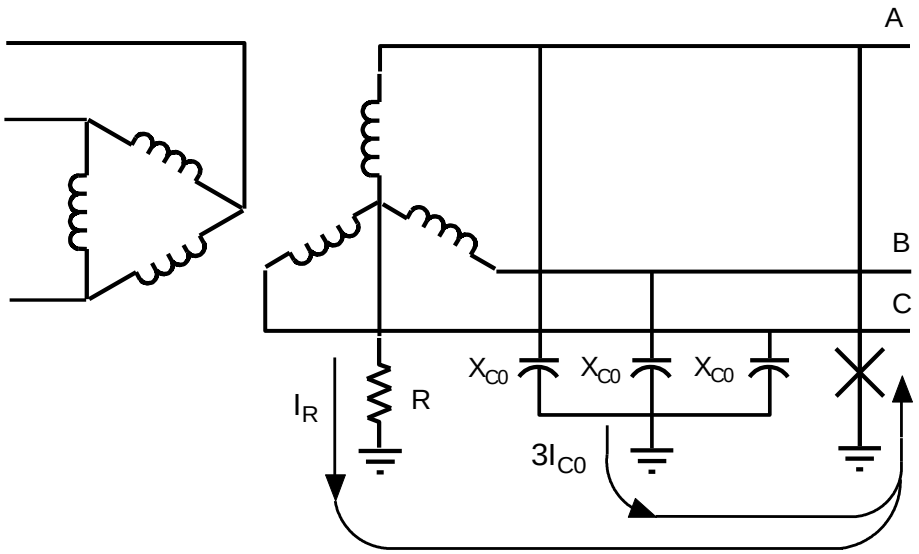
- Used on LV and MV systems to limit ground fault current
- No arcing ground faults as with solid grounding
- No overvoltages as with ungrounded systems
- Used in Process Industries, Water and Waste Water, Hospitals, Data processing Centers

Resistance Grounding

- Resistor inserted between neutral and ground to limit ground fault current
- Resistor rated for line-to-neutral voltage



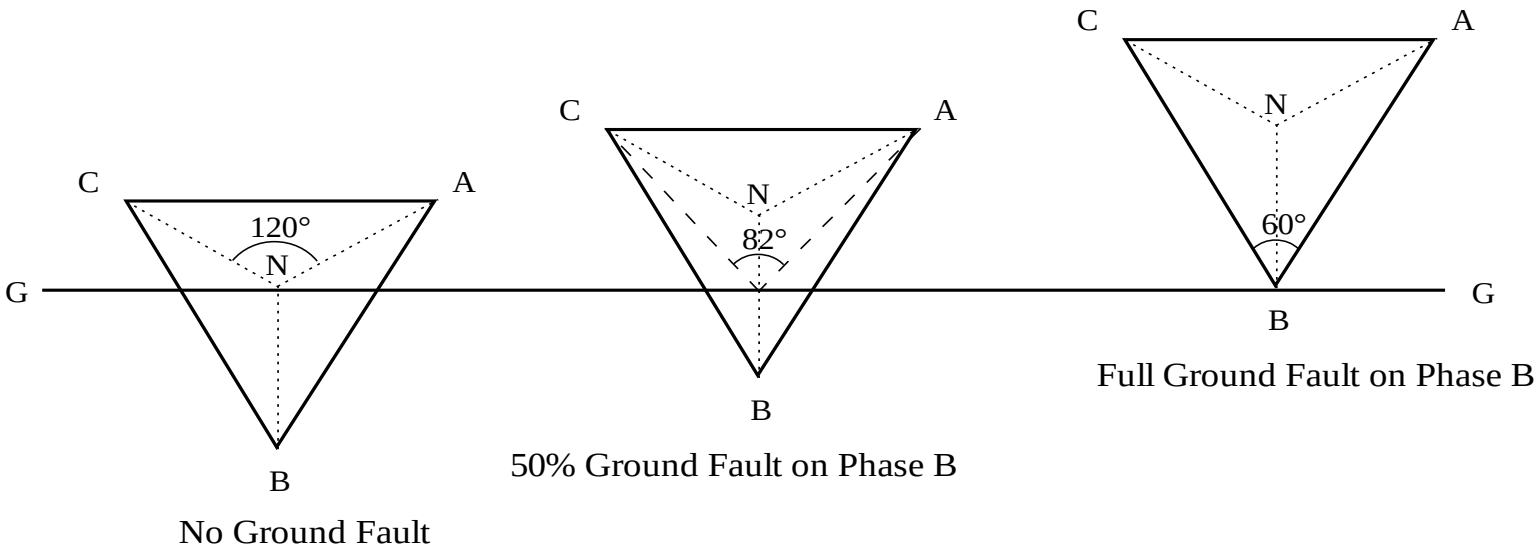
Fault Current on HRG System



$$I_F = \sqrt{(I_R)^2 + (3I_{C0})^2}$$

$$I_{F_{MIN}} = \sqrt{2}(3I_{C0}) \qquad \text{At minimum fault current, } I_R = 3I_{C0}$$

Ground Fault on Ungrounded and High Resistance Systems



High Resistance Grounding

Canadian Electrical Code Rule 10-1102 (3):

- Where a neutral grounding device is used on an electrical system operating at 5 kV or less, provision shall be made to automatically de-energize the system on the detection of a ground fault, unless:
  - The ground fault current is controlled at 10 A or less; and
  - A visual or audible alarm, or both, clearly identified to indicate the presence of a ground fault, is provided.

Resistance Grounding - IEEE

IEEE Std. 142-1991 Recommended Practice for Grounding of Industrial and Commercial Power System 1.4.3

The reasons for limiting the current by resistance grounding may be one or more of the following:

1. to reduce burning and melting effects in faulted electric equipment, such as switchgear, transformers, cables and rotating machines.
2. to reduce mechanical stresses in circuits and apparatus carrying fault currents
3. to reduce electric-shock hazards to personnel caused by stray ground fault currents in the ground return path
4. to reduce arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the fault current
5. to reduce the momentary line-voltage dip occasioned by the occurrence and clearing of a ground fault

High Resistance Grounding – IEEE

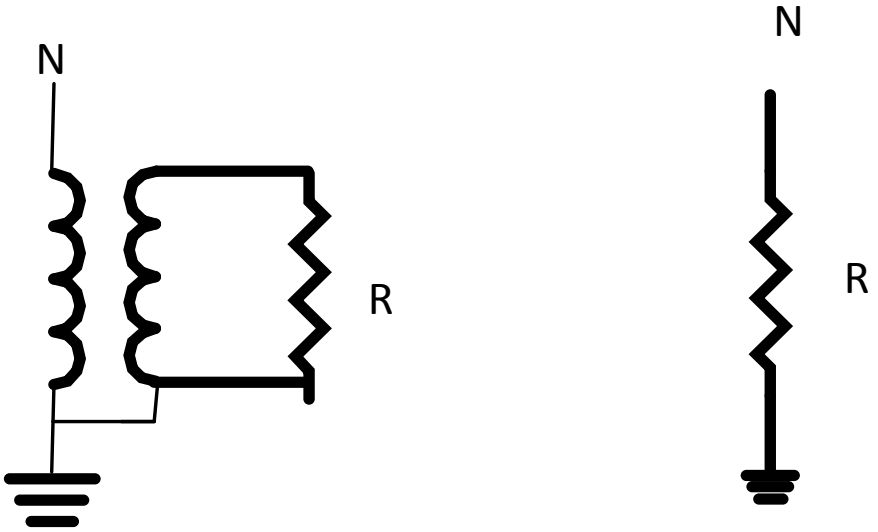
IEEE Std 242-2001 (Buff Book) 8.2.4

High-resistance grounding helps ensure a ground-fault current of known magnitude, helpful for relaying purposes. This makes it possible to identify the faulted feeder with sensitive ground-fault relays.

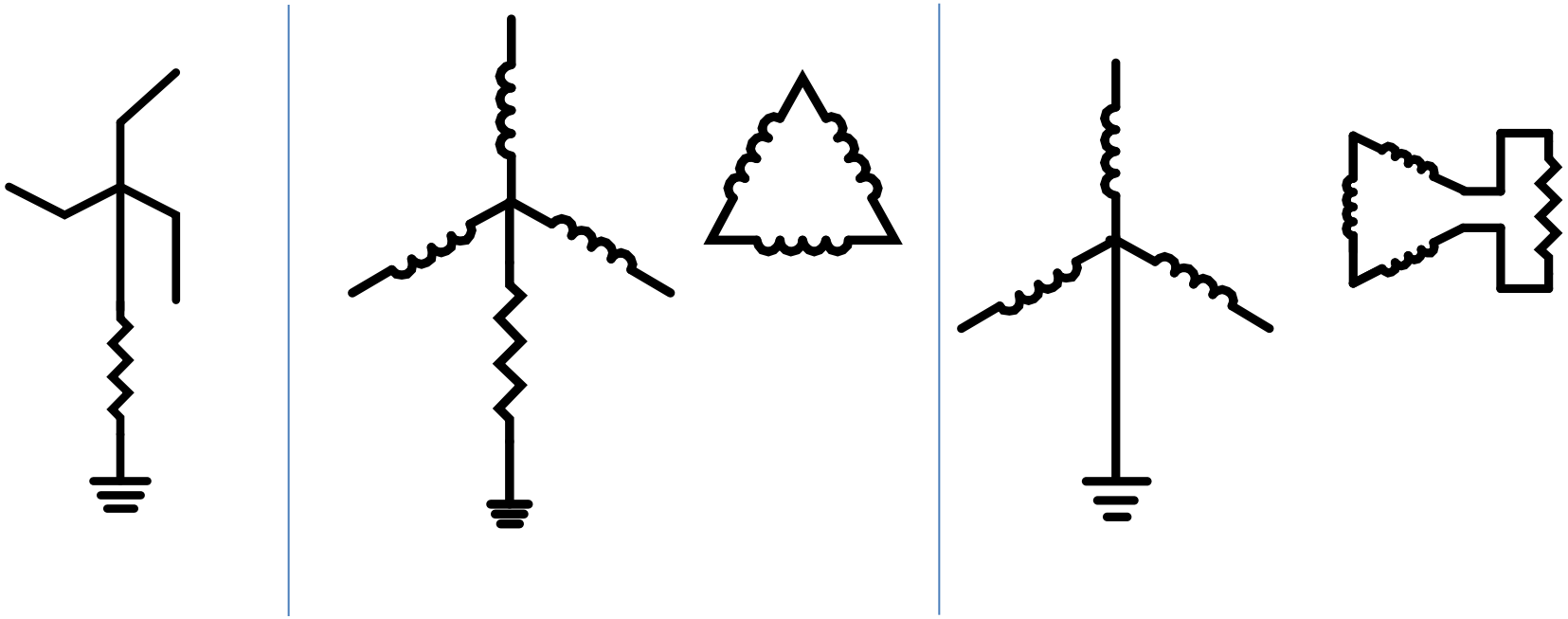
IEEE Std 141-1993 (Red Book) 7.2.2

High-resistance grounding provides the same advantages as ungrounded systems yet limits the steady state and severe transient over-voltages associated with ungrounded systems. There is no arc flash hazard *[for a ground fault on 480V and 600V systems]*, as there is with a solidly grounded system, since the fault current is limited to approximately 5A.

