UNDERSTANDING POWER CONCEPTS BASIC COURSE PARTS 1, 2, & 3

PART 4 WILL BE ADDED IN REV 1.

Continuing Education Course

Revision 0 (April 2013)

References

- IEEE, NFPA,
- Schneider Electric
- General Electric
- Chevron
- DuPont
- Phillips
- Allen Bradley
- Siemens
- Powell Electric
- Fluke
- SEL
- ABB
- Readily available power points on the internet.
- ExxonMobil
- ECM
- Baldor
- Toshiba
- Post Glover

Understanding Power Concepts

- This course was put together using readily available material from the internet, and from older IEEE presentations. It is for educational purposes only. The user of this material should consult a licensed professional engineer on all topics presented in this basic electrical power course.

- This material has not been checked for accuracy. It should be assumed to be out of date.

- This material is again for educational purposes only. No profits have been made in the making of this course or in its presentation. This course is solely to help educate our engineers and society on electrical power topics.

Understanding Power Concepts

- This REV 0 April 2013 course covers Parts 1, 2, and 3.
- Part 4 will be added at a later date, REV 1.

Understanding Power Concepts

- Part 1
  - Introduction
  - Formulas (AC/DC Basics)
  - Standards
  - Codes/Personal Safety
  - Grounding

Understanding Power Concepts

Part 2

- Electrical Studies
  - One lines
  - SC
  - LF
  - I2T
- Transfer Schemes
- Cable types
- Feeder Designs

Understanding Power Concepts

Part 3

- Motors
  - AC Induction Motors
  - Motor Efficiency and Assessment
  - Motor Controllers (VFD and Harmonics)
  - Application Considerations
- Transformers
- Substations
- Switchgear
- Panels (Lighting and Power)
- MCC
- DC/UPS Systems

Understanding Power Concepts

Part 4 ***(has not been added as of REV 0)***

- Protective Relaying
  - Bus
  - Feeders
  - Motors
  - Generators
  - Transformers

Power System Engineering

- During the last 50 years electrical engineering has become very diversified.
- It is a much broader scope than ever before.
- In order to keep pace with emerging technologies a need has been identified to provide the fundamental knowledge of electrical power engineering.

Electrical Power Engineering

- Manufacturing
  - Generators, and motors
  - Transformers
  - Skidded packages (electro chlorination units, pump packages, filtration units, process packages)
  - MCC, SWGR, power houses
- Relay programming
- System studies
- Industrial Distribution systems (LV, MV)
- Transmission design (HV, EHV)

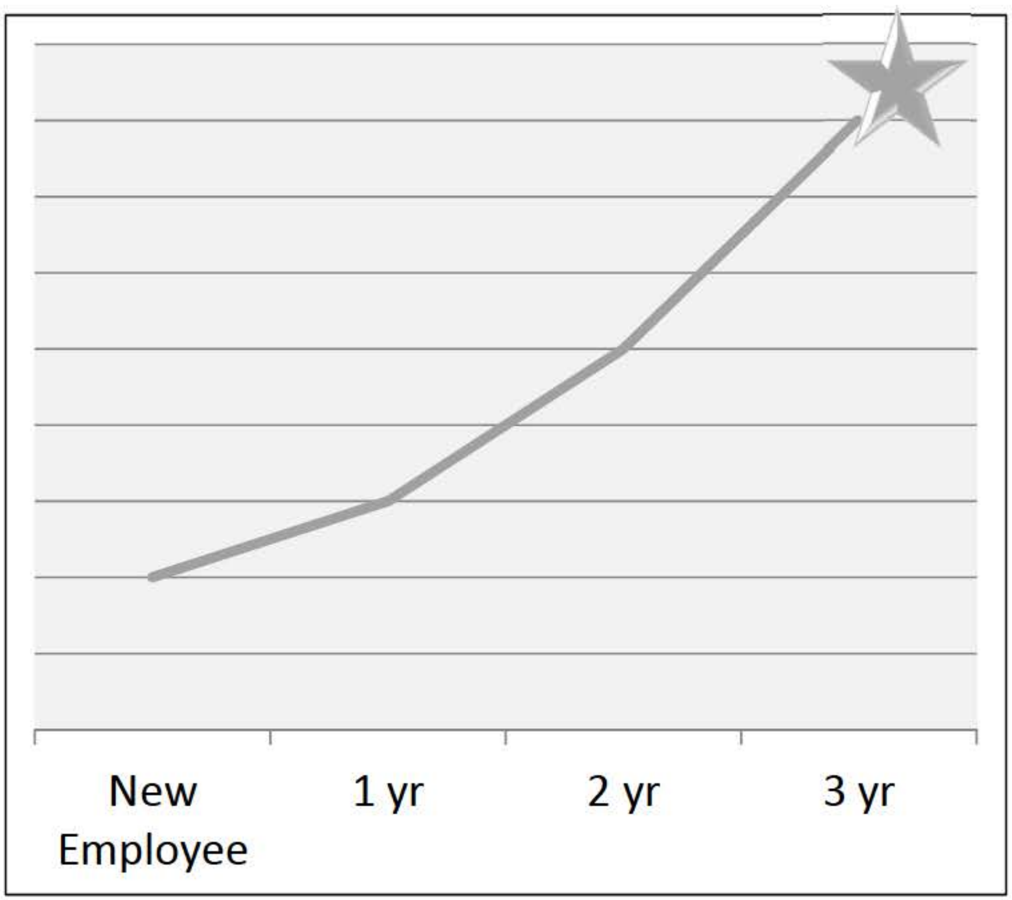
- VISUAL / MENTAL COMPREHENSION OF THE COMPONENTS BASED ON PROJECT SINGLE LINE AND SPECIFICATION.

