

Advantages and Disadvantages of Different Types of Neutral Grounding Systems

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NEUTRAL GROUNDING OF POWER SYSTEMS

OBJECTIVES

1. Discuss five types of grounding for power systems.
2. Discuss advantages of high resistance grounding.
3. Show equipment

POWER SYSTEM GROUNDING

Power system grounding is a connection between an electrical circuit or equipment and the earth or to some conducting body that serves in place of earth.

This presentation concerns the design of power system grounding for industrial and commercial facilities – not utility systems.

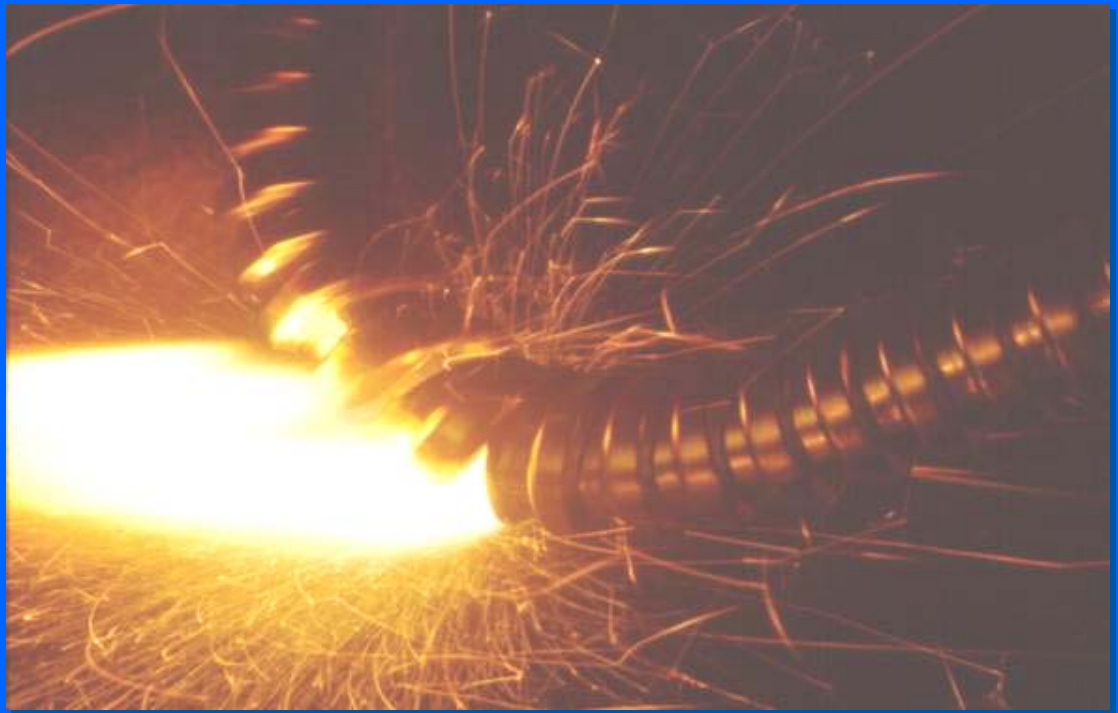
DISCUSSION OF GROUNDING

1. The ungrounded system
2. The solidly grounded system
3. Reactive grounding
4. Low resistance grounding of power systems
5. High resistance grounding of power systems

Are You at Risk?

**Do you use
electricity?**

Electrical deficiencies
are the leading ignition
source and cause of
fire and explosion.

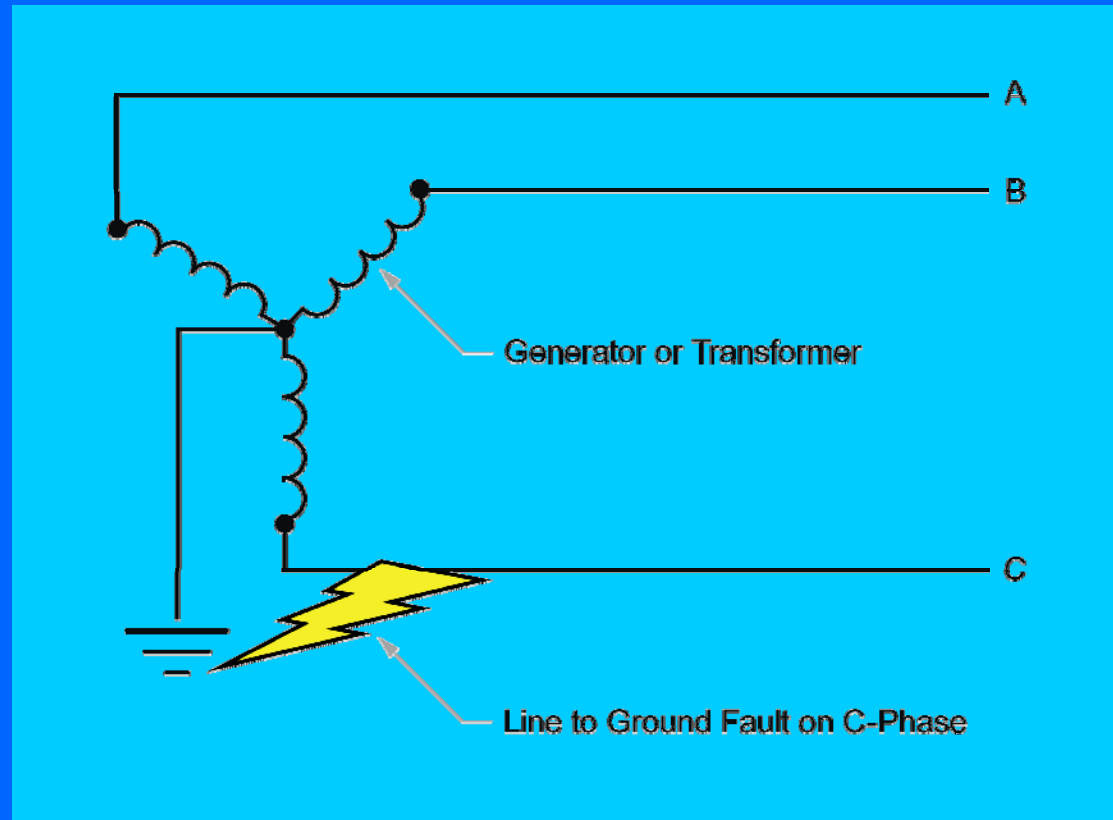


What is a Ground Fault?

Contact between ground and an energized conductor

Unleashes large amount of electrical energy

Dangerous to equipment and people



POWER SYSTEM GROUNDING SYSTEM FAILURES – SHORT CIRCUITS (FAULTS) INDUSTRIAL POWER SYSTEMS

<u>FAILURE MODE</u>	<u>PERCENTAGE OF FAILURES</u>
1. LINE TO GROUND	98 %
2. PHASE - PHASE	<1.5 %
3. THREE PHASE	<.5 %

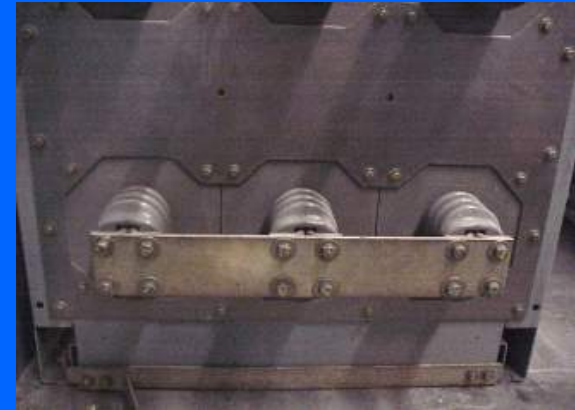
Most three phase faults are man-made:
I.E. Accidents caused by improper operating procedure.

Two Types of Faults

Bolted Faults

Solid connection between two phases or phase and ground resulting in high fault current.

Stresses are well contained so fault creates less destruction.



Arc Faults

Usually caused by insulation breakdown, creating an arc between two phases or phase to ground.

Intense energy is not well contained, and can be very destructive.



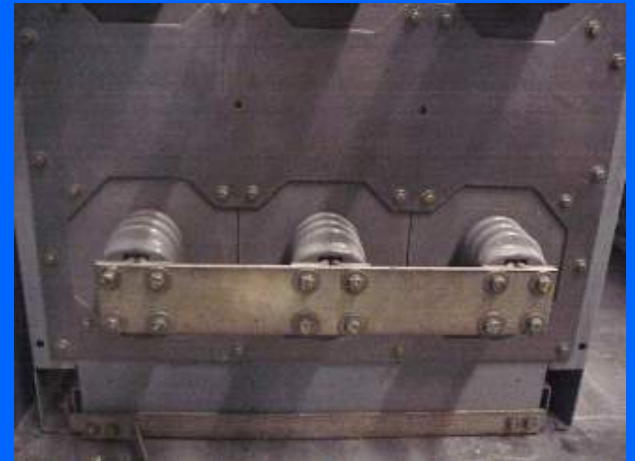
Bolted Faults

Result from a solid connection accidentally being made between two phases of the system or between one phase and an adjacent grounded metal surface.

Because they are low resistance, high current events, this type of fault may actually be less destructive because the energy is spread over a large area and the protective devices are activated very rapidly by the large current.

All types of electrical equipment with a withstand and/or interrupting rating are tested using bolted fault conditions.

The majority of the stresses (thermal and mechanical) are confined within the bus-bar and associated supports, so very little arc flash / blast occurs, if any at all.



600 Volt “THHN” Power Cable on “Ungrounded” System



**Arcing
Fault**

Arc Fault

Usually caused by insulation breakdown, an arc jumps between two phases or between one phase and a grounded metal surface.

The resulting fault current is smaller because of the relatively high resistance of the arc (25-40% of a bolted fault).

Protective devices may be slow in responding to the smaller fault current.

Arc faults can be the most destructive because of the intense energy that is concentrated in the small area of the arc.

The majority of the stresses (thermal and mechanical) are not confined within the bus-bar and associated supports, it extends to the space in the compartment.



THE ARCING FAULT

An arcing fault is an intermittent failure between phases or phase to ground. It is a discontinuous current that alternately strikes, is extinguished and restrikes again. For solidly grounded systems, the arc currents are: in percent of bolted three phase faulted

FAULTS

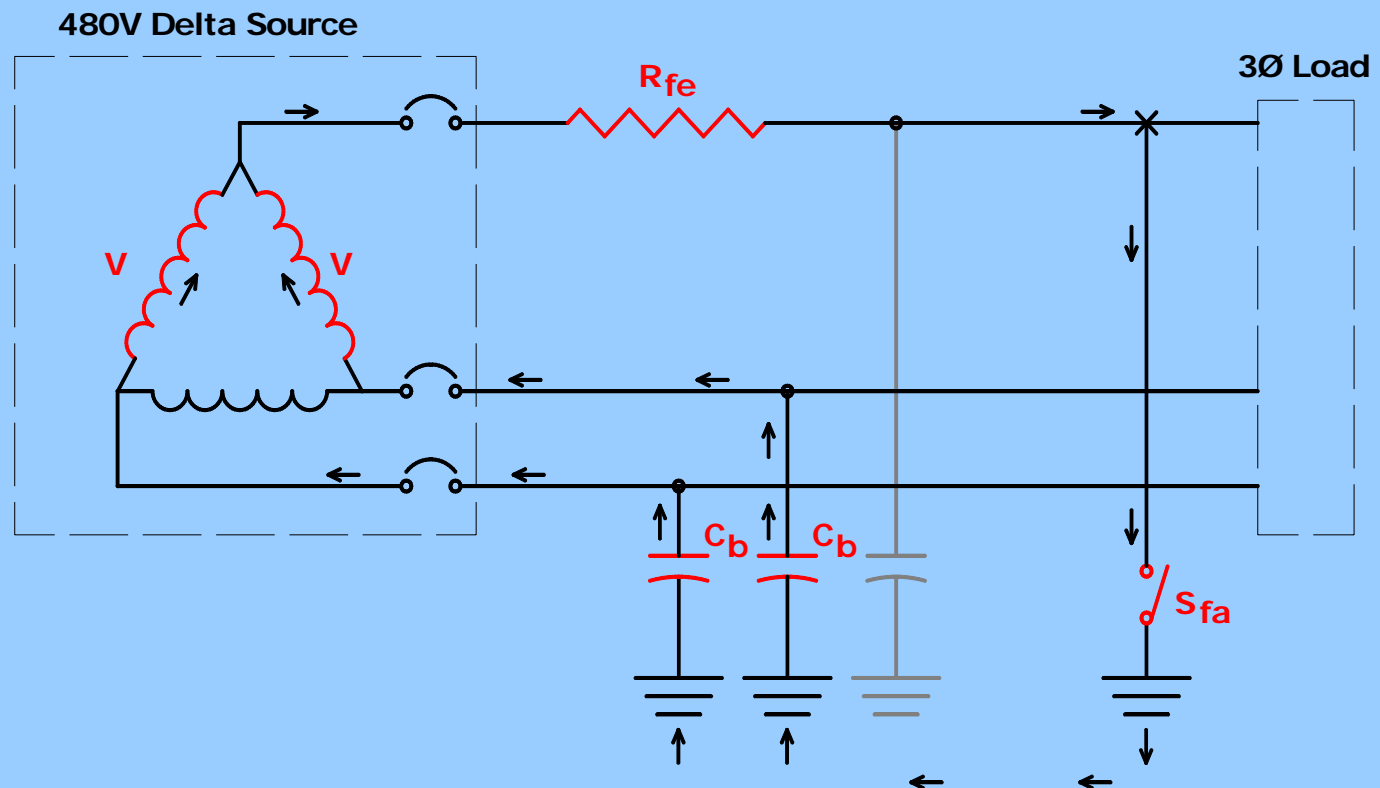
THREE PHASE	89%
LINE-LINE	74%
LINE-GROUND	38%

Arcing Ground Faults

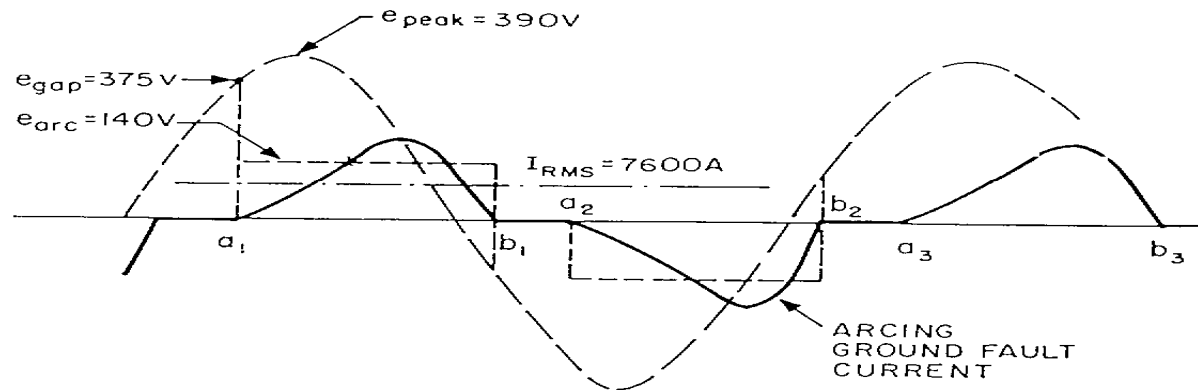
Intermittent or Re-strike

Intermittent ground fault: A re-striking ground fault can create a high frequency oscillator (RLC circuit), independent of L and C values, causing high transient over-voltages.

- i.e. re-striking due to ac voltage waveform or loose wire caused by vibration



ARCING LINE-GROUND FAULT 480/277 VOLT POWER SYSTEM



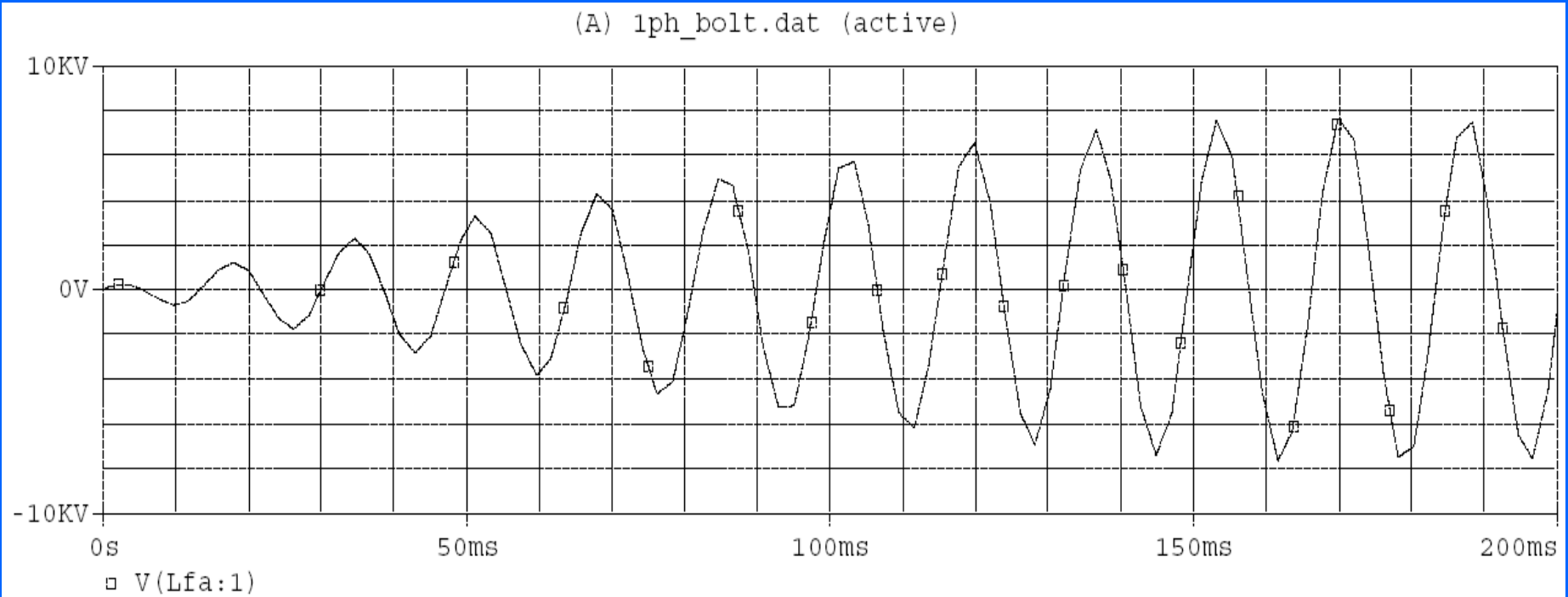
FROM: THE IMPACT OF ARCING GROUND FAULTS ON LOW VOLTAGE
POWER SYSTEM DESIGN J.R. DUNKI-JACOBS GET-6098
12-70, PG. 19, FIG 4-2 GENERAL ELECTRIC

NOTE: CURRENT IS A DISCONTINUOUS, NON-SINUSOIDAL WAVE

Arcing Ground Faults

Intermittent or Re-strike

Plot of transient over-voltage for an arcing ground fault



Industry Recommendations

IEEE Std 242-2001 (Buff Book)

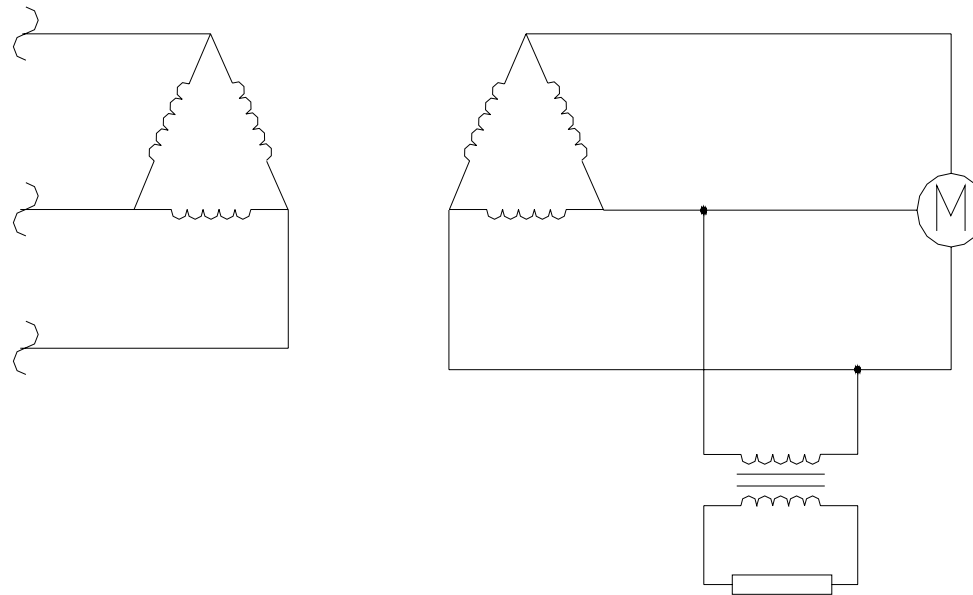
Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

8.2.5 If this ground fault is intermittent or allowed to continue, the system could be subjected to possible *severe over-voltages to ground, which can be as high as six to eight times phase voltage*. Such over-voltages can puncture insulation and result in additional ground faults. These over-voltages are caused by repetitive charging of the system capacitance or by resonance between the system capacitance and the inductance of equipment in the system.

