Unparalleled Protection

Grounding of LV and MV Power Distribution Systems

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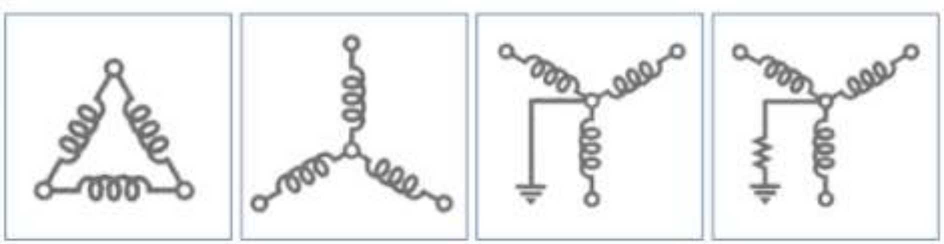
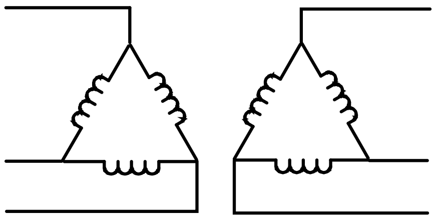
> www.i-gard.com

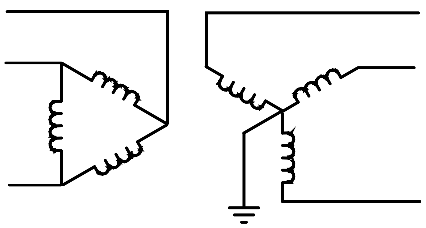


Power System Grounding Methods

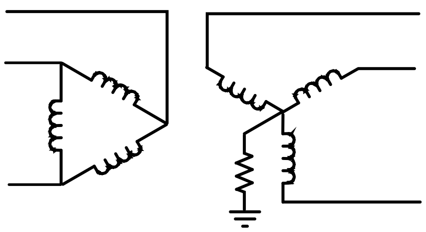
- Ungrounded



- Solidly Grounded



- Resistance Grounded

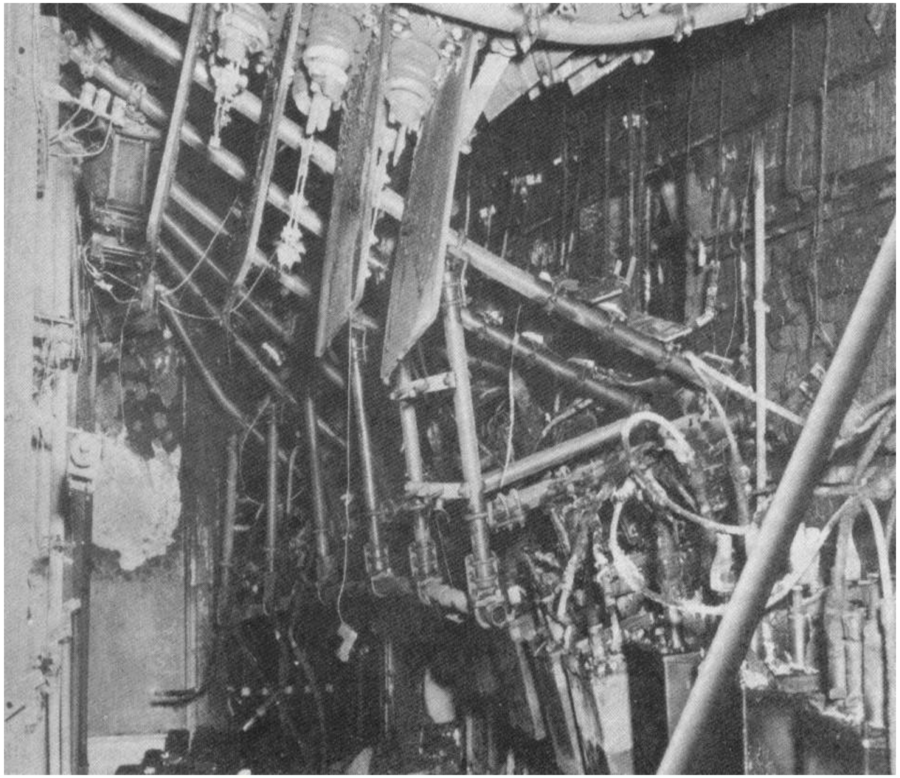


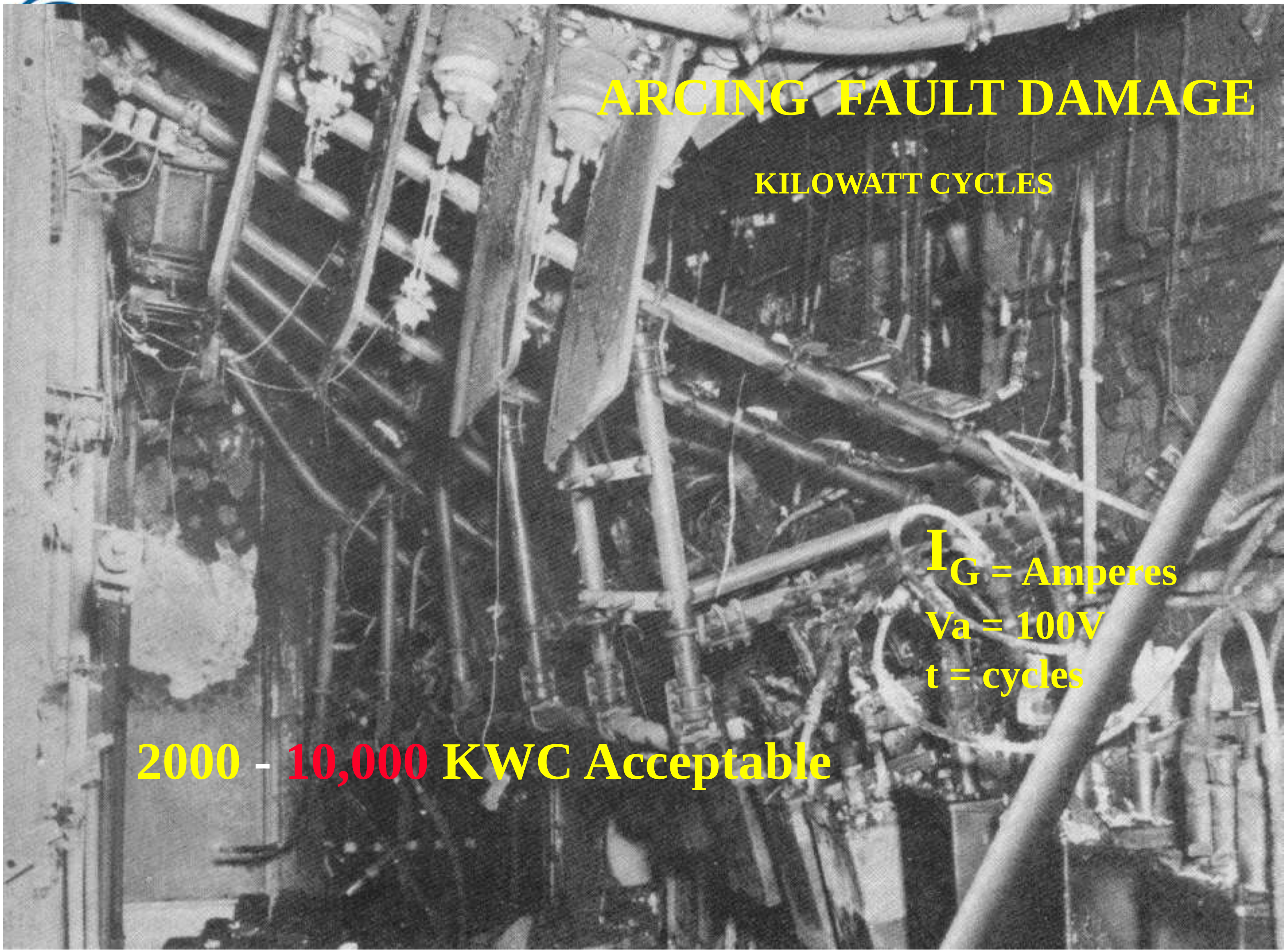
Solidly Grounded Systems

- Eliminates transient overvoltage problem
- Permits line-to-neutral loads (lighting, heating cables)
- Ground faults easy to locate, but cause unscheduled service interruption
- Danger from low-level arcing ground faults
- Since 1970's, ground fault protection mandatory for solidly grounded 600V services rated 1000A and higher by the CEC and the NEC

Low Level Arcing Ground Faults

- Sustained arcing faults can release intense heat and mechanical energy causing severe damage and injury





$$KWC = \frac{I_G \times Va \times t}{1000} \approx \frac{I_G t}{10}$$

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

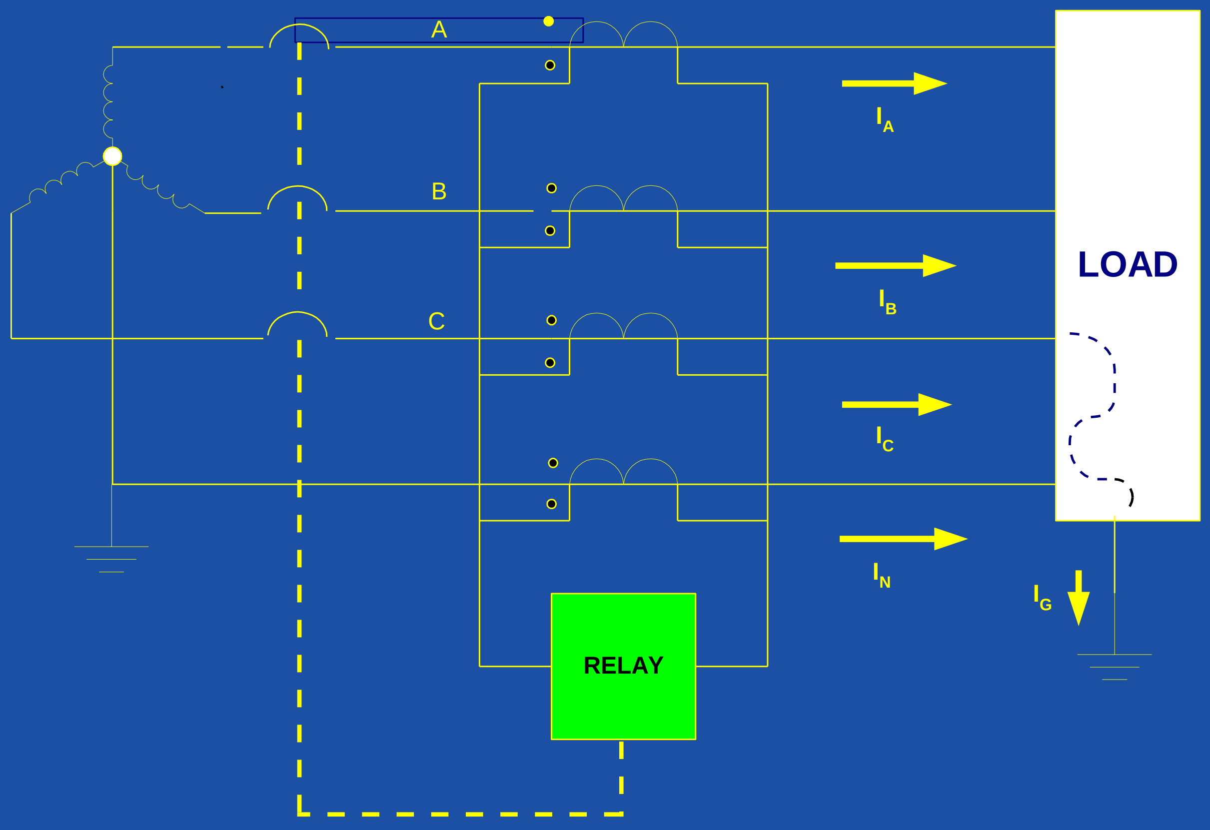
F) Over 20,000 Kilowatt Cycles
Considerable destruction in proportion to the let-through energy

IEEE – Arcing Faults

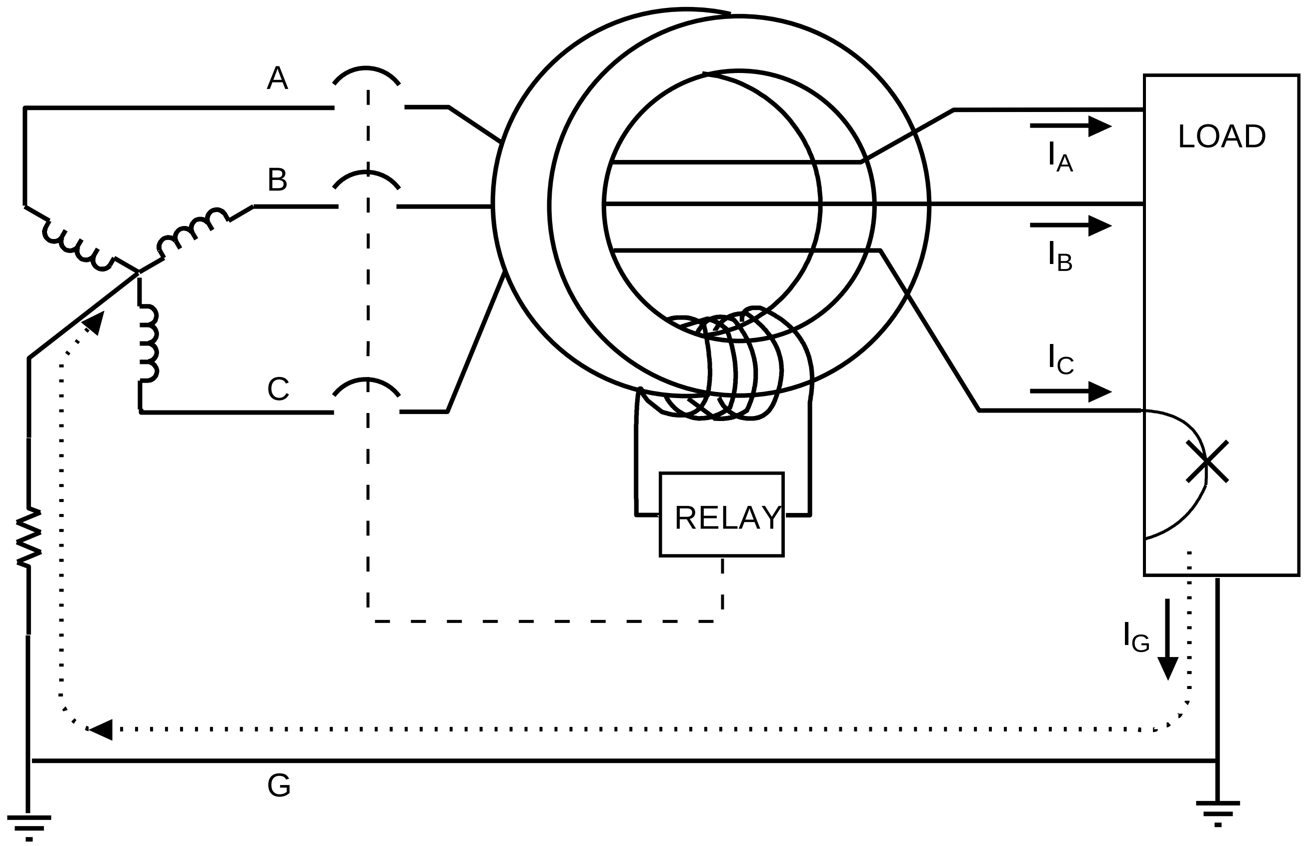
- **IEEE Std 242-2001**
  Recommended Practice for the Protection and Coordination of Industrial and Commercial Power Systems
  8.2.2
  One disadvantage of the solidly grounded 480 V system involves the high magnitude of destructive, arcing ground-fault currents that can occur.

- **IEEE Std 141-1993**
  Recommended Practice for Electric Power Distribution for Industrial Plants
  7.2.4
  The solidly grounded system 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.

Sensing Ground Faults Using Residually Connected CTs



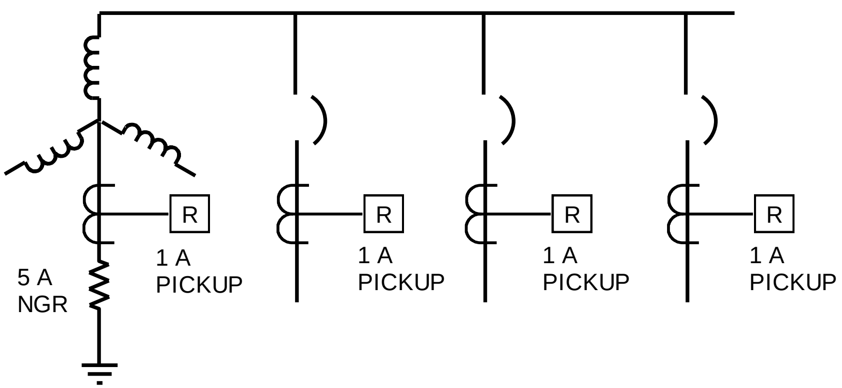
Sensing Ground Faults Using a Zero Sequence (Core Balance) CT



GARD

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 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 Metalen closed circuit breaker switchgear
- Fast acting tripping system uses circuit breakers to trip and isolate.

I-Gard Falcon

- 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 over current protection.

Falcon

- Main Module – up to 20 sensor inputs
- 4- Isolated fast triac outputs
- 6- isolated relay out put contacts
- Programmability including delay and logic functions for selectivity and back up protection
- Continuous self test function
- Expandable to 256 optical sensor inputs

Falcon Main Unit

Falcon 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.