Methods of grounding: Neutral available



Methods of grounding: Neutral available



Distribution System Design Criteria

High Resistance Grounded

- Reliability — Power continuity, No trips on ground fault
- Safe — No Arc Blast or Flash Hazard on Ground Fault
- Cost effective — 3 Wire Systems are cheaper than 4 wire
- Scheduled Maintenance — Faulty equipment can continue to run, scheduled shut downs and lower repair costs

- Prioritized load — Overcurrent Coordination maintained
  Selective second fault protection available

High Resistance Grounding

- Limit ground fault current to 10 A or less
- Provides service continuity on first ground fault
- Prevents arc flash incidents on first ground faults
- Allows faults to be located without de-energizing feeders (ground fault pulse locating)
- Used in 3 phase 3 wire circuits at 480. 600 and 4160 V specially in continuous process industries, hospitals, data centers and station service in gen stations where unscheduled downtime is costly or cannot be tolerated.

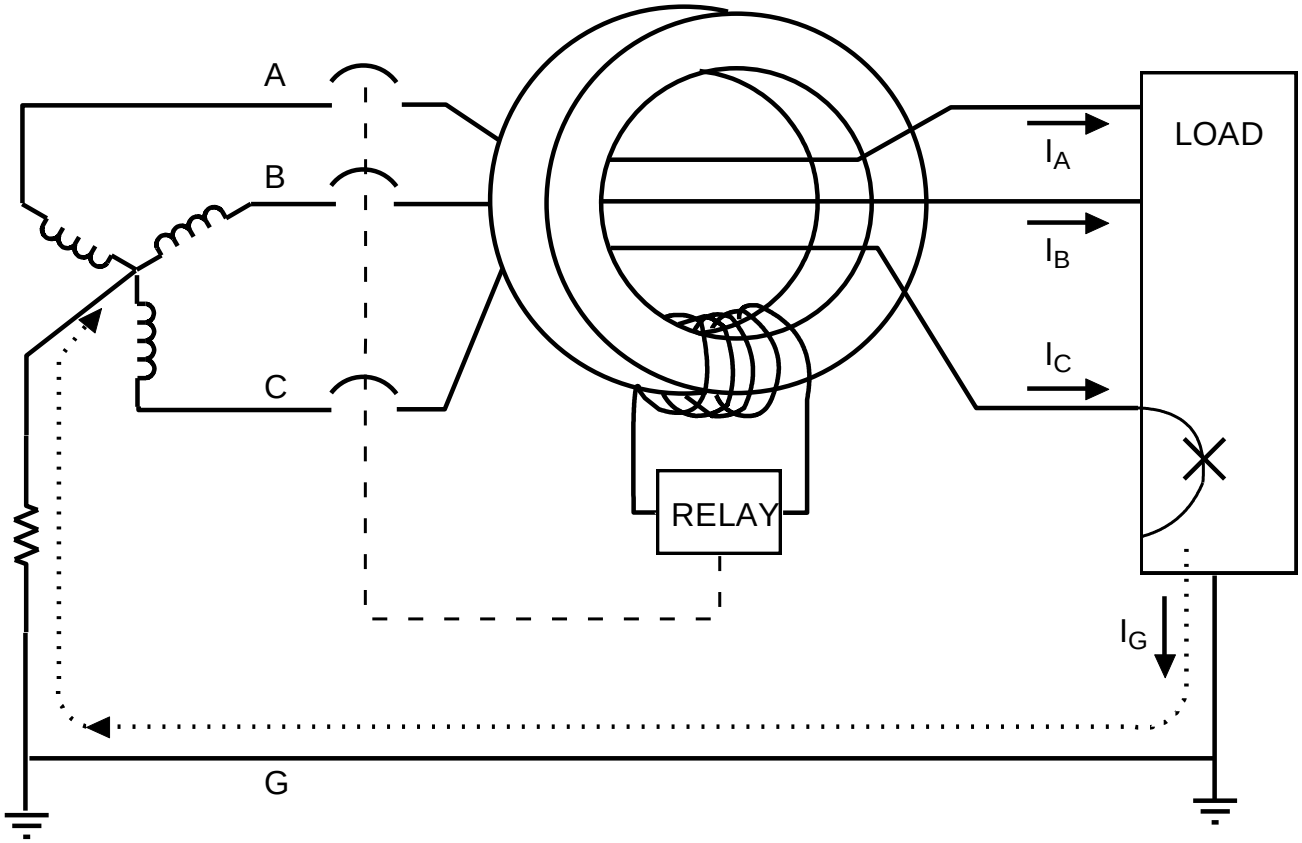
Approaches for ground detection

- Voltage Sensing GF Relay
- Current Sensing GF Relay
- Swbd Multi-Feeder GF Alarm Relay
- Swbd GF Relay with 2nd Fault Protection
- GF Relay for MCC’s
- Combination wall-mounted NGR and GF Relay for Retrofits

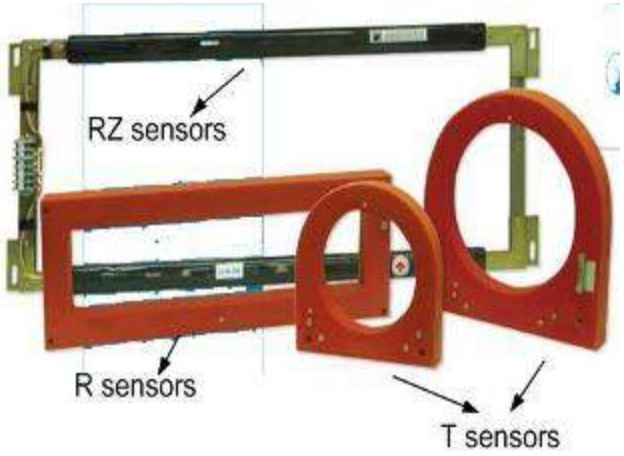
VIA Voltage Alarm Indicator

Description:
The I-Gard VIA is a Ground Fault Alarm Indication unit. It is designed to provide an alarm when a single ground fault occurs, and to indicate on which phase the fault occurred.

Sensing Ground Faults Using a Zero Sequence Sensor



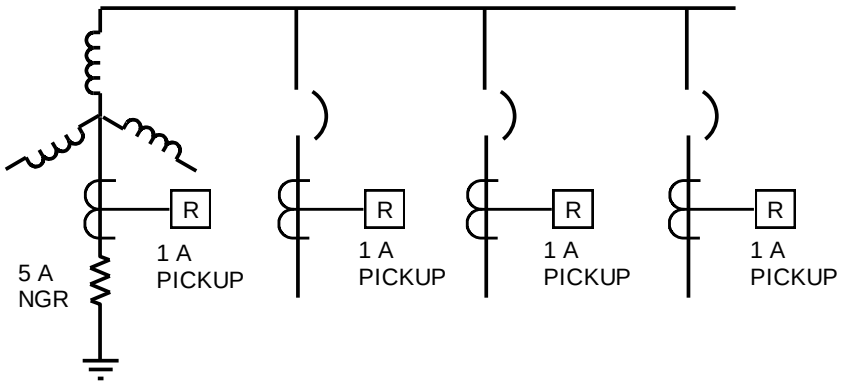
Zero Sequence Sensors



Description:
The I-Gard zero sequence current sensors are used to detect ground leakage currents on medium or low voltage, grounded or ungrounded AC electrical systems. The output from the sensors is used to operate I-Gard ground relays to provide equipment or life protection depending on the relay selected. The sensor should encircle the phase conductors and the neutral, if it exist s and is used, but not the grounding conductor or the shield of the cable.