THE UNGROUNDED POWER SYSTEM

THE UNGROUNDED POWER SYSTEM

DELTA - DELTA CONNECTION

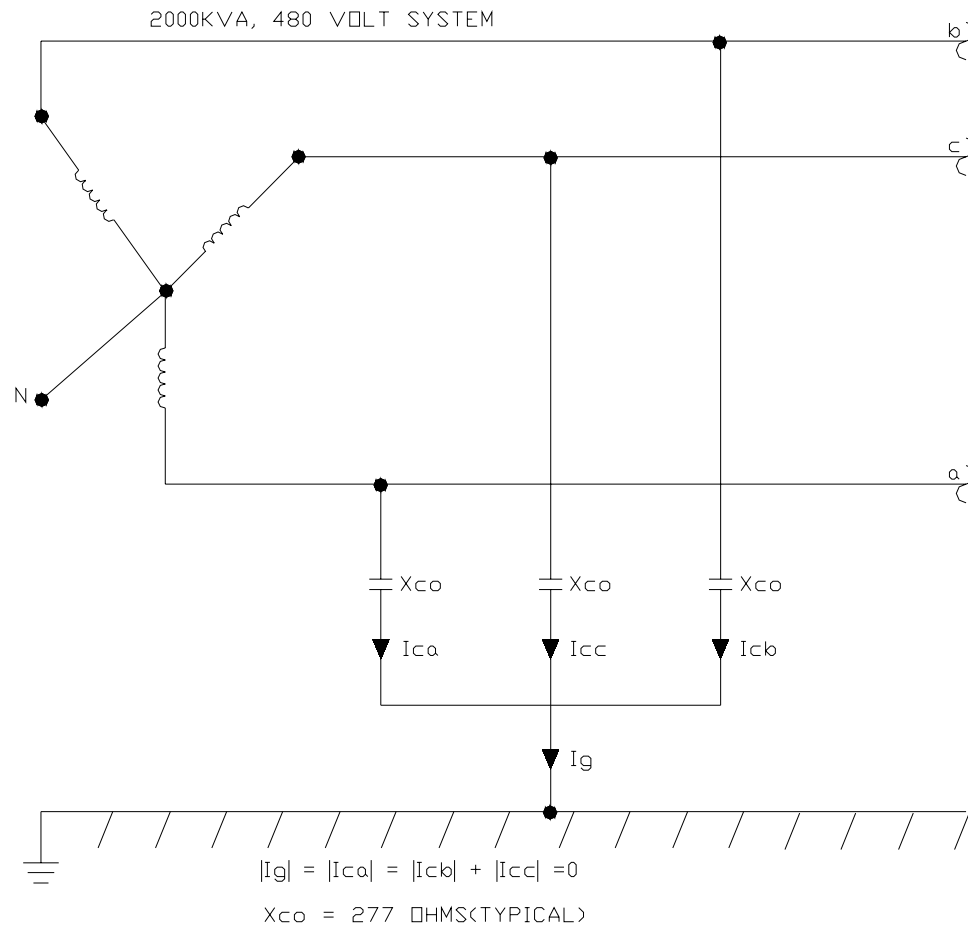


SINGLE PHASE LOAD

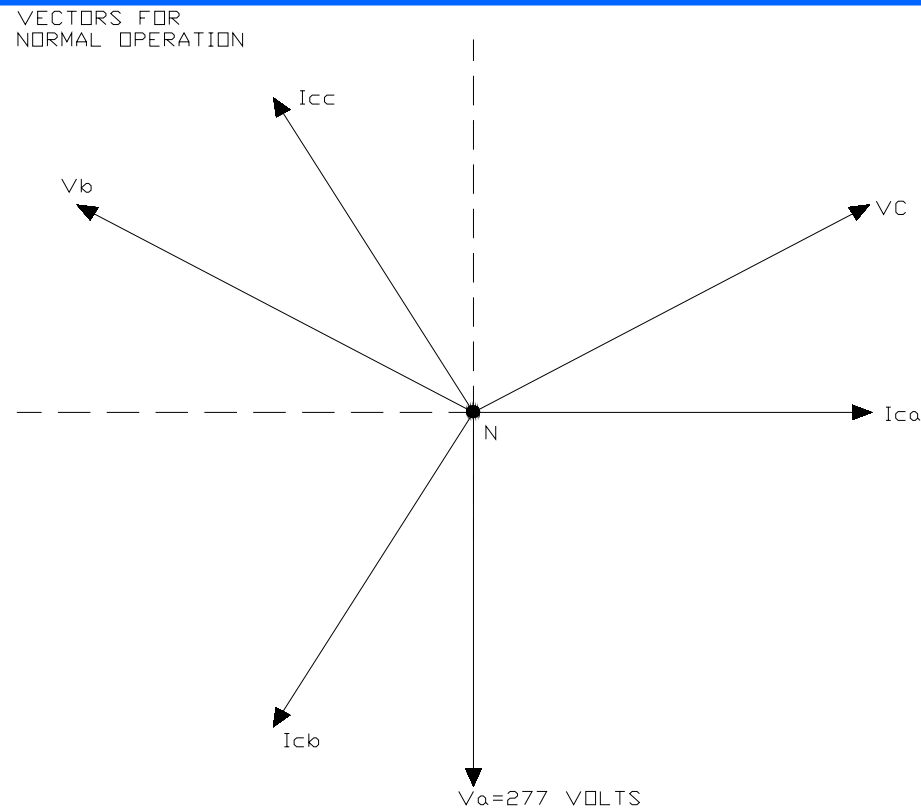
SUITABLE FOR

TWO WIRE, SINGLE PHASE LOADS
THREE WIRE, THREE PHASE LOADS

UNGROUNDED SYSTEM NORMAL CONDITIONS

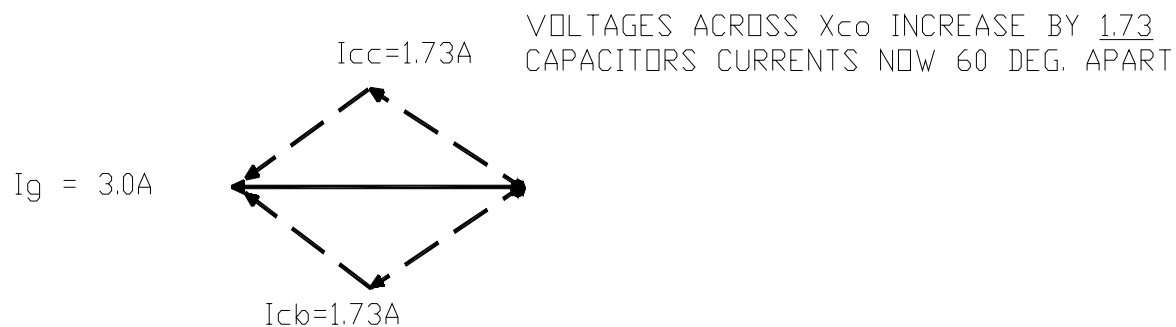
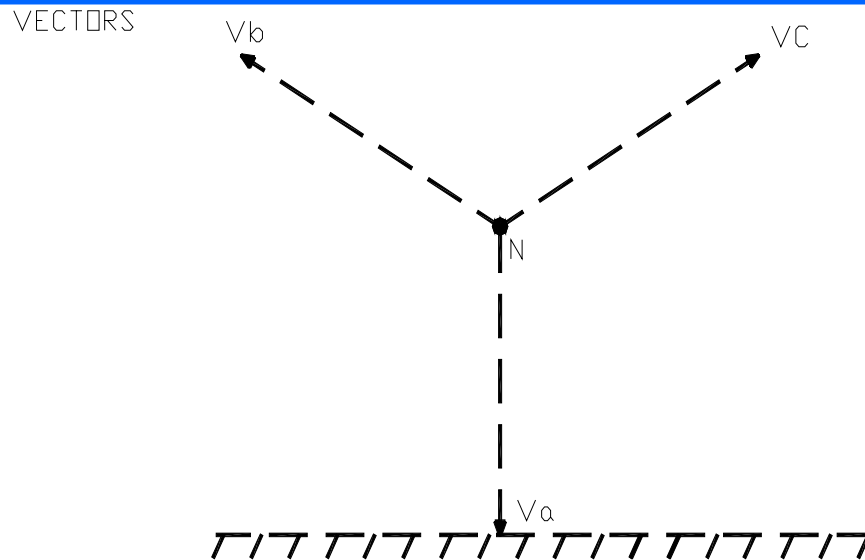


UNGROUNDED SYSTEM NORMAL CONDITIONS

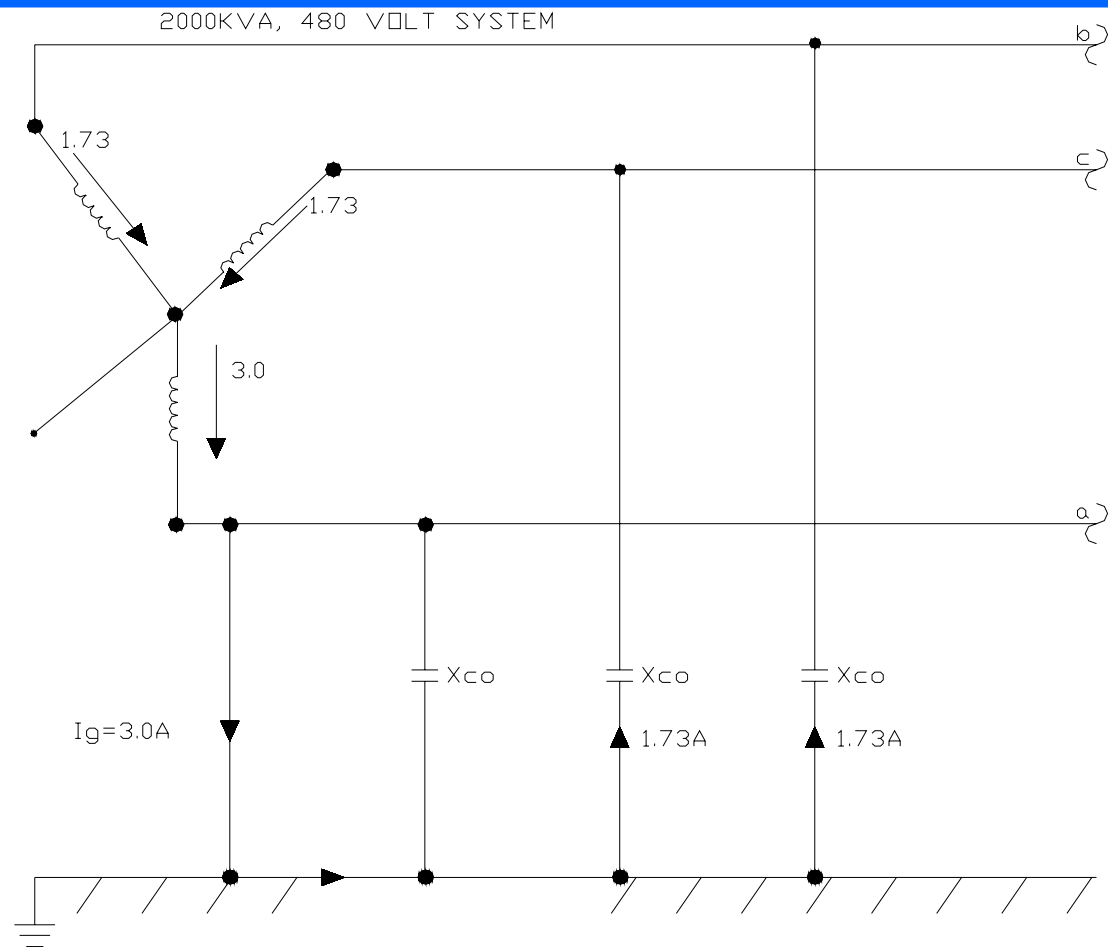


- BALANCED CONDITIONS
- CURRENTS DISPLACED 120 DEGREES
- CAPACITOR NEUTRAL AT SAME POTENTIAL AS TRANSFORMER NEUTRAL
- CAPACITOR CURRENT LEADS CAPACITOR VOLTAGE BY 90 DEGREES

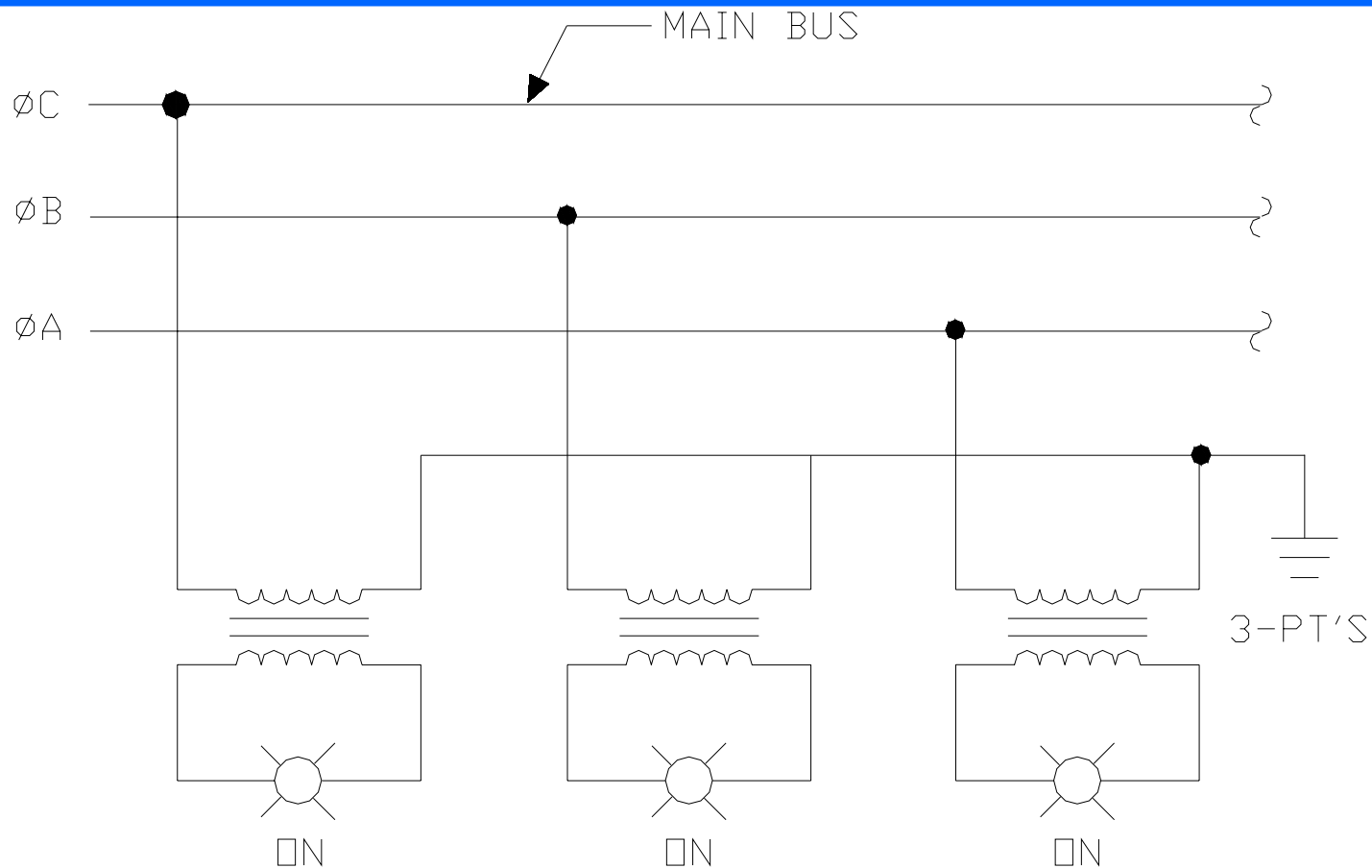
UNGROUNDED SYSTEM GROUND FAULT ON PHASE A



UNGROUNDED SYSTEM GROUND FAULT ON PHASE A

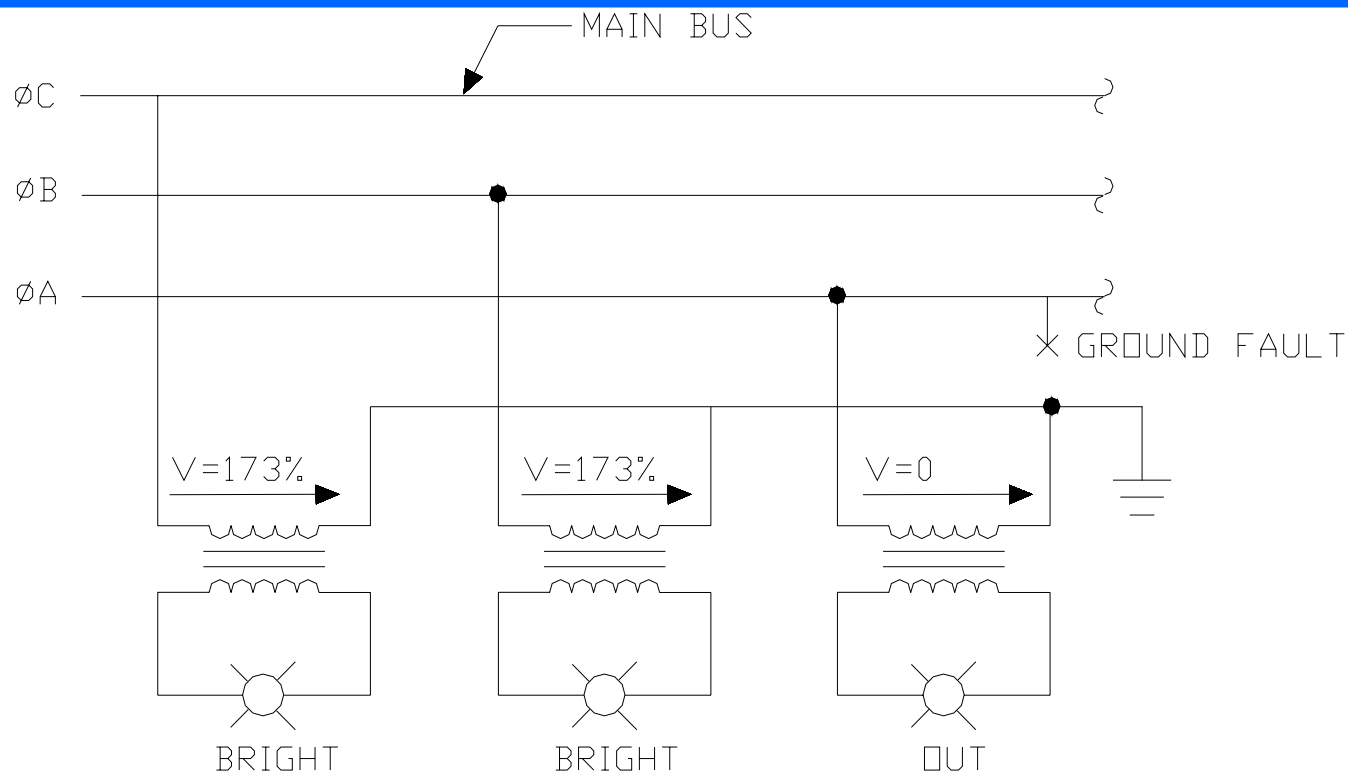


THE UNGROUNDED POWER SYSTEM GROUND DETECTION CIRCUIT



SYSTEM NORMAL
ALL LIGHTS ON WITH EQUAL BRIGHTNESS

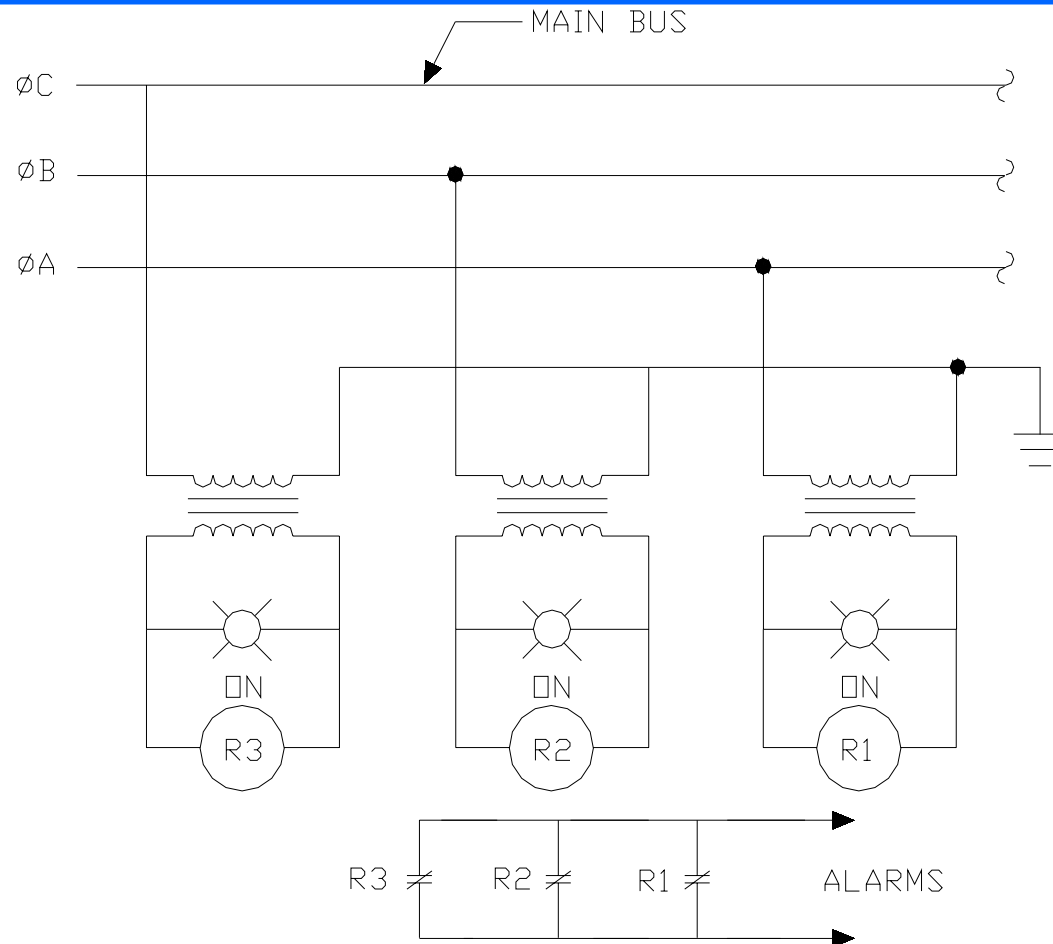
THE UNGROUNDED POWER SYSTEM GROUND DETECTION CIRCUIT