Learning Objectives

- Close the knowledge gap.
- Real world examples.
- Check lists.
- Work problems.
- Survey the industry.

New Work

The technology learning curve



Understanding Power Concepts

Part 1

- ***<u>Introduction</u>***
- Formulas (AC/DC Basics)
- Standards
- Codes/Personal Safety
- Grounding

Before starting a project you should know the answers to the following questions.

- What is the nature and magnitude of the load?
- Where is the power coming from?
- How much will the electric power systems cost?
- What voltage levels should be selected for the plant primary system and secondary system?
- What circuit arrangement is best suited, i.e.; radial, secondary selective, or secondary network?
- What size substations are most economical?
- Secondary distribution.
- Combined light and power?
- Are voltage regulating means required?
- Short-circuit protection?
- Grounding.
- Overcurrent protection?
- Is the lightning protection adequate?
- Power factor correction?
- Types of Lights required.

In order to understand this...

Outline

- E&M Principles
- Types of Power Plants
- Power System Components

Principles

- energy = "the ability to do work"

  measured in Joules
- power = rate of energy generation or use

  measured in Watts = Joules / sec
- current = rate of charge flow

  measured in Amps Water pipes analogy
- voltage = "pressure" pushing current

  measured in Volts

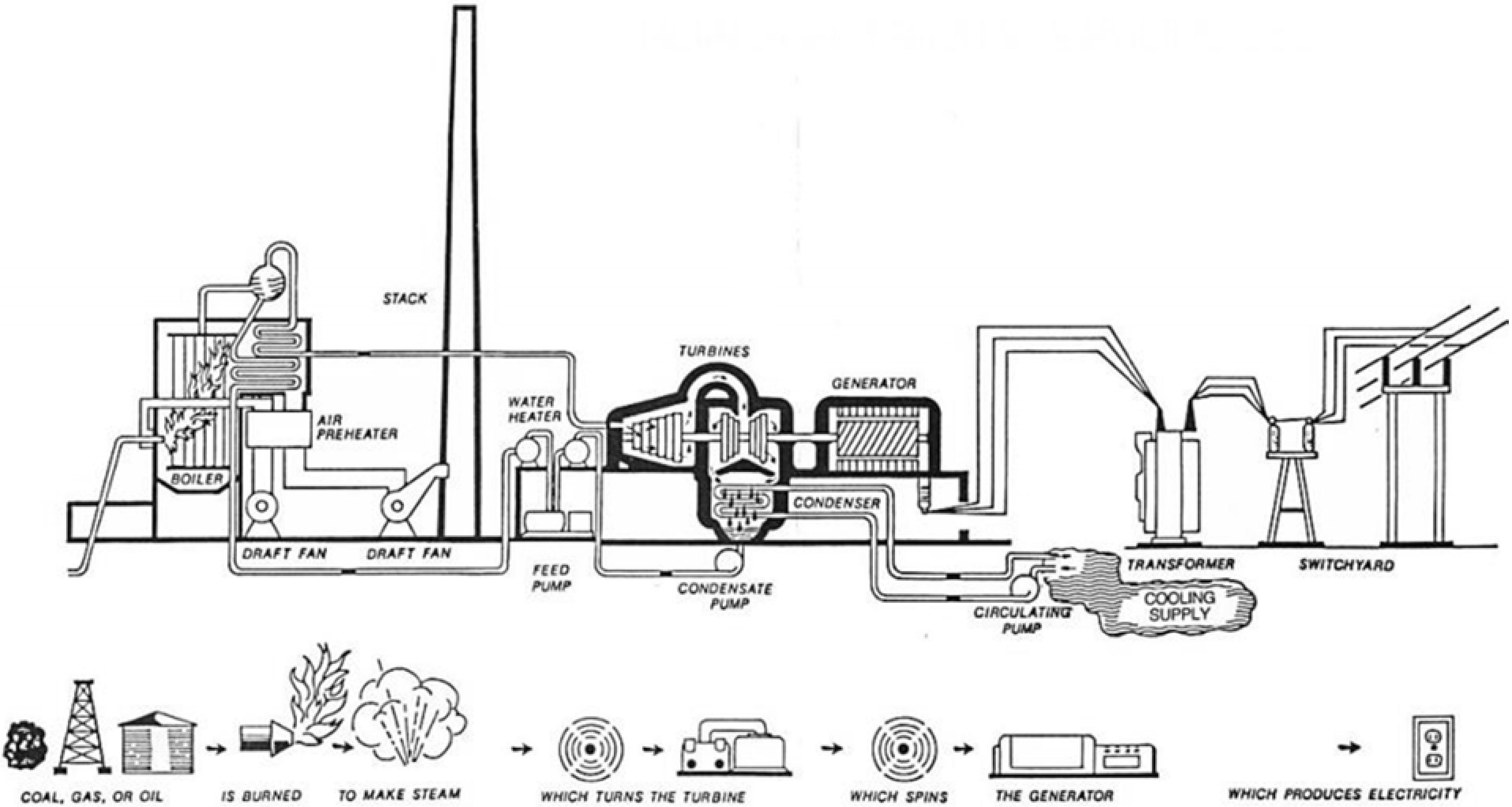
Powerhouse @ Hoover Dam

Types of Power Plants

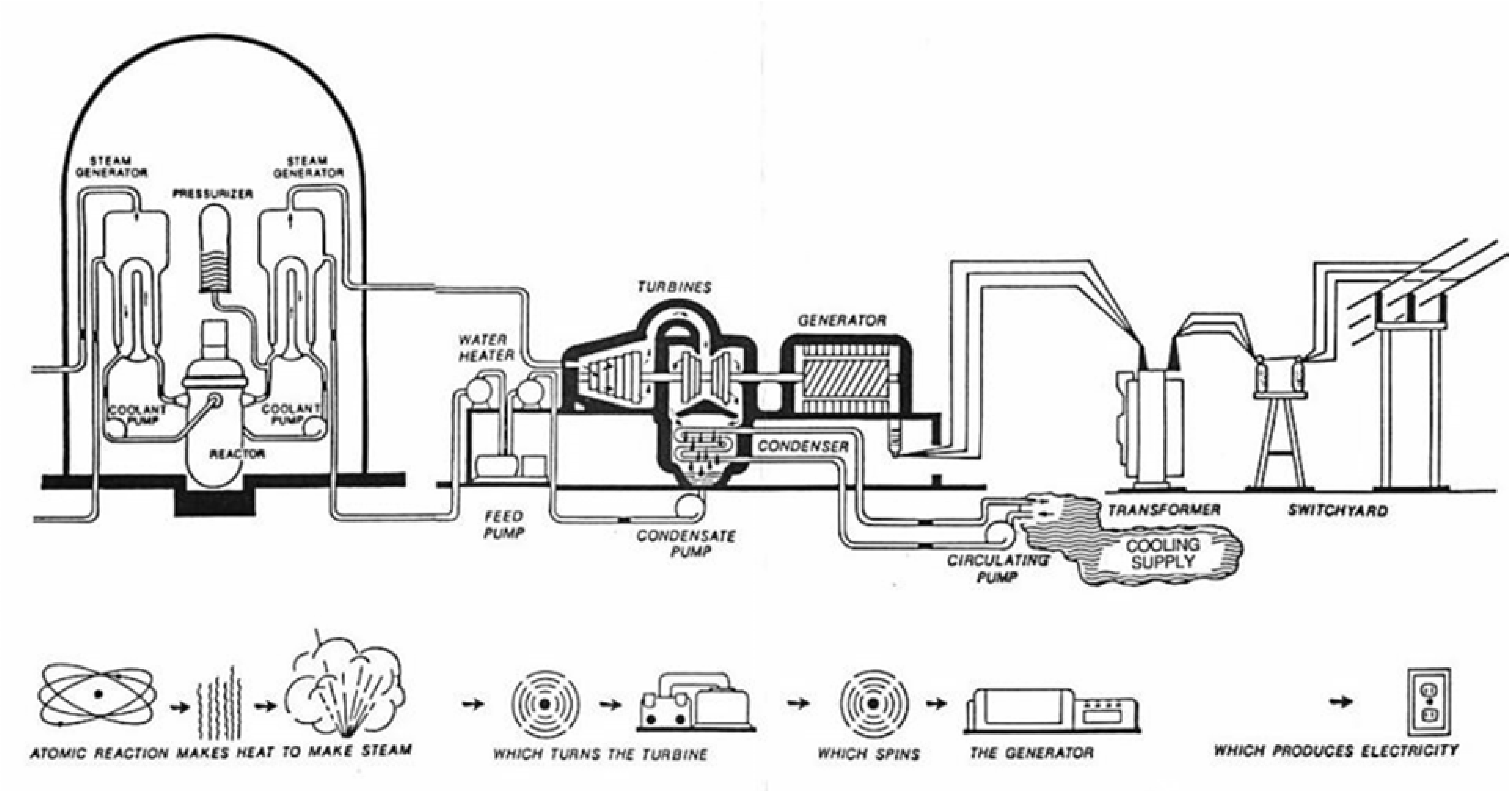
Classification by the “mechanical means” used to turn the generator...