Falcon Arc Unit

- 10 light receivers
- Detection level of light receiver can set by potentiometer
- Tripping can be tested from TEST-button
- Indication LED flashes green when functioning is normal
- LED is turned red when light is detected
- Flashing red indicates no longer light detection

Falcon Current unit

- Can be used for 1, 2 or 3 phases
- Current measurement can be from 1A, 2A or 5A current transformers
- Current level can set from 50… 500% of nominal current
- Tripping can be tested from TEST-button
- Indication led flashes green when functioning is normal
- Led is turned red when over current is detected
- Flashing red indicates no longer over current

Arc Detection and Mitigation

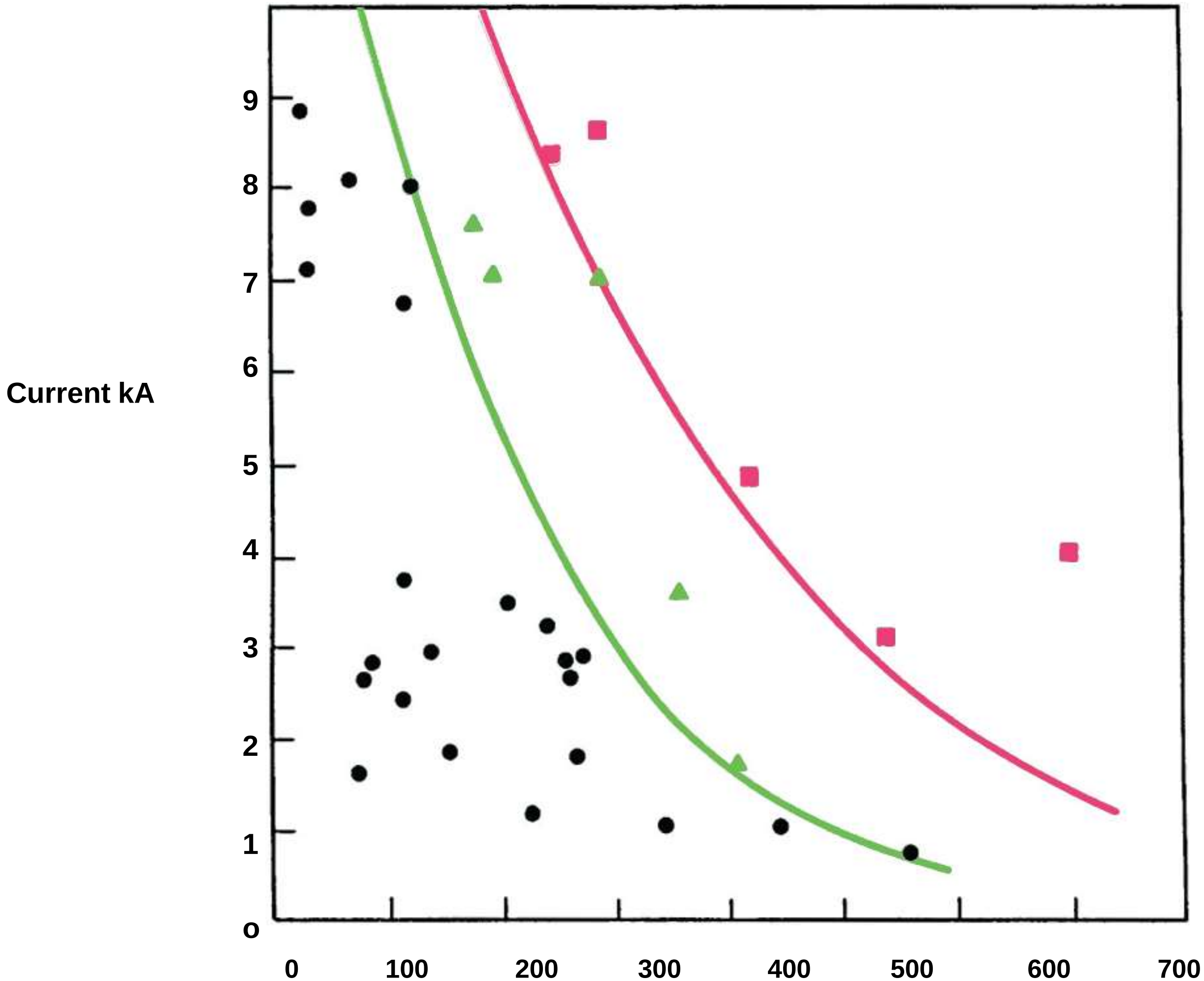
Total Clearing Time is Critical

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 damage curve showing arc current versus arc time



An arc is developed within milli-seconds and leads to the discharge of enormous amounts of destructive energy. The energy in the arc is directly proportional to the square of the short-circuit current and the time the arc takes to develop.

Reduce the Time,

Reduce the Damage,

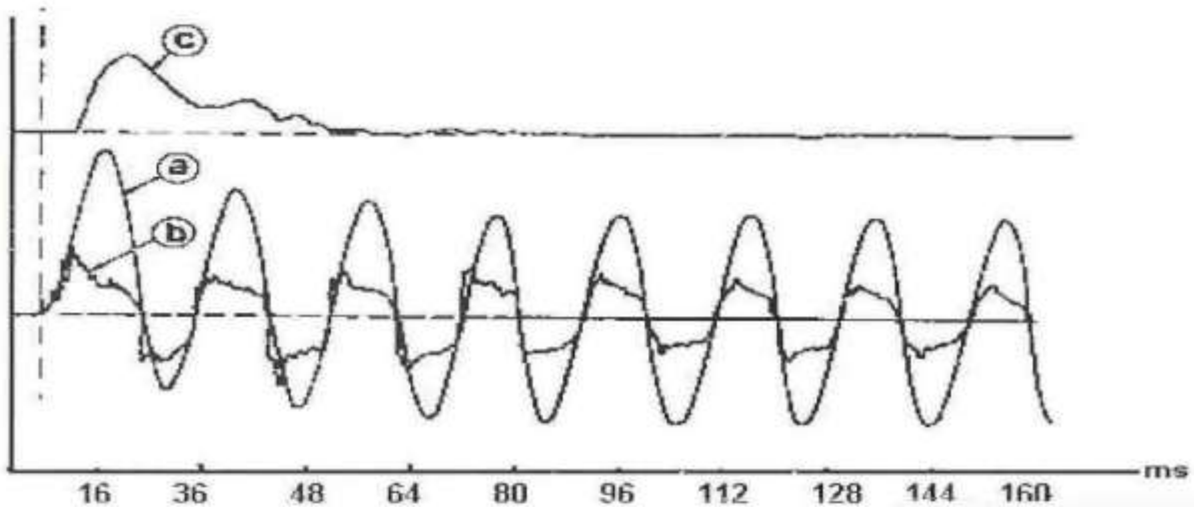
Reduce the Incident Energy.

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

Arc Detection and Mitigation
Optical Arc Detections

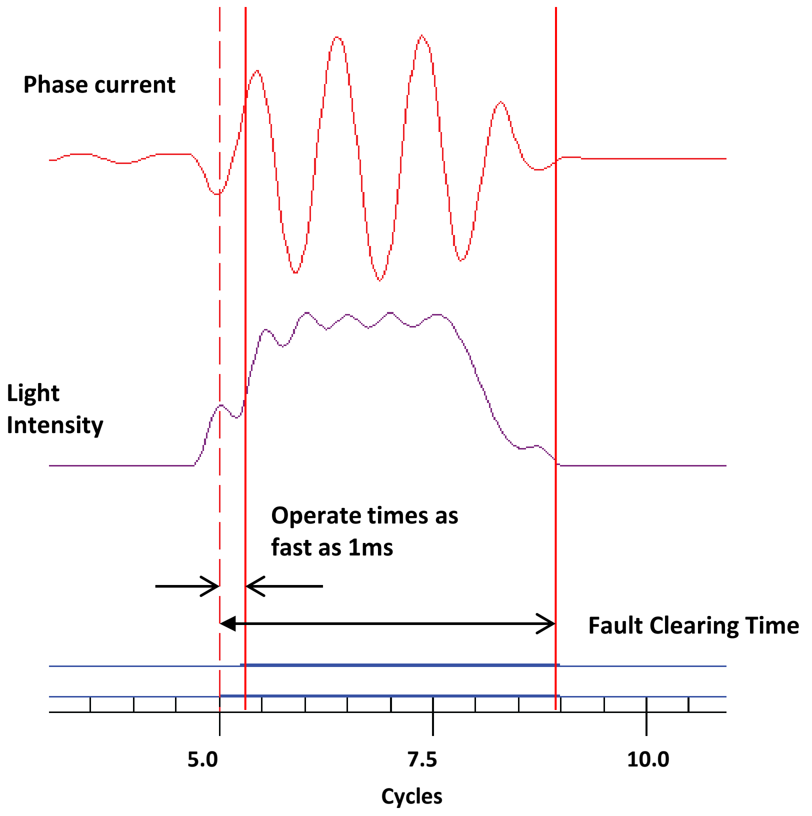
Improved Safety –

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

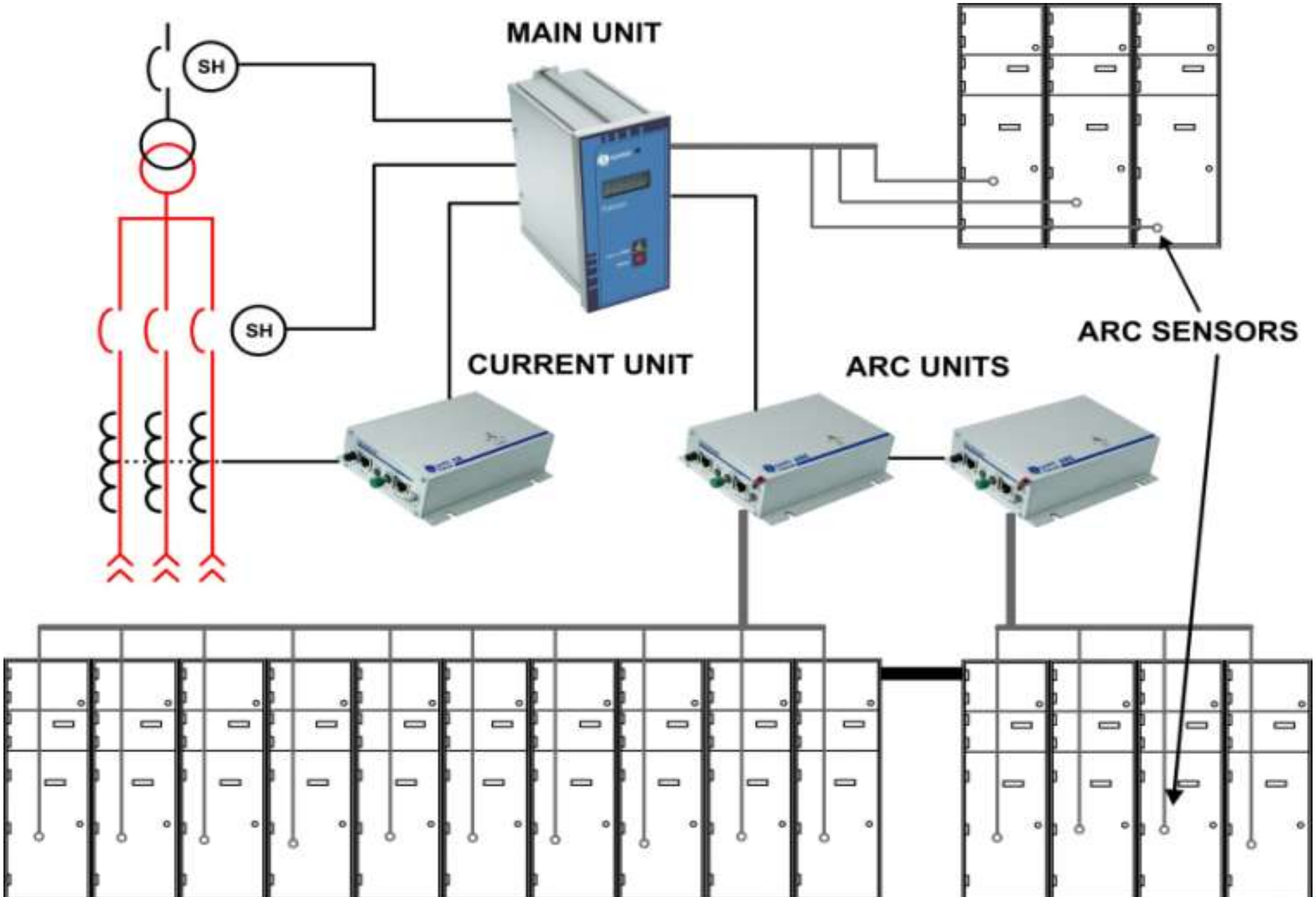
Reacting at the speed of light minimizes the total fault-clearing time.

Reliability –

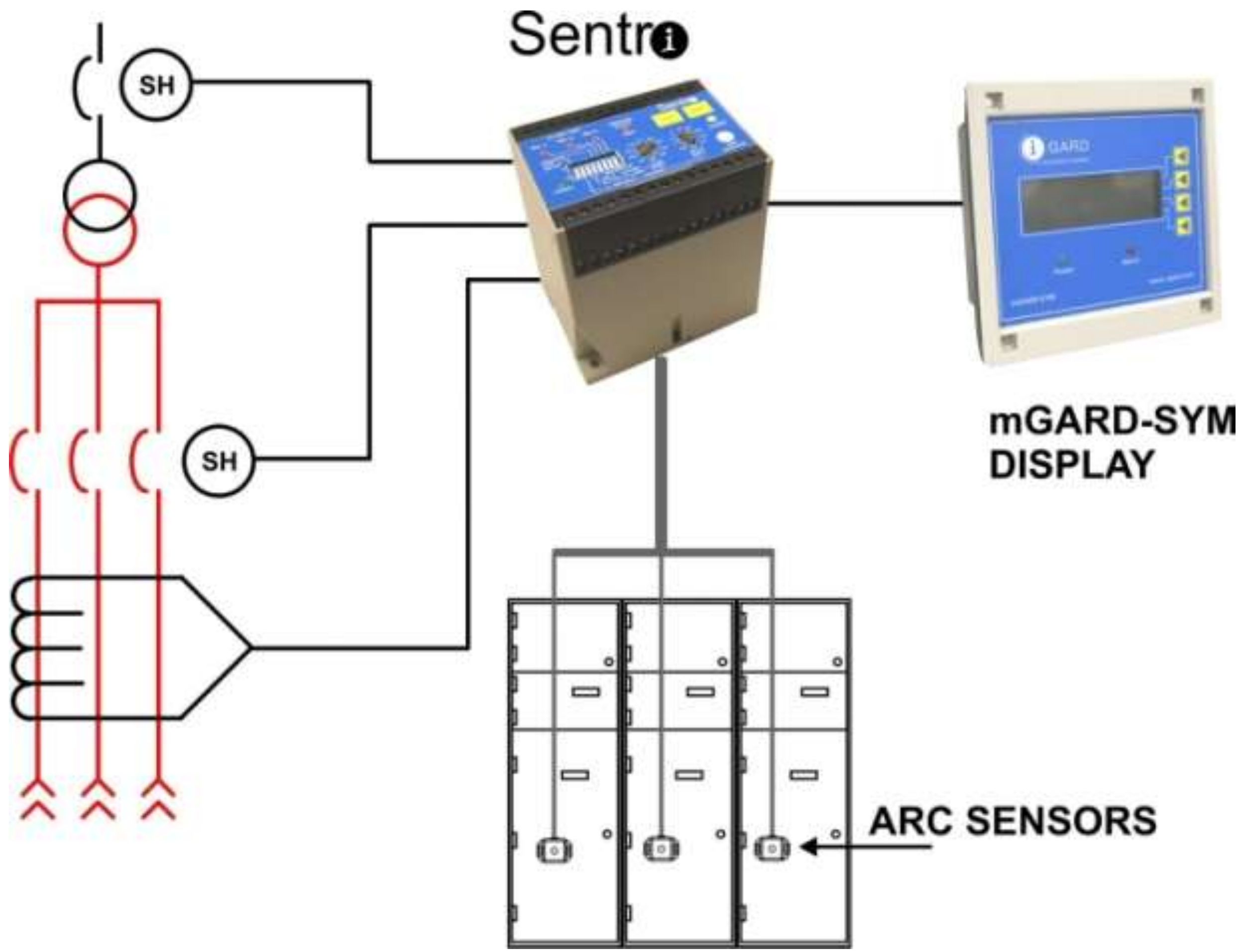
Optional over-current module combines light sensing technology with fast over current protection to ensure the fastest possible reaction time without nuisance tripping.