GROUND FAULT ON PHASE A

PHASE A LIGHT OUT
PHASE B & PHASE C LIGHTS ON AT GREATER
BRIGHTNESS - i.e. VOLTAGE ON THE LIGHTS HAS
INCREASED BY 73%

THE UNGROUNDED POWER SYSTEM GROUND DETECTION CIRCUIT WITH ALARM



DURING NORMAL OPERATIONS R1, R2 & R3
ARE ENERGIZED, SO CONTACTS ARE OPEN

THE UNGROUNDED POWER SYSTEM ADVANTAGES

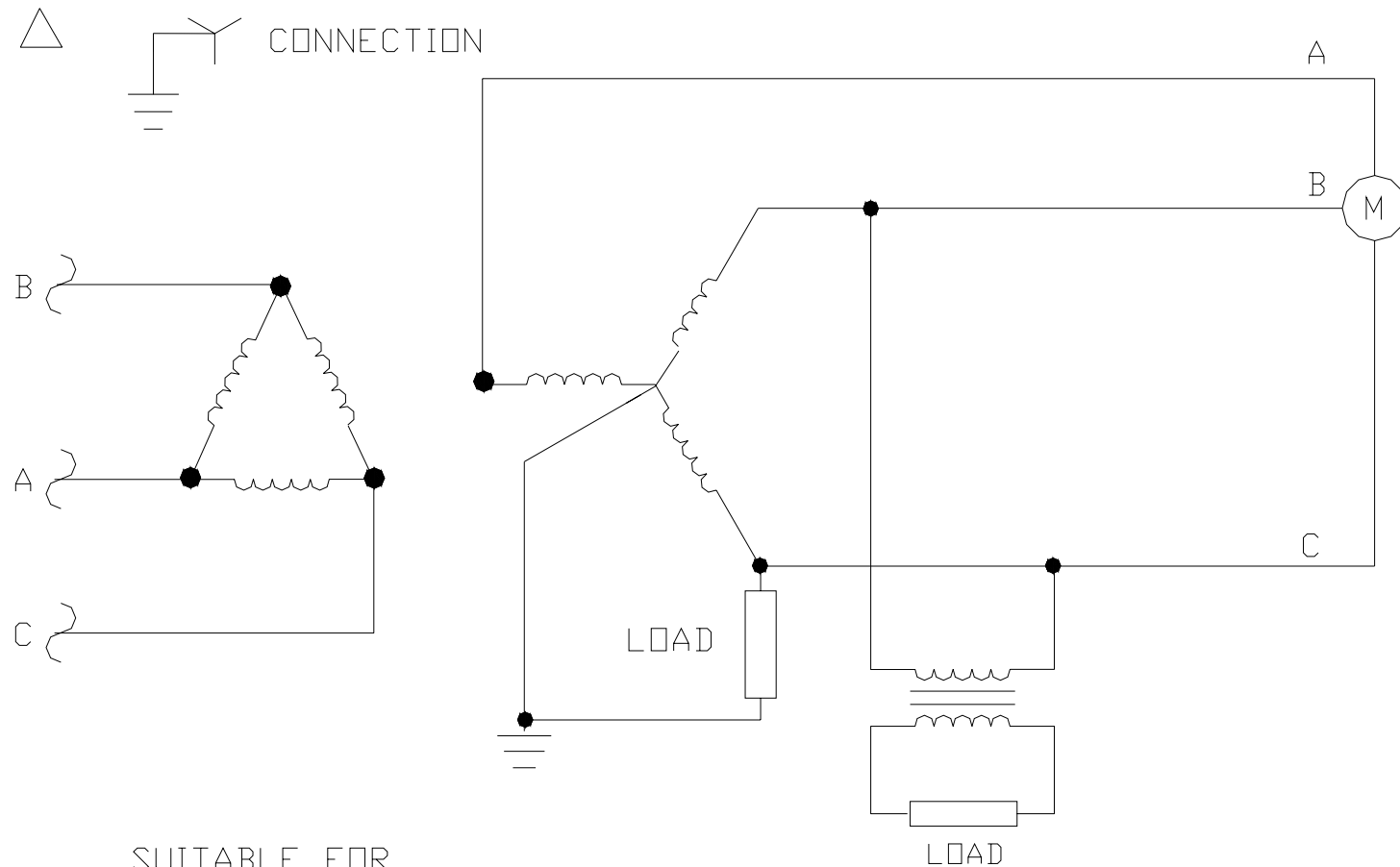
1. Low value of current flow for line to ground fault- 5amps or less.
2. No flash hazard to personnel for accidental line to ground fault.
3. Continued operation on the occurrence of first line to ground fault.
4. Probability of line to ground arcing fault escalating to line – line or three phase fault is very small.

THE UNGROUNDED POWER SYSTEM DISADVANTAGES

1. Difficult to locate line to ground fault.
2. The ungrounded system does not control transient overvoltages.
3. Cost of system maintenance is higher due to labor of locating ground faults.
4. A second ground fault on another phase will result in a phase-phase short circuit.

THE SOLIDLY GROUNDED POWER SYSTEM

THE SOLIDLY GROUNDED POWER SYSTEM

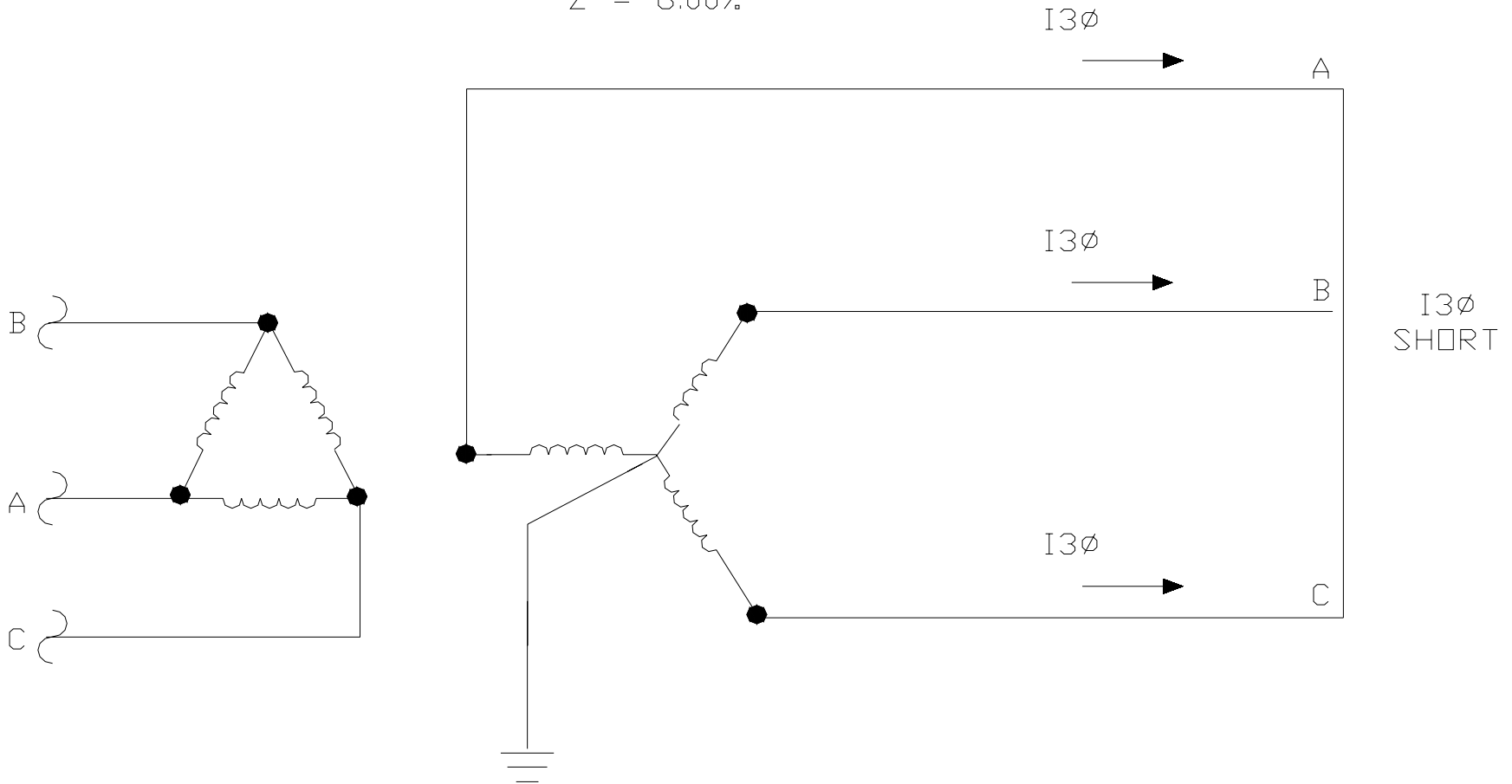


SUITABLE FOR

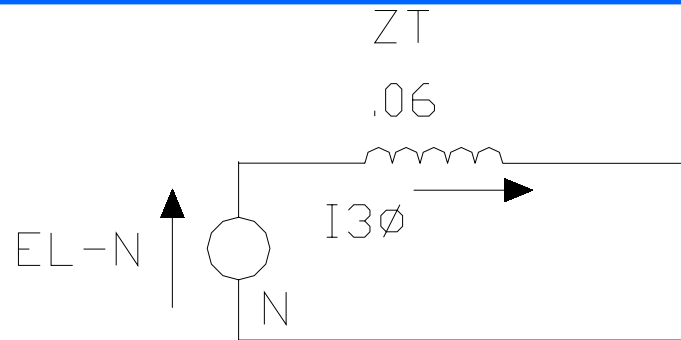
- TWO WIRE, SINGLE PHASE LOADS (LINE-LINE)
- TWO WIRE, SINGLE PHASE LOADS (LINE-NEUTRAL)
- THREE PHASE, THREE WIRE LOADS

SOLIDLY GROUND SYSTEM THREE PHASE SHORT CIRCUIT

1500 KVA
13.8 KV - 480 VOLT
Z = 6.00%



SOLIDLY GROUNDED SYSTEM THREE PHASE SHORT CIRCUIT



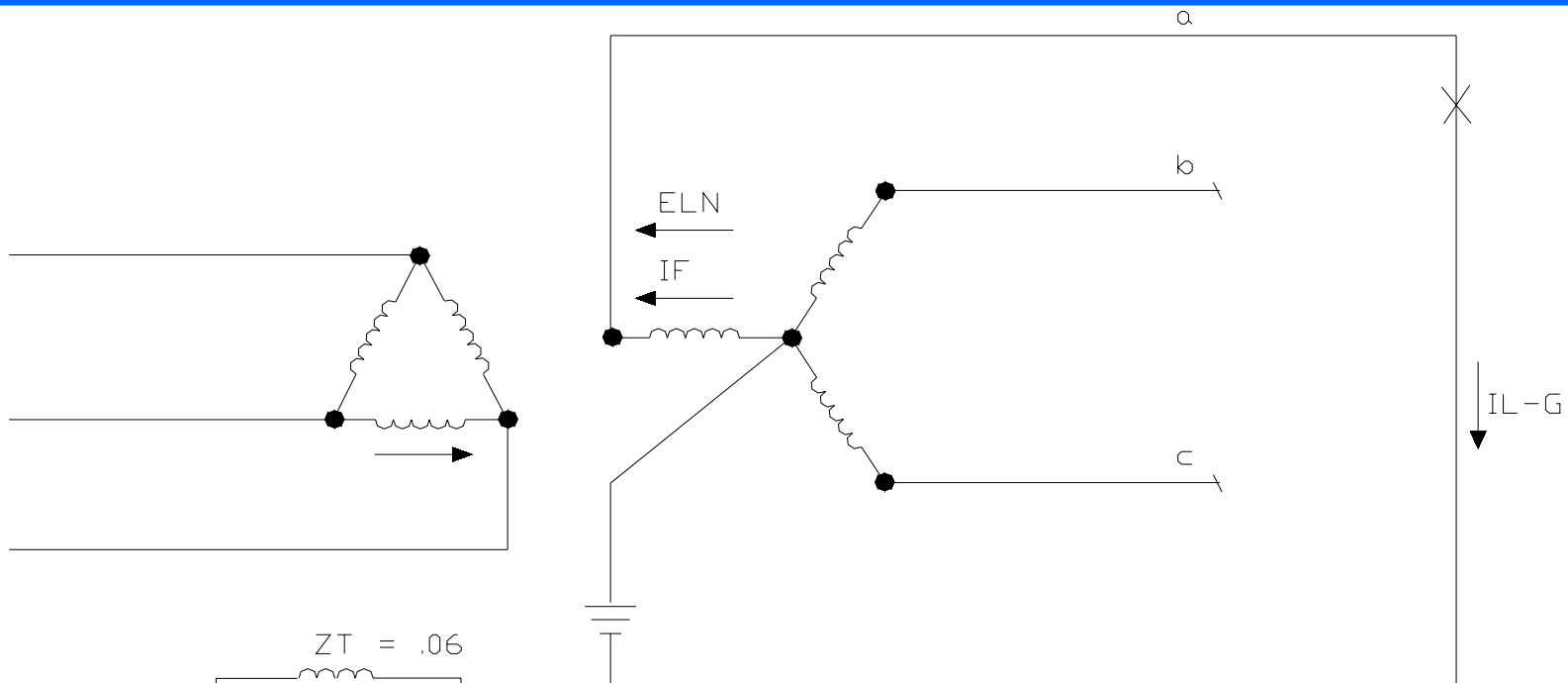
$$I_{FL} = \frac{1500 \text{ KVA}}{3 \times .48 \text{ KV}} = 1804 \text{ AMPS} = 1 \text{ PER UNIT}$$

$$I_{3PH} = \frac{E_{L-N}}{Z_T} \times \frac{1.0 \text{ PER UNIT}}{.06 \text{ PER UNIT}} = 16.67 \text{ P.U.}$$

$$I_{3\phi} = 16.67 \times 1804$$

$$I_{3\phi} = 30,065 \text{ AMPS}$$

SOLIDLY GROUNDED SYSTEM LINE – GROUND SHORT CIRCUIT

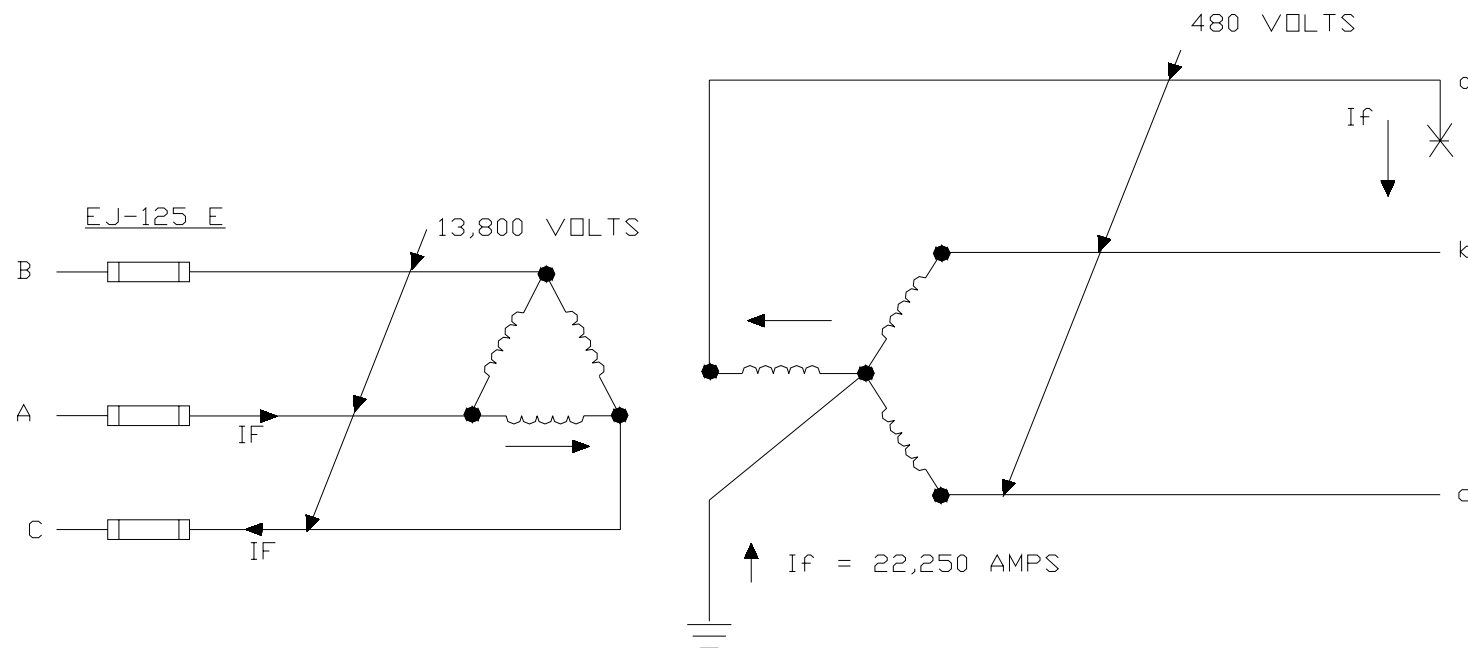


$Z_G = .02$ (GROUND RETURN PATH)

$$I = \frac{E_{L-N}}{Z_T + Z_G} = \frac{1.0}{.06 + .02} = 12.5 \text{ PER UNIT}$$

$$I_{LG} = 12.5 \times 1804 = 22,550$$

SOLIDLY GROUNDED SYSTEM LINE – GROUND SHORT CIRCUIT



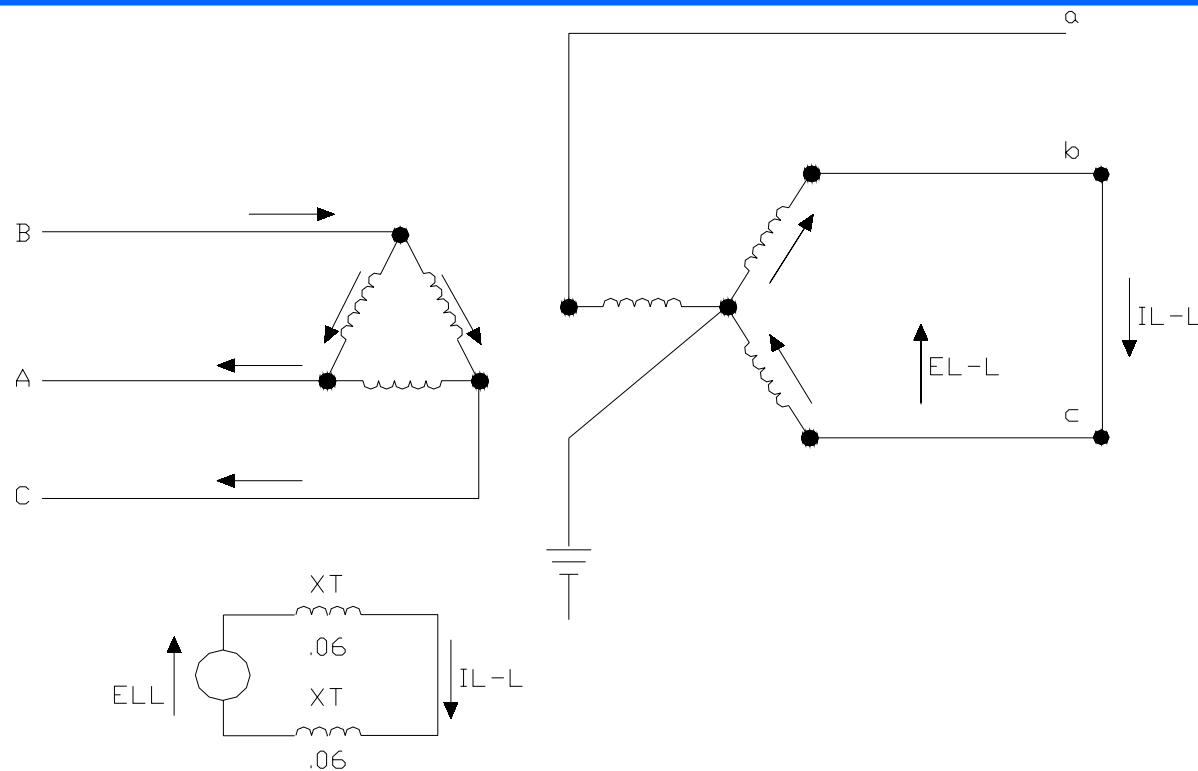
$$I_{\text{PRIMARY}} = I_{\text{SEC}} \times \frac{V_s / \sqrt{3}}{V_p}$$

$$= 22,250 \text{ A} \times \frac{480 / \sqrt{3}}{13,800}$$

$$I_{\text{PRIMARY}} = 447 \text{ AMPS}$$

THE LINE-GROUND FAILURE ON THE SECONDARY HAS CAUSED A
SIGNIFICANT PROBLEM ON THE PRIMARY OF THE SYSTEM.