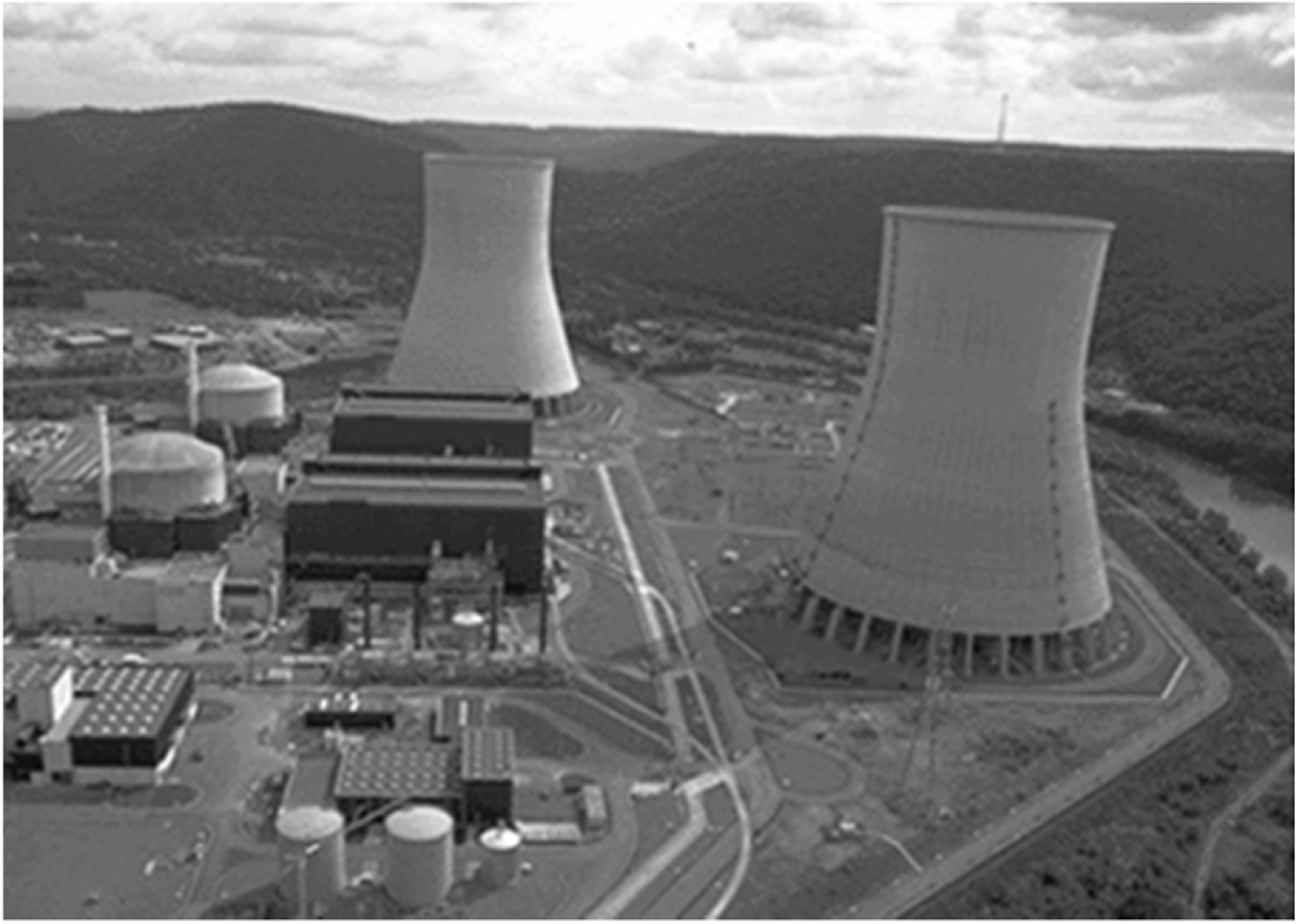
- Thermal (water steam by burning Coal, Oil, NG)
- Nuclear (water steam by Uranium or Plutonium fission)
- Geothermal
- Hydroelectric (falling water)
- Wind
- Solar