Arc Detection and Mitigation Current and Light Schematic Falcon

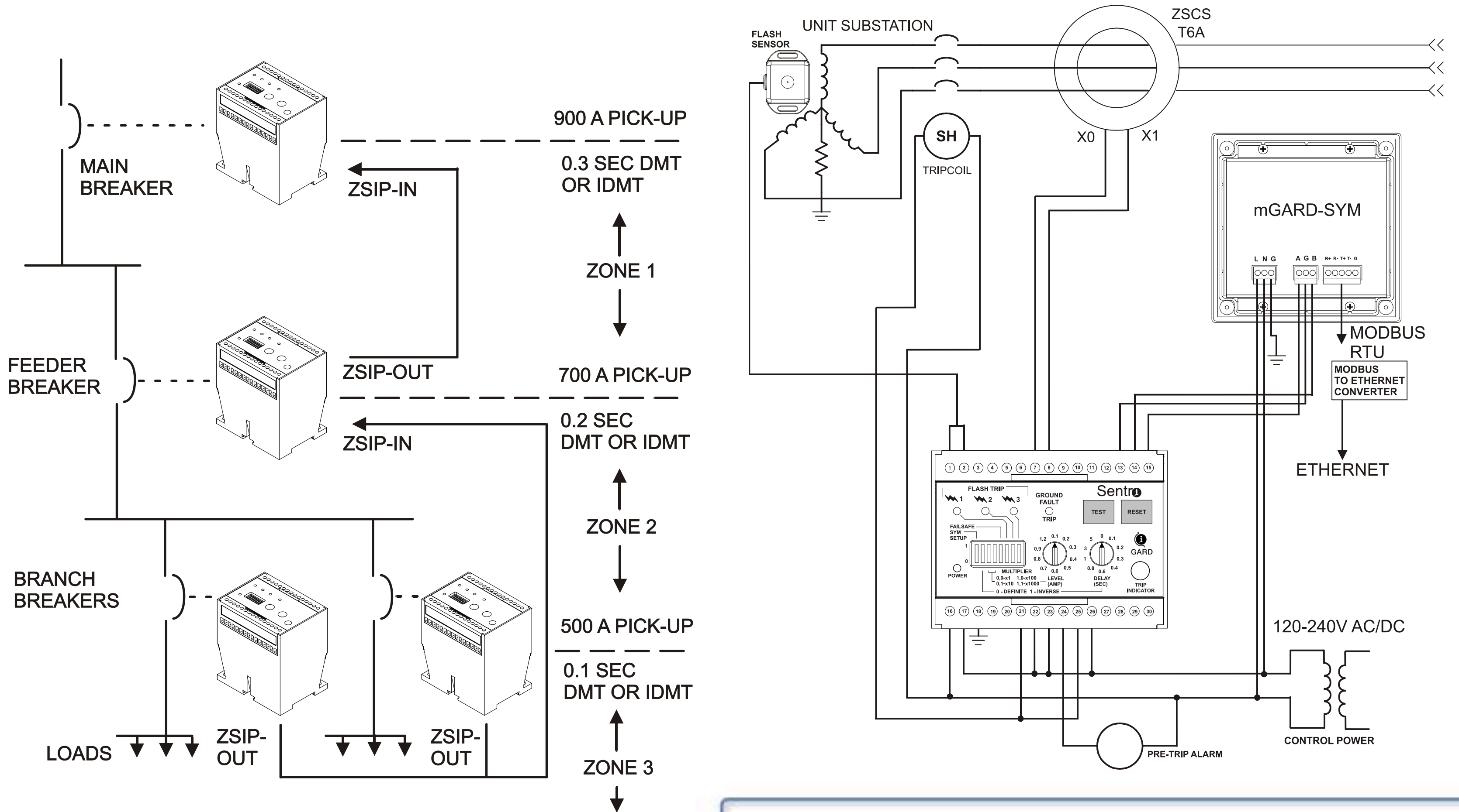


Arc Detection and Mitigation Current and Light Schematic Sentri



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



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

Impact Comparison

For Video Comparison visit www.i-gard.com/ technical library/ power problems and solutions

Video 5 - Without Optical Arc Detection.wmv

Video 4 -With Optical Arc Detection.wmv

FALCON

- Reduce the time = Reduces the damage

  = Reduces Hazard cal/cm2

  = Reduces Hazard Risk Category for the PPE *4 to 0*

For Application support and typical specifications
Contact I-Gard 905-673-1553
www.i-gard.com

Arc Flash Hazard Summary

- Z462 and NFPA70E addresses worker safety and work practices
- Z462, Z460 , NFPA70E will be referenced in work injury litigation
- Requirements for compliance:
  - Perform Arc Flash Hazard Analysis
  - Label electrical equipment designating the required PPE
  - Train workers and update work practice procedures
  - Deploy products, solutions, and methods to limit arc flash hazards whenever possible

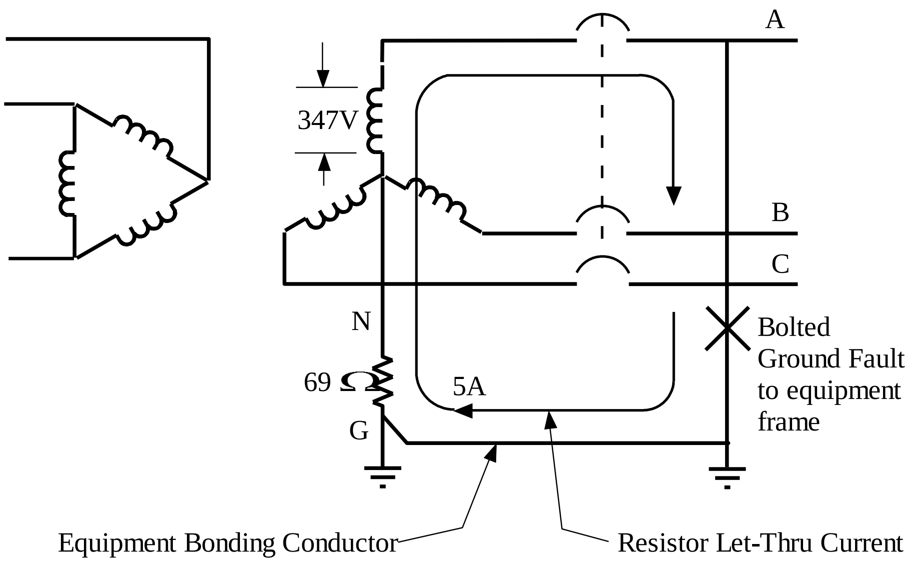
Reduce PPE requirements by ARC Flash Protection

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



High Resistance Grounding

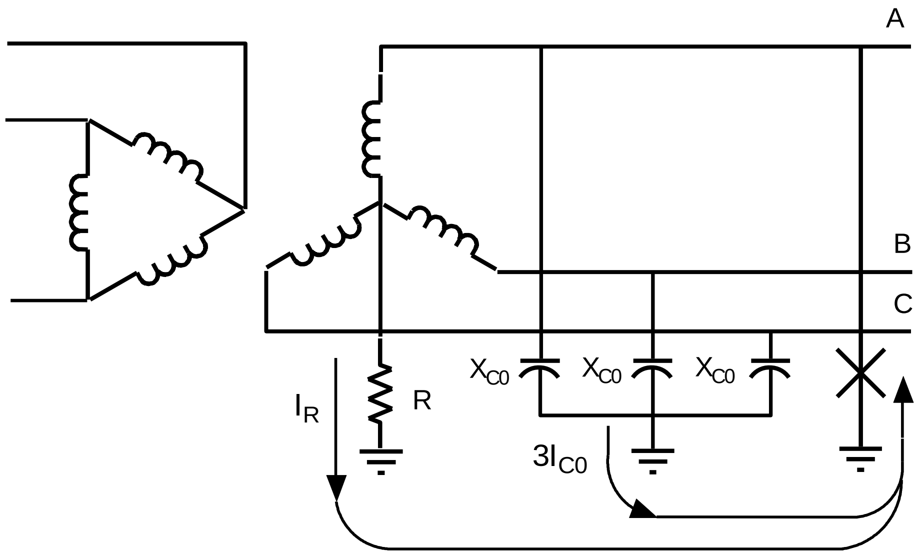
Canadian Electrical Code Rule 10-1102 (3):

- 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.

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 continuous process industries, hospitals and data centers where unscheduled downtime is costly

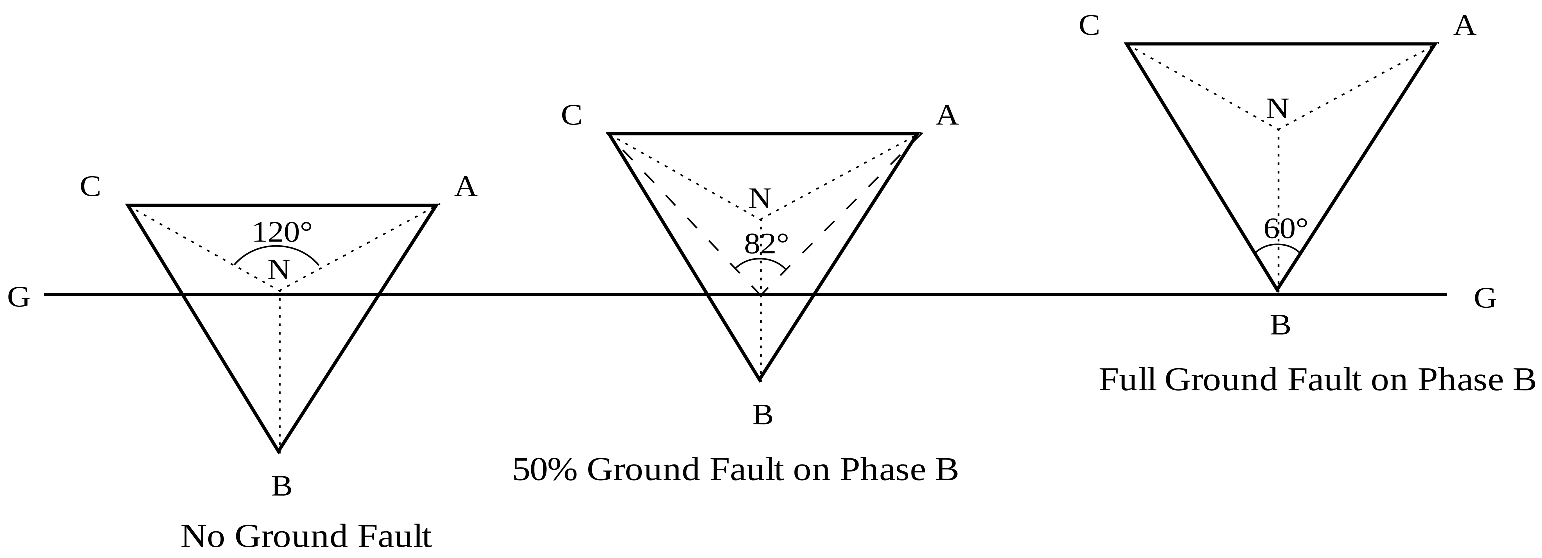
Fault Current on HRG System



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

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

Ground Fault on Ungrounded and High Resistance Systems



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-W Systems are cheaper than 4-W
• **Scheduled Maintenance**	Faulty equipment can continue to run, scheduled shut downs and lower repair costs
• **Prioritized load**	Over current coordination maintained Selective second fault protection available

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.

Resistance Grounding - IEEE

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

1.4.3

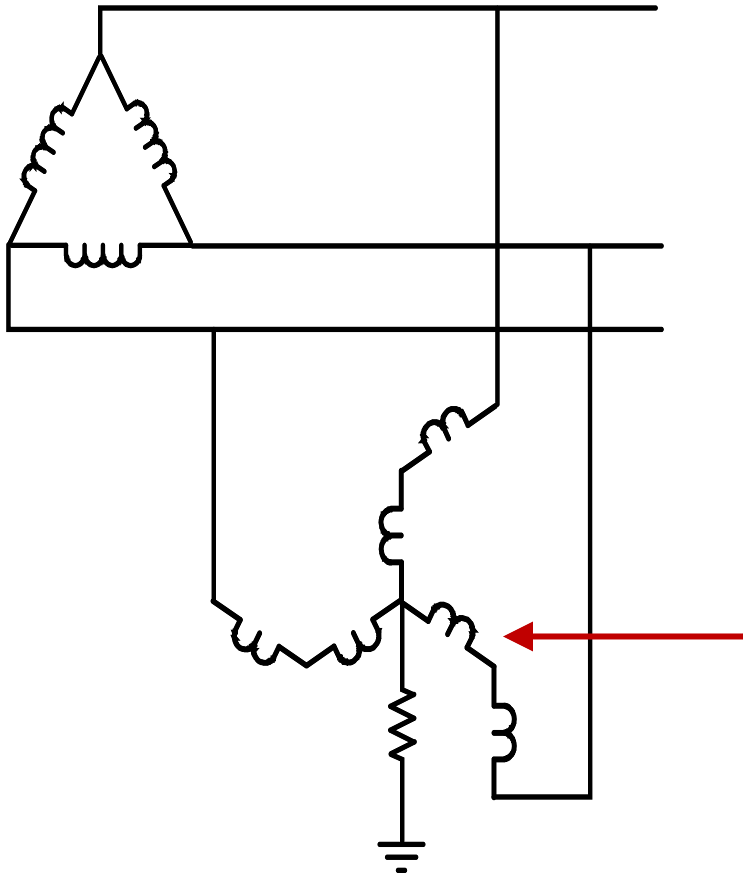
The reasons for limiting the current by resistance grounding may be one or more of the following:

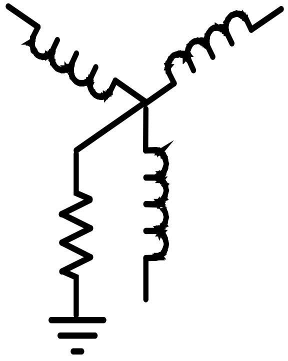
1. to reduce burning and melting effects in faulted electric equipment, such as switchgear, transformers, cables and rotating machines.
2. to reduce mechanical stresses in circuits and apparatus carrying fault currents
3. to reduce electric-shock hazards to personnel caused by stray ground fault currents 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

Low Resistance Grounding

- Used on medium voltage (MV) premises distribution systems
- System charging current too high for high resistance grounding
- Ground fault current limited to 25 – 400 A typically
- Trip on ground fault
- Prevents arc flash incident on ground fault

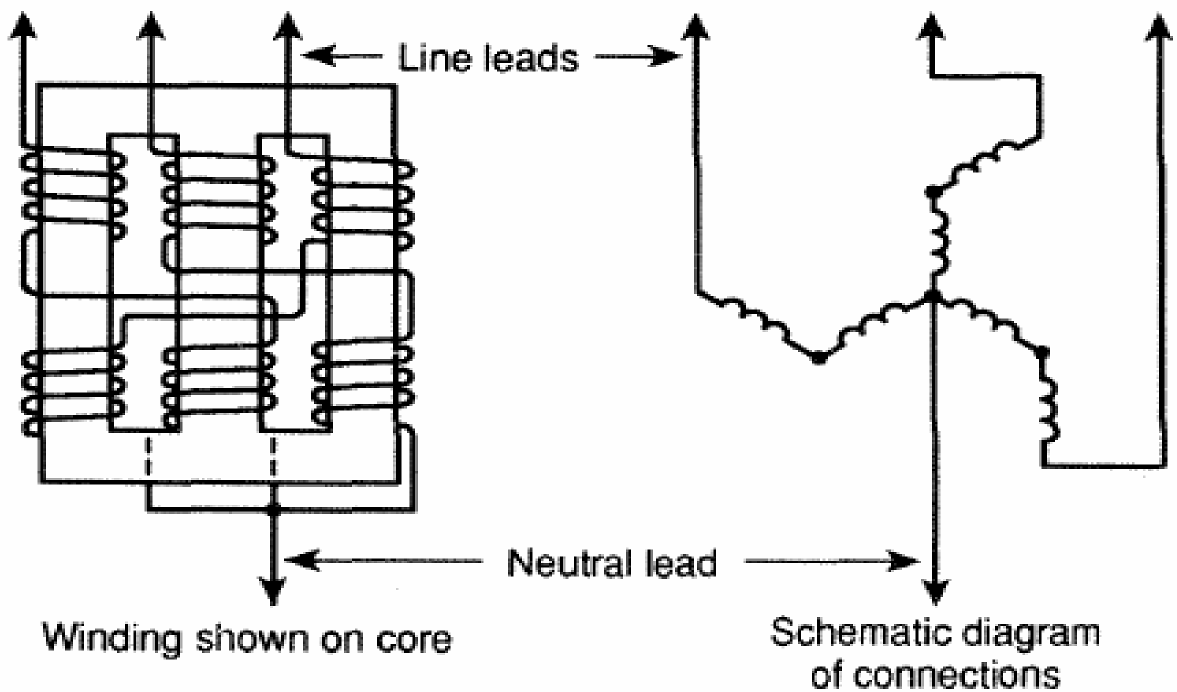
Resistance Grounding Methods





Zig-Zag Grounding Transformer rated for <u>Line-to-Line</u> Voltage

Zig-Zag Grounding Transformer



Alarming and Relaying

- Resistance grounding is not enough
- Must sense ground faults
- Take action
- Either alarm only, and locate the fault
- Or trip on fault

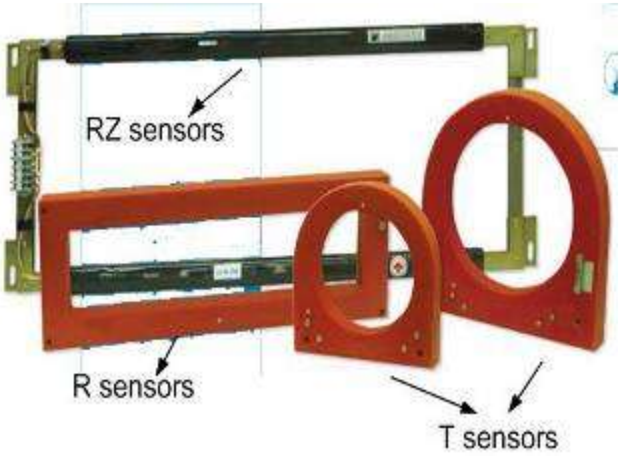
Approaches for ground detection

- 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.

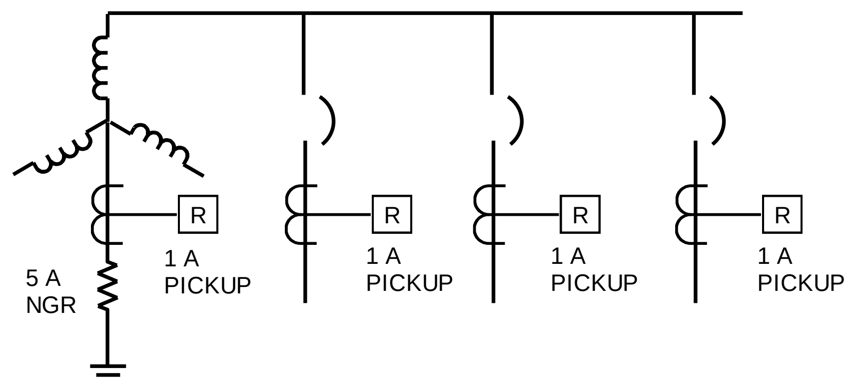
Zero Sequence Sensors



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.