SOLIDLY GROUNDED SYSTEM LINE-LINE SHORT CIRCUIT

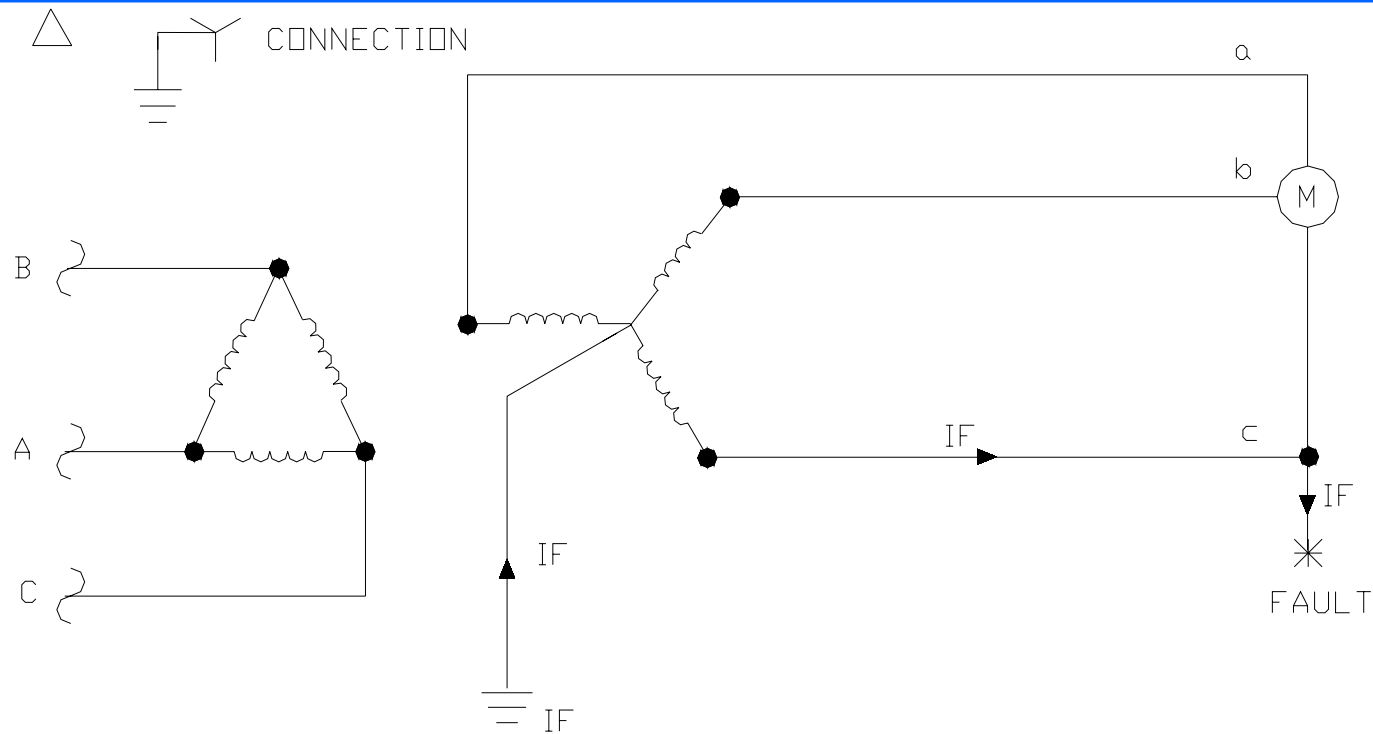


$$I_{L-L} = \frac{E_{L-L}}{2X_T} = \frac{E_{L-N} \times \sqrt{3}}{2 \times T} = \frac{\sqrt{3}}{2} \frac{E_{L-N}}{X_T}$$

$$I_{L-L} = .877 I_{3\phi}$$

$$I_{L-L} = 26,367 \text{ AMPS}$$

THE SOLIDLY GROUNDED POWER SYSTEM LINE TO GROUND FAULT



I_{FAULT} 500MVA SHORT CIRCUIT CAPACITY
UTILITY POWER SYSTEM

TRANSFORMER
SIZE

I_{FAULT} @
480 VOLT BUS

I_{FAULT} @
MOTOR

1000KVA
1500KVA
2000KVA

20,000 AMPS
30,000 AMPS
40,000 AMPS

10,000 AMPS
15,000 AMPS
20,000 AMPS

Industry Recommendations

IEEE Std 141-1993 (Red Book)

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 480V and 600V systems. The danger of sustained arcing for phase-to-ground fault probability is also high for the 480V and 600V systems, and low for the 208V systems. For this reason ground fault protection is shall be required for system 1000A or more (NEC 230.95). *A safety hazard exists for solidly grounded systems from the severe flash, arc burning, and blast hazard from any phase-to-ground fault.*

THE SOLIDLY GROUNDED POWER SYSTEM

ADVANTAGES

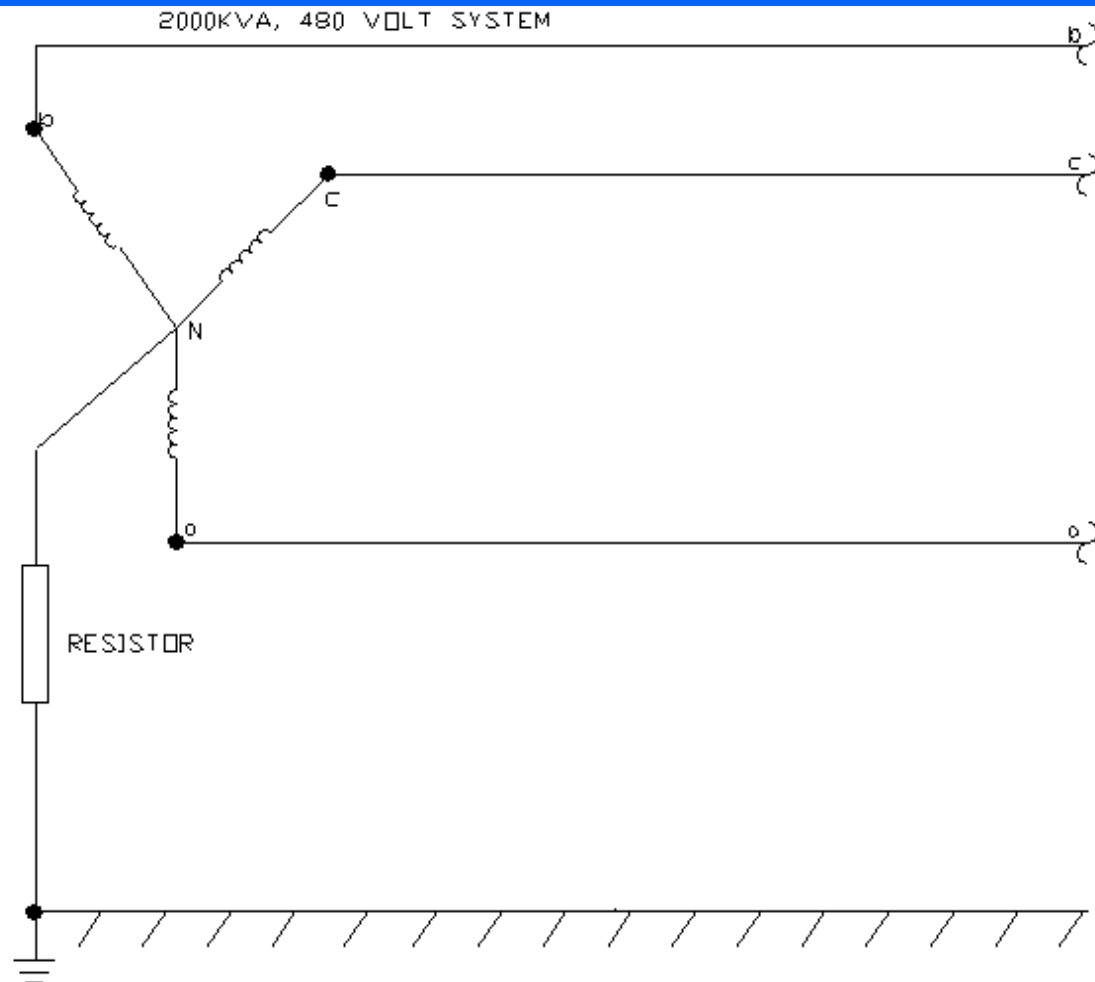
1. Controls transient over voltage from neutral to ground.
2. Not difficult to locate the fault.
3. Can be used to supply line-neutral loads

THE SOLIDLY GROUNDED POWER SYSTEM

DISADVANTAGES

1. Severe flash hazard
2. Main breaker required
3. Loss of production
4. Equipment damage
5. High values of fault current
6. Single-phase fault escalation into 3 phase fault is likely
7. Creates problems on the primary system

NEUTRAL GROUNDING RESISTOR



Reactive Grounding

Uses reactor not resistor

Fault values of transient-overvoltages are unacceptable in industrial environments

Typically found in high voltage applications (>46 kV)



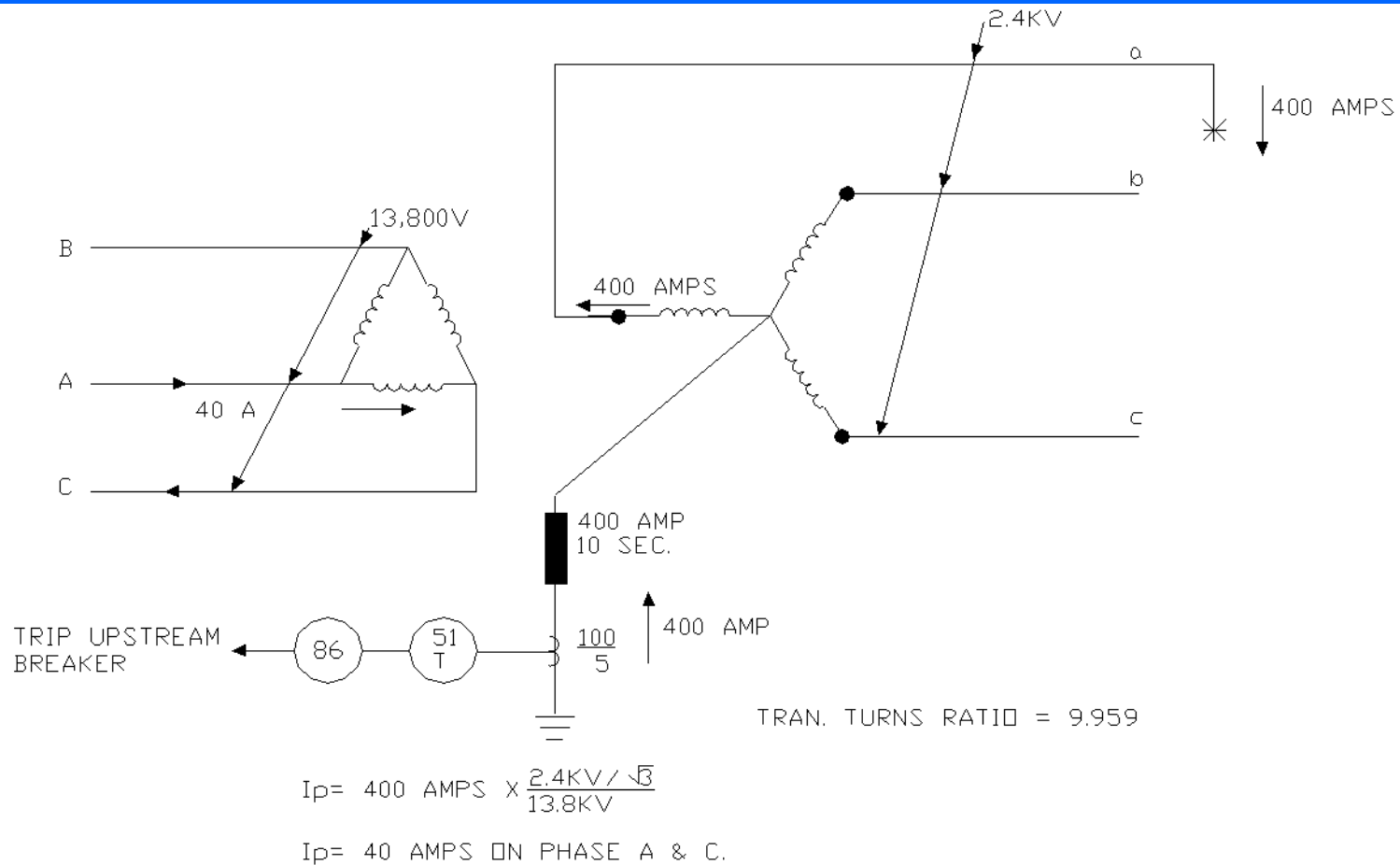
LOW RESISTANCE GROUNDING OF POWER SYSTEMS

LOW RESISTANCE GROUNDING OF POWER SYSTEMS

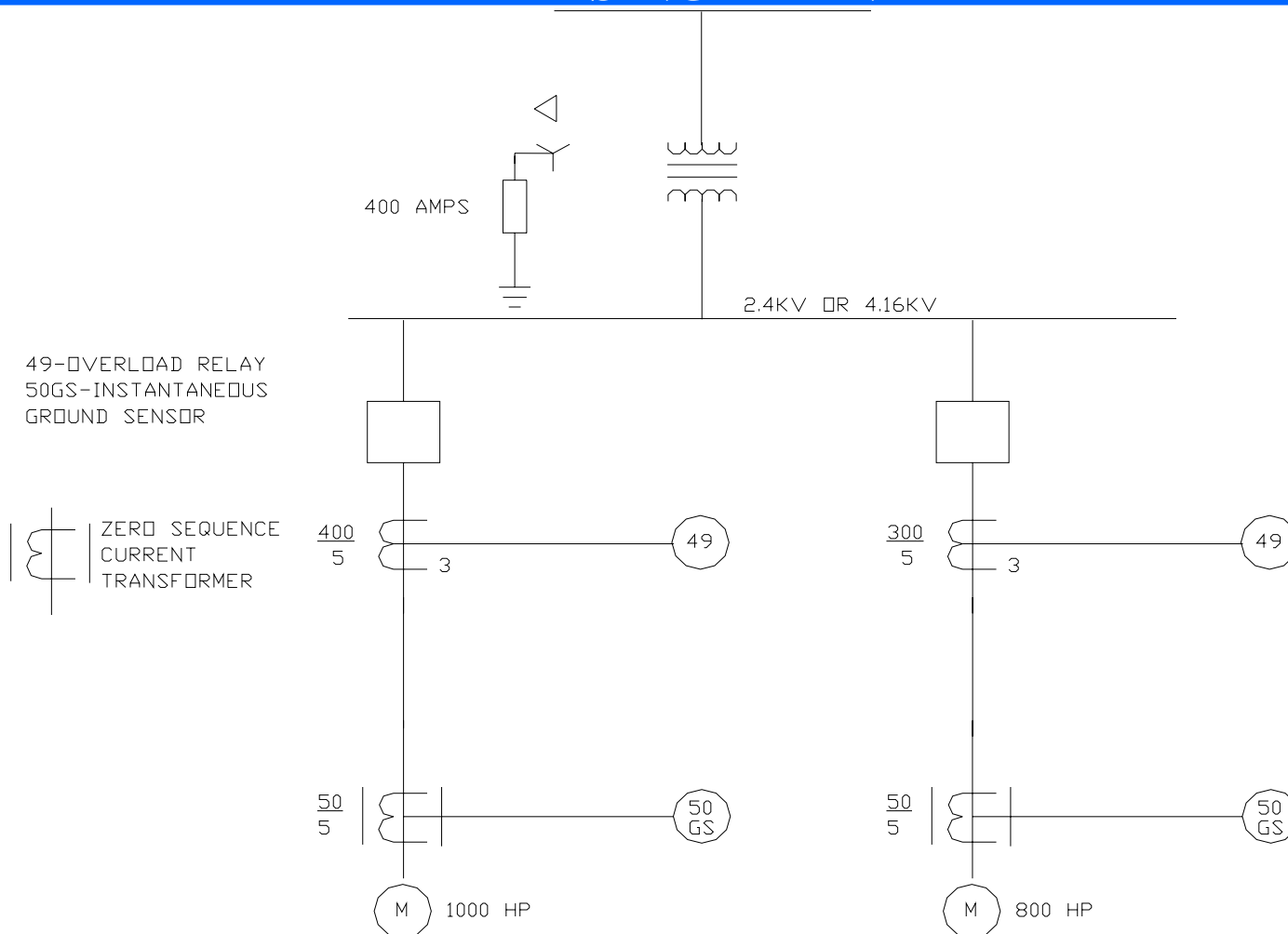
This design is generally for the following systems:

- At 2.4 kv through 14,400 kv.
- Systems serving motor loads
- Current is limited to 200 to 400 amps
- Systems typically designed to shut down in 10 seconds

LOW RESISTANCE GROUNDED POWER SYSTEMS



LOW RESISTANCE GROUNDED ZERO SEQUENCE RELAYING PARTIAL SINGLE LINE



LOW RESISTANCE GROUNDED POWER SYSTEMS

400 AMP GROUNDING

Disadvantages

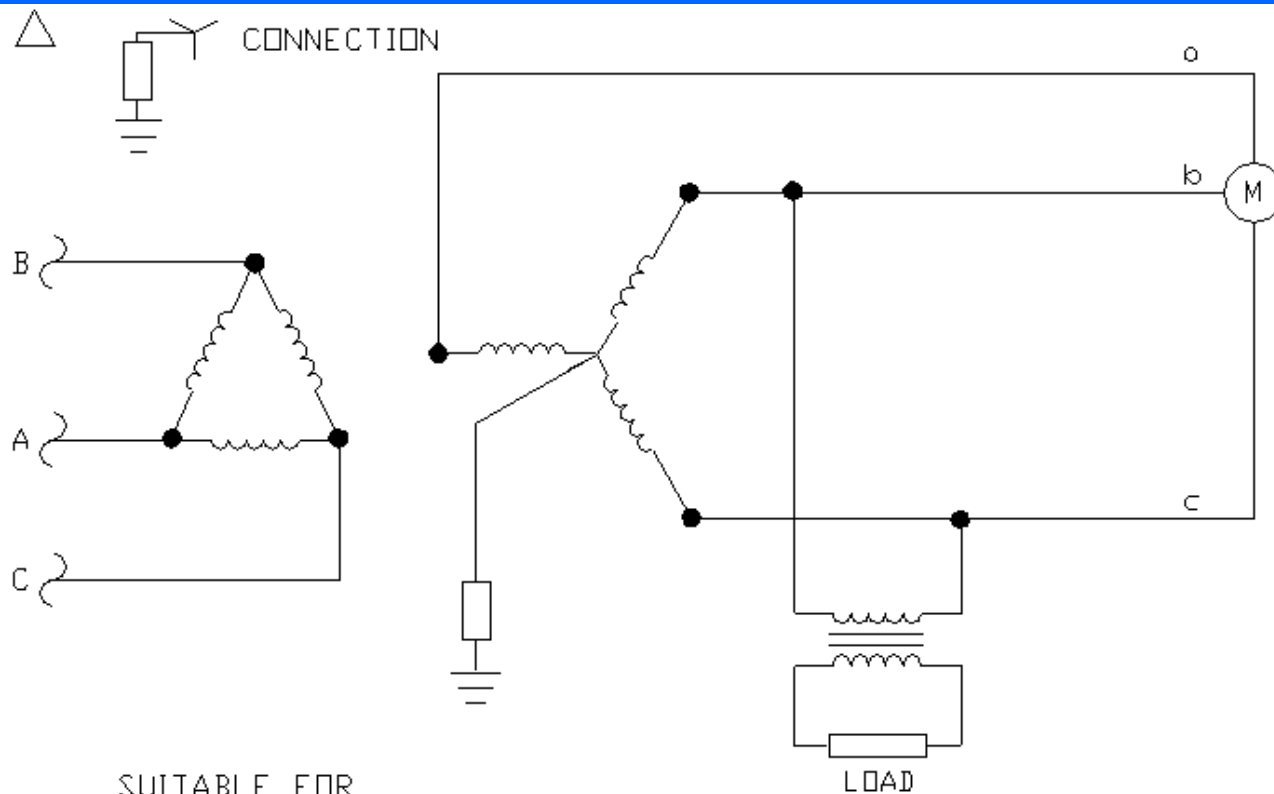
- Relatively large ground fault is required and thermal damage and core restacking is possible
- The faulted machine is shutdown
- Starter fuse may also operate
- Must trip upstream circuit breaker.
- Has been replaced by high resistance grounded systems with modern CT's and relays.

Advantages

- 400 amp grounding does look at a large part of the machine winding.