Thermal Power Plant

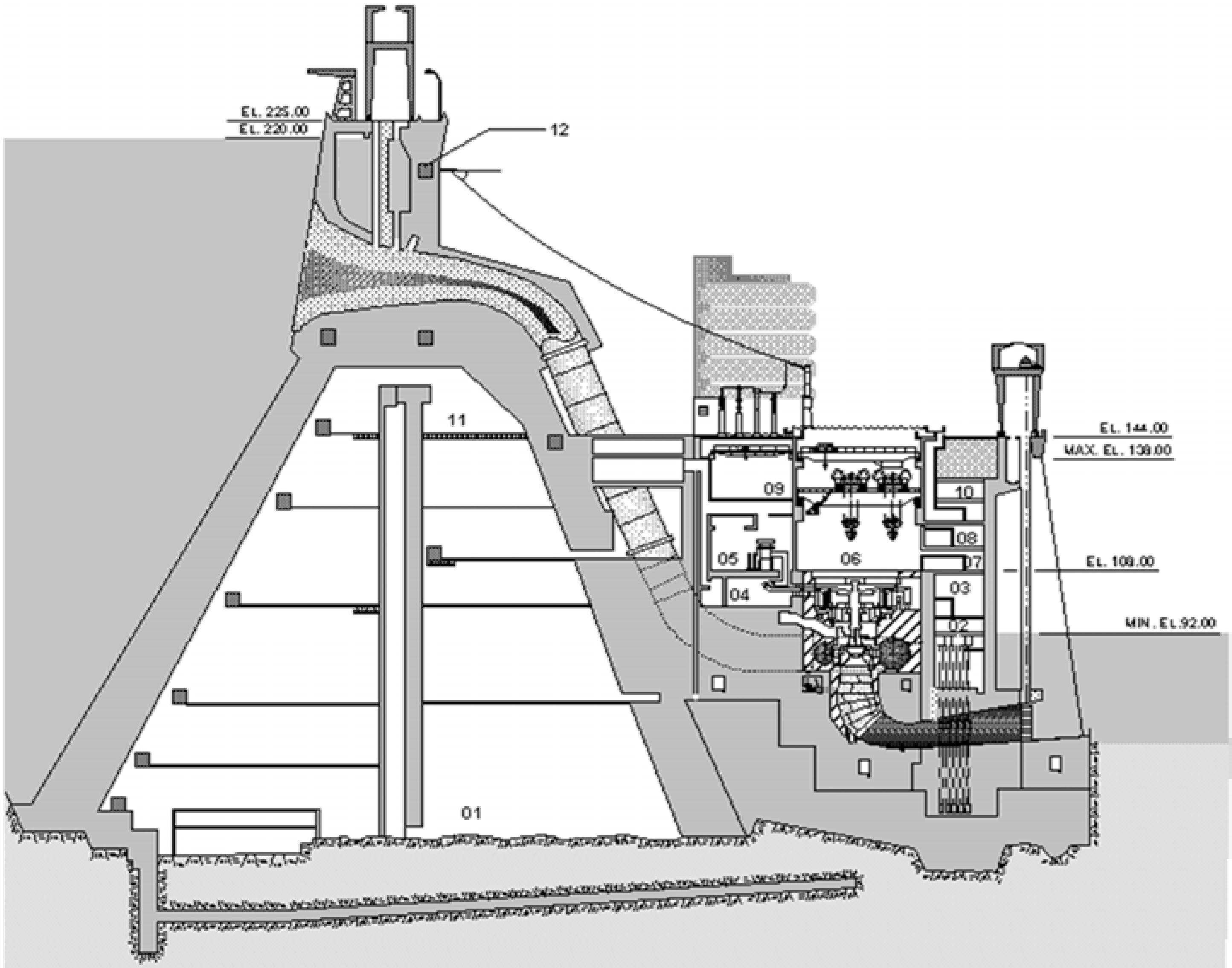


Nuclear Power Plant





Hydroelectric Power Plant



Hoover

Itaipu

Power Plant Components