Current Sensing GF Relay - MGFR

- Selective – identifies faulted feeder



Multi-Feeder Ground Alarm Relay – OHMNI

Voltage Sensing Relay

Current Sensing Relay Modules

GARD

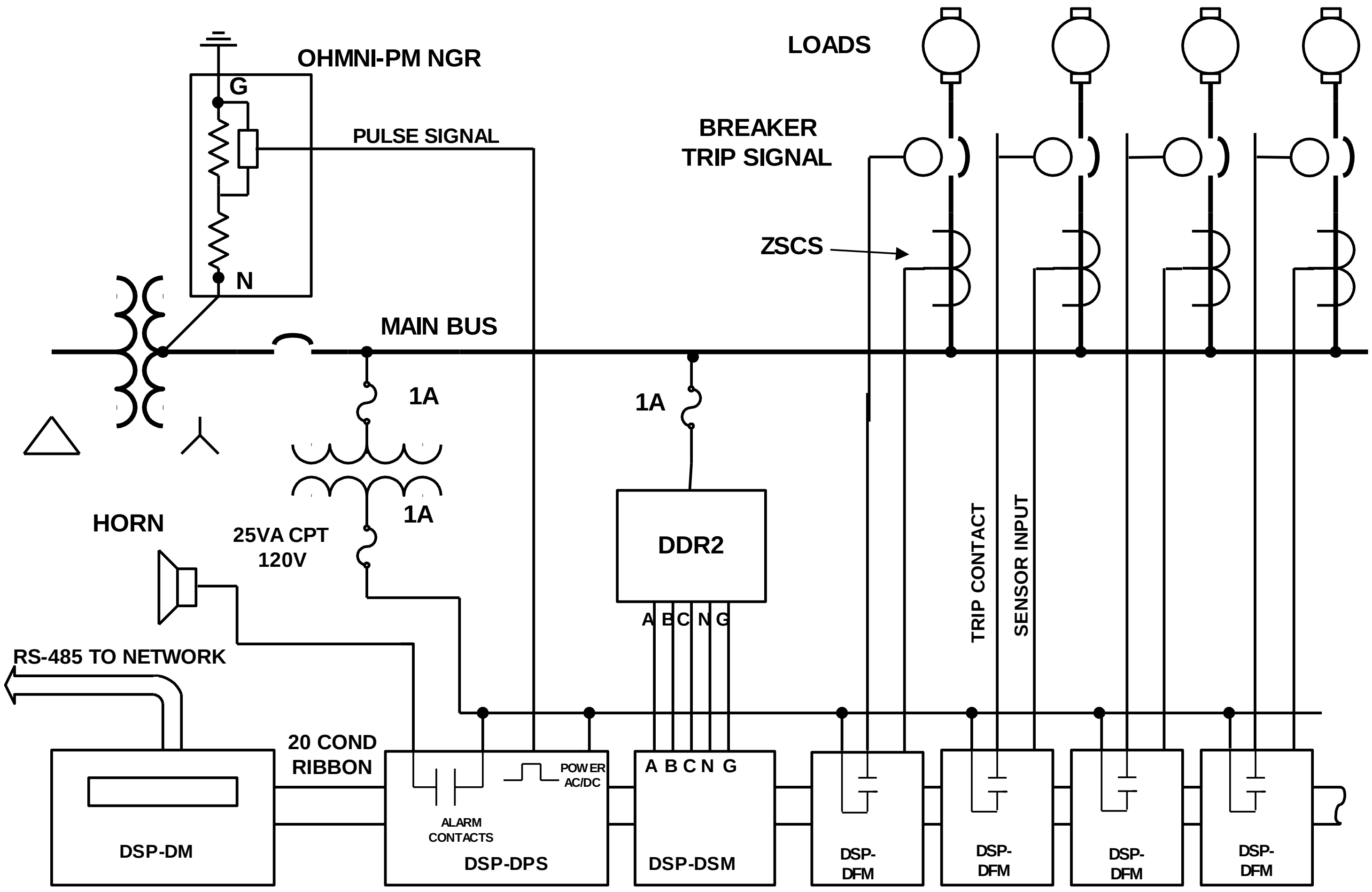
SIGMA Relay

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.

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

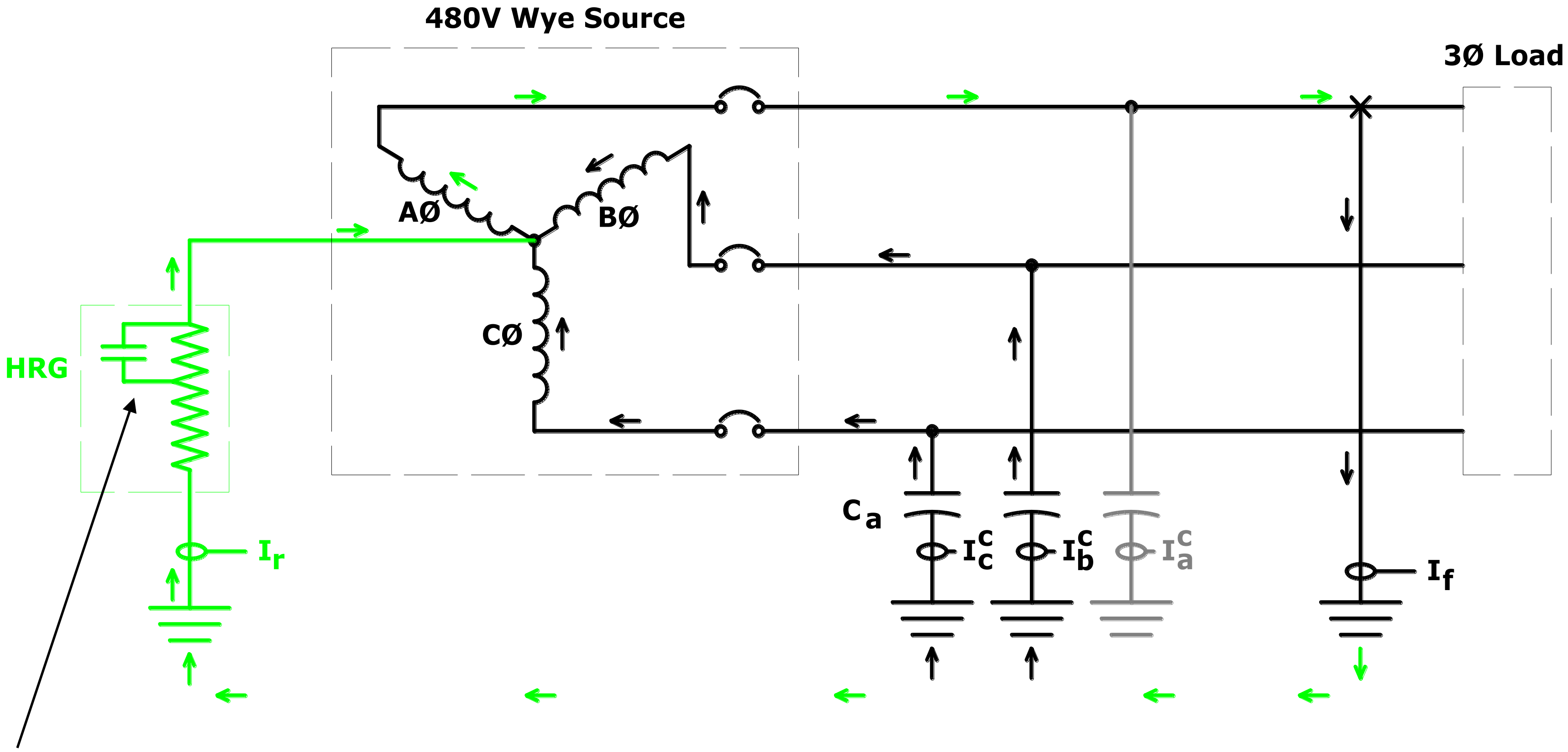
OHMNI Relay
First Fault Alarm and Second Fault Trip OR First Fault Trip



GARD

High Resistance Grounding

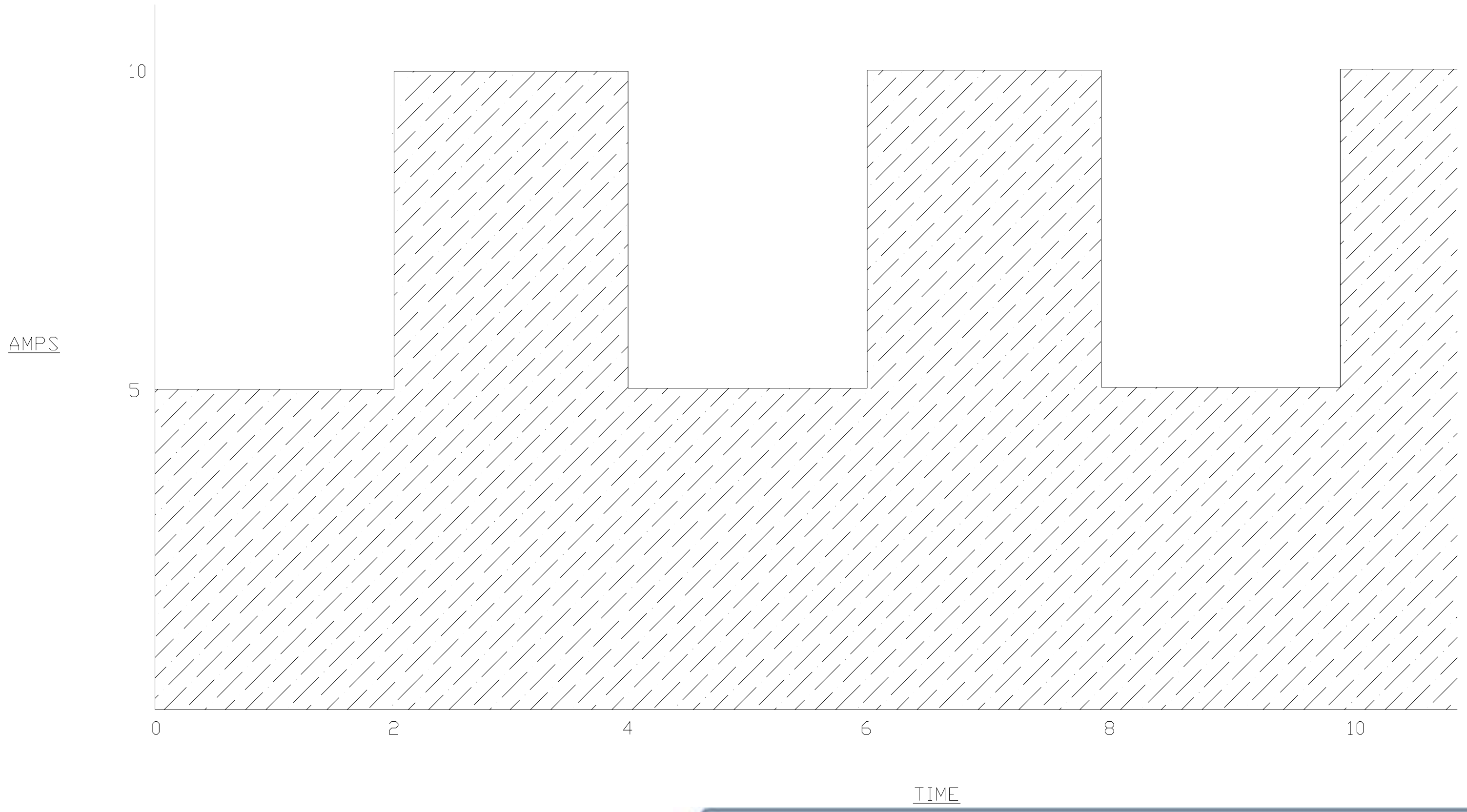
- Another advantage of return path: ground fault location



Contactor shorts out part of the resistor changing the resistance, hence, changing the current. Ground fault current now is a pulse signal that allows for detection!

High Resistance Grounding

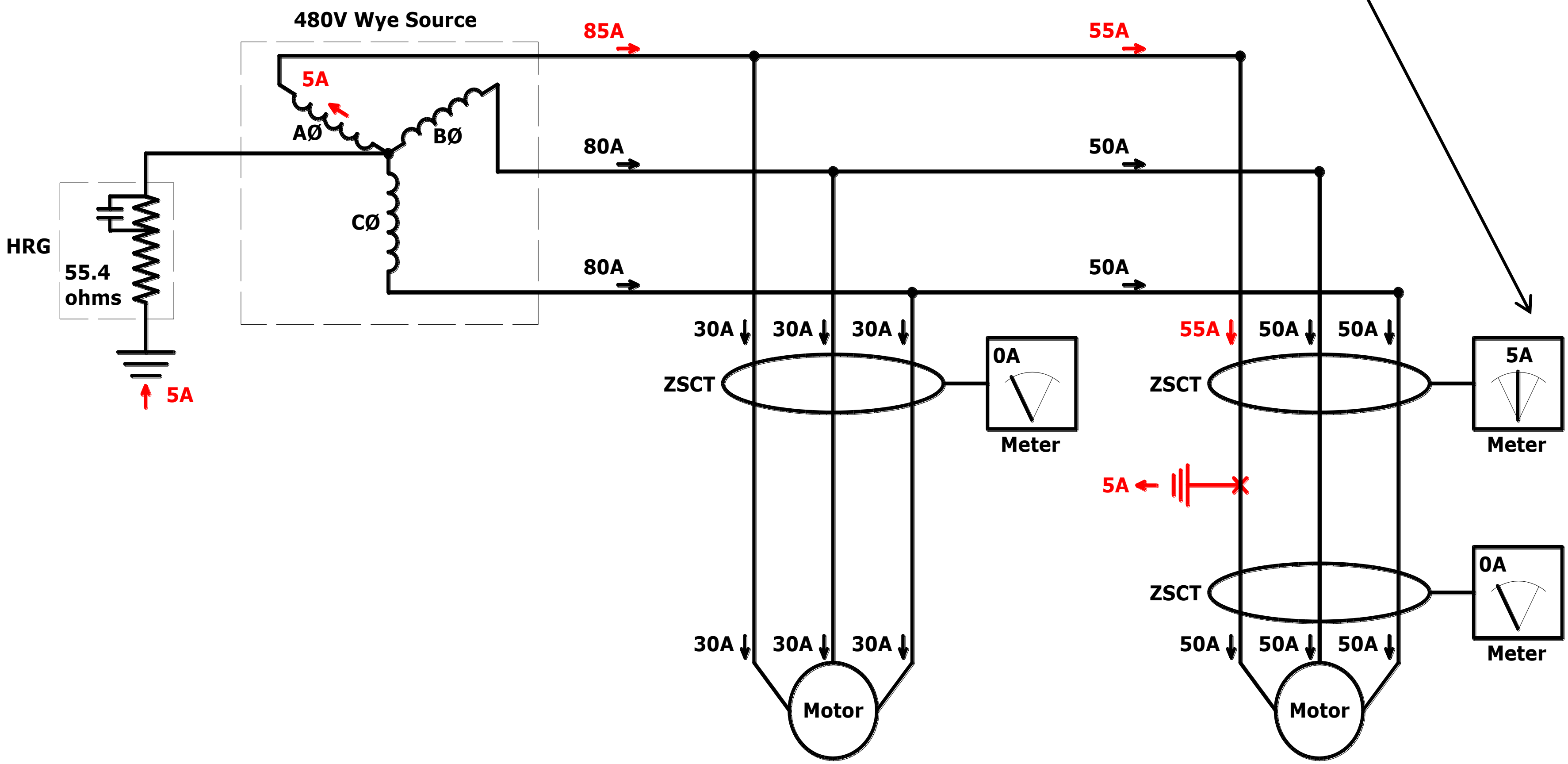
- Contactor shorts out ½ resistance, thus, doubling current to 10A at ~30 pulses / minute.



High Resistance Grounding

Method to quickly locate ground faults.

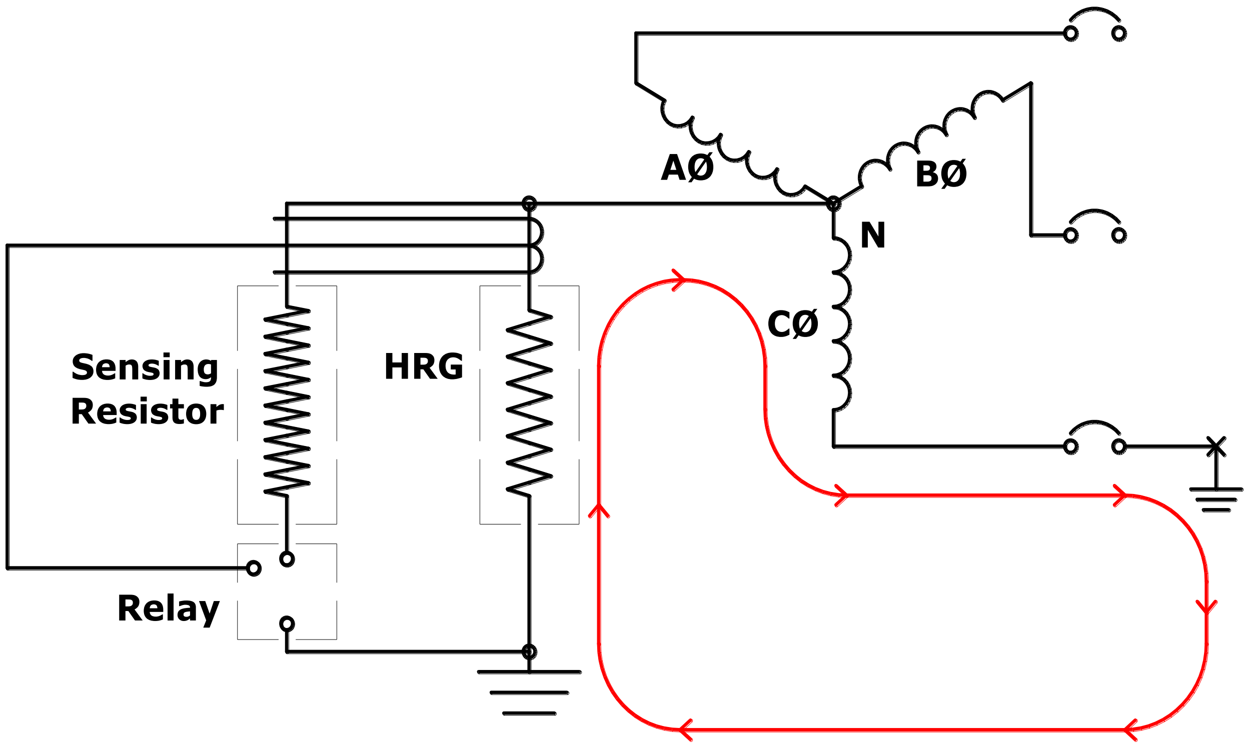
Meter reading will alternate showing high low pattern every 2 seconds.