HIGH RESISTANCE GROUNDING OF POWER SYSTEMS

THE HIGH RESISTANCE GROUNDED POWER SYSTEM



SUITABLE FOR

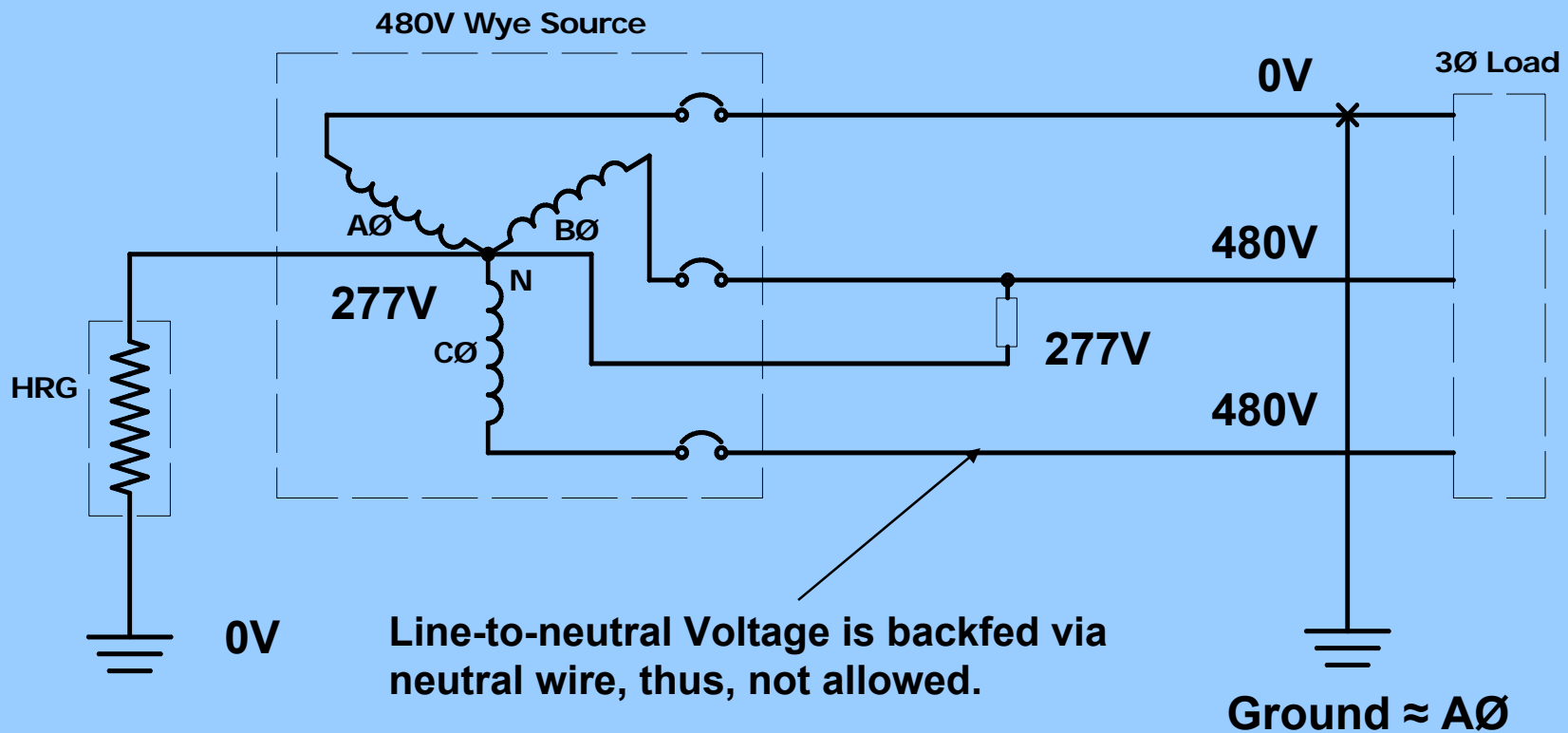
- TWO WIRE, SINGLE PHASE LOADS
- THREE WIRE, THREE PHASE LOADS

NOT SUITABLE FOR

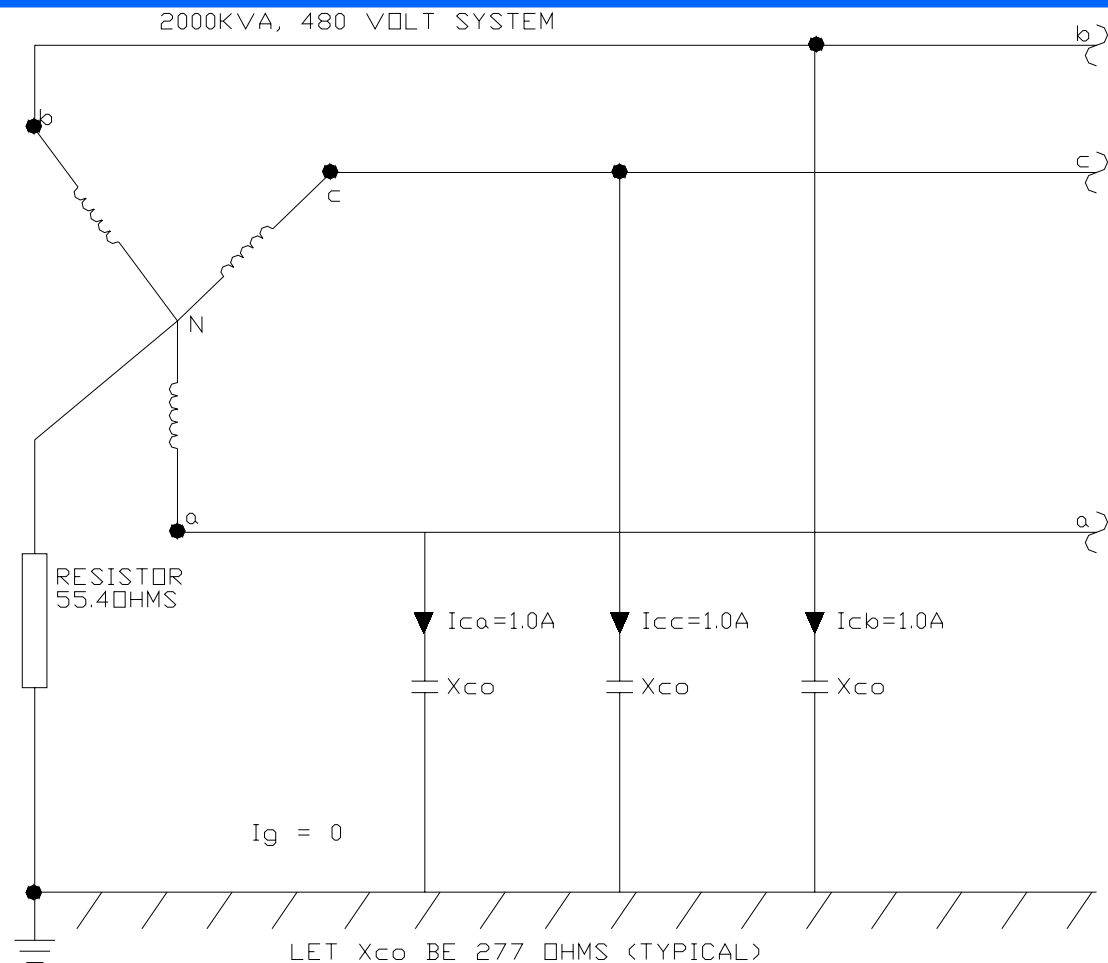
- TWO WIRE, LINE TO NEUTRAL LOADS

No Single Phase Loads

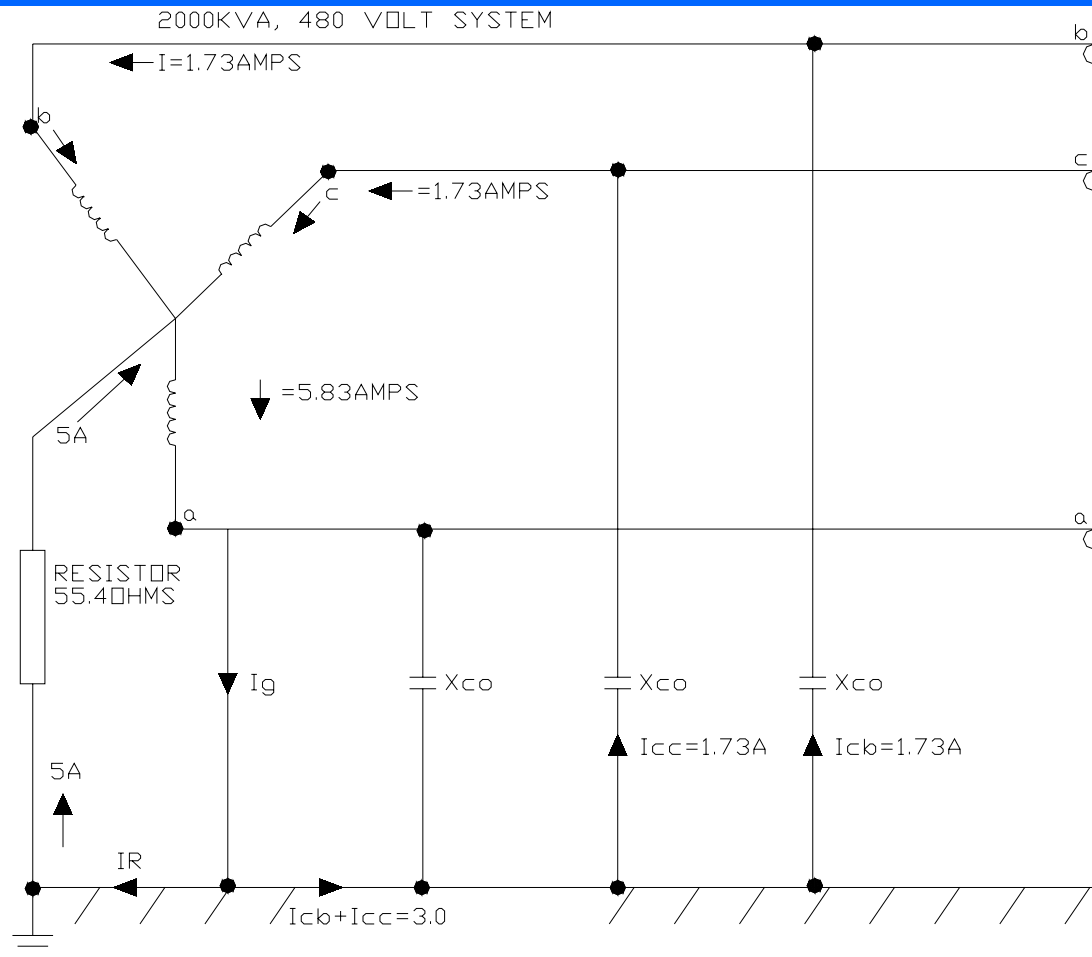
No line-to-neutral loads allowed, prevents Hazards.



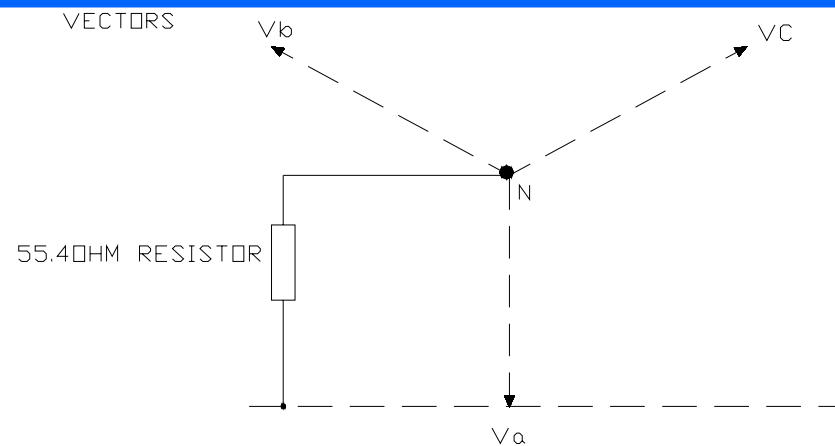
HIGH RESISTANCE GROUNDING AN EXAMPLE



HIGH RESISTANCE GROUNDING – GROUND FAULT ON PHASE A

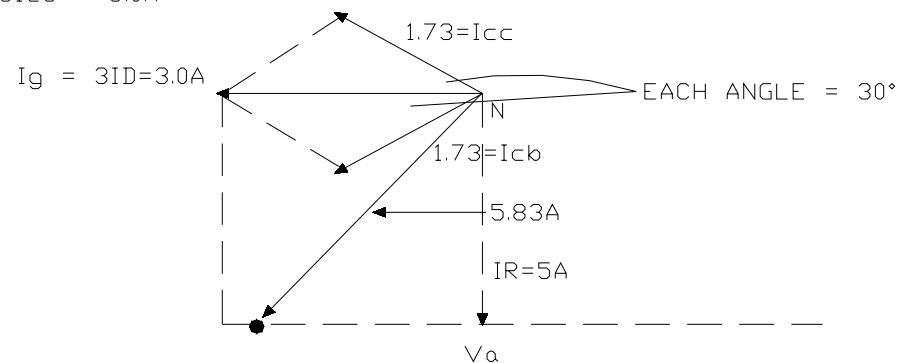


HIGH RESISTANCE GROUNDING – GROUND FAULT ON PHASE A



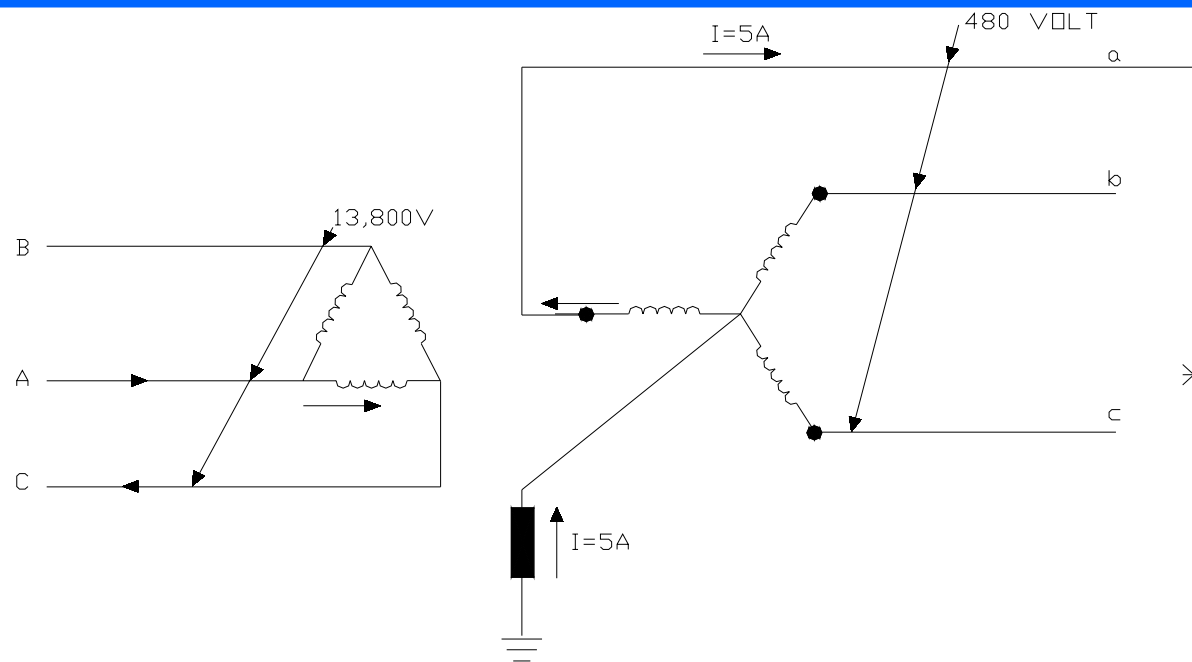
$$I_{cc} = (1.0\text{AMP} \times \sqrt{3}) = 1.73\text{A}$$

$$I_g = 3I_{co} = 3.0\text{A}$$



$$I_g = \sqrt{(5)^2 + (3.0)^2} = 5.83\text{AMPS}$$

HIGH RESISTANCE GROUNDED SYSTEM LINE-GROUND SHORT CIRCUIT

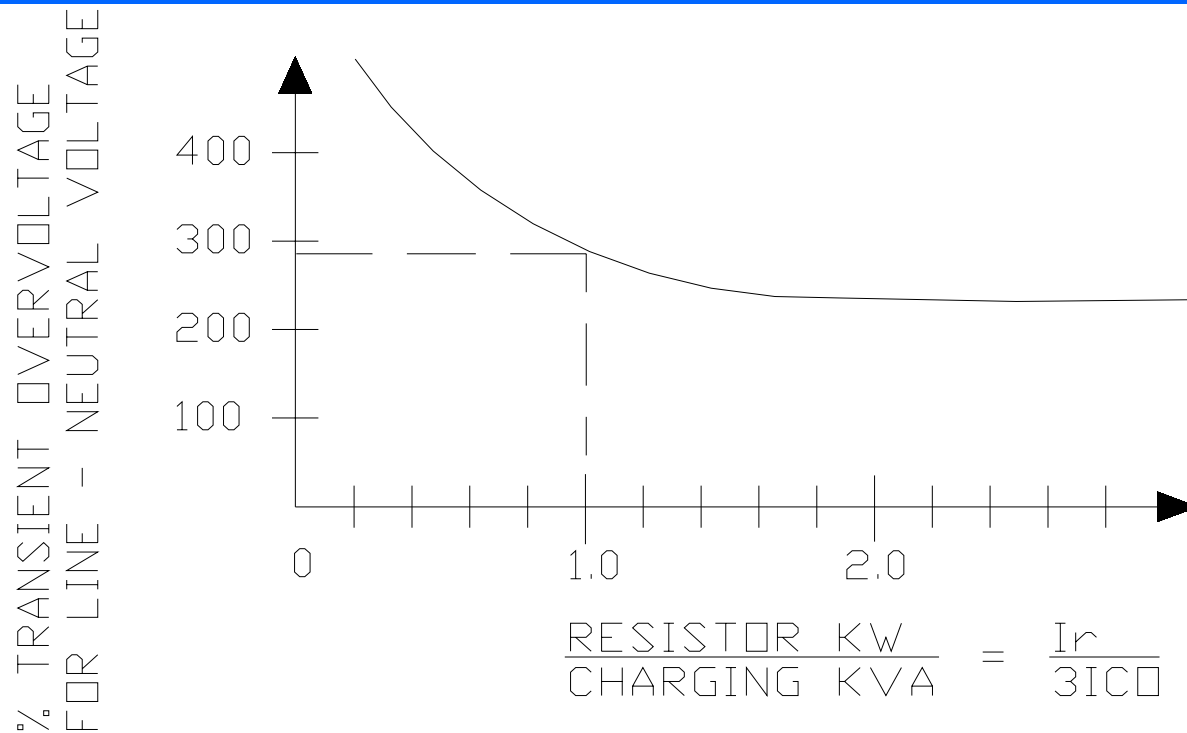


$$\text{TRANSFORMER TURNS RATIO} = \frac{13,800 \text{ VOLTS}}{(480/\sqrt{3}) \text{ VOLTS}} = 49.79$$

$$I_P = \frac{5A}{49.79} = .1 \text{ AMP}$$

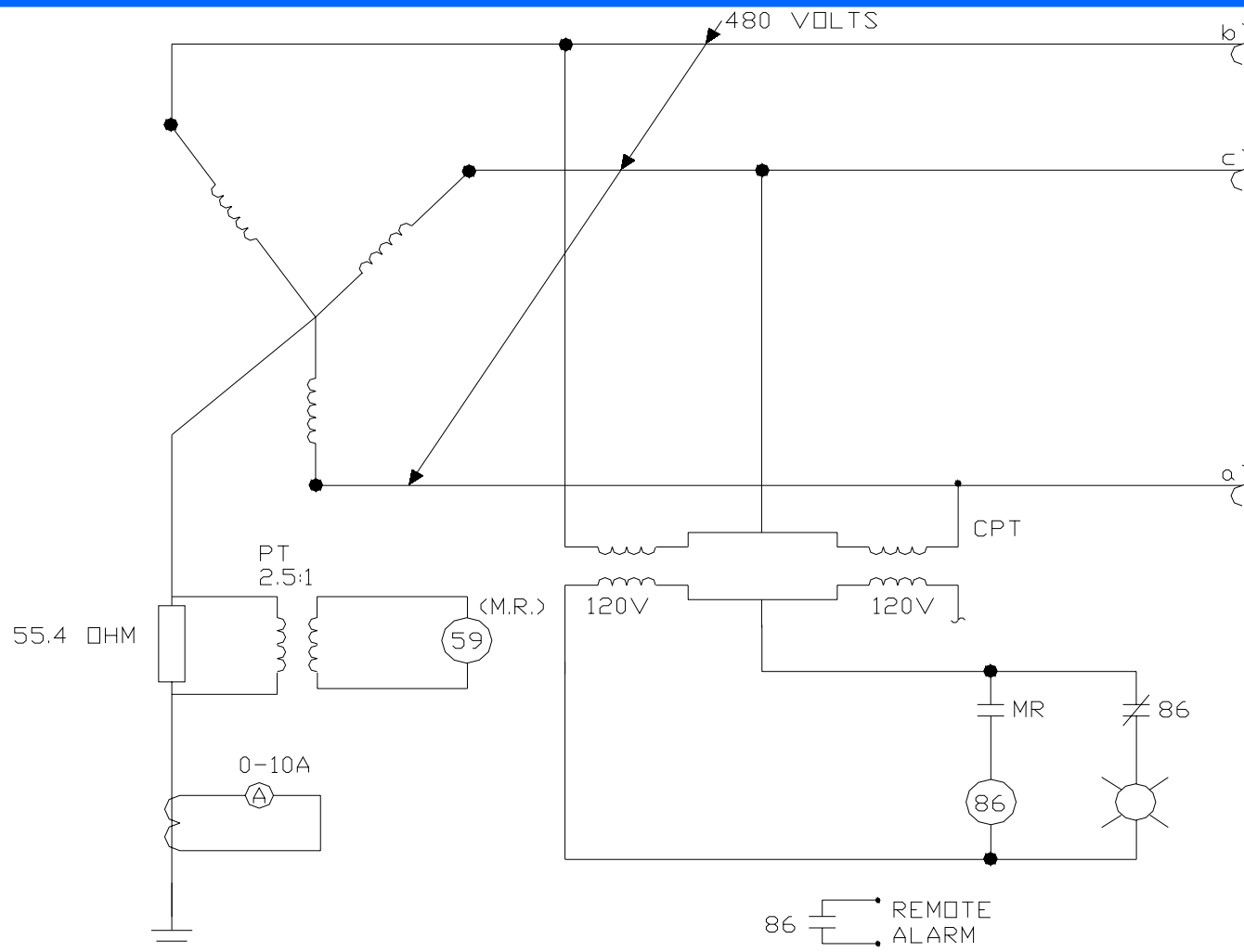
THUS, UNLIKE THE SOLIDLY GROUNDED SYSTEM, THE HIGH RESISTANCE GROUNDED SYSTEM CREATES NO PROBLEMS ON THE PRIMARY SYSTEM.