ELECTRICAL

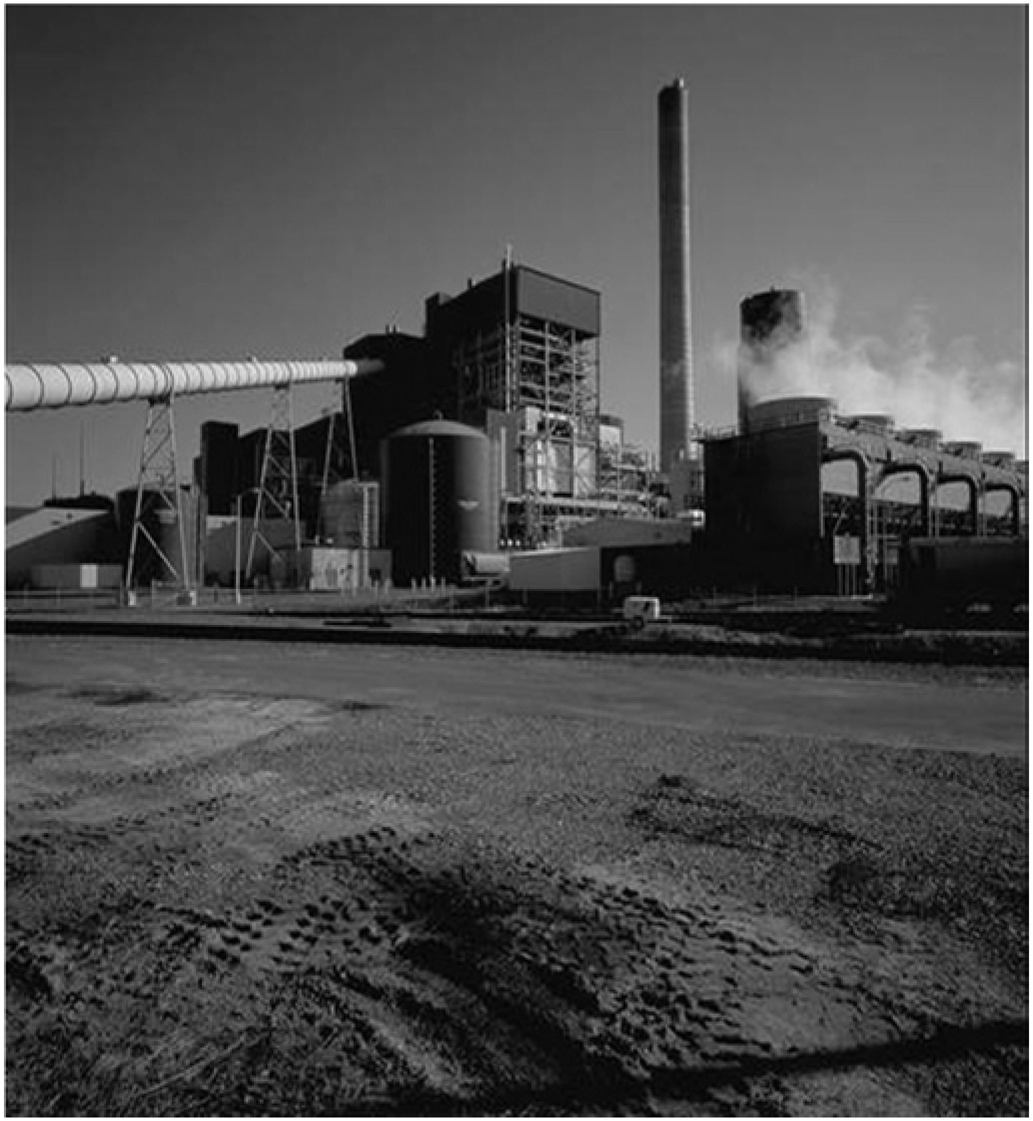
- Generators & Turbines
- Transformers
- Switches
- Busses
- Cables
- Motors
- Circuit Breakers
- Capacitor Banks