High Resistance Grounding

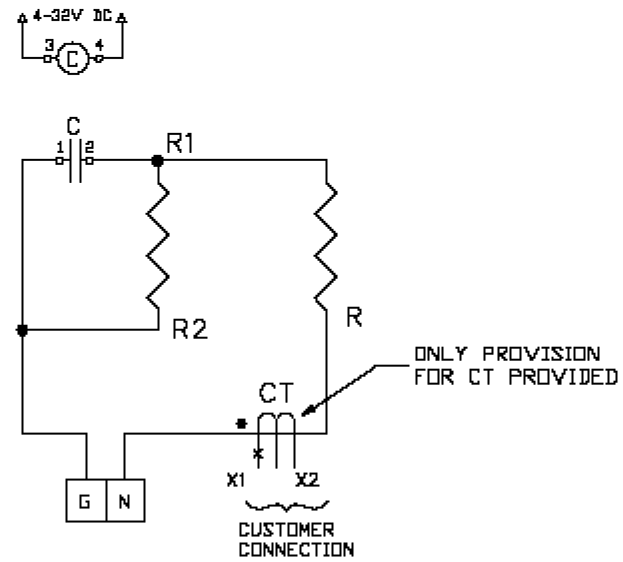
NGR Monitoring Ground Fault Relay & Sensing Resistor

Detects Open / Short Circuits and maintains Grounding



Loss of Ground in HRG Systems

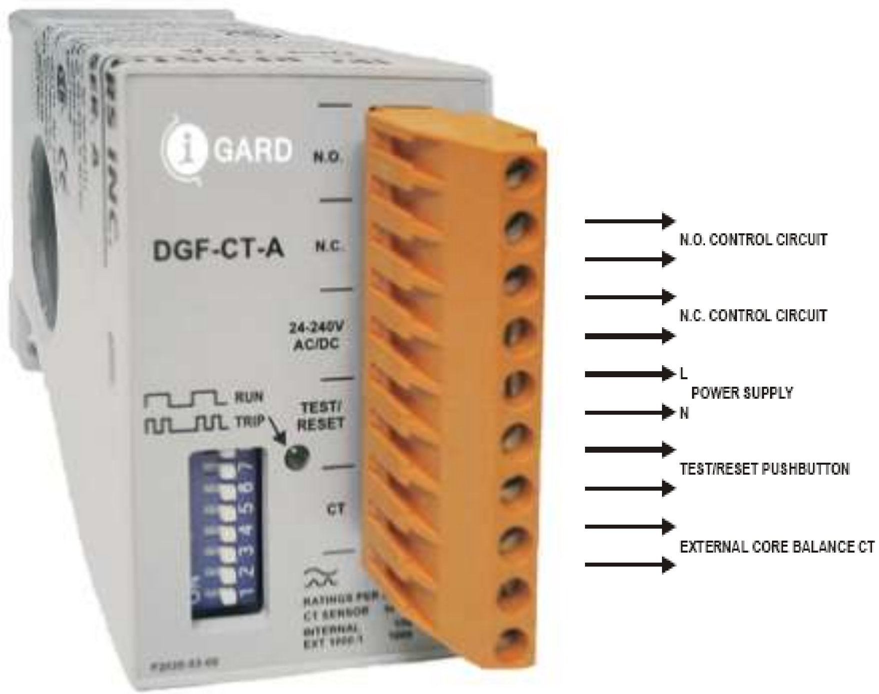
Portable Current Sensor for Fault Tracing



Pulsing NGR

Ground Fault Pulse Locating

GF Relay for Motor Control Centres – mGARD Relay



Can use external sensor

Communication to mGARD Sym, up to 50 units daisy chained

MGARD 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

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.

Application considerations

1. Where to apply the Grounding Resistor

- At the transformer or
- At the main bus

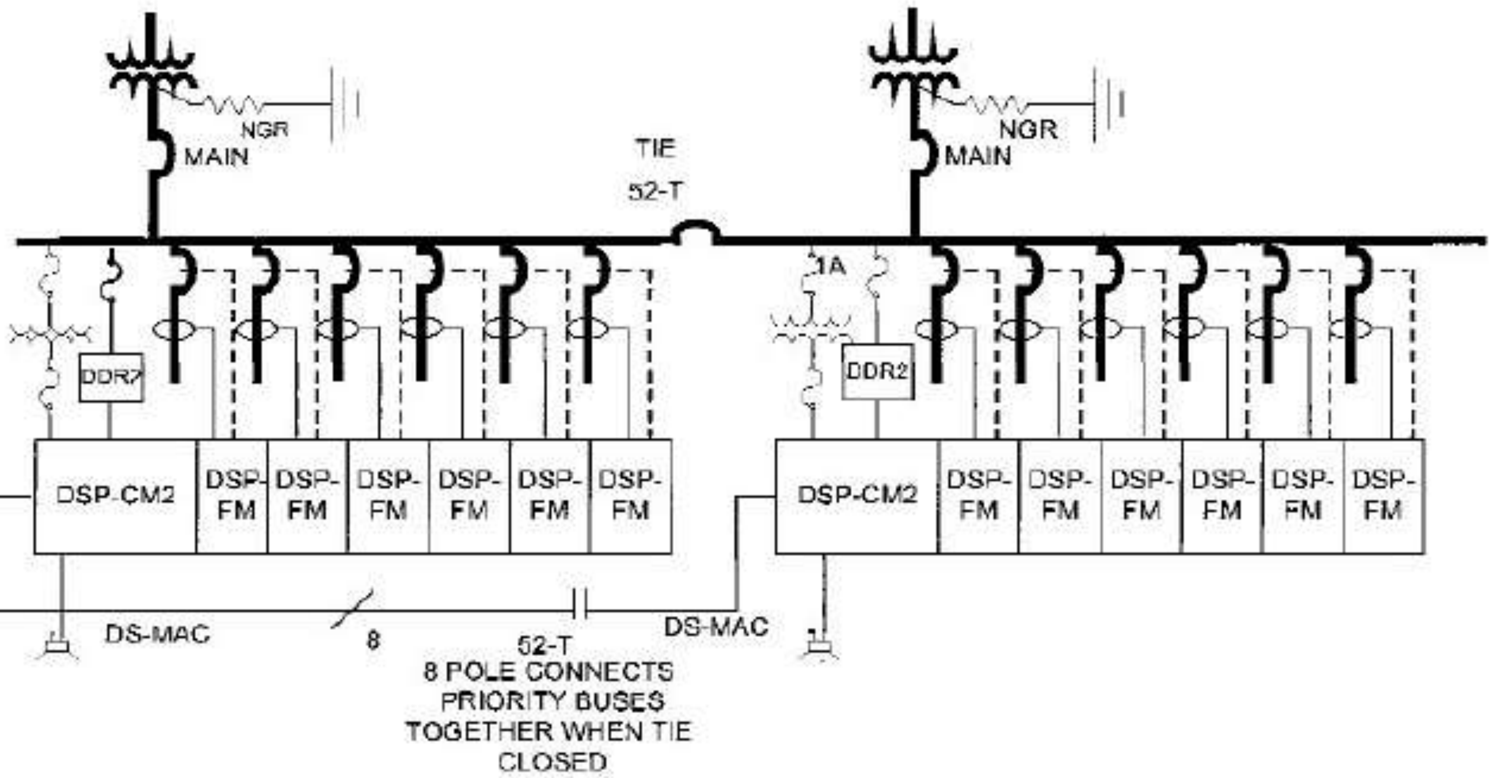
2 When to apply first fault alarm only

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

Double ended Unit sub Application



Generator Grounding

- Generators are not braced for ground fault currents – only for three-phase bolted faults. The phase to ground fault current can be higher than the three phase bolted fault current
- Generators should be resistance grounded according to IEEE and NEMA to limit ground fault current

Why Excessive Ground Fault Current in Solidly Grounded Generators?

- *Generators have low zero-sequence impedance*
- Example: typical standby generator rated 600 V, 1500 kW, 1800 rpm
- Per unit sequence impedances:
  $X_1'' = 0.235$
  $X_2 = 0.263$
  $X_0 = 0.068$
- Solid grounding and low zero sequence impedance cause excessive triplen harmonic current flow in neutral or ground, and excessive ground fault current.

Formulas for Generator Fault Current (per unit)

- Bolted three-phase fault current:
  - $I_F = V_S / X_1''$
  - $= 1.05 / 0.235$
  - $=$ **4.5 per unit**

- Bolted single phase-to-ground fault current (solidly grounded):
  - $I_F = 3V_S / (X_1'' + X_2 + X_0)$
  - $= 3(1.05) / (0.235 + 0.263 + 0.0681)$
  - $=$ **5.6 per unit**

- *Ground fault current 24% higher than 3-phase fault current!*

ANSI/NEMA Std MG 1-2003 Motors and Generators

32.13 Short Circuit Requirements

A synchronous generator shall be capable of withstanding, without damage, a 30-second, *three-phase short circuit* at its terminals. The generator shall also be capable of withstanding, without damage, at its terminals any other short circuit of 30 seconds or less provided…

b. *The maximum phase current is limited by external means to a value which does not exceed the maximum phase current obtained from the three-phase fault*.

ANSI/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 of a generator should not be solidly grounded unless the generator has been specifically designed for such operation. With the neutral solidly grounded, the maximum line-to-ground fault current may be excessive*, *and in parallel systems excessive circulating harmonic currents may be present in the neutrals*.

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IEEE Std. 142-1991, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*:

1.8.1 Discussion of Generator Characteristics

Unlike a transformer…a generator will usually have higher initial ground-fault current than three-phase fault current if the generator has a solidly grounded neutral. According to NEMA, the generator is required to withstand only the three-phase current level unless it is otherwise specified…

If the winding is designed with a two-thirds pitch…third-harmonic voltage will be suppressed but the zero-sequence impedance will be lowered, increasing the ground fault current…

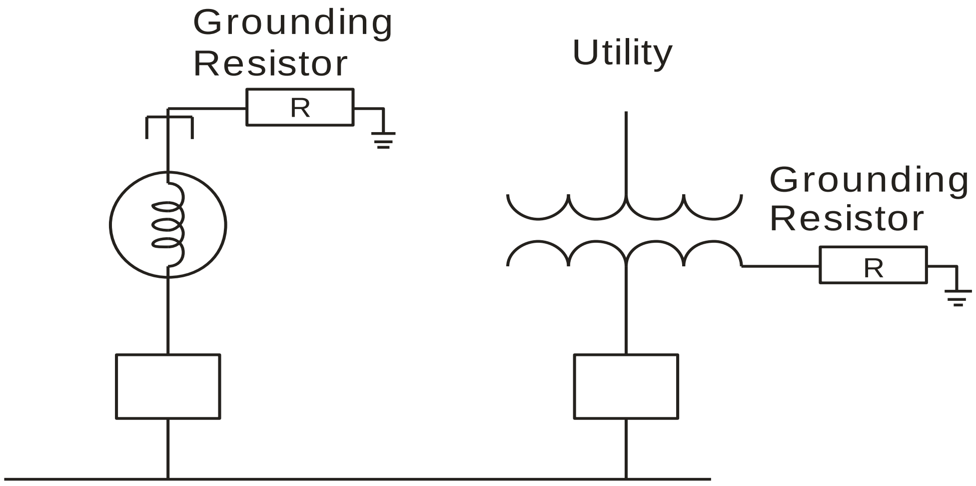
Internal ground faults in solidly grounded generators can produce large fault currents…Both the magnitude and duration of these currents should be limited whenever possible.

1.8.3 Paralleled Generators in Isolated System

High resistance grounding of the generators will adequately limit harmonic currents. Thus, it is attractive to use high-resistance grounding on the generators even if there are load feeders directly connected to the generator bus, and to use low-resistance grounding to provide selective relaying on the load feeders.

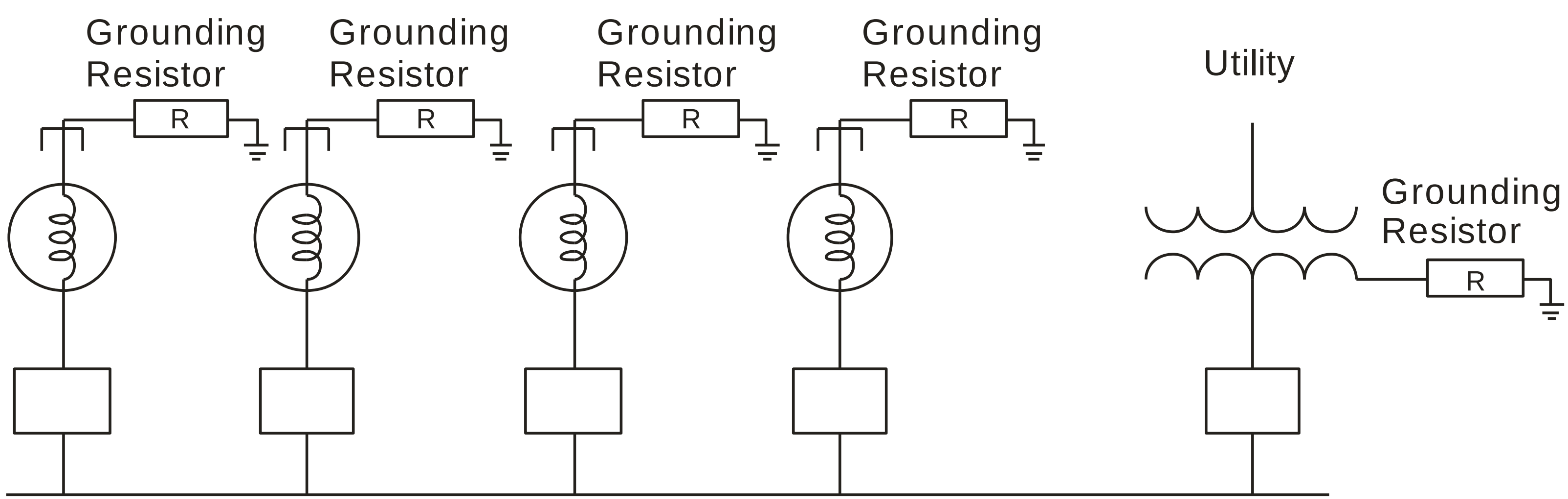
Generator Grounding
Low Resistance Grounded

- Typically 200 A to 800 A Was useful for selective relaying in the past
- Fault current too high causes lot of damage.



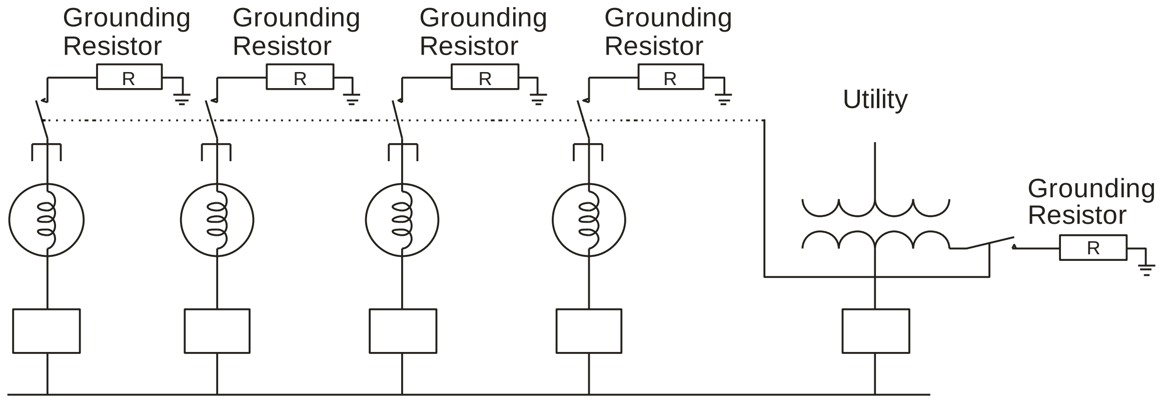
Multiple Generators Low Resistance Grounded

- Fault current is variable depending upon number of connected sources and damage can be very high if LRG 200 A – 800 A



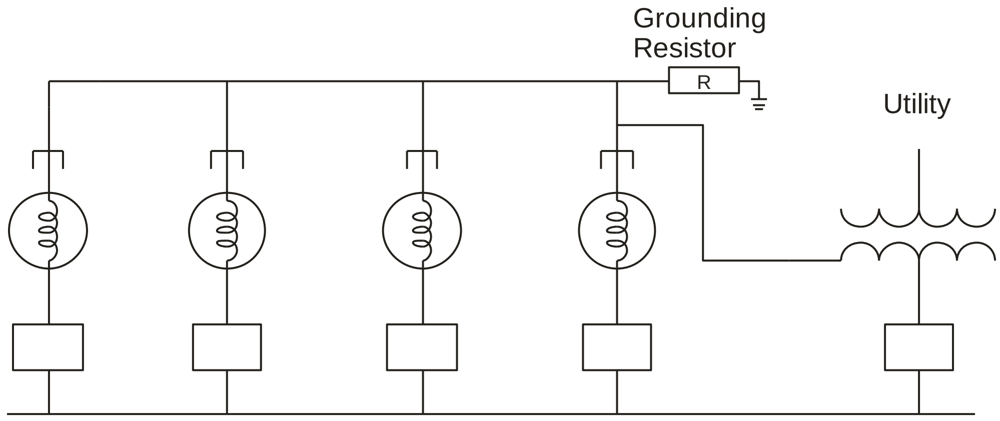
Multiple Generators
Single Point Ground, Switched

- Very complex, switching required, danger of system becoming ungrounded if supply main breaker trips