THE HIGH RESISTANCE GROUNDED POWER SYSTEM CONTROL OF TRANSIENT OVERVOLTAGE



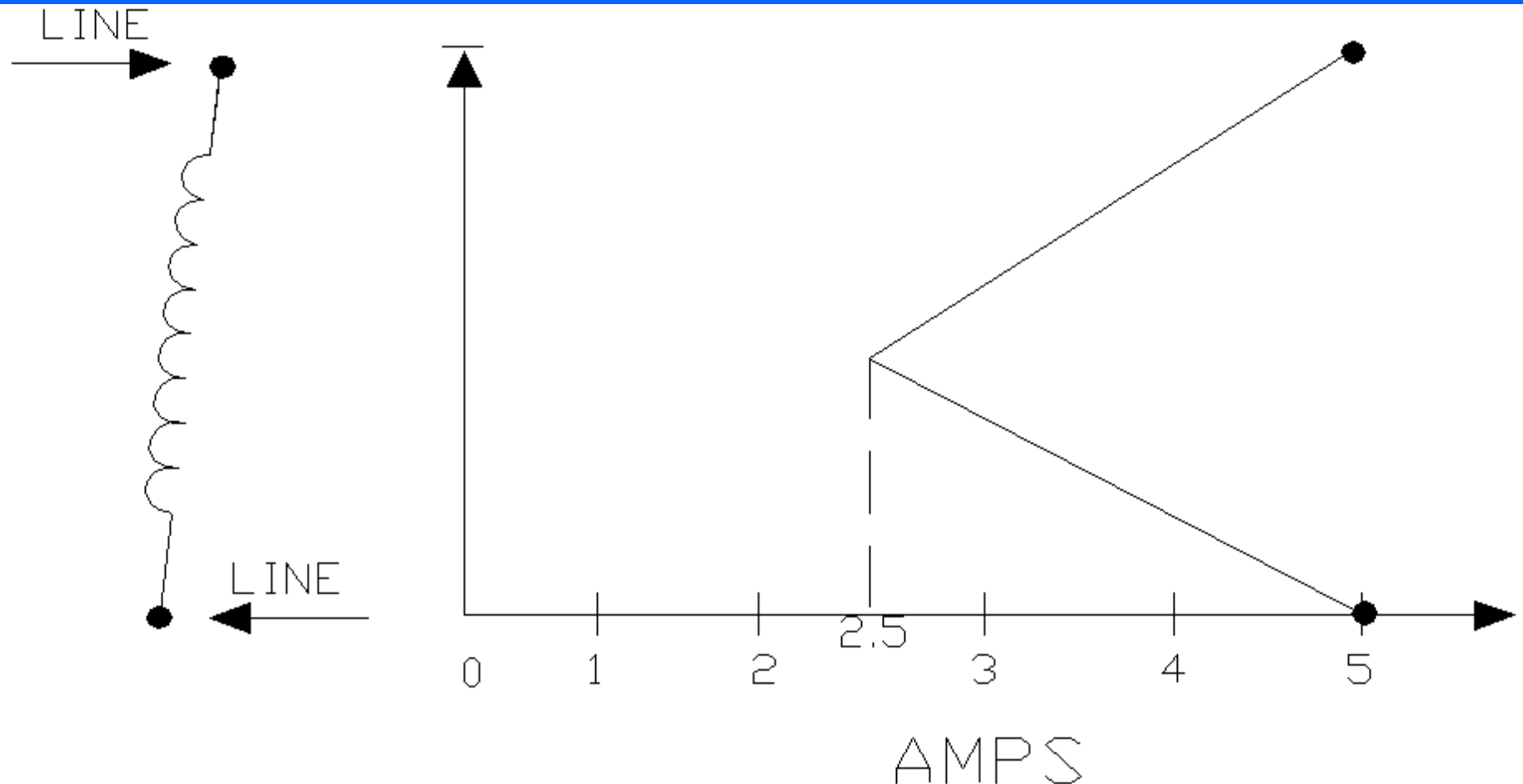
REF. WESTINGHOUSE TRANSMISSION & DISTRIBUTION
REFERENCE BOOK p. 521

HIGH RESISTANCE GROUNDING



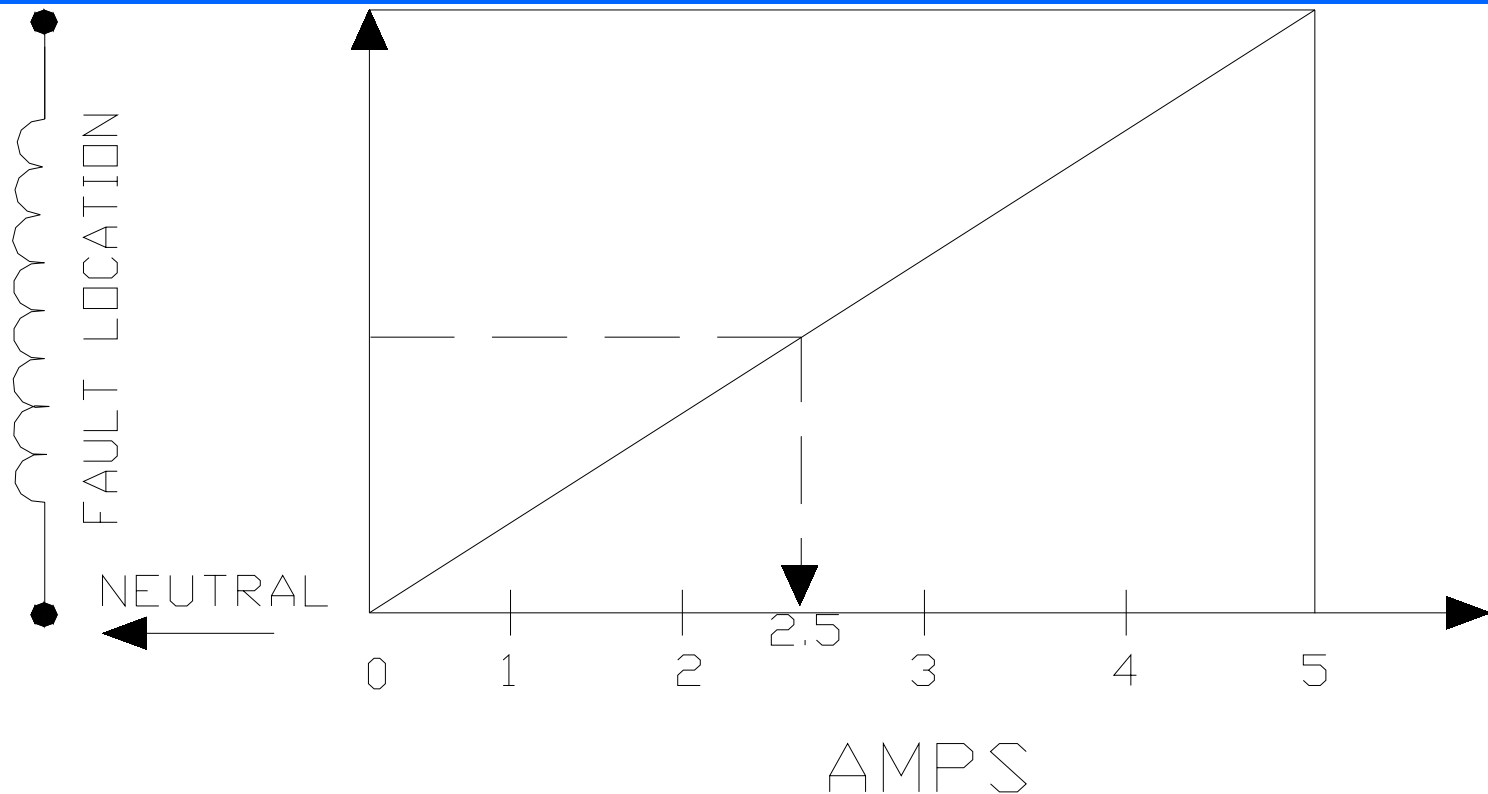
THE HIGH RESISTANCE GROUND POWER SYSTEM

LINE – GROUND FAULTS – DELTA CONNECTED MOTORS



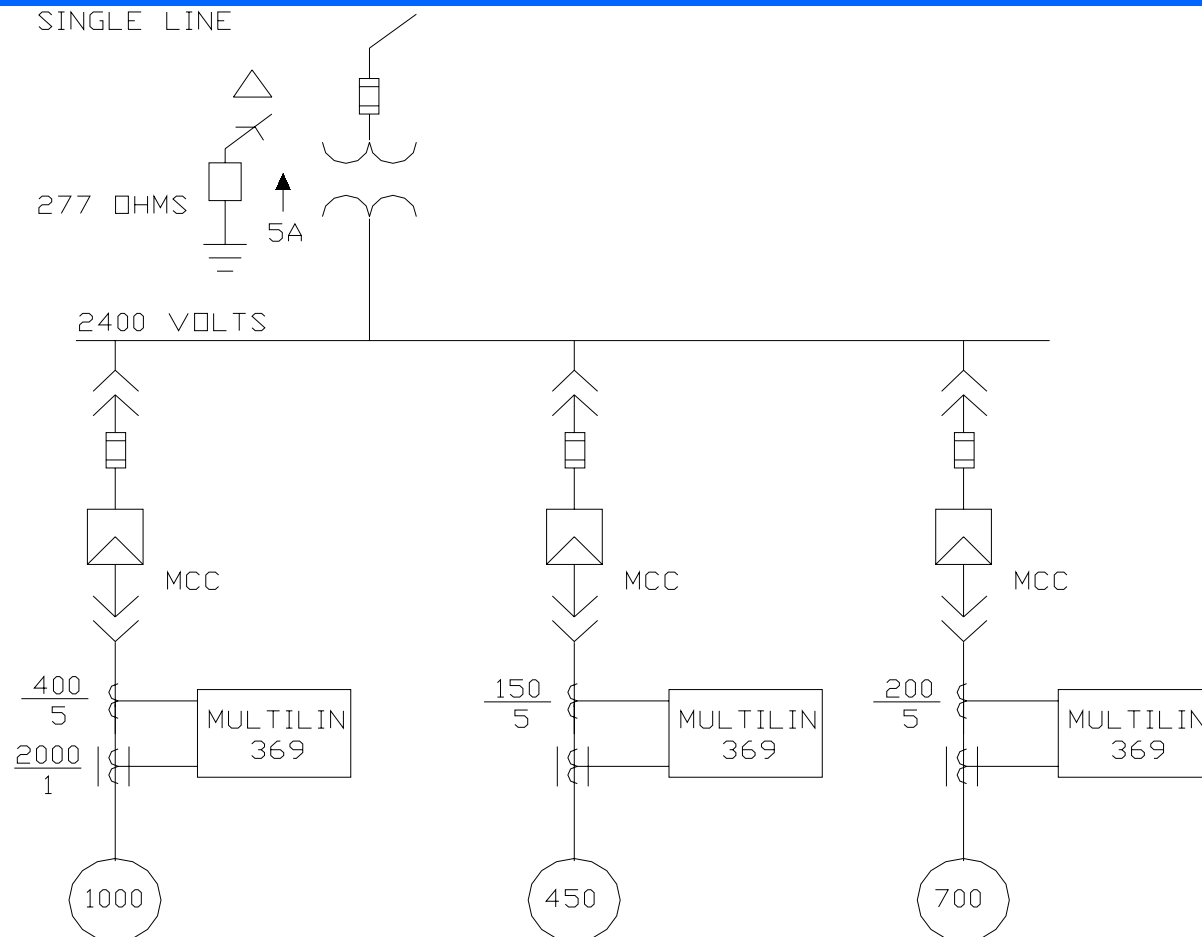
THE HIGH RESISTANCE GROUND POWER SYSTEM

LINE-GROUND FAULTS WYE CONNECTED MOTORS



5 AMPS - IN THE TERMINAL BOX
~2.5 AMPS - IN THE MIDDLE OF THE WINDING

HIGH RESISTANCE GROUNDING OF A 2400 VOLT SYSTEM



THE HIGH RESISTANCE GROUNDED POWER SYSTEM CHOOSING THE GROUND RESISTOR

Always specify a continuously rated resistor for 5 amps for all system voltages.

<u>SYSTEM VOLTAGE</u>	<u>RESISTOR AMPS</u>	<u>RESISTOR OHMS</u>	<u>RESISTOR WATTS (CONTINUOUS)</u>
380	5	43.88	1,097
415	5	47.92	1,198
480	5	55.4	1,385
600	5	69.3	1732
2400	5	277	6,925
3300	5	295	7,375
4160	5	480	12,000

THE HI-R GROUNDED POWER SYSTEM

ADVANTAGES

1. Low value of fault current
2. No flash hazard
3. Controls transient over voltage
4. No equipment damage
5. Service continuity
6. No impact on primary system

HOW DO YOU FIND GROUND FAULTS?

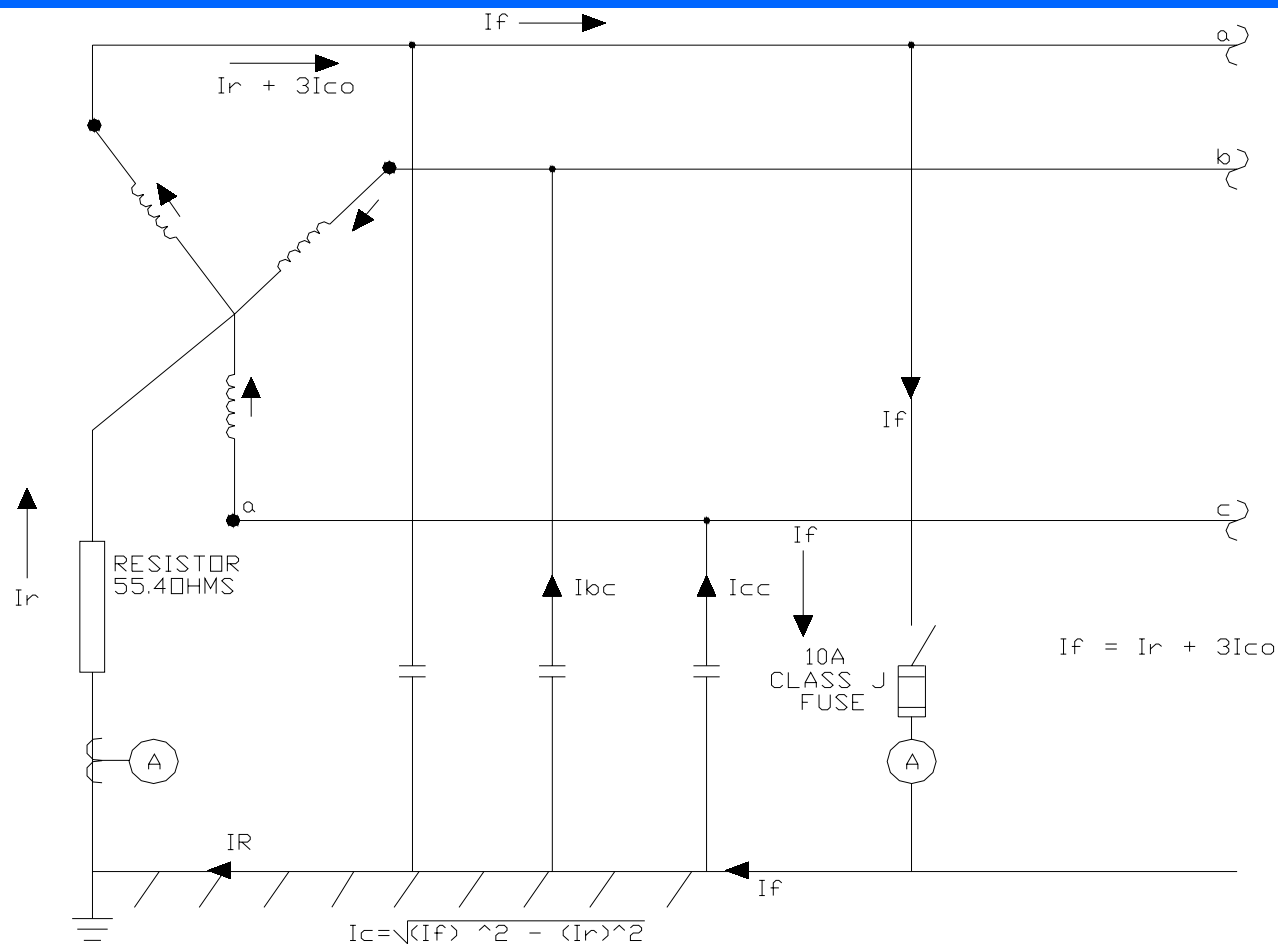
Ungrounded

Solidly grounded

Low resistance grounded

High resistance grounded

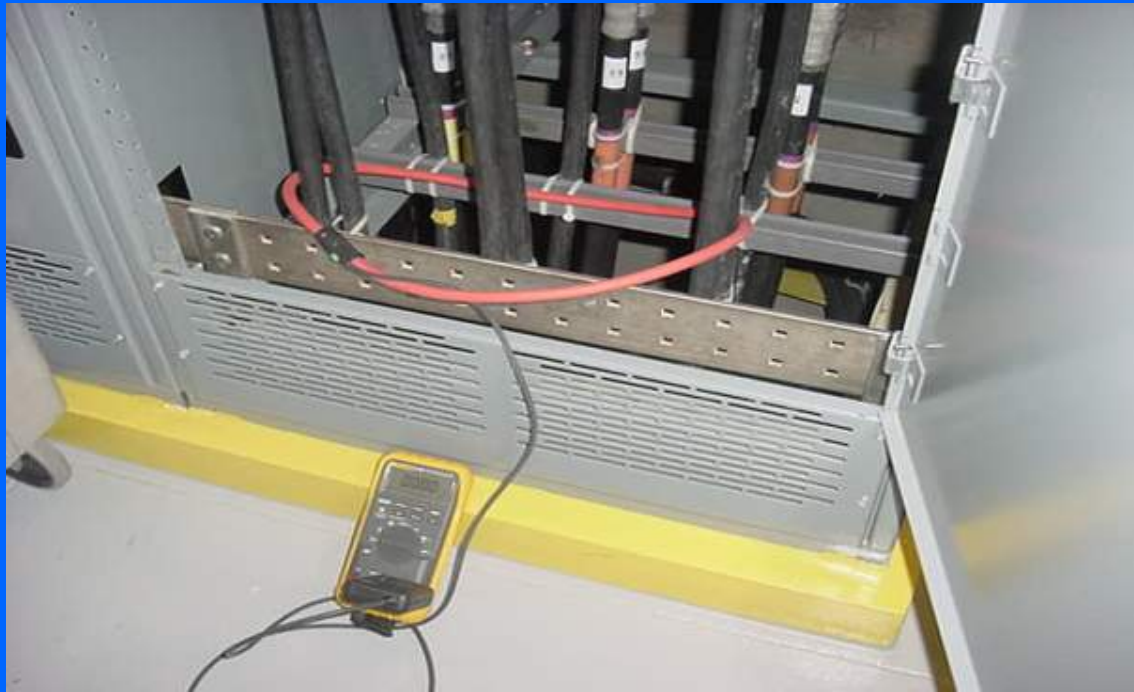
HIGH RESISTANCE GROUNDING – GROUND FAULT ON PHASE A



PROCEDURE FOR LOCATING GROUND FAULT

1. Alarm indicates ground fault.
2. Technician confirms ground faults by visiting substation.
3. Voltage on meter relay
4. Current through ground resistor.
5. Substation zero sequence feeder ammeters will indicate specific feeder to MCC or Power Distribution Panel.
6. Go to specific MCC or PDP, open wireway and use clamp-on ammeter around outgoing leads to determine failed circuit.
7. Evaluate need to replace or fix component.

Ground Fault Location Method

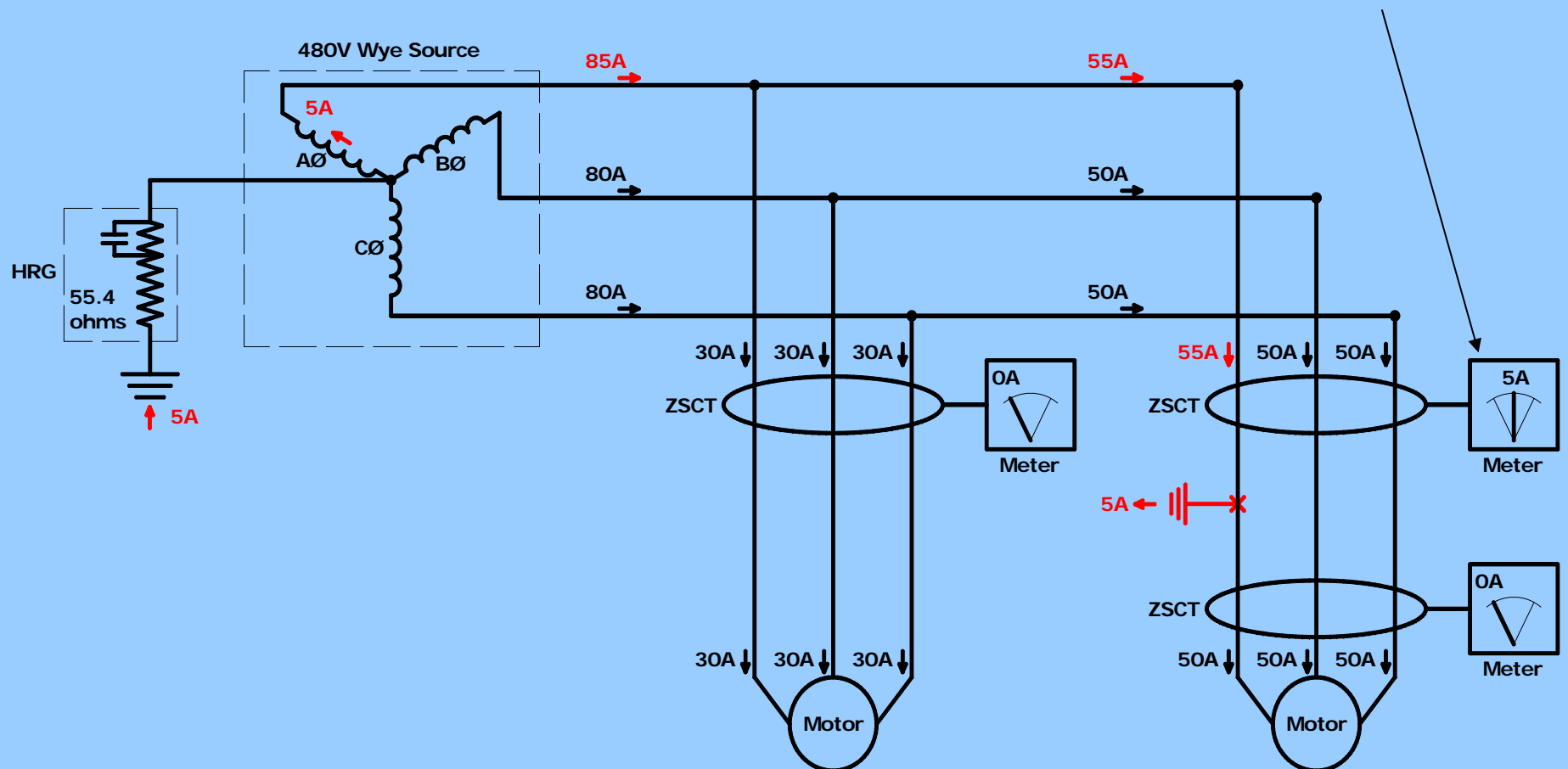


NOTE: *Tracking a ground fault can only be done on an energized system. Due to the inherent risk of electrocution this should only be performed by trained and competent personnel.*

Fault Location

Method to quickly locate ground faults.