MECHANICAL

- Conveyors
- Silos
- Boilers
- Scrubbers & Stacks
- Pumps
- Cooling Towers

At the front end

- Conveyors
- Boilers
- Scrubbers and Stacks
- Pumps
- Cooling Towers

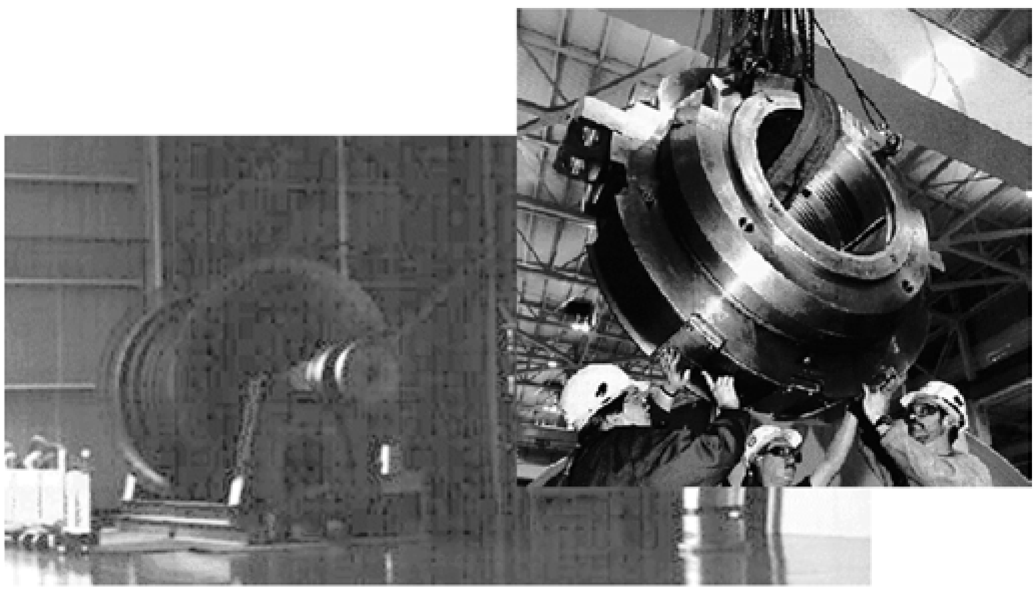


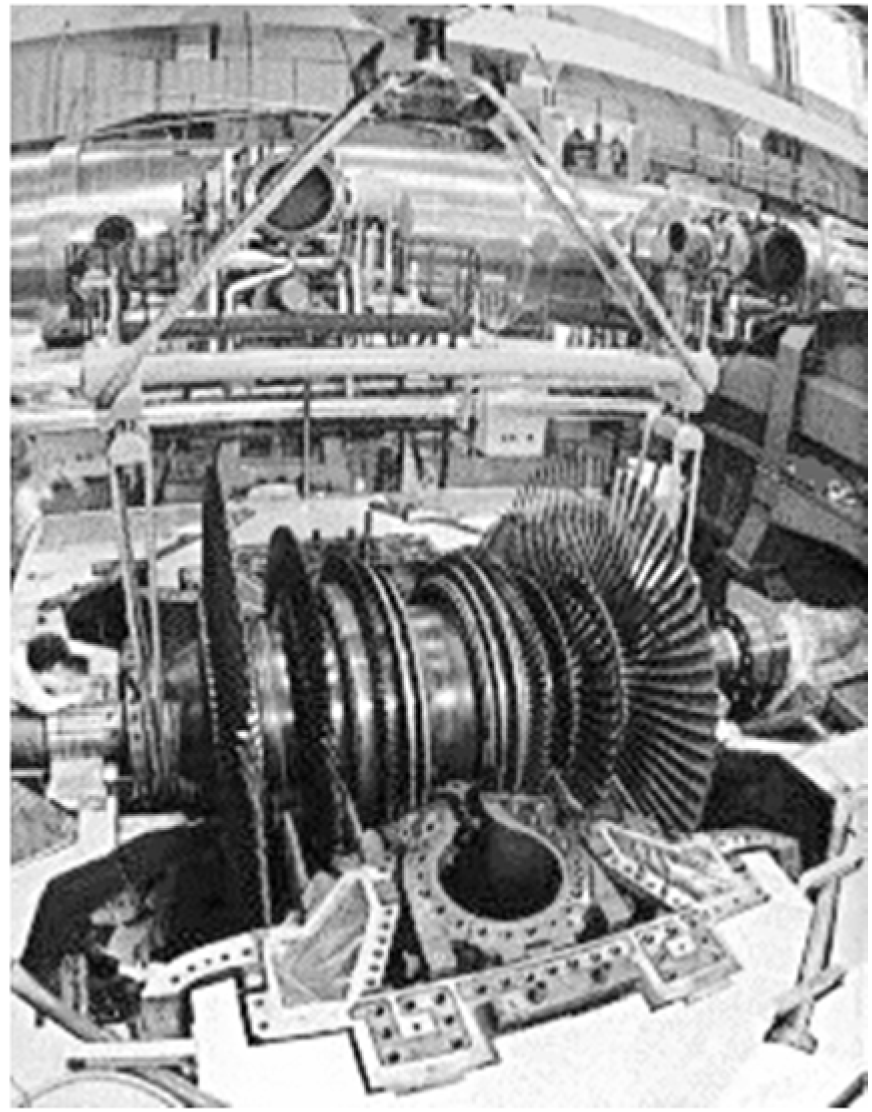
Generators

- The whole point of the power plant is to turn the generators to produce electrical energy.

Turbines

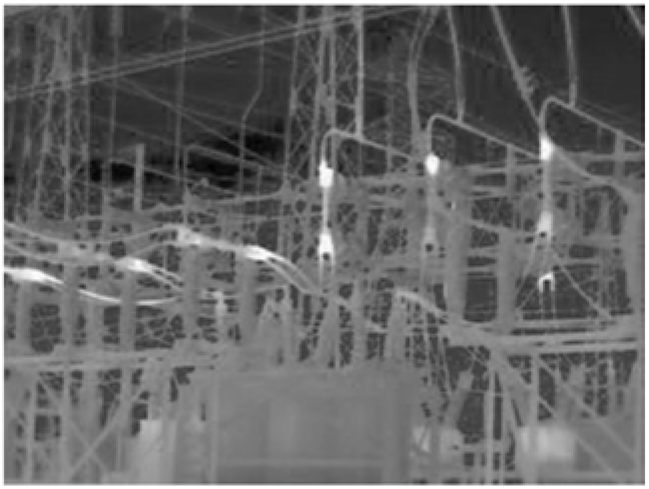
- Difficult to replace
- A spare is often kept





Busses

- non-insulated electrical conductors
- large cross-section = low resistance
- must be far from ground and other components to avoid arcing