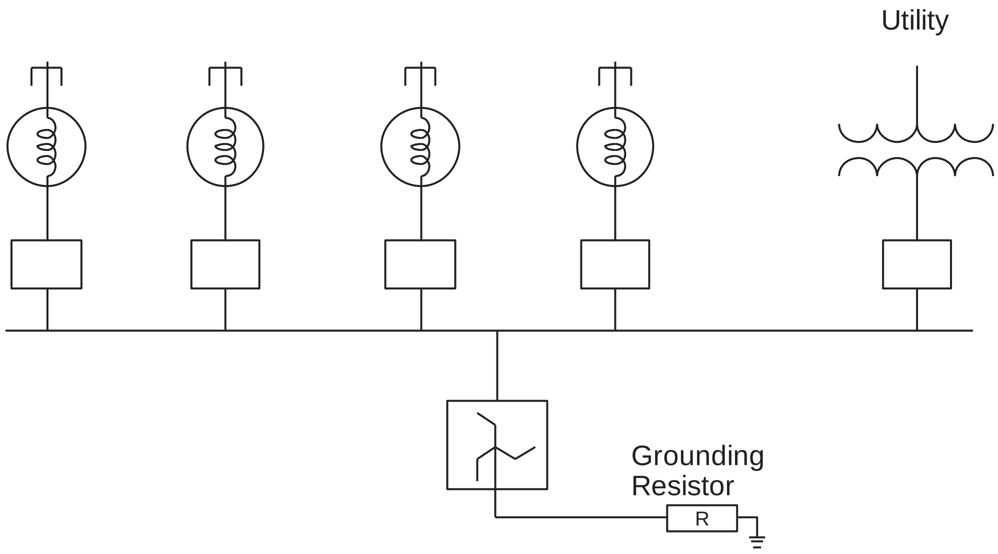
Common neutral low resistance Grounded

- Circulating currents will flow causing generator de-rating



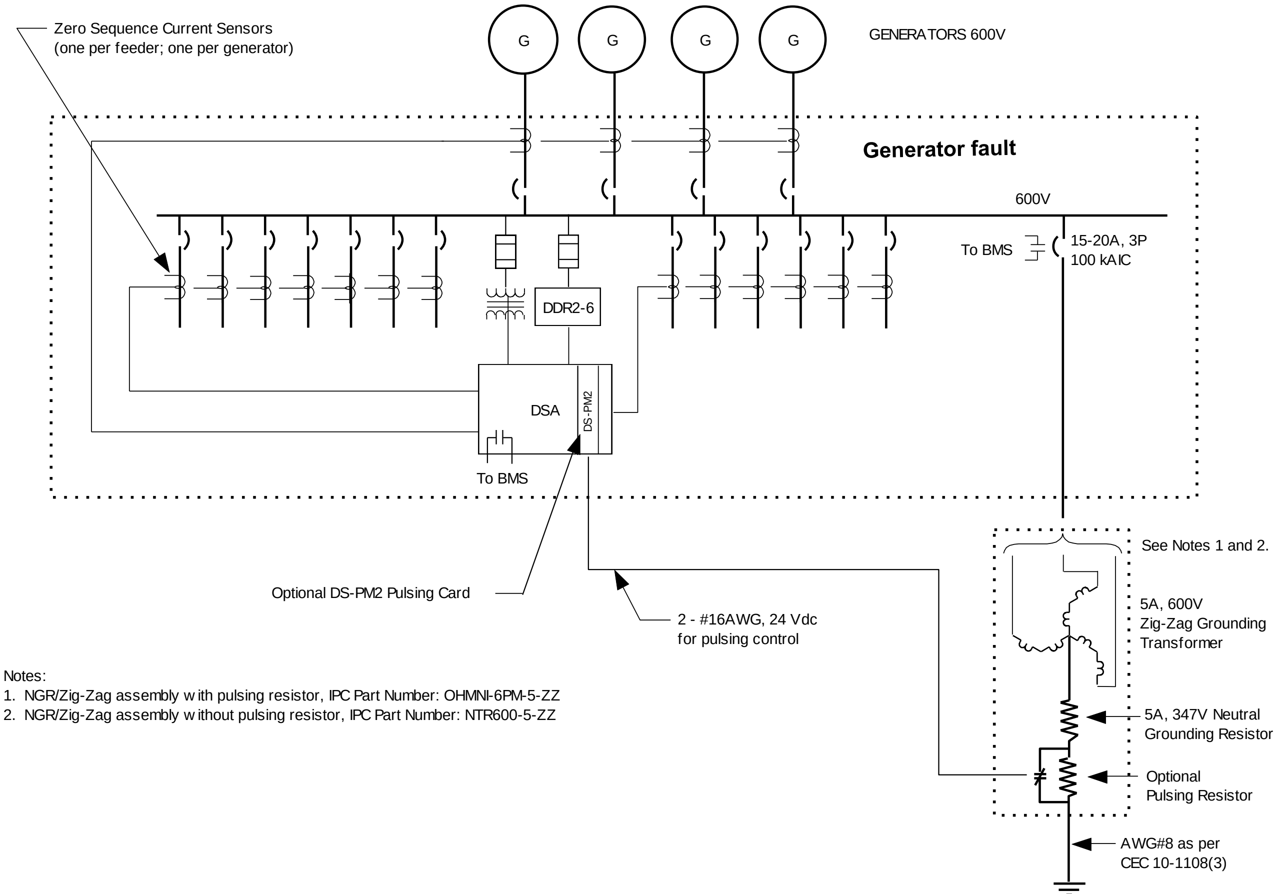
Multiple Generators Single Point Ground at the Main Bus

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



Parallel Generators

TYPICAL PARALLEL GENERATOR HIGH RESISTANCE GROUNDING SCHEME

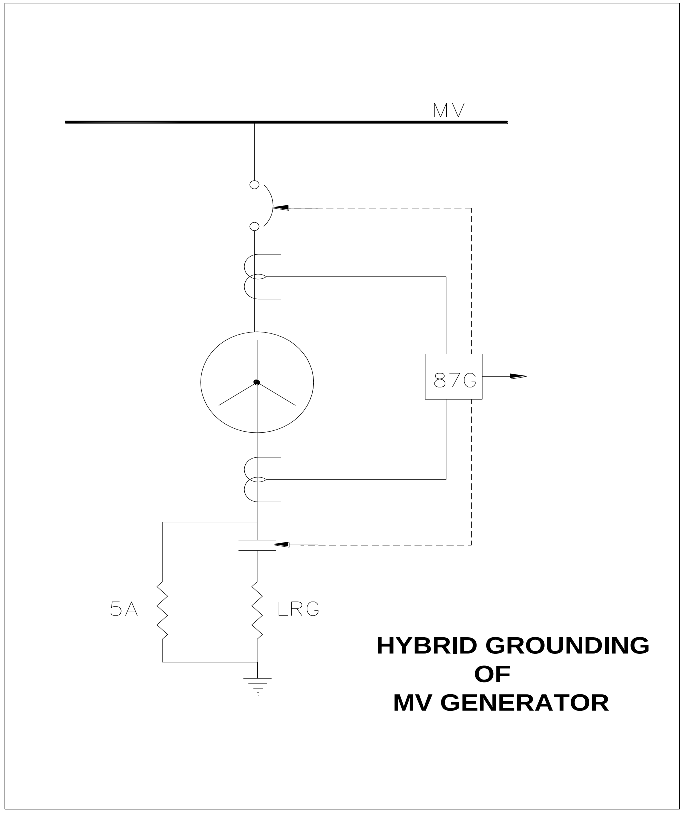


Notes:
1. NGR/Zig-Zag assembly with pulsing resistor, IPC Part Number: OHMNI-6PM-5-ZZ
2. NGR/Zig-Zag assembly without pulsing resistor, IPC Part Number: NTR600-5-ZZ

Hybrid Grounding of Generator

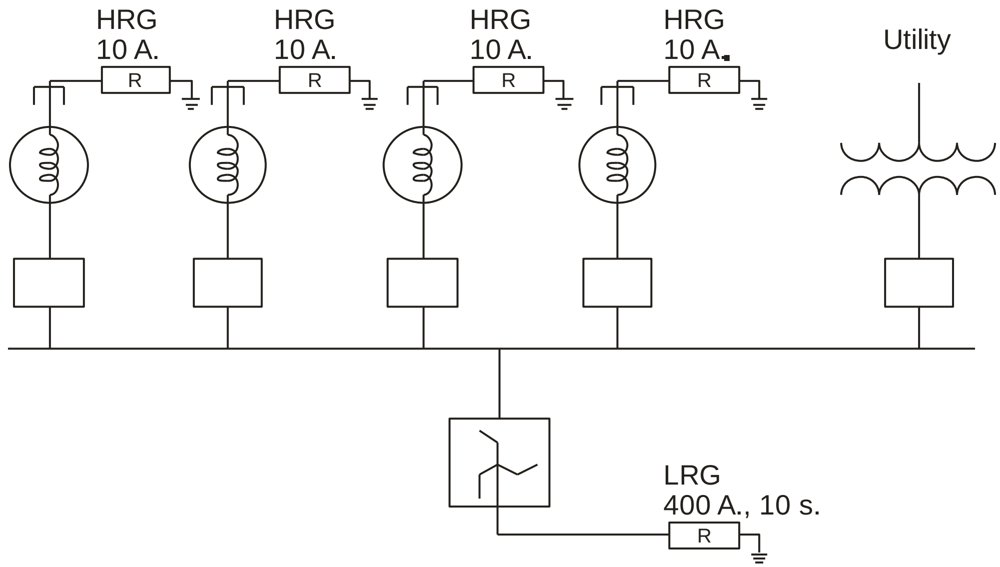
Applied to limit damage due to stator winding fault when LRG is 100A or more

MV Large Generators 20 MW and higher



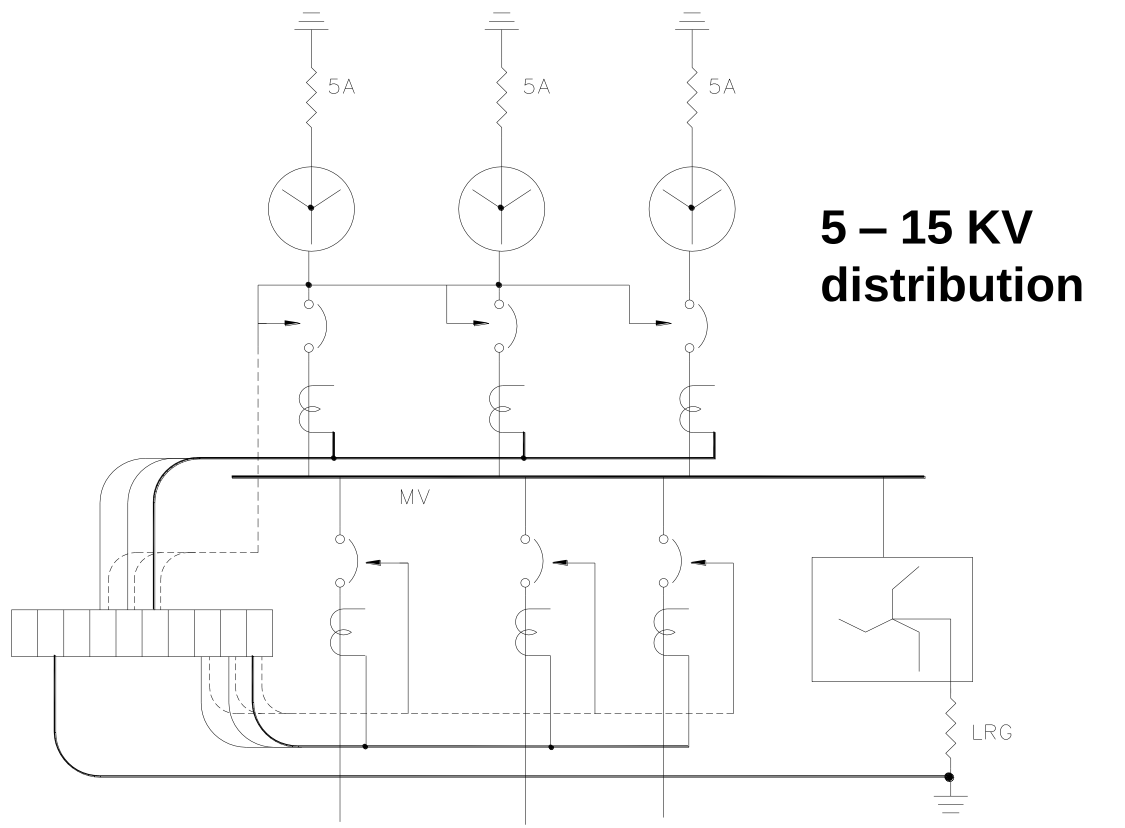
Hybrid Grounding of Multiple Generators

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



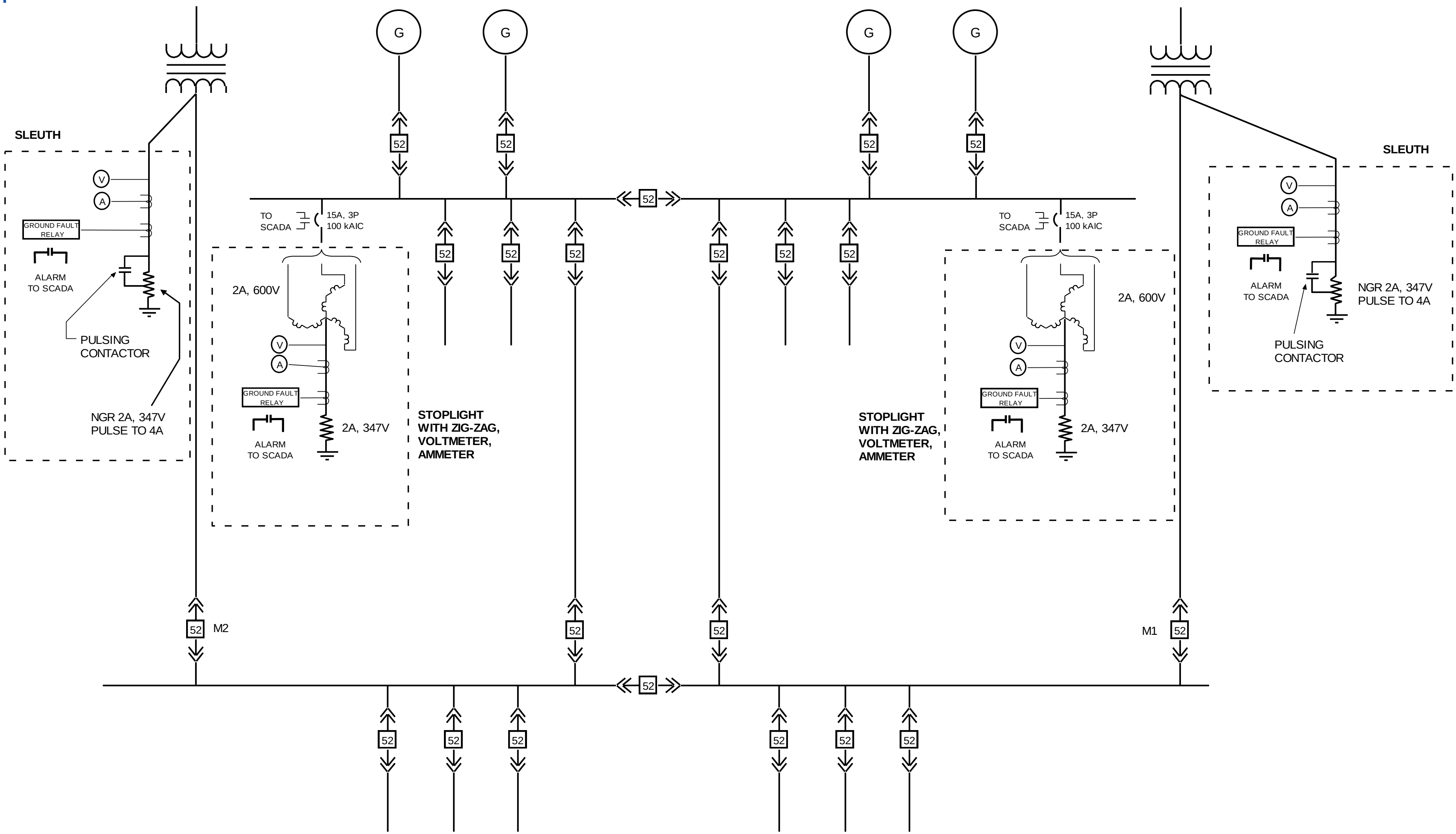
Hybrid Grounding of Generators

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



HYBRID GROUNDING
MV SYSTEM

HRG Retrofit of Parallel LV Generators



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Other related topics

- Arc flash Hazard
- Application of TVSS in HRG systems
- Integration of UPS systems in HRG distribution
- Protection from Electric Shock
- Multiple Neutral Grounding in Solidly grounded systems with multiple sources
- Coordination issue and use of Zone selective Interlocking in Solidly grounded systems
- IEC Earthing Systems
- Mining Application

Other related topics

- Application of Transfer Switches and Generators
- How to estimate capacitive charging current
- Selecting CTs for sensitive ground fault pick up.
- Specifying Neutral Grounding Resistors
- Hybrid Grounding in LV and MV systems
- Application Examples
- For application info. Typical specs and data sheets www.i-gard.com