Meter reading will alternate from 5A to 10A every 2 seconds.



Per IEEE...

TO HRG OR NOT TO HRG?

IEEE Std 142-1991 (Green Book)

Recommended Practice for Grounding of Industrial and Commercial Power Systems

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.

Per IEEE...

TO HRG OR NOT TO HRG?

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Recommended Practice for Grounding of Industrial and Commercial Power Systems

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

- 4) *To reduce the arc blast or flash hazard to personnel* who may have accidentally caused or who happen to be in close proximity to the ground fault.
- 5) *To reduce the momentary line-voltage dip* occasioned by the clearing of a ground fault.
- 6) *To secure control of transient over-voltages while at the same time avoiding the shutdown of a faulty circuit* on the occurrence of the first ground fault (high resistance grounding).

Per IEEE...

TO HRG OR NOT TO HRG?

IEEE Std 141-1993 (Red Book)

Recommended Practice for Electric Power Distribution for Industrial Plants

7.2.2 *There is no arc flash hazard, as there is with solidly grounded systems, since the fault current is limited to approximately 5A.*

Another benefit of high-resistance grounded systems is the limitation of ground fault current to prevent damage to equipment. High values of ground faults on solidly grounded systems can destroy the magnetic core of rotating machinery.

Per IEEE...

TO HRG OR NOT TO HRG?

IEEE Std 242-2001 (Buff Book)

Recommended Practice for Electric Power Distribution for Industrial Plants

8.2.5 *Once the system is high-resistance grounded, over-voltages are reduced; and modern, highly sensitive ground-fault protective equipment can identify the faulted feeder on the first fault and open one or both feeders on the second fault before arcing burn down does serious damage.*

Design Considerations with HRG Systems

National Electrical Code (2005)

250.36 High-impedance 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 where all the following conditions are met:

- 1) The conditions of maintenance and supervision ensure that only qualified persons service the installation.
- 2) Continuity of power is required.
- 3) Ground detectors are installed on the system.
- 4) Line-to-neutral loads are not served.

Duty Ratings for NGR's

IEEE Std 32

Time Rating and Permissible Temperature Rise for Neutral Grounding Resistors

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

Increased Fault Time Requires Larger Resistor

Duration Must Be Coordinated With Protective Relay Scheme

COMPARISON OF THE FOUR METHODS

HIGH RESISTANCE GROUNDING OF A 2400 VOLT MOTOR SYSTEM

COMPARISON OF SOME CHARACTERISTICS

CHARACTERISTIC	UNGROUND	HIGH R. GROUNDING	LOW R. (400A) GROUNDING	EFFECTIVE GROUNDING
1. CURRENT FOR A PHASE-GROUND FAULT AS A PRECENTAGE OF 3Ø FAULT CURRENT	LESS THAN .05%		~ 5%	~ 100%
2. TRANSIENT OVERVOLTAGE	UP TO 6X	MAX OF 2.5 TIMES		
3. AUTO FAULT LOCATION	NO	YES		
4. IMMEDIATE DISCONNECTION OF PHASE-GROUND FAULT	NO	OPTIONAL NECESSARY		
5. EXPECTED REPAIRS AFTER AN INITIAL PHASE-GROUND FAULT IN A MOTOR	<div>←————NEW WINDING INSULATION————→</div>			
			PROBABLY CORE RESTACKING	CORE RESTACKING
6. MULTIPLE FAULTS	OFTEN	SELDOM		
7. I^2t DAMAGE	LOW		HIGH	

THE HIGH RESISTANCE GROUNDED POWER SYSTEM

DAMAGE TO POWER SYSTEM COMPONENTS

1. Thermal damage $(I_{RMS})^2 t$
2. Mechanical damage $(I_p)^2$

Comparison of solidly grounded and high resistance grounding methods – 2000 KVA transformer at 480 volts

<u>SYSTEM</u> GROUNDING	<u>LINE-GROUND</u> FAULT AMPS	<u>DAMAGE TO</u> EQUIPMENT
Hi – R	5 A	1 per unit
Solidly	20,000 A	16×10^6

$$\text{Increase in damage} = \left(\frac{20,000 \text{ A}}{5 \text{ A}} \right)^2 = 16,000,000$$

THE HIGH RESISTANCE GROUNDING OF POWER SYSTEM

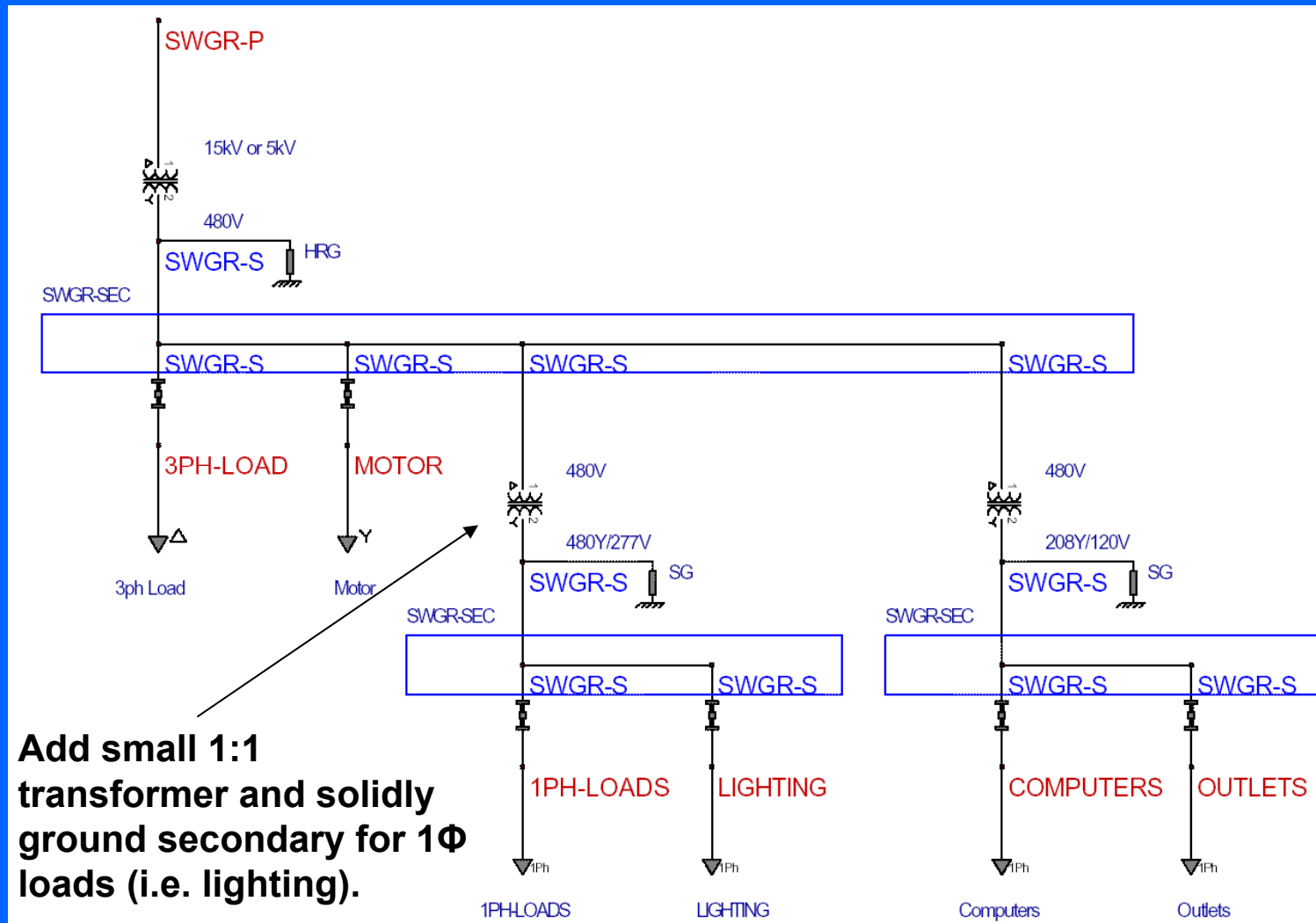
The high resistance grounded power system is the “*the best*”. This system provides the following advantages:

1. No shutdowns when a ground fault occurs
2. Quick identification of the problem
3. Safer for personnel & equipment
4. Offers all of advantages of the ungrounded & solidly grounded systems
5. No known disadvantages

Retrofit from Solidly or Ungrounded Grounded System to High Resistance Design Considerations

1. Are cables rated line to line or line to neutral. On a 480 Volt system some people have installed 300 Volt cable.
2. Are there surge arrestors and MOV's on the system. Are they sufficiently rated?
3. Are the Neutrals on the transformers fully insulated?
4. Are there other sources of power on the circuit?
Generators or Tie Breakers

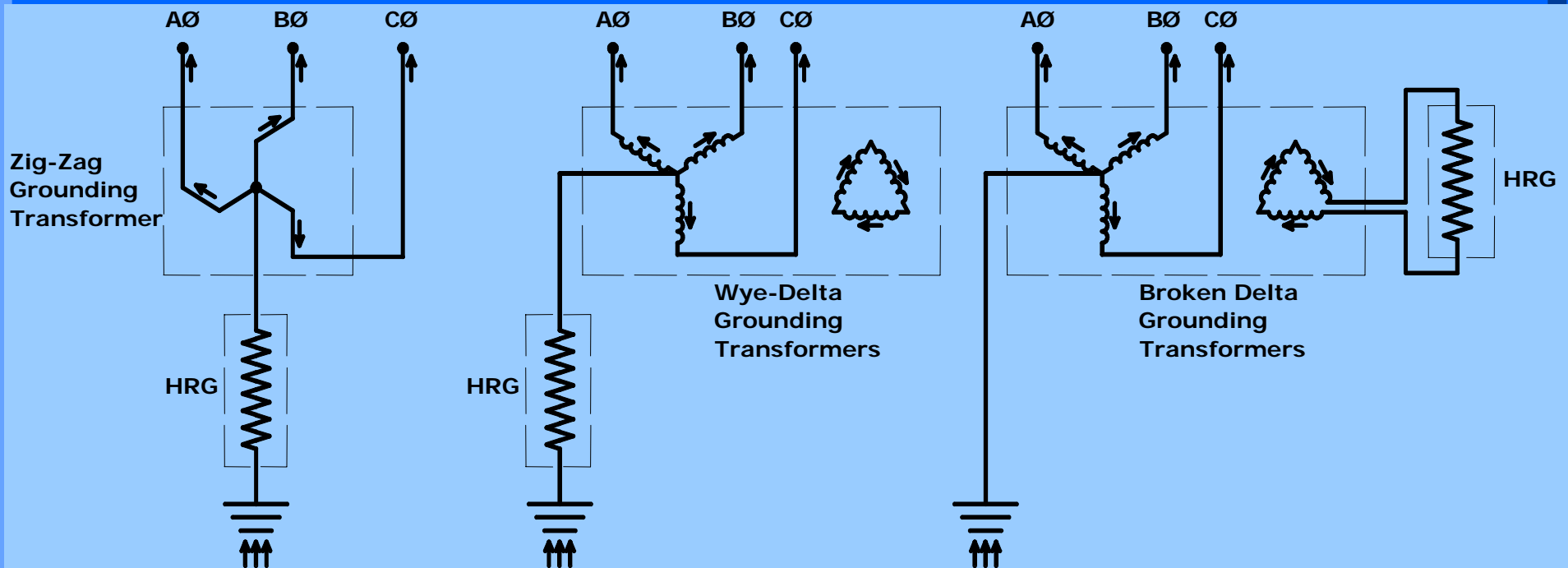
Resolve NEC requirement



High Resistance Grounding

What if no neutral exists (i.e. delta systems)?

- A grounding transformer is installed (either a zig-zag or a wye-delta) from all three phases to create an artificial neutral for grounding purposes only.



Minimum Specifications

120 Volt Control Circuit

385°C Temperature Rise Resistor

Line Disconnect Switch

Ground Bus (freestanding units only)

Pulser, Including Pulsing Contractor, Pulsing Timer, Normal/Pulse Selector Switch

Relays for under and over voltage

Relays for under and over current measuring only fundamental

Auxiliary contacts

Test Push-button

Fault Reset Push-button

Green Indicating Light for “Normal” Indication

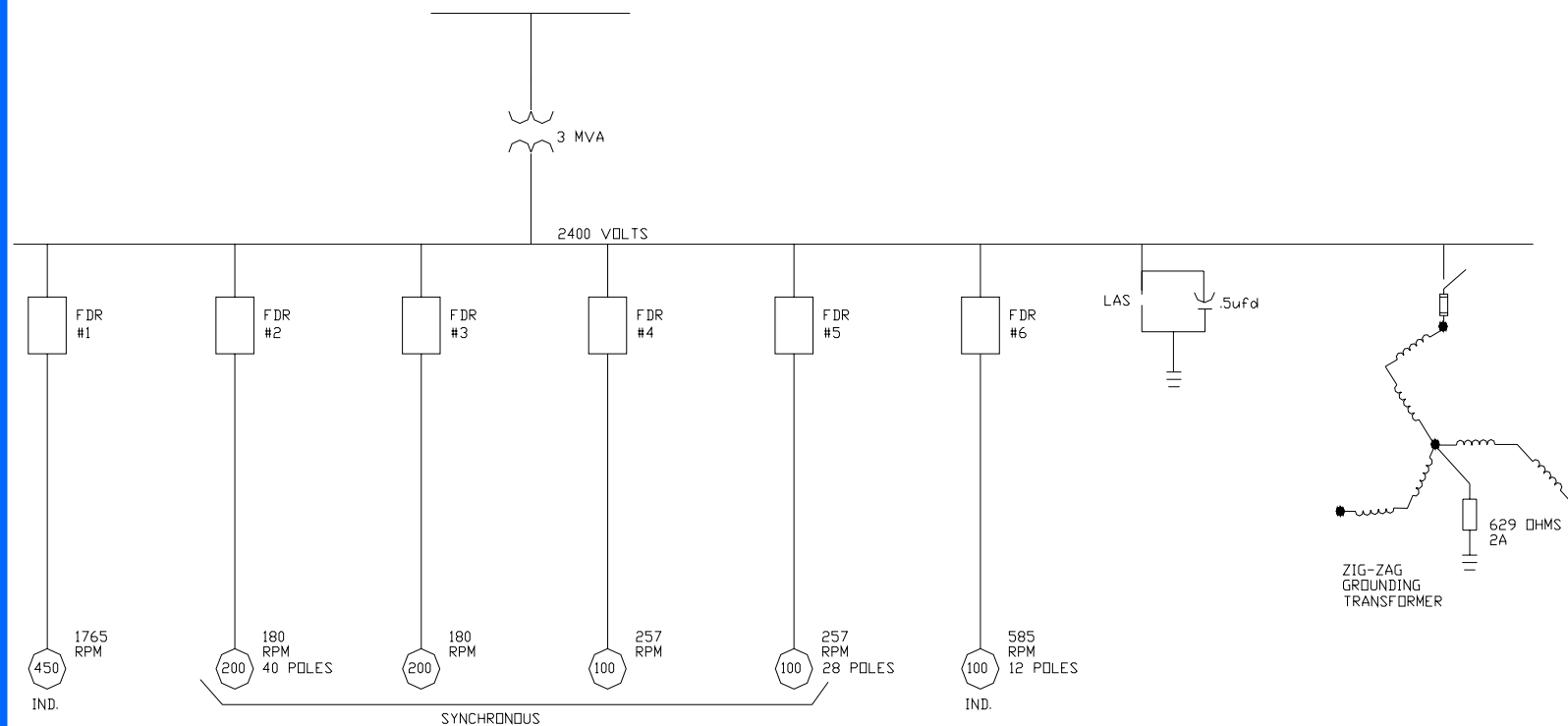
Red Indicating Light for “Fault” Indication

CHARGING CURRENT CALULATIONS

Slides hidden due to time allowed for
Presentation

HIGH RESISTANCE GROUNDING – 2.4KV SYSTEM

CALCULATION OF SYSTEM CHARGING CURRENT



CHARGING CURRENT TESTS ON POWER SYSTEMS

Tests made by federal pioneer of Canada at several pulp and paper sites in Canada.

.02-.06 amps per 1000kva of transformer nameplate KVA.
For system with no aerial construction.

TRANSFORMER

KVA

1000

1500

2000

2500

CHARGING

CURRENT

.02 - .06 AMPS

.03 - .09 AMPS

.04 – .12 AMPS

.05 – .15 AMPS

HIGH RESISTANCE GROUNDING 2.4KV SYSTEM

CALCULATION OF CHARGING CURRENTS

1. SURGE CAPACITORS

$$3 \text{ ICO} = 3(2\pi f \text{ CE}/10^6) = 3(\frac{2\pi * 60 * .5(2400\text{V}/3^{1/2})}{10^6}) = 3 \times .261 = .783 \text{ AMPS}$$

2. MOTORS

$$3 \text{ ICO} = [0.005 \times (\frac{\text{HP}}{\text{RPM}})] \text{ REF. ALVIN KNABLE}$$

$$450 \text{ HP MOTOR } 0.05 \times \frac{450}{1765} = .013 \text{ AMPS}$$

$$200 \text{ HP MOTOR } 0.05 \times \frac{200}{180} = .06 \text{ AMPS}$$

$$100 \text{ HP MOTOR } 0.05 \times \frac{100}{257} = .02 \text{ AMPS}$$

$$125 \text{ HP MOTOR } 0.05 \times \frac{125}{585} = .01 \text{ AMPS}$$

3. ZIG-ZAG TRANSFORMER – APPROXIMATE VALUE .01 TO .001 MICRO FARAD

$$XC = \frac{10^6}{377 \times 10^{-2}} = 2.65 \times 10^5 \text{ TO } 2.65 \times 10^6 \text{ OHMS}$$

$$3 \text{ ICO} = \frac{2400/3^{1/2}}{2.65 \times 10^5} = .0156 \text{ TO } .00156 \text{ AMPS. DISREGARD THIS VALUE}$$

HIGH RESISTANCE GROUNDING 2.4KV SYSTEM CALCULATION OF SYSTEM CHARGING CURRENT

4. CABLE CAPACITANCE

$$C = \frac{0.00735(\text{SIG})}{\text{LOG}(D/d)} \frac{\text{mfd}}{100 \text{ ft.}}$$

WHERE SIG= SPECIFIC INDUCTIVE CAPACITANCE =3
D= DIAMETER OVER INSULATION
d=DIAMETER OF CONDUCTOR

AVERAGE LENGTH OF CABLE RUNS = 75 FT, #2 5KV UNSHIELDED.

$$C = \frac{0.00735 \times 3}{\text{LOG}(56.34)}$$

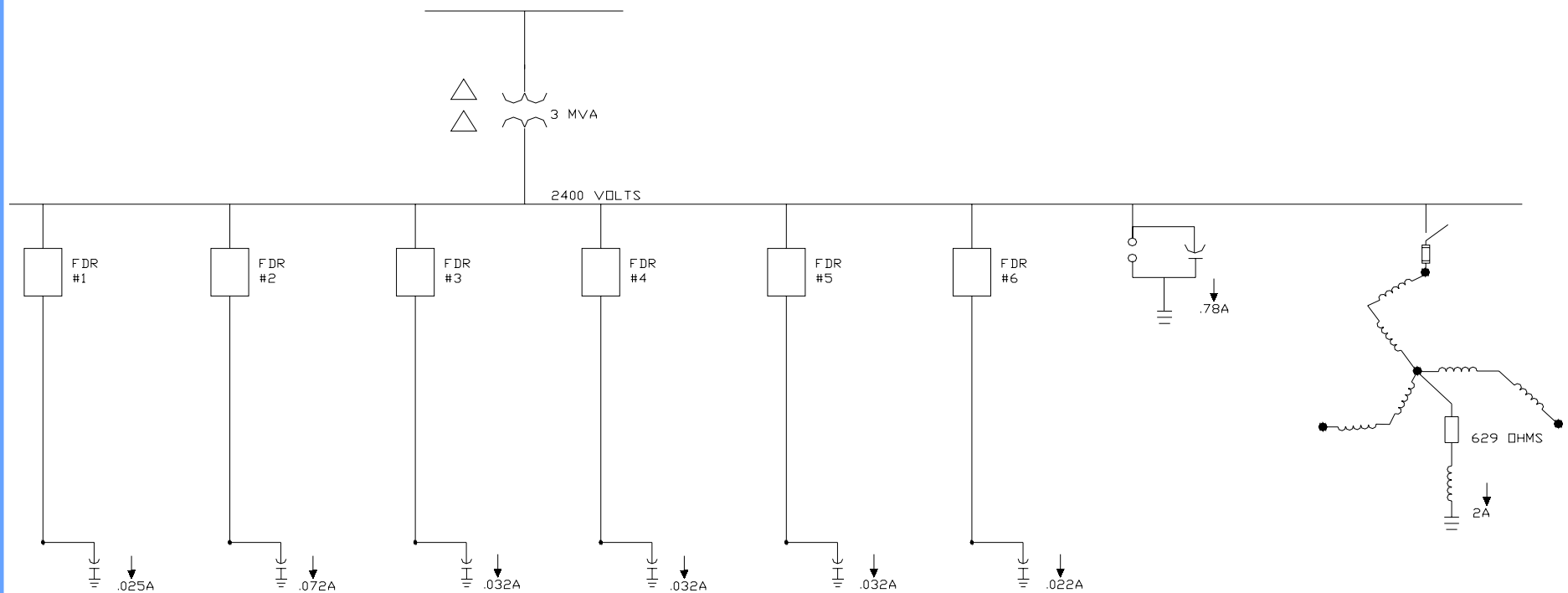
$$C = .1017 \times \frac{75 \text{ f}}{1000 \text{ ft}} = 7.63 \times 10^{-3} \text{ ufd}$$

$$X_C = \frac{10^6}{377 \times 7.63 \times 10^{-3}} = 3.47 \times 10^5 \text{ OHMS.}$$

$$3I_{C0} = \frac{2400 / 3^{(1/2)}}{3.47 \times 10^5 \text{ OHMS}} = .0119 \text{ AMPS} = .012 \text{ AMPS PER FEEDER}$$

HIGH RESISTANCE GROUNDING – 2.4KV SYSTEM

CALCULATION OF SYSTEM CHARGING CURRENT



HIGH RESISTANCE GROUNDING 2.4KV SYSTEM CALCULATION OF SYSTEM CHARGING CURRENT

SUMMARY OF CAPACITIVE FAULT CURRENT VALUES

3MVA Transformer = .15A.

FDR#1 = .013 + .012 = .025A.

#2 = .06 + .012 = .072A.

#3 = .06 + .012 = .072A

#4 = .02 + .012 = .032A

#5 = .02 + .012 = .032A

#6 = .01 + .012 = .022A

SURGE CAPACITORS = .783A

1.188 AMPS

CHOOSE GROUNDING RESISTOR OF 5 AMPS

NOTE: SURGE CAPACITORS ACCOUNT FOR 75% OF THE TOTAL

GENERATOR APPLICATIONS OF NEUTRAL GROUNDING RESISTORS

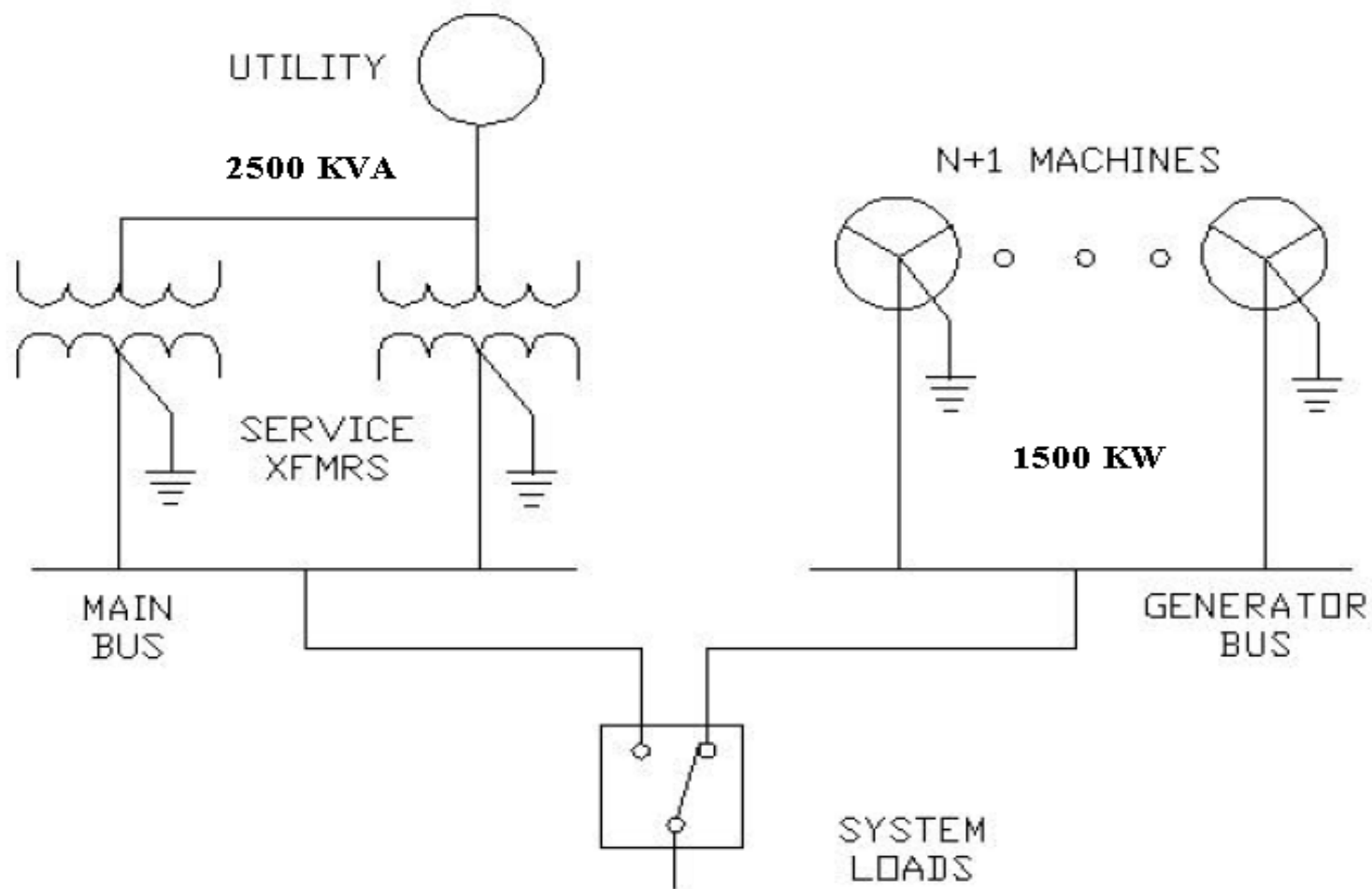


Figure 1 – One line Diagram

GENERATOR APPLICATIONS OF NEUTRAL GROUNDING RESISTORS

1. All generators should use a NGR.
2. If you have 2 generators on a system with different pitches you will need to use 2 NGRs to limit the harmonics that are generated.
3. On a delta generator you should use an NGR with a zig-zag transformer.

Generator Grounding – IEEE

IEEE Std 242-2001 (Buff Book)

12.4 Generator Grounding

- ***A common practice is to ground all types of generators through some form of external impedance.*** The purpose of this grounding is to limit the mechanical stresses and fault damage in the machine, to limit transient voltages during fault, and to provide a means for detecting ground faults within the machine...

Solid grounding of a generator neutral is not generally used because this practice can result in high mechanical stresses and excessive fault damage in the machine...

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

Generator Grounding – IEEE

IEEE Std. 142-1991 (Green Book)

1.8.1 Discussion of Generator Characteristics

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

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

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

AIC Rating

(Amps Interrupting Current)

This example is taken from [lowzero.pdf](#) by Power Systems Engineering

- 3 Phase Short Circuit Calculations for the Generator is 11.1 kA
- Line to Ground Fault Current for the Generator is 13.8 kA because the zero sequence impedance (X_0) is lower than the positive sequence impedance (X_1)

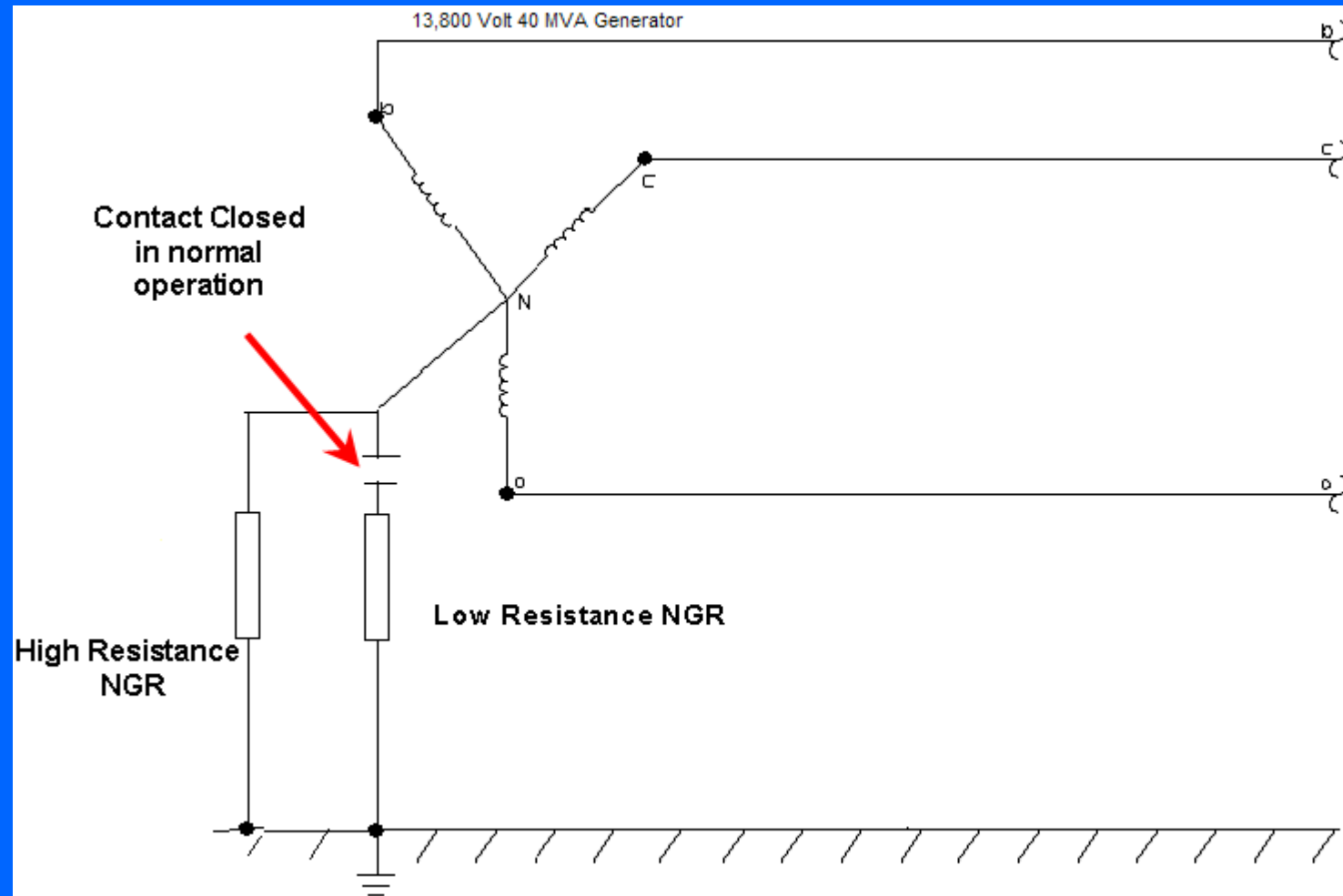
Line to Ground Fault Current is 125% of the Phase Current
Fault in this example

Solution – Make sure you check your AIC rating of the equipment and use a Neutral Grounding Resistor.

GENERATOR APPLICATIONS OF NEUTRAL GROUNDING RESISTORS

A large generator (≥ 20 MVA, 13,800 volt) may take 5 to 20 seconds to stop. A IEEE working group wrote a series of four papers. They proposed a hybrid system having a low resistance grounding system and when the fault occurred switch to a high resistance grounded system.

HYBRID SYSTEM

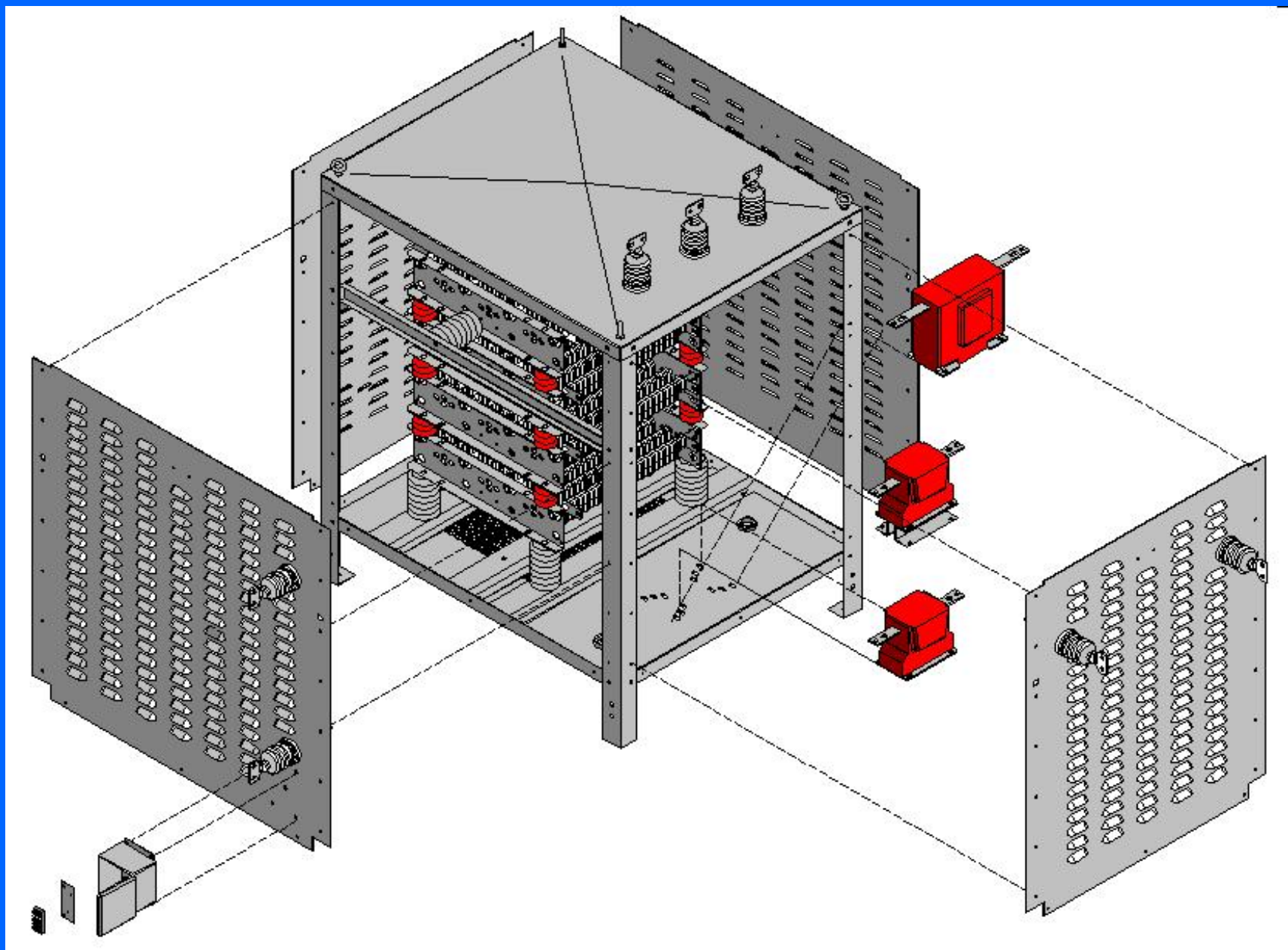


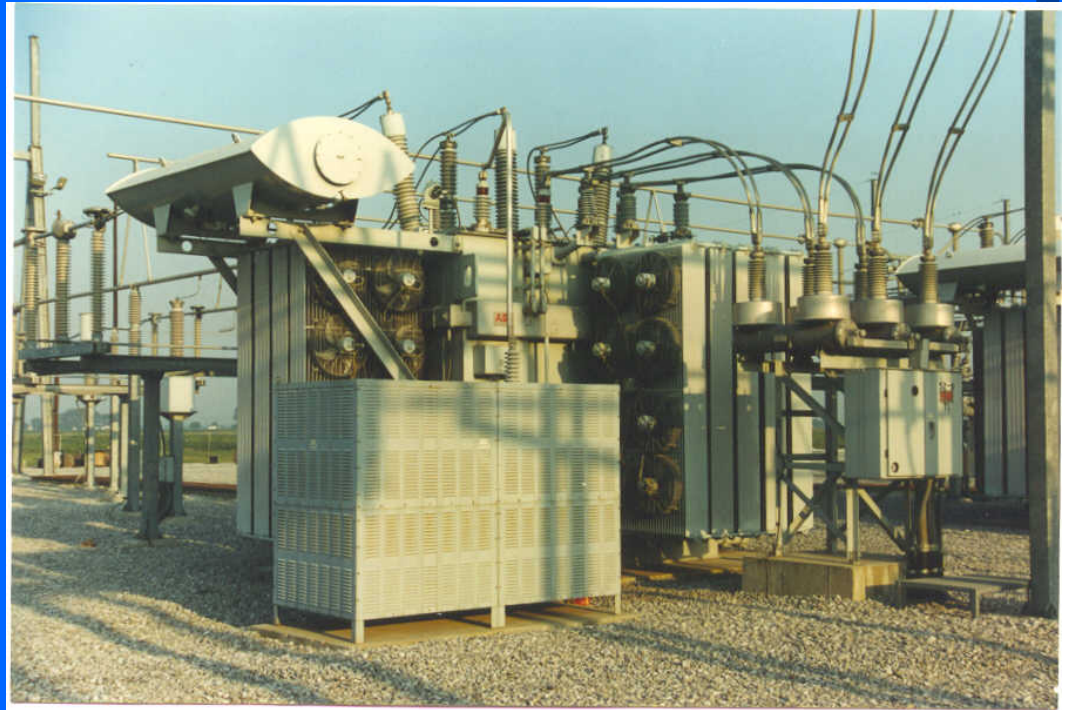
Pictures of Equipment

Common options

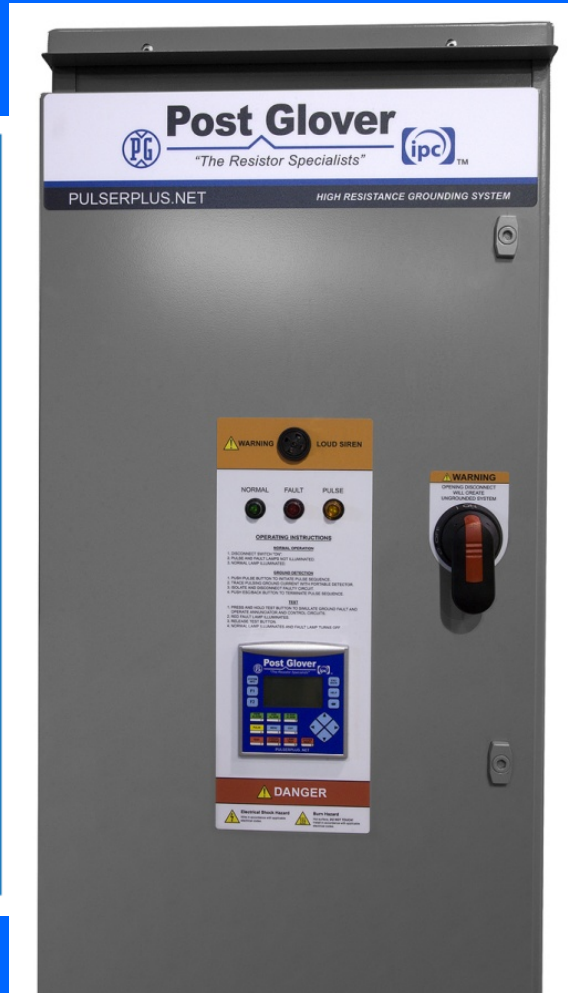
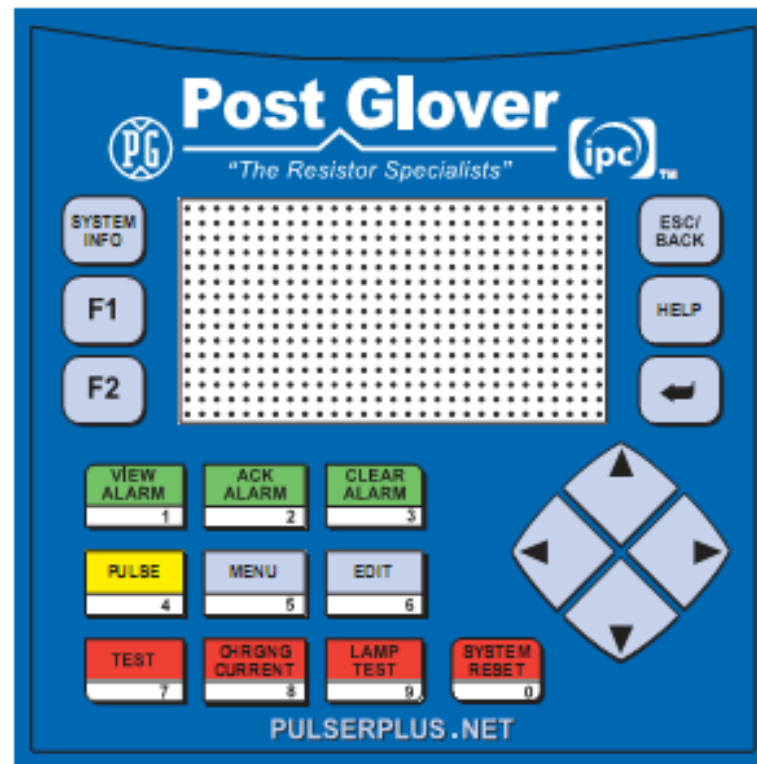
- Enclosure rating
- Enclosure finish
- Current transformer
- Potential transformer
- Disconnect switch
- Entrance/exit bushings
- Elevating stand
- Seismic rating
- Hazardous area classification
- Third party certification











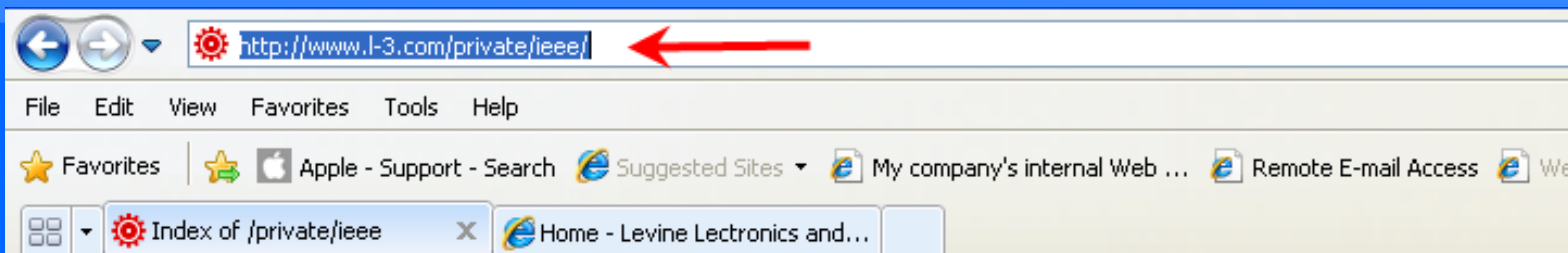




















This presentation can be found at:

<http://www.1-3.com/private/ieee/>

post_glover_resistance_grounding_2010.pdf



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Thank You

Questions?