Zero Sequence Current Sensing and Arc Flash sensing Relay - Sentri

- Selective – identifies faulted feeder
- 3- Optical sensor Inputs

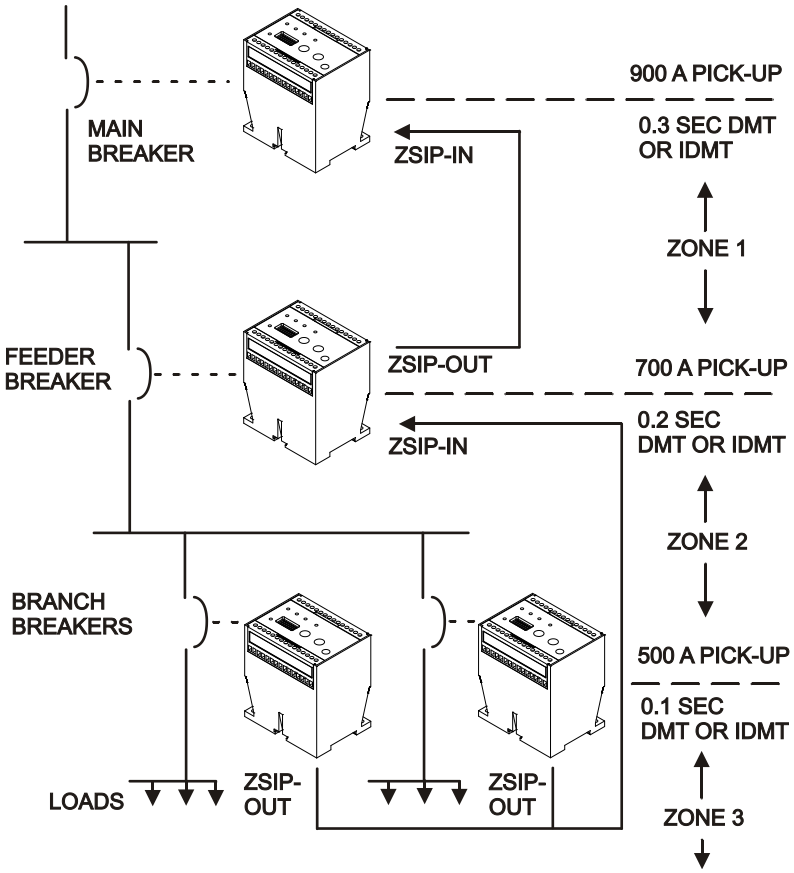


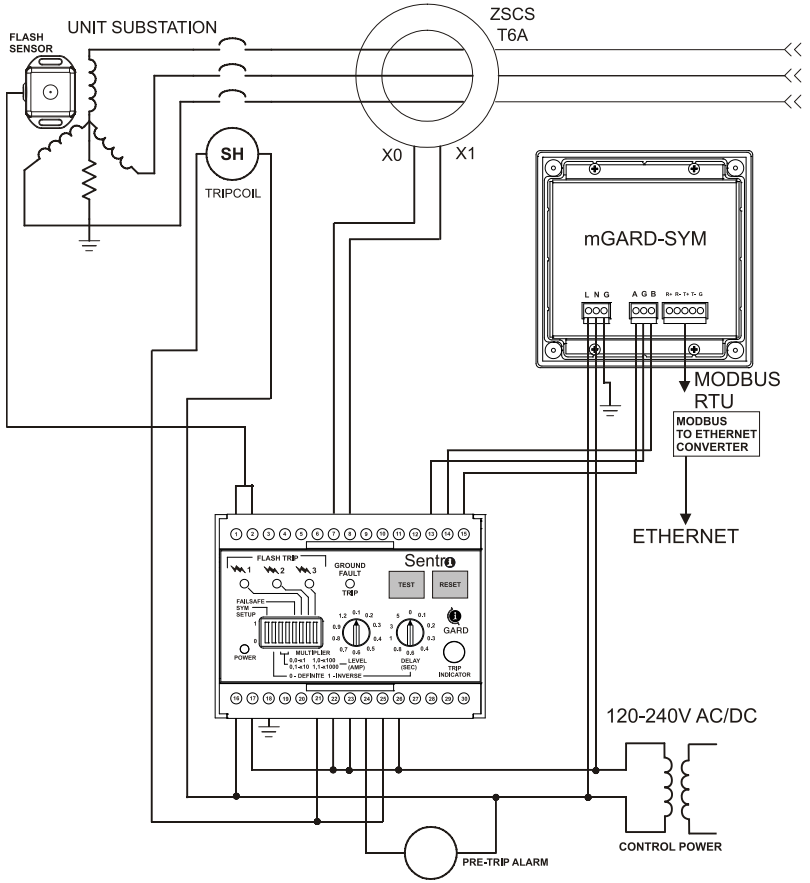
Sentri

- Ground fault and arc flash built into 1 relay.
- Solidly grounded or Resistance grounded systems.
- 0.1 A to 1200 A trip settings.
- Can connect to 3 self-monitoring arc flash sensors.
- Less than 1ms trip time on arc flash.
- Solid state relays with mechanical relay backup.
- Pre-trip relay for indication prior to main relay tripping.
- 1 A and 5 A CT inputs as well as ZSCS inputs for sensitive protection.
- Monitor current with mGARD-SYM display.
- Modbus capability with mGARD-SYM display.
- ZSIP Selective Instantaneous Protection

Arc Detection and Mitigation Current and Light Schematic

Ground Fault Protection, Zone Interlocking Protection (ZSIP) Remote Monitoring and Arc Flash Mitigation all in one relay





Multi-Feeder Ground Alarm Relay – OHMNI

Voltage Sensing Relay

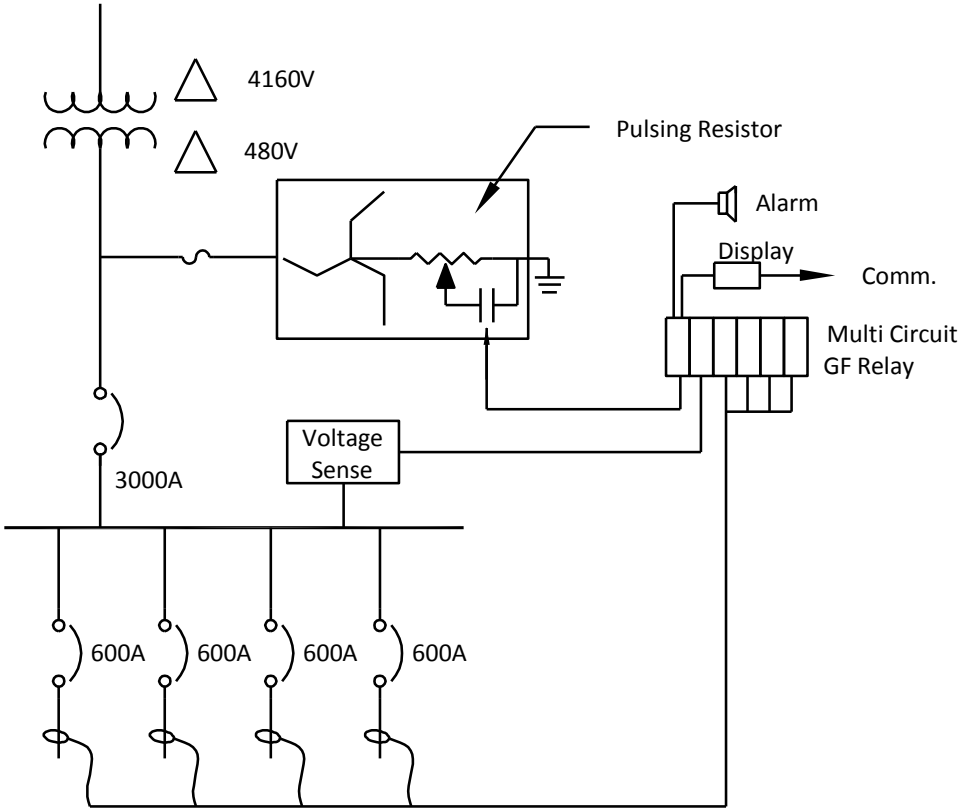
Current Sensing Relay Modules

OHMNI Features

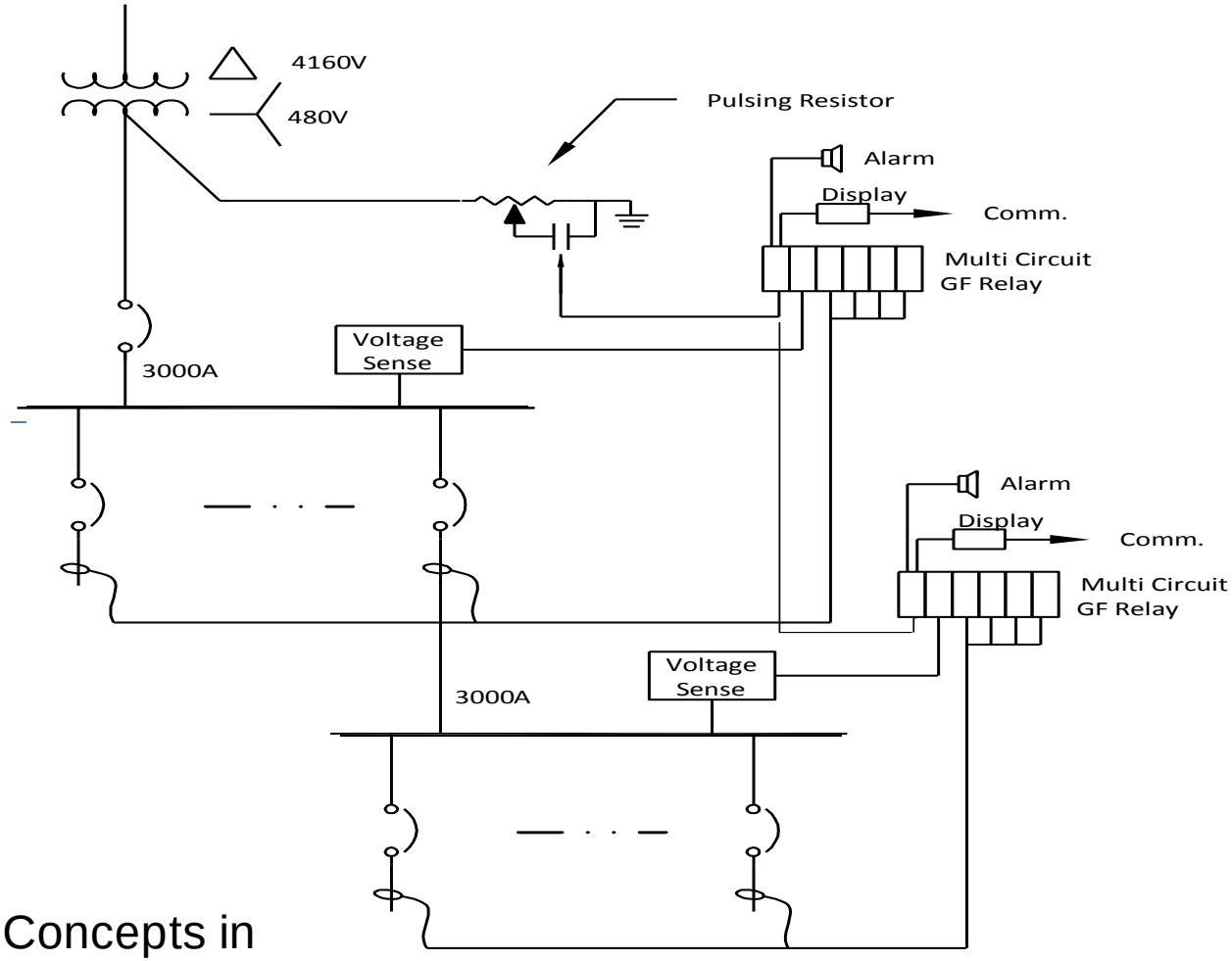
- Identifying faulty phase and faulty feeder. First Fault Alarm and Selective Second Fault trip or First fault trip
- Modbus communications
- Enhanced relay security - inrush detection prevents nuisance tripping on severe magnetizing inrush
- DIN rail mounted – takes much less space on switchgear – now fits in 22”-wide sections
- Pulsing system
- Sigma NGR monitoring Relay
- Local Display -

Single Source Systems

- Apply Ground fault detection with Voltage to ground and Zero sequence current measurement on feeders – Alarm on first fault



Single Source Fully Selective System

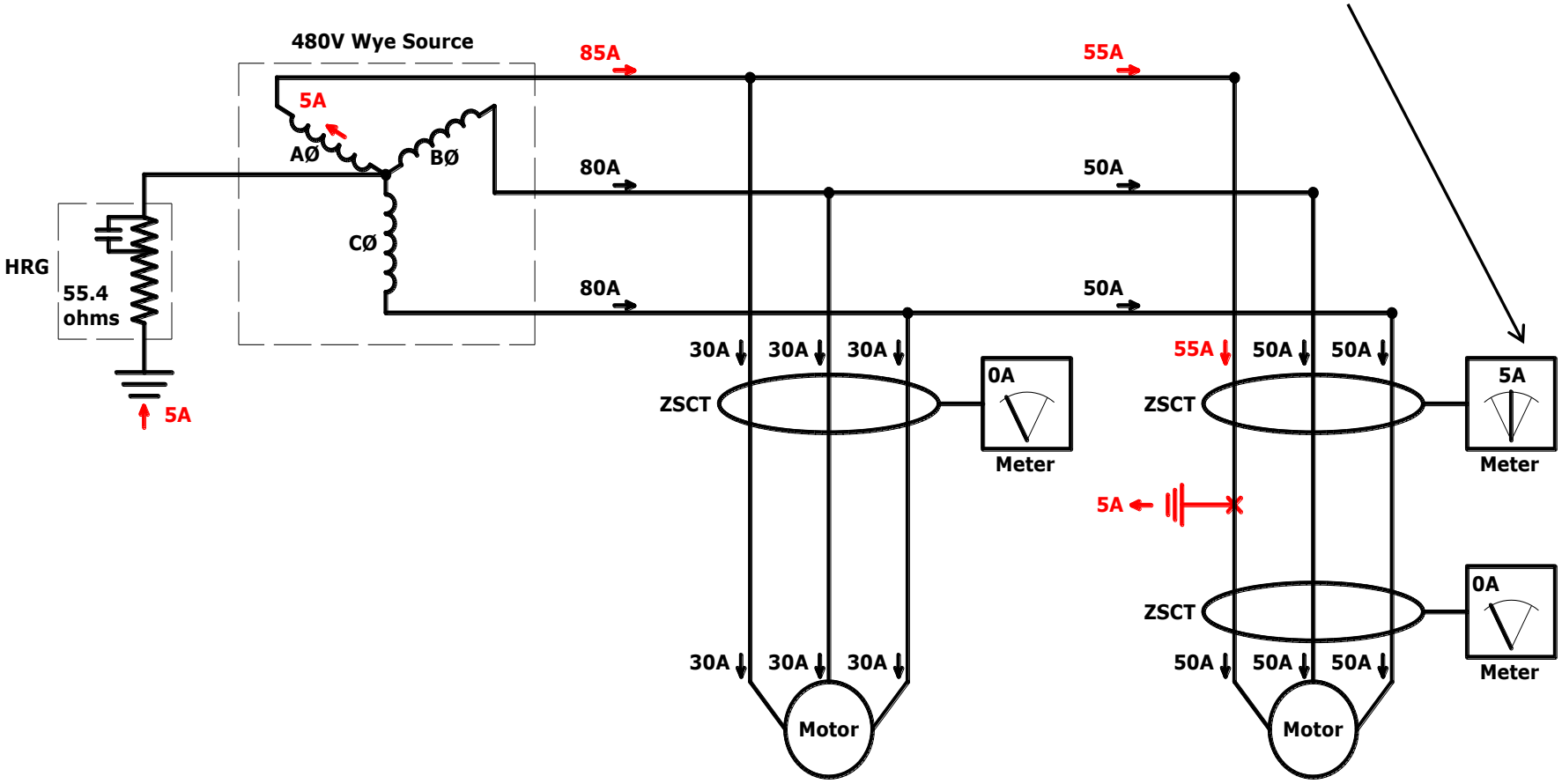


Advanced Concepts in
High Resistance
Grounding
IEEE IAS PCIC 2012

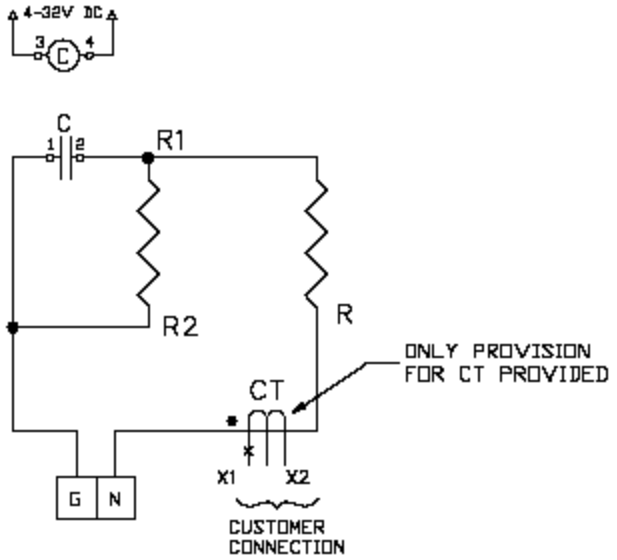
High Resistance Grounding

Method to quickly locate ground faults.

Meter reading will alternate showing high low pattern every 2 seconds.



Portable Current Sensor for Fault Tracing



Pulsing NGR

Ground Fault Pulse Locating

GF Relay for Motor Control Centres – m-Gard

Can use external sensor
Communication to m-Gard-Sym, up to 50 units daisy chained

m-Gard Fits In MCC Bucket

mGARD Ground Fault Relay and mGARD-SYM

DIN Rail and flush mountable

- Built-in current transformer
  - Ideal for Motor Control Center (MCC buckets)
- DIP Switch selectable trip and delay levels
  - 4 Types available

  mGARD-10-A

  mGARD-10-A1

  mGARD-10-A2

  mGARD-100

  Communication to mGARD-SYM

Combination NGR and GF Relay

- SLEUTH
- For retrofit applications

Sentinel:
Ohmni Relay and Pulsing Resistor

The SENTINEL is designed to detect the event of a single ground fault, signal an alarm, and point to the affected branch or feeder. Thus maintenance can be immediately alerted of the problem and an operator may be dispatched to locate the fault and to isolate it promptly.
The SENTINEL system can assist in locating the fault with a pulsing fault location circuit. In the event of a second ground fault, the SENTINEL acts quickly to prevent the loss of two feeders by selectively tripping the lower priority feeder only.

Lower PPE with Advanced HRG

The Gardian *combines HRG technology and* optical arc mitigation that provides protection at the speed of light and lowers incident energy to safer levels resulting in needing lower category PPE.

Gardian

Protects against both ground faults and arc flash.

NGR Monitoring Ground Fault Relay

SIGMA

Description:

The I-Gard SIGMA RELAY is a combination of a Ground Fault relay and a Neutral-Ground path monitor.

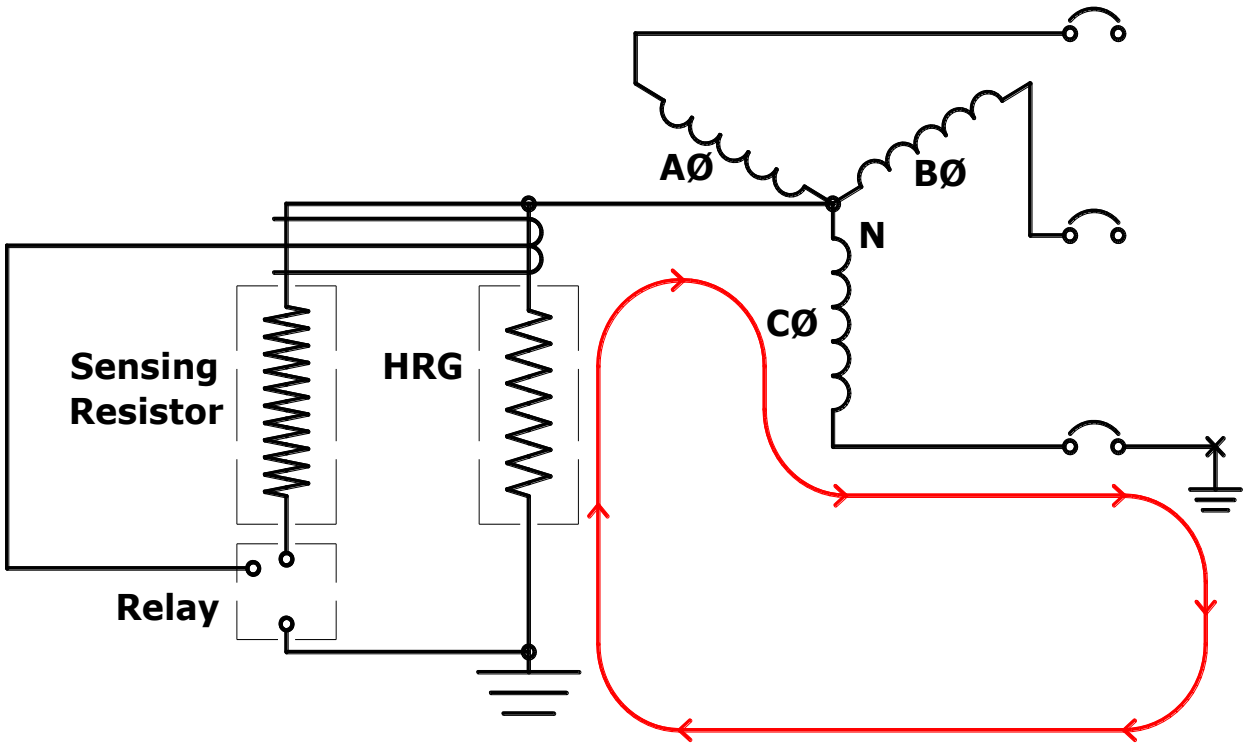
In distribution systems employing Resistance Grounding the SIGMA RELAY protects against ground faults and abnormal resistance values of the Neutral Grounding Resistor (NGR).

The SIGMA RELAY is specifically designed for a variety voltages and a variety of NGRs .

High Resistance Grounding

NGR Monitoring Ground Fault Relay & Sensing Resistor

Detects Open / Short Circuits and maintains Grounding



Loss of Ground in HRG Systems

SIGMA Resistor Monitor

- Applies on 480 to 25 KV systems

Provides three functions :

- Measures Current through NGR using a sensor– Ground fault trip 8 settings 5% to 50% and 32 time delay settings – 60millisecs to 3 secs
- Measures Neutral to ground voltage using a sensing resistor connected from Neutral to ground
- Determines NGR resistance value and trips if the value is larger than 150% and smaller than 70% with a delay of 1.5 secs

Provides three output relays GF trip, NGR trip and Aux GF trip

- Has Zone Interlocking feature to provide coordinated GF trips
- NGR let through current measuring range 5A – 400A using 1000:1 Sensor
- When current and Voltage are less than 1% the resistance value cannot be determined and the relay turns off
- Selectable mode : Failsafe or Normal

GEMINI

Twin path high Reliability Resistor and Monitoring Relay

GEMINI is a unique patented, fail safe, all-in-one neutral grounding system that combines ground fault protection with a redundant resistor system, in addition to a built-in resistor integrity monitoring relay. Providing protection against any compromising of the resistor integrity, the patented twin resistance paths in combination with the integrity monitoring relay form the heart of the GEMINI system.

What type of Grounding System do you Employ?

Ungrounded

ViA

- Ground Fault Indication on Wye or Delta-connected, 3-phase, 3-wire
- No external hardware
- Protection Relay

Turbo Sleuth

- Portable HRG System
- Fault Limiting Resistor
- Pulsing Circuitry

Insulation Monitoring

- Automatic Operation
- Early warning of insulation problems
- Usable with variable speed drives
- Integral Self-test capability

Resistance Grounding

High

Gemini

- Dual path current limiting resistor
- Redundant fail-safe resistor circuit
- Integral ground fault relay
- Integral ground monitoring relay
- Fault location through pulsing
- Harmonic filter and time / current adjustments to reduce false trips

Sentinel

- Current limiting resistor
- Voltage and current sensing
- Integral ground fault relay
- Integral ground monitoring relay
- Fault location through pulsing
- Harmonic filter and time / current adjustments to reduce false trips
- Inrush detection restraint
- Multi-feeder protection
- Second fault protection
- MODBUS for remote monitoring

DSP-OHMNi

- Monitors and protects up to 50 feeders on one relay
- 1st Fault Alarm, 1st Fault Trip or 1st Fault Time Delay Trip
- Resistor Monitoring Module
- Selective Instantaneous Feeder Trip on 2nd ground fault

Gardian

- HRG reduces the frequency of arc flash incidents and optical detection reducing impact, all in one.

Low

Sigma

- Monitoring Relay

Solid Grounded

Sentri

- Arc Flash Mitigation
- ZSIP Selective Instantaneous Protection
- 40 trip levels from 100 mA up to 1200A

m-Gard (10,100,125,250)

- Microprocessor based ground fault relay
- Built-in zero sequence current sensor (ZSCS)
- MODBUS connection to external Network
- Monitors up to 50 devices
- Remote Data Collection
- Remote Relay Reset

ARC-i-TEC

- Fastest Arc Detection Technology
- Combines monitoring for abnormal current to avoid nuisance tripping
- 4 output relays for tripping and alarming

Pressure Arc Detector

- Fast detecting of the pressure wave generated by the arc
- Detection time in 10ms
- Easily integrates with other arc mitigation technology

Hybrid Grounding

Contact I-Gard for a system solution that works with your needs!

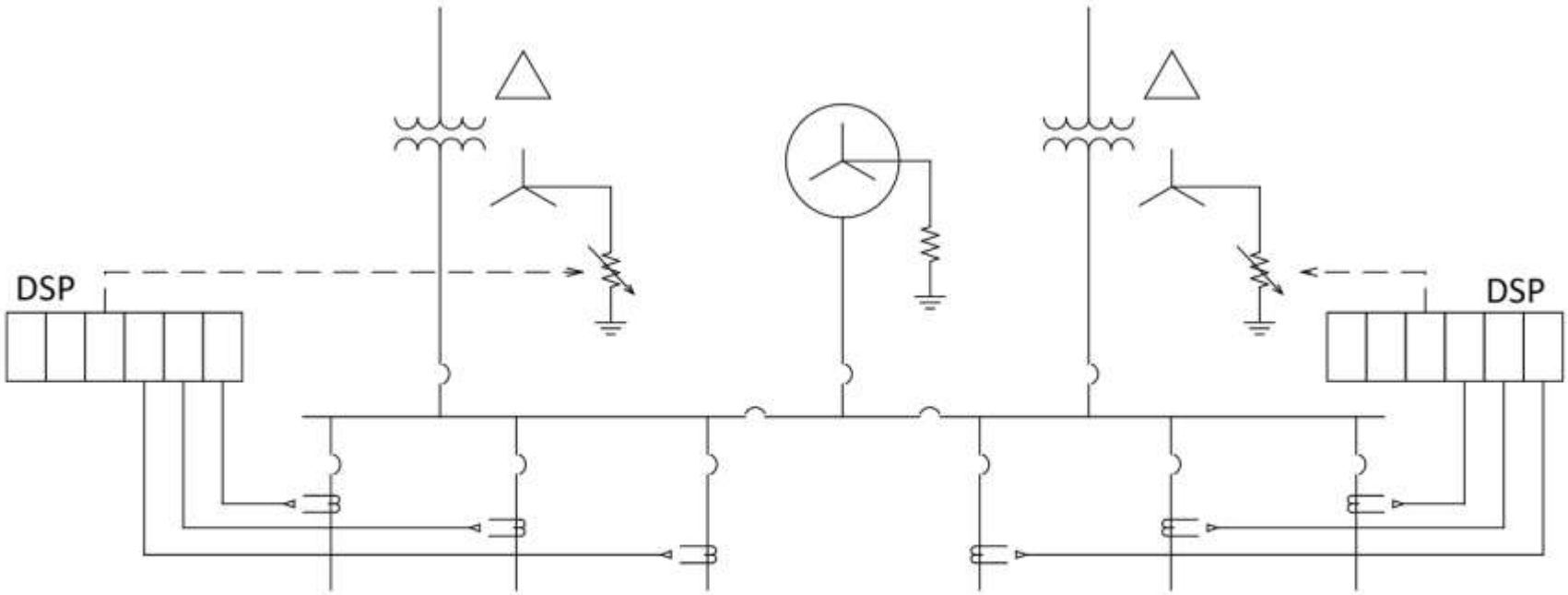
Application Considerations

1. Where to apply the Grounding Resistor
- At the transformer or
- At the main bus

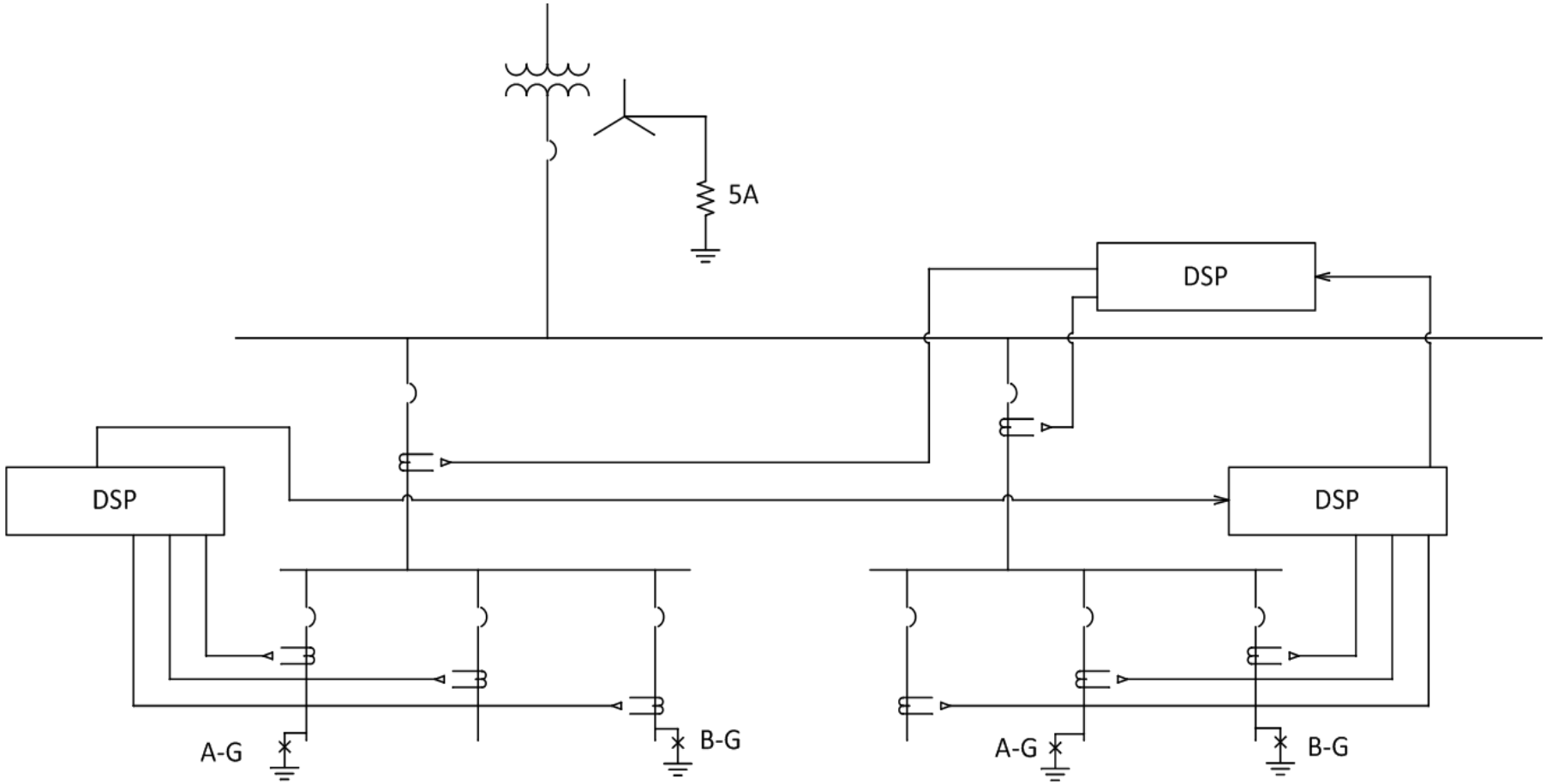
2 When to apply first fault alarm only

3. When to add 2nd fault trip function
- Selective Instantaneous feeder tripping
- Coordination with down stream Over current in 2nd fault trip

4. When to use 1st fault trip



Main-Tie-Main DSP System

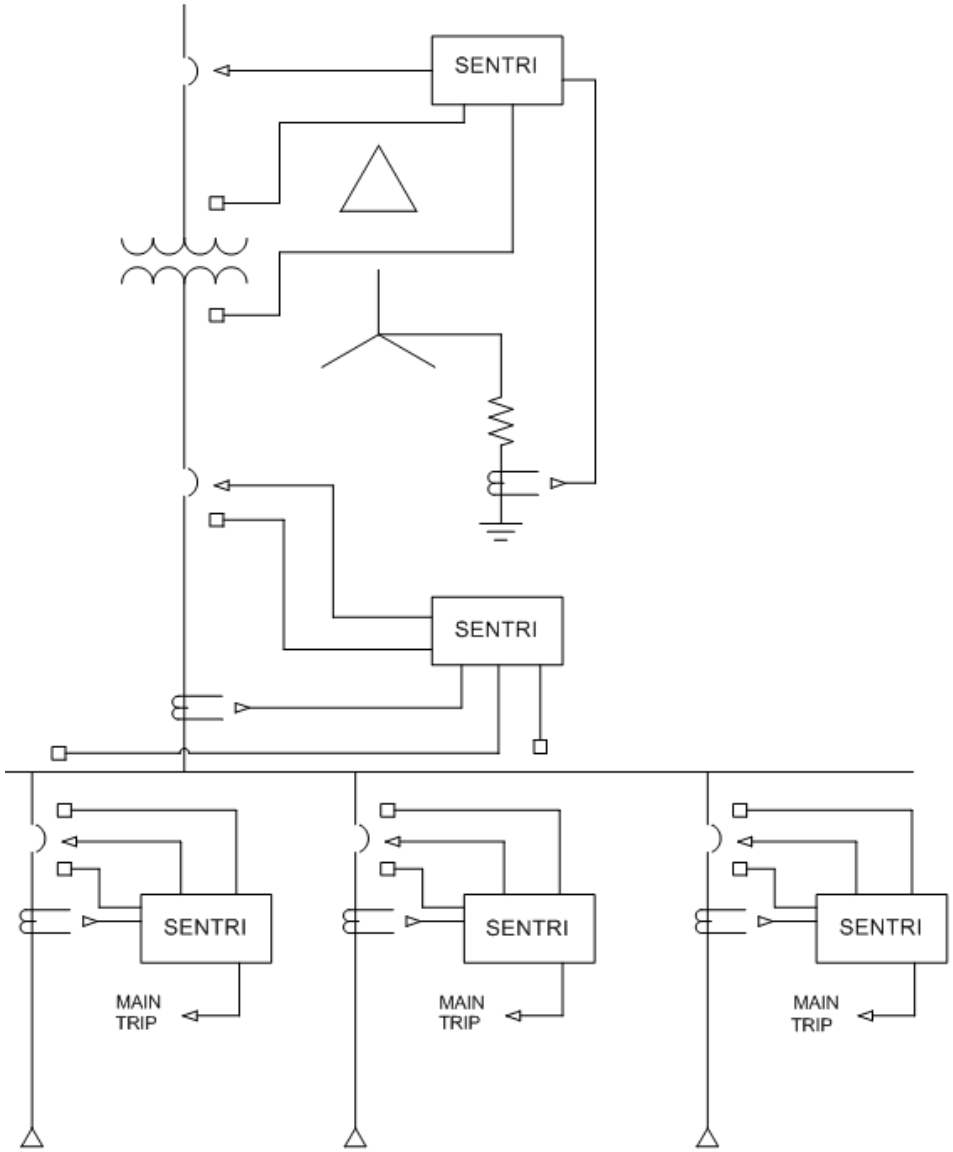


Distribution System with DSP

Reducing Arc Flash energy exposure on the line side of LV main breaker

- Use Arc Flash sensing relay and trip the Primary side MV device, It has to be a fast breaker Load break switches even if they are trippable are too slow

  Vac breaker has to be used



HRG and Arc Flash Protection

Integrating Standby Generator

Incorrect Grounding Generator 3-Pole ATS with Solid Neutral

- Multiple neutral grounds
- Code violation, load current on bonding conductor
- Nuisance tripping on Neutral circulating current
- GFP may fail to trip

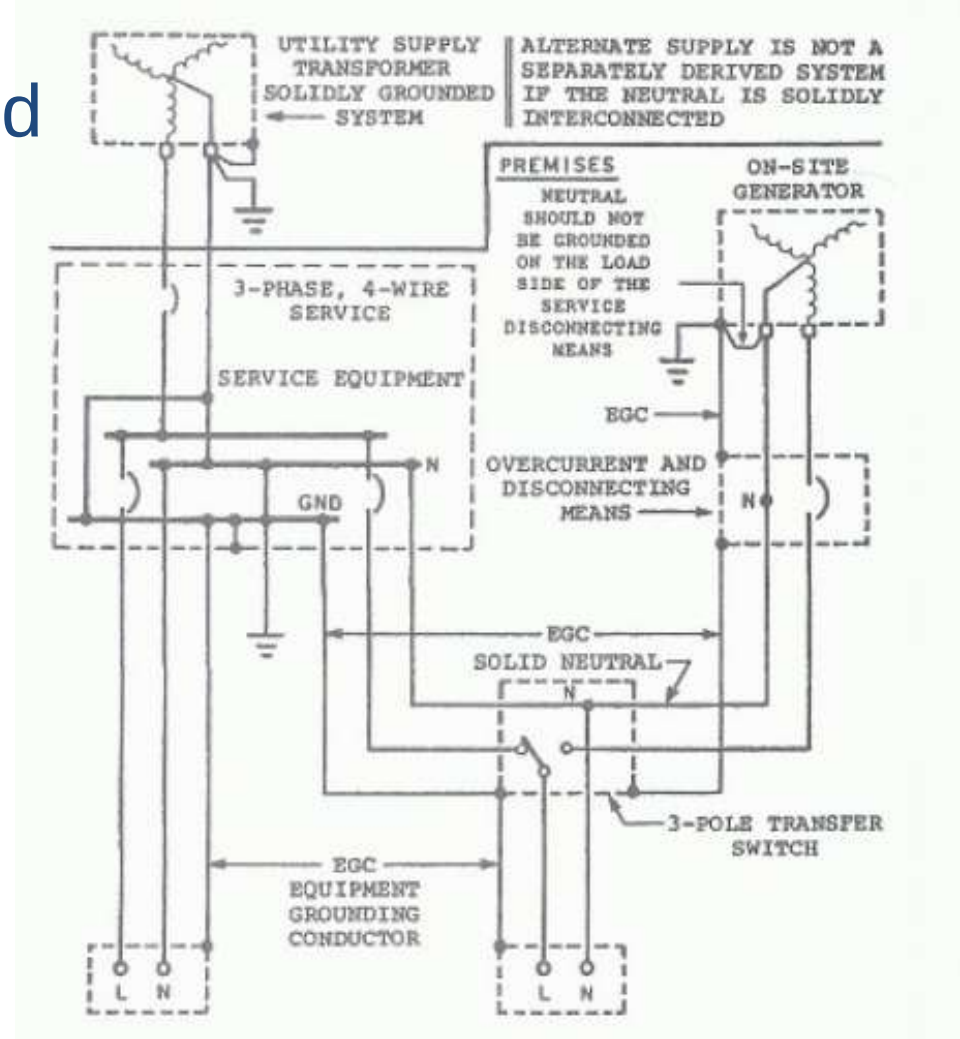


Figure 7-7
IEEE Orange Book
Std. 446-1995

Multiple Transfer Switches – Nuisance Ground Fault Trips

Must use four pole transfer switches

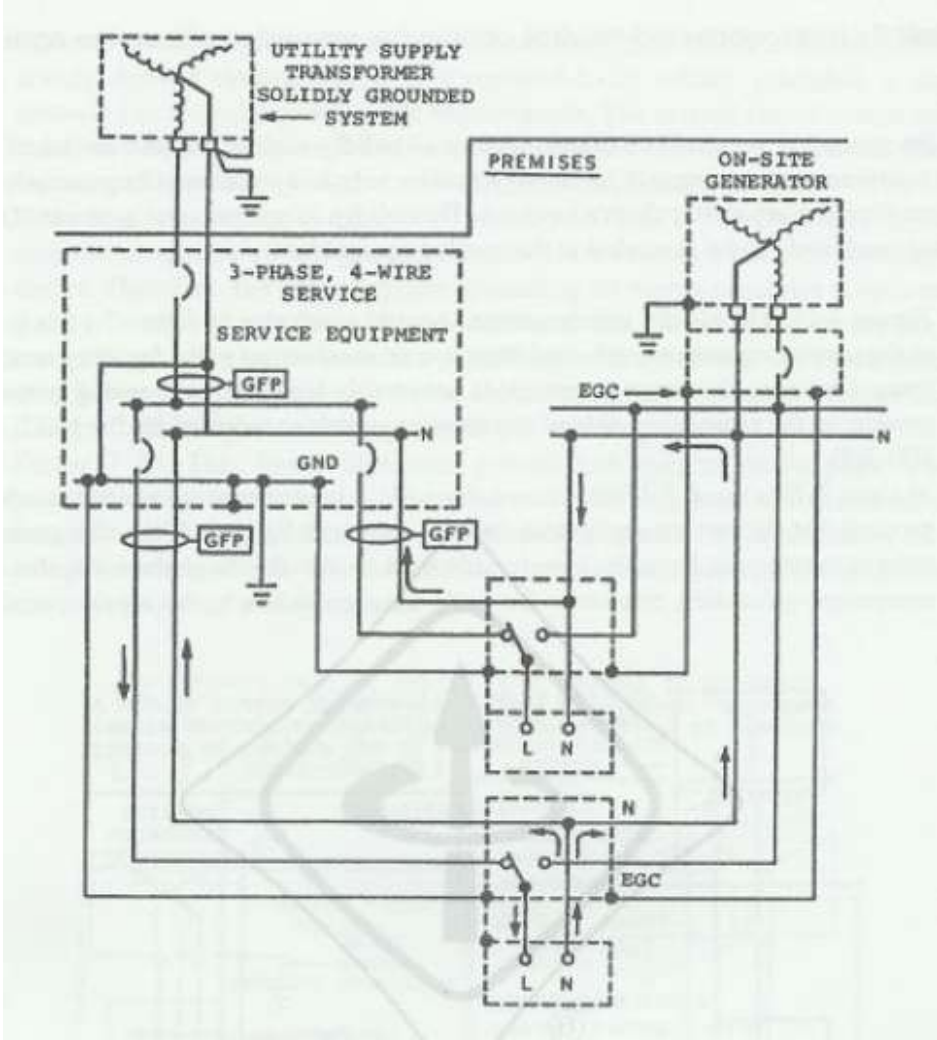
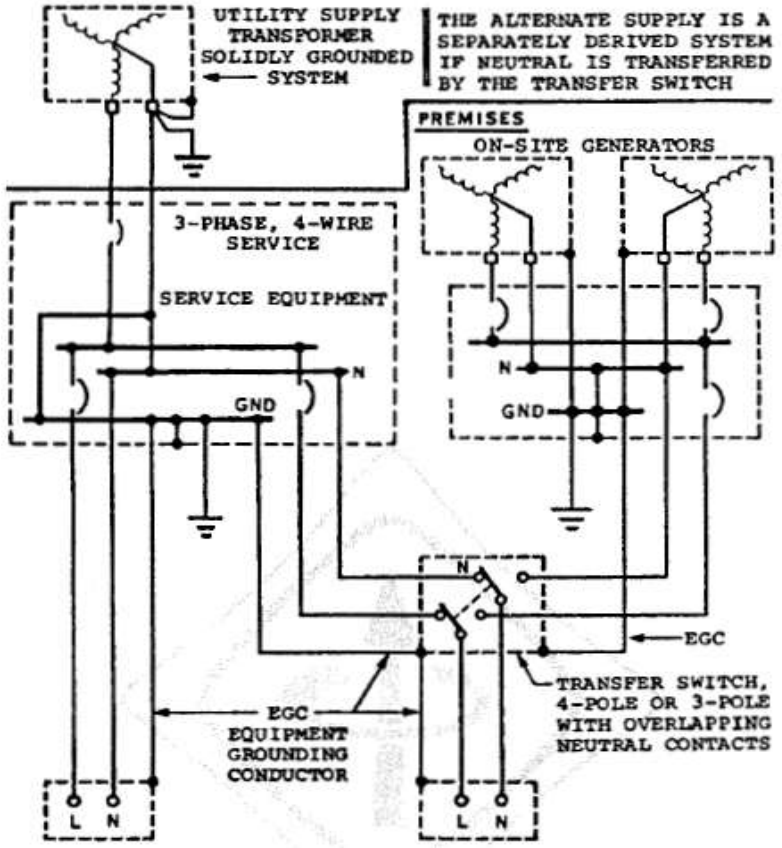


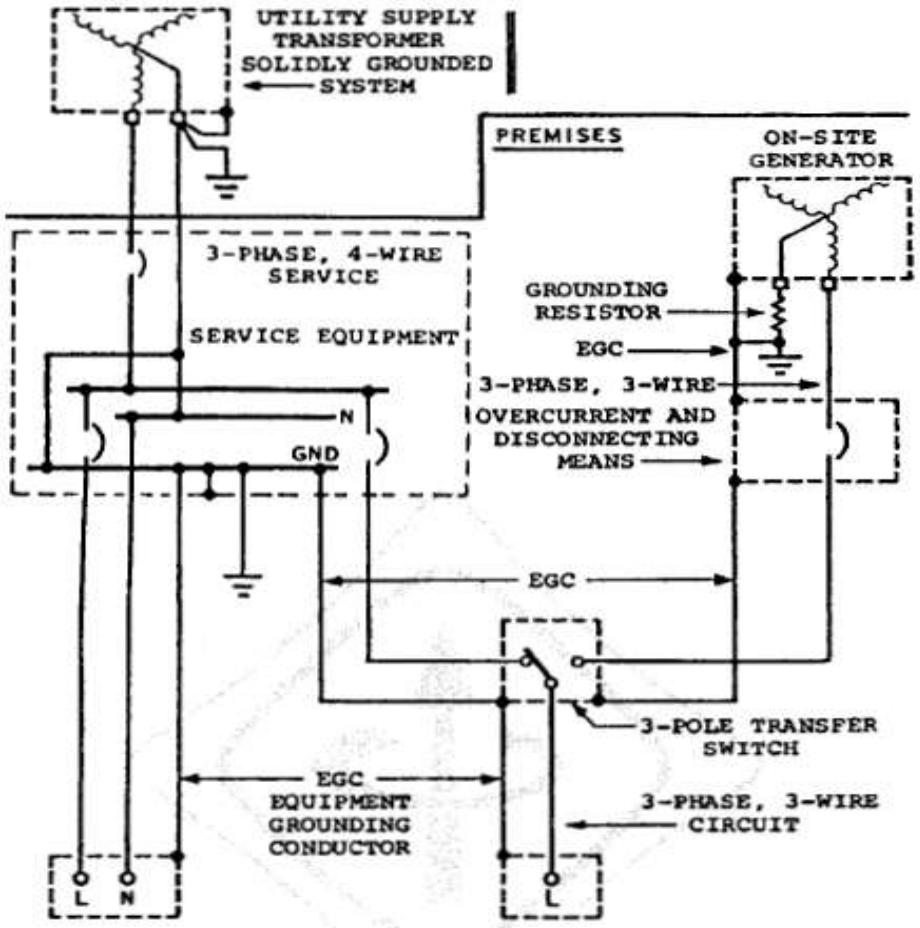
Figure 7-17 (a)
IEEE Orange Book
Std. 446-1995

4-Wire Emergency Loads: Parallel Generators



Source: IEEE Std 446-1995, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, Figure 7-13, p. 236.

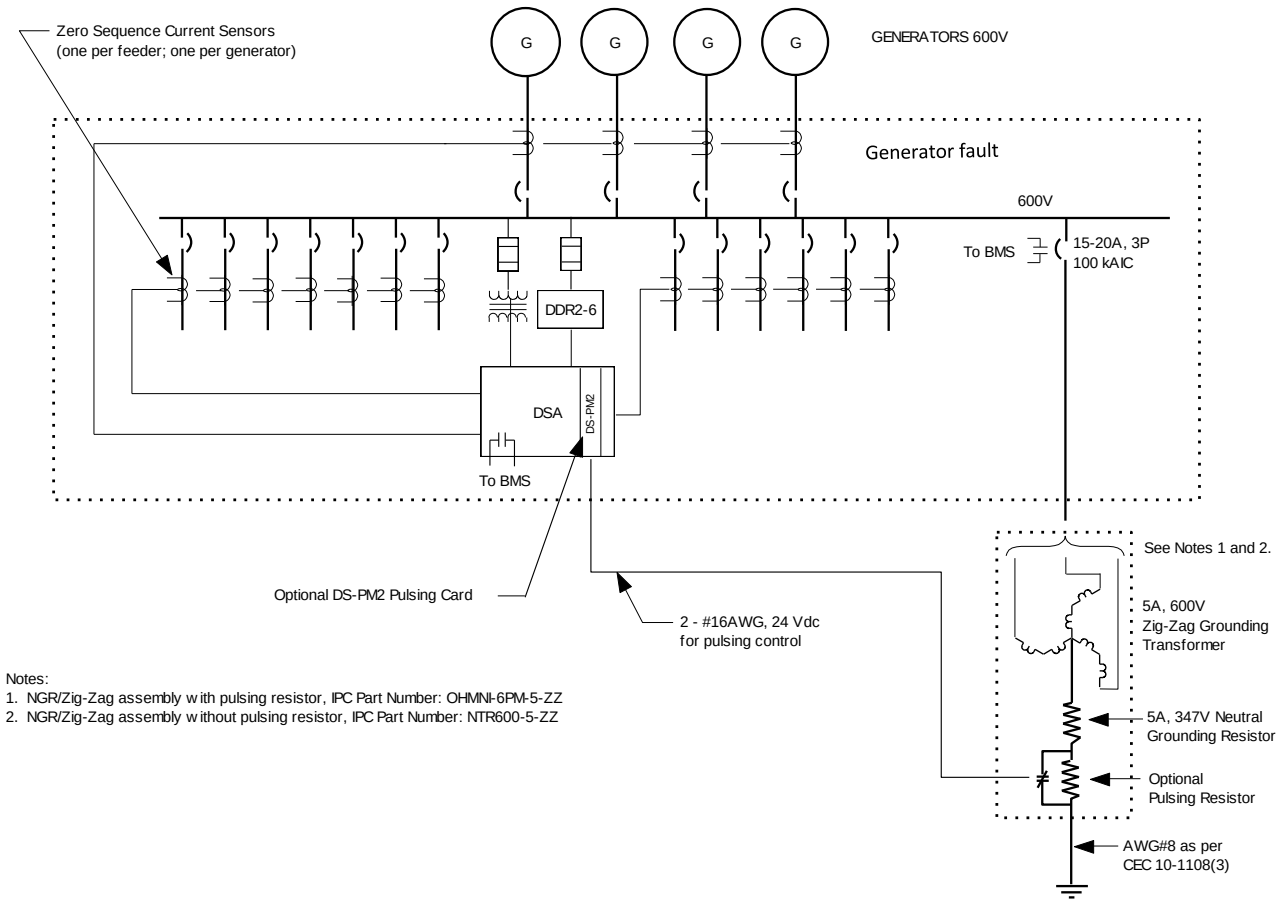
Normal supply - 4wire solidly grounded 3-Wire standby *High Resistance Grounded*



Source: IEEE Std 446-1995, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, Figure 7-13, p. 246.

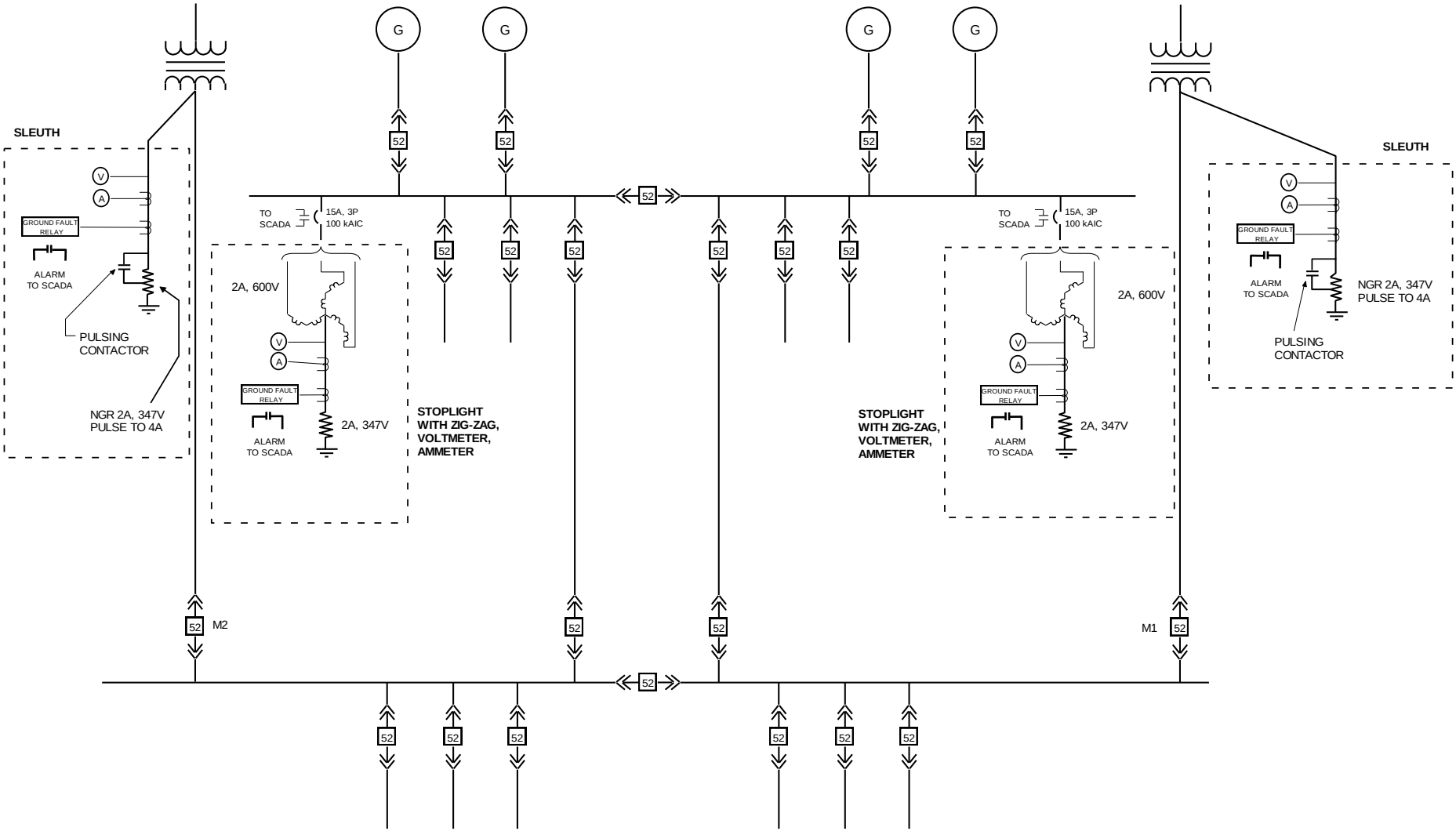
Parallel Generators

TYPICAL PARALLEL GENERATOR HIGH RESISTANCE GROUNDING SCHEME



Notes:
1. NGR/Zig-Zag assembly with pulsing resistor, IPC Part Number: OHMNI-6PM-5-ZZ
2. NGR/Zig-Zag assembly without pulsing resistor, IPC Part Number: NTR600-5-ZZ

HRG Retrofit of Parallel LV Generators



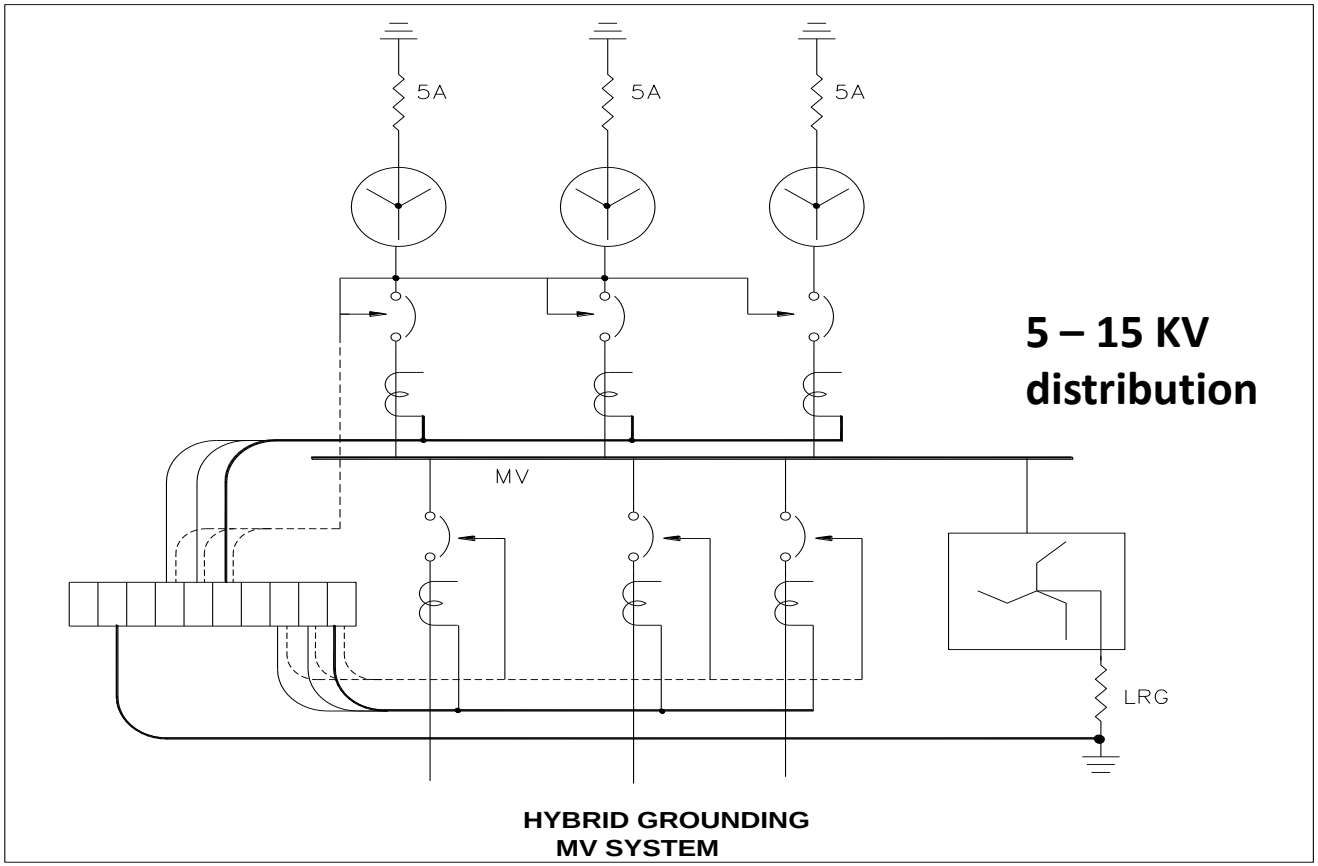
Low Resistance Grounding

- Used on medium voltage (5 KV -36 KV) distribution systems where system charging current is too high for high resistance grounding
- Ground fault current limited to 15 – 100 A typically ($I_R > 3I_{co}$)
- Trip on ground fault
- Prevents arc flash incident on ground fault

MV Neutral Grounding Resistor

Hybrid Grounding of MV Generators

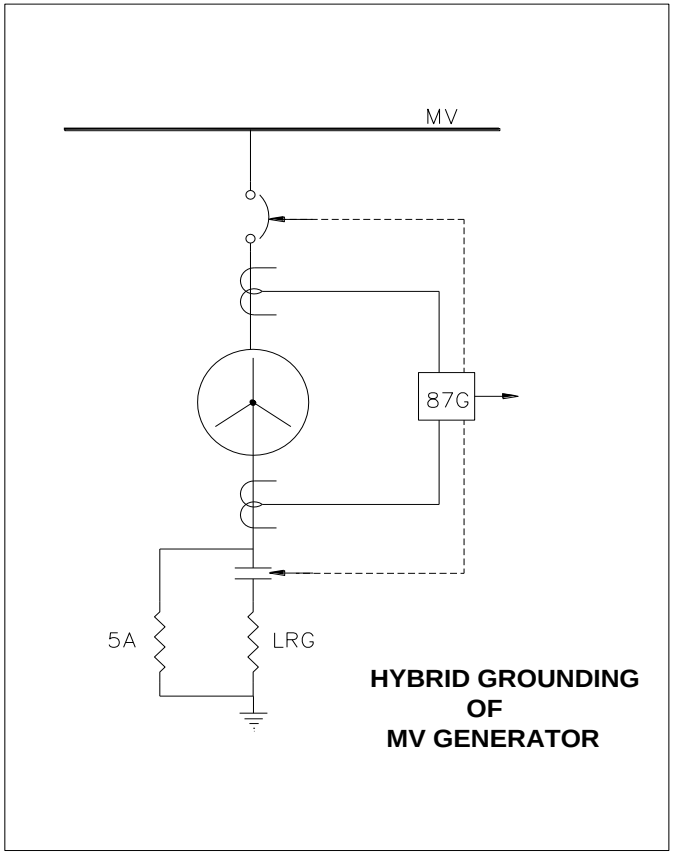
Applied when 3Ico is larger than the current contributed by the generator NGRs



Hybrid Grounding MV Bus Connected Generator

Applied to limit damage due to stator winding fault when LRG is 100A or more

MV Generators
ANSI C37.101
ANSI C37.102



Products and Solutions

- GF Relays and Panels for Shock protection

  10 ma - 50 ma , to 600 V
- GF Protection and Alarm Systems for Resistance grounded LV and MV distribution
- Relays for Mining application
- Arc Flash Protection Relays
- Insulation Resistance Monitoring for machines

Thank You

Questions?