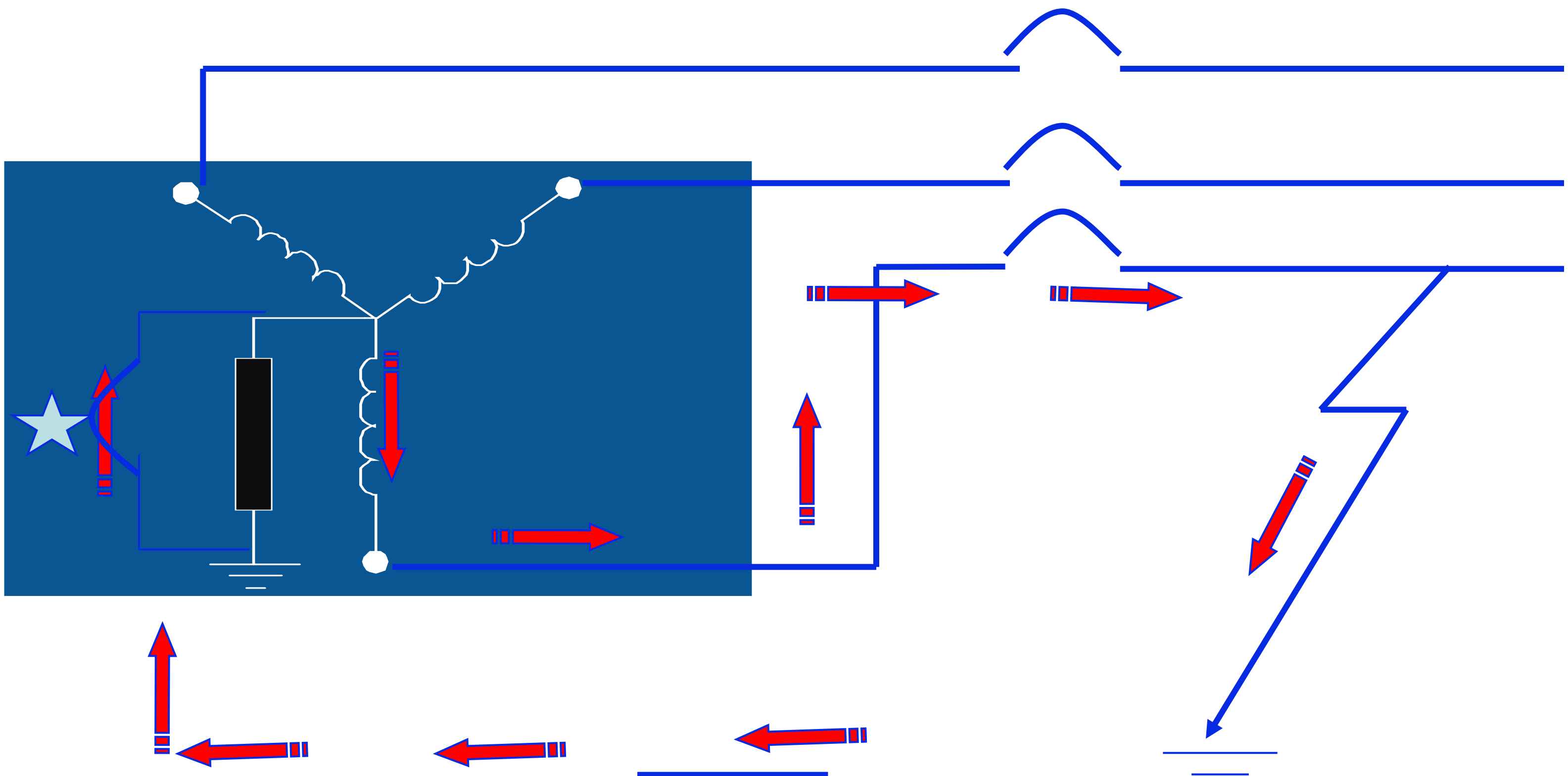
New Concepts in System Grounding

- **Hybrid Grounding in Distribution:** Solid Grounding changes to high resistance grounding up on sensing a ground fault. Example: FUSION

- **Hybrid Grounding of Generators:** Usually generators are low resistance grounded. To provide protection for the stator winding of the generator hybrid grounding is used. Low resistance grounding changes to high resistance when an internal generator ground fault is detected.

New Concept in Grounding
Hybrid Grounded Systems

Ground fault changes the impedance in the ground circuit….



☆ **Circuit breaker or Fuse** ▭

FUSION

FUSION converts from solid grounding to high resistance grounding giving an immediate reduction in fault current. This allows the fault to remain on the system without causing further damage and without unplanned process interruptions.
This product is custom-made to each electrical system in accordance to the customer requirements. Please call I-Gard for assistance in selecting the right product for the application.

When to Estimate System Charging Current?

- When high resistance grounding at 5 kV
- To determine smallest resistor let-thru current for low resistance grounding on a 15 kV system

References for System Charging Current Calculation

- Ground Fault Protection on High Resistance Grounded Systems, Appendix I
  I-Gard Application Guide

- Charging Current Data for Guesswork-Free Design of High-Resistance Grounded Systems,
  D. Baker, IEEE Transactions on Industry Applications, Mar/Apr 1979, pp. 136-140

Sources of System Charging Current

1. Cables
2. Surge Capacitors
3. Motors
4. Generators
5. Transformers (0.001 – 0.01 μF, negligible)

System Charging Current Calculation

1. Estimate lengths of feeder cables for each cable size.
2. Obtain capacitance-to-ground per phase from cable manufacturer, in μF/1000 ft.

   From above data calculate capacitance for each feeder cable (C_0, a per-phase value)

System Charging Current Calculation

4. If cable manufacturer's data not available, use:
   - Figure 2 from Baker, or
   - Figures A1.1 & A1.2 from I-Gard App Guide

System Charging Current Calculation

5. Sum the capacitance per phase of all feeder cables, calculate system charging current:

$$3I_{C0} = \frac{2\sqrt{3}\pi V_{LL} f C_0}{10^6} \quad \text{Amperes}$$

$$\text{f} = \text{frequency, Hz}$$

$$\text{C}_0 = \text{capacitance-to-ground per phase, } \mu\text{F}$$

$$V_{LL} = \text{Volts}$$

System Charging Current Calculation

6. Obtain generator charging currents from generator supplier.

7. If manufacturer’s data not available, use Table II from Baker.

System Charging Current Calculation

8. For motors use Table II from Baker, or the following formula from the I-Gard Application Guide:

$$3I_{C0} = 0.05 \frac{HP}{RPM} \quad Amperes$$

System Charging Current Calculation

9. Calculate surge capacitor charging currents from IPC Application Guide,

$$3I_{C0} = \frac{2\sqrt{3}\pi f C_0 V_{LL}}{10^6} \quad \text{Amperes}$$

$$C_0 = \text{Capacitance per phase in } \mu\text{F}$$

Or use Table III from Baker.

Incorrect Grounding of 3-Pole ATS with Solid Neutral

Multiple neutral grounds!

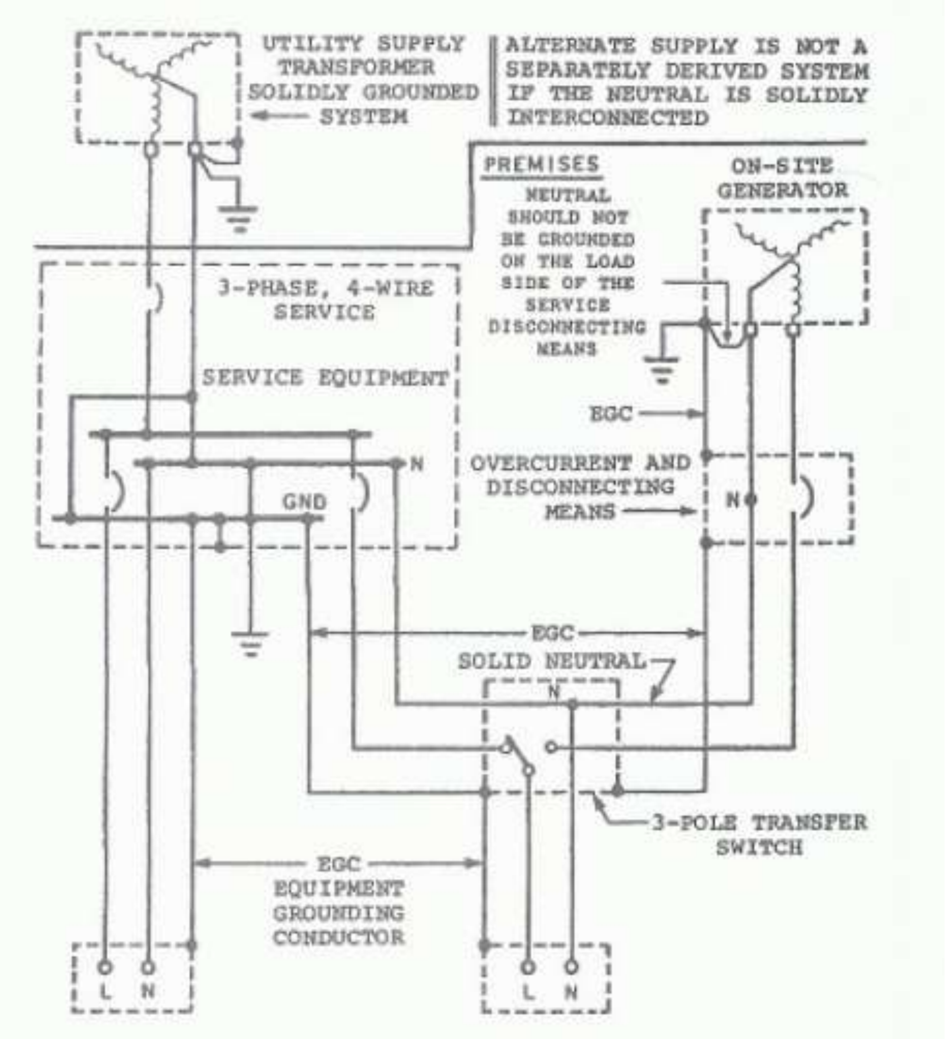


Figure 7-7
IEEE Orange Book
Std. 446-1995

Multiple Neutral Grounds – Stray Neutral Current & Nuisance Ground Fault Trip

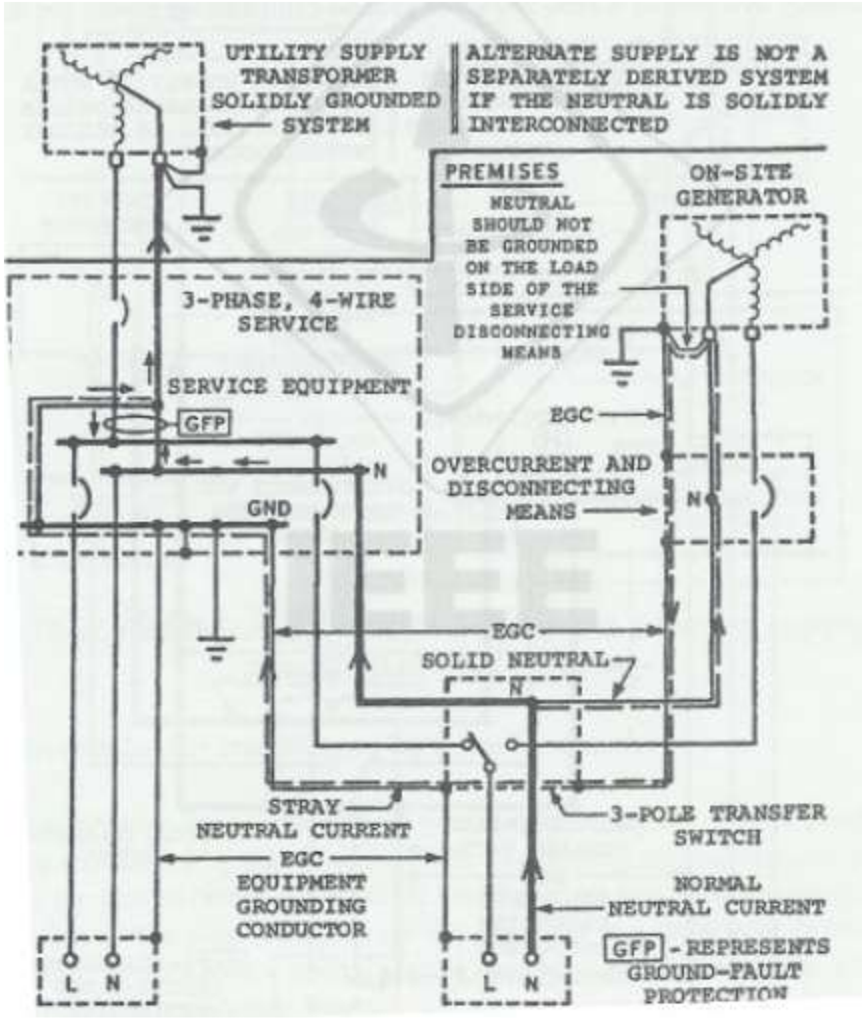
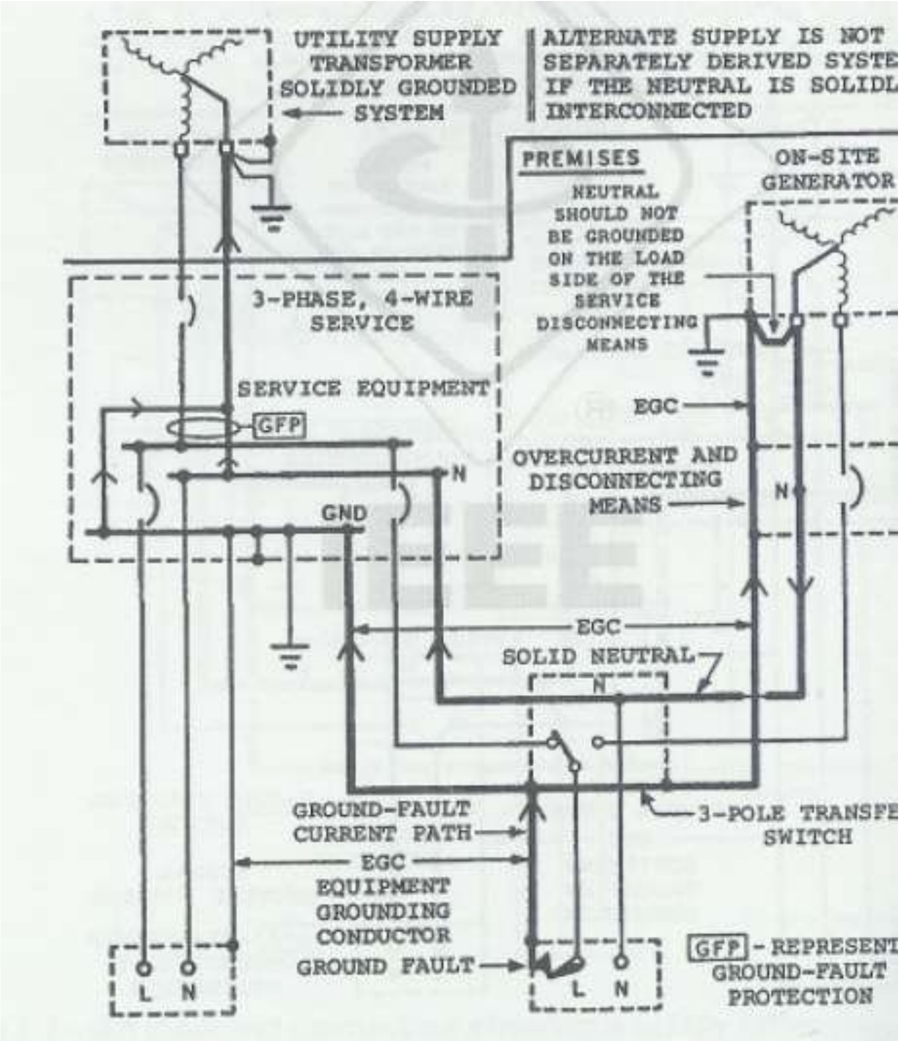


Figure 7-8
IEEE Orange Book

Multiple Neutral Grounds – Ground Fault Relay Fails to Trip

Figure 7-9
IEEE Orange Book
Std. 446-1995



Multiple Transfer Switches – Nuisance Ground Fault Trips

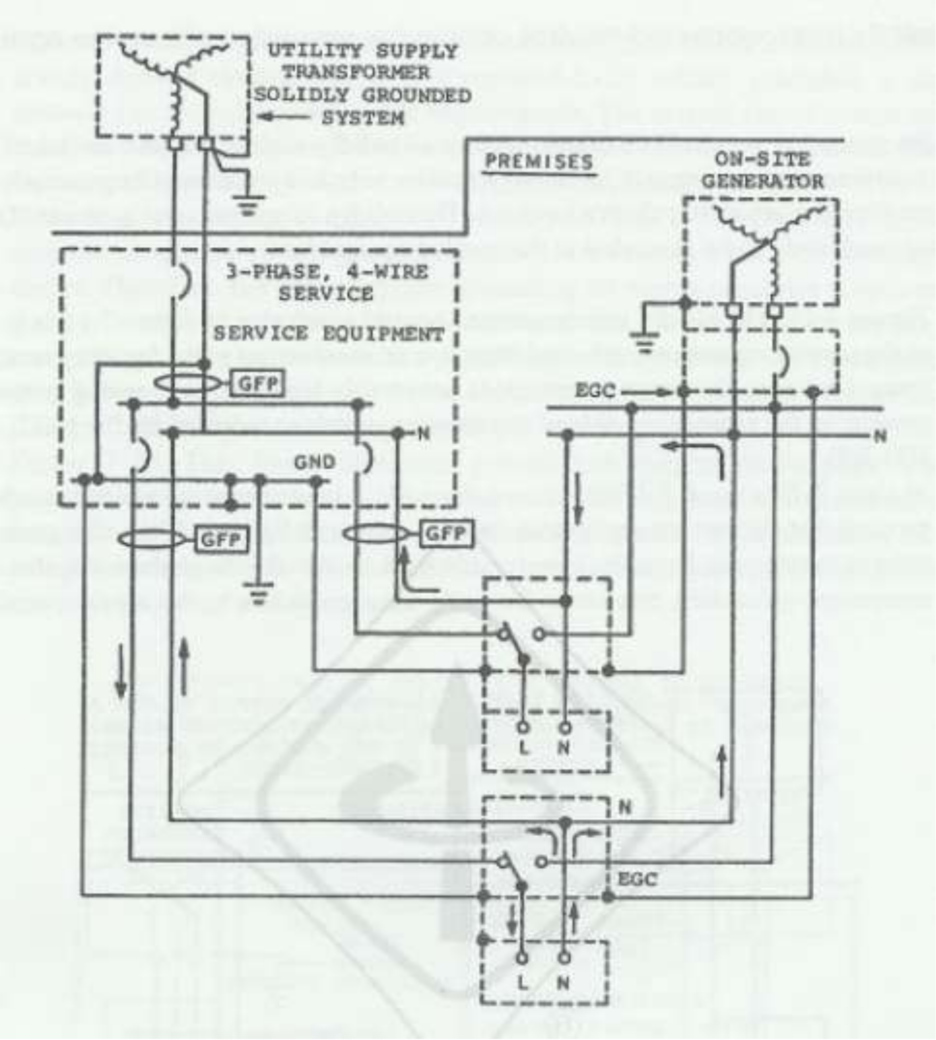


Figure 7-17 (a)
IEEE Orange Book
Std. 446-1995

ATS with Switched Neutral

Required for all other LV generators serving 4-wire loads.

Switched neutral – two types:
- simultaneously switched neutral (4-pole transfer switch)
- make-before-break overlapping neutral contacts

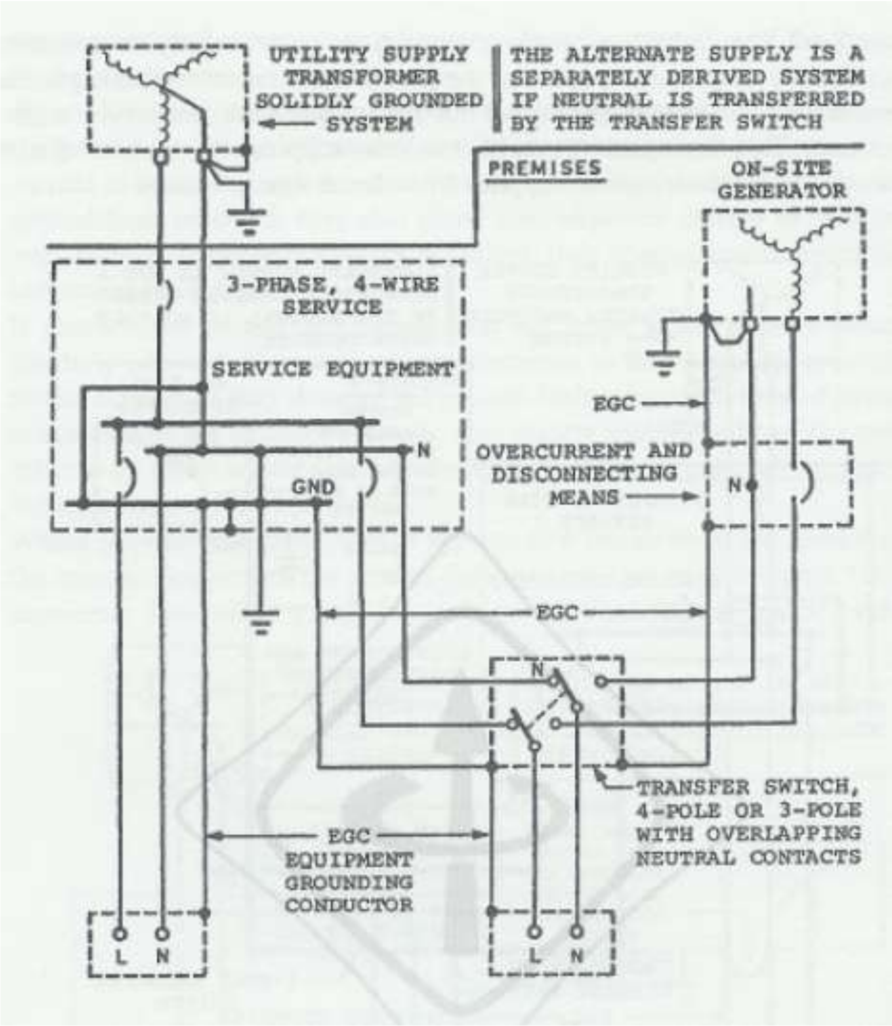
Permits grounding at the generator.

Benefits:
- generator can be remotely located
- allows ground fault protection for generator
- stray neutral currents eliminated
- proper operation of ground fault relays (security and reliability)

IEEE Orange Book says (7.9.1):
For most emergency and standby power systems with ground-fault switches, switching of the grounded circuit conductor by the transfer switch is the recommended practice.

4-Pole Transfer Switch

Figure 7-13
IEEE Orange Book
Std. 446-1995



ATS with Solid Neutral

LV generator with 4-wire loads can use a 3-pole ATS with solid neutral to ground the generator at the transformer when:

- single ATS only
- generator neutral grounded at transformer only
- no ground fault protection on generator (transformer only)
- generator not remotely located

Otherwise:
Stray neutral currents from unbalanced loads and ground faults.

- nuisance trips of ground fault relays
- failure-to-trip of ground fault relays
- different ground potential at transformer and remote generator

3-Pole ATS with Solid Neutral

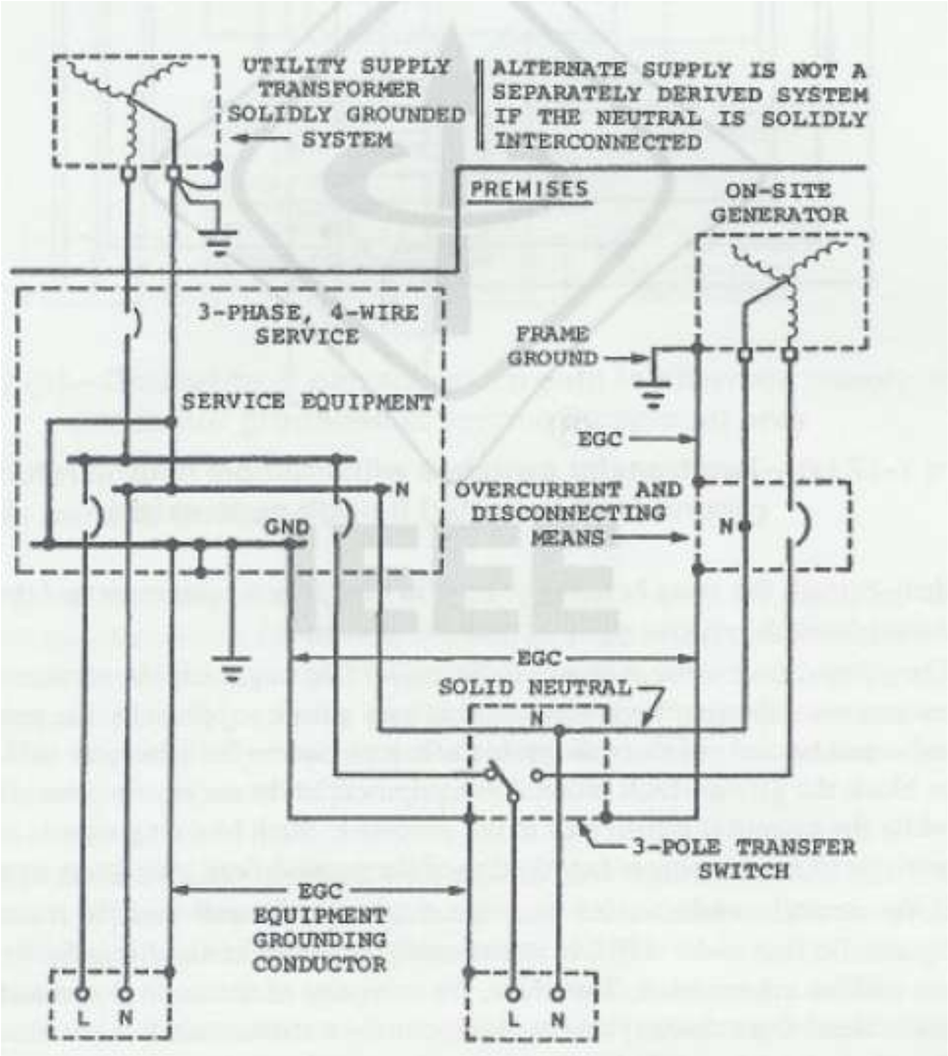


Figure 7-16
IEEE Orange Book
Std. 446-1995

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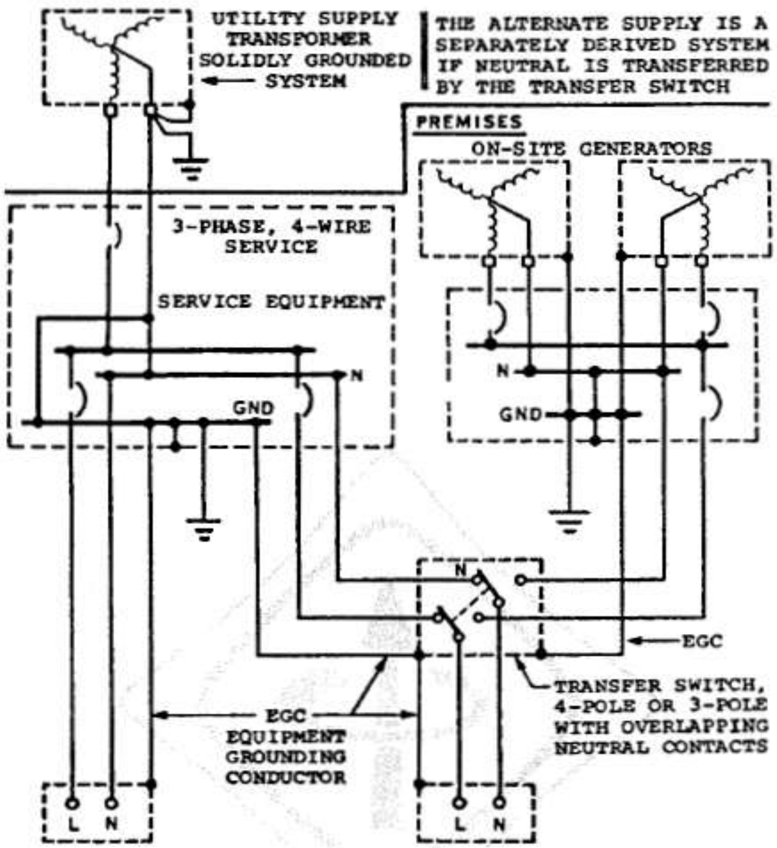
4-W Emergency Loads: Parallel Generators

- If 4-W parallel generators are a must, then a switched neutral ATS is recommended
- Must have one, single system ground for generators, located close to the generators
- Triplen harmonic circulating currents in the common neutral between generators may or may not be excessive

4-W 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.

3-W Emergency Loads: Parallel Generators

- Individual solid grounding of a 3-wire generator system will produce excessive triplen harmonic circulating currents in the ground circuit

- Instead, each generator neutral should be connected to a common neutral bus in the paralleling switchgear and grounded at one point.

- Triplen harmonics will then circulate in the common neutral instead of ground circuit

- **IEEE Orange Book says (7.9.3):**
  For a 3-wire system, it is generally recommended that the neutral of the generator not be solidly grounded so as to reduce circulating neutral currents within the ground system.

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3-Wire Emergency Loads

- Require 3-pole ATS only
- Generator neutral grounded at generator
- No nuisance tripping of ground fault relays

3-Wire Emergency Load – 3-Pole Transfer Switch No Stray

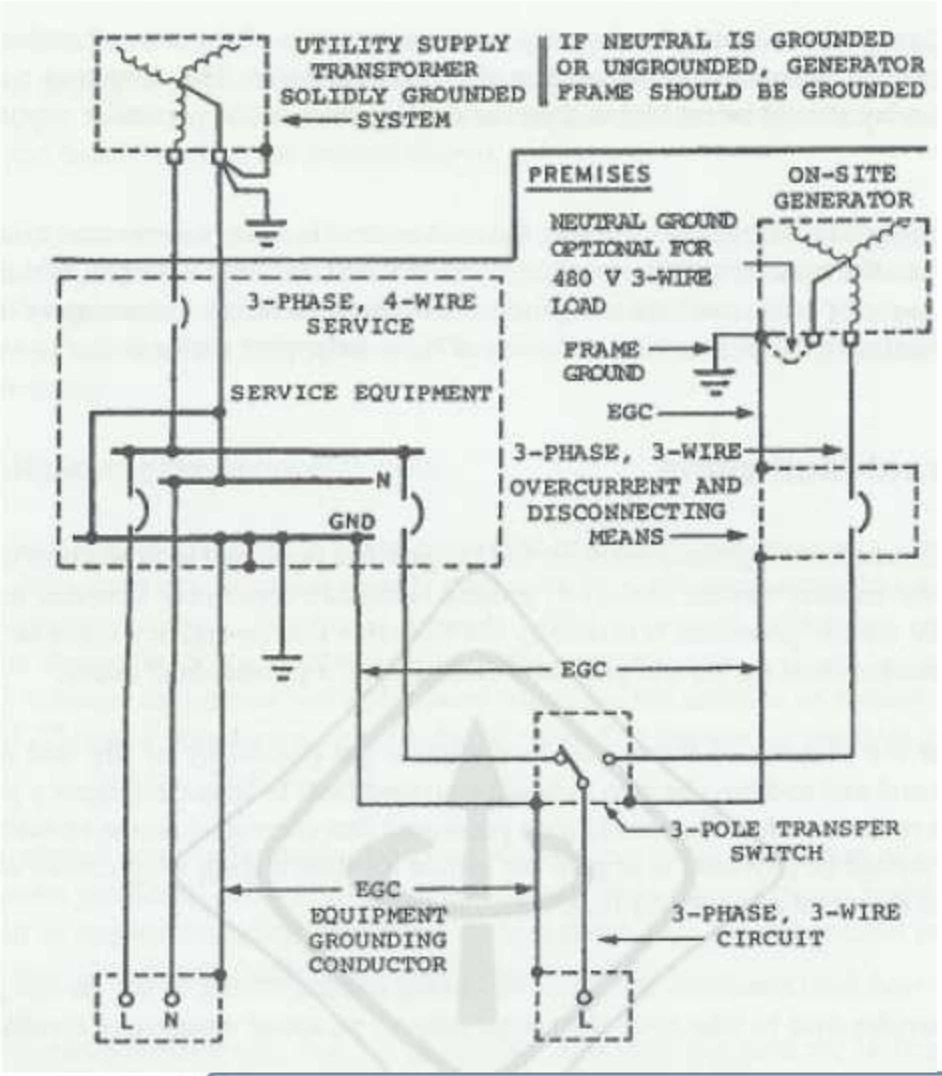
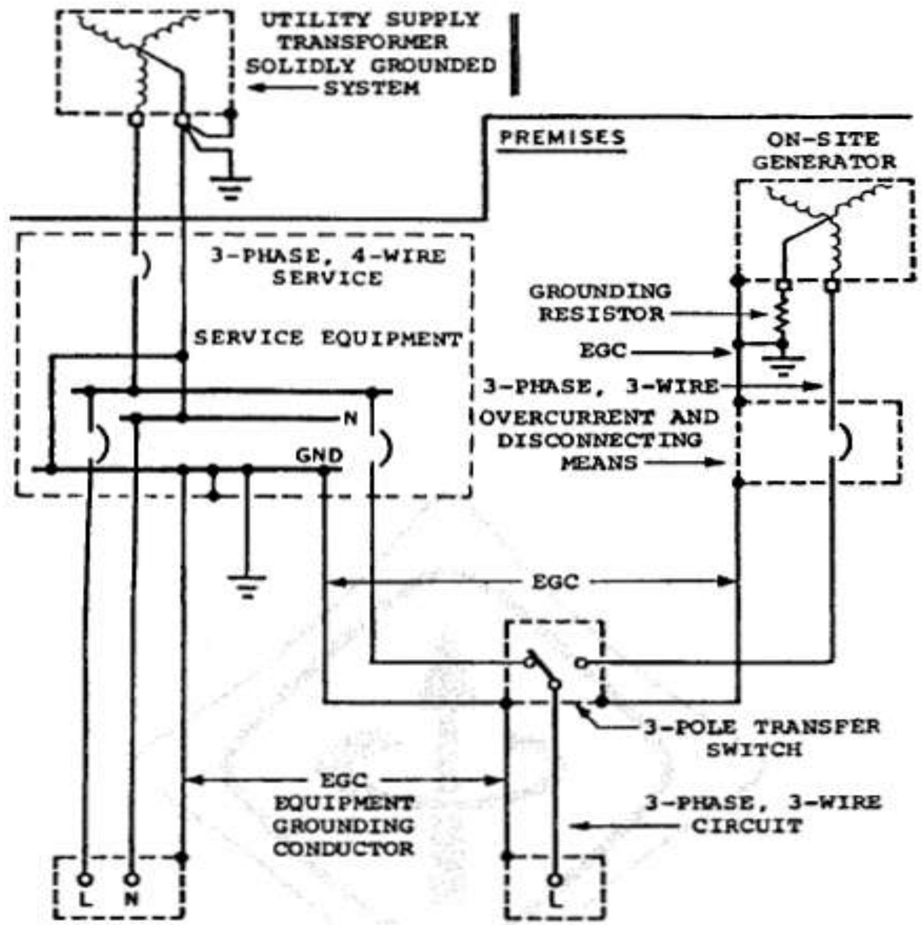


Figure 7-18
IEEE Orange Book
Std. 446-1995

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



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

Neutral Grounding Resistor

- Specifying Resistor Elements
- Commonly used materials:
  - Aluminum Chrome Steel 1JR (Ohmalloy)
  - Stainless Steel 18SR
  - 304 Nickel Chrome
- For low resistance grounding, 10-sec resistors have temp rise of 760^{o}C
- For high resistance grounding, continuous duty resistors have temp rise of 375^{o}C
- 304 increases resistance 43% for 760^{o}C rise
- 1JR and 18SR increase resistance less than 20% for 760^{o}C rise

Specifying Resistor Elements

- No longer sufficient to specify:
  - Element material should be made from electrical alloy with low temperature coefficient of resistance.
- Should specify instead:
  - Element material should not have a temperature coefficient greater than 0.0002 ohms/C
  - The resistor let-thru current shall not decrease by greater than 20% from ambient to full operating temperature.

Suggested Ground Fault Pickup Ranges for LRG (Non-Mining Applications)

Feeders	20-60% of resistor let-thru current
Motors	10-20% of resistor let-thru current
NGR	50-80% of resistor let-thru current

Specifying Resistor Elements

- Commonly used materials:
  - Aluminum Chrome Steel 1JR (Ohmalloy)
  - Stainless Steel 18SR
  - 304 Nickel Chrome
- For low resistance grounding, 10-sec resistors have temp rise of 760^{o}C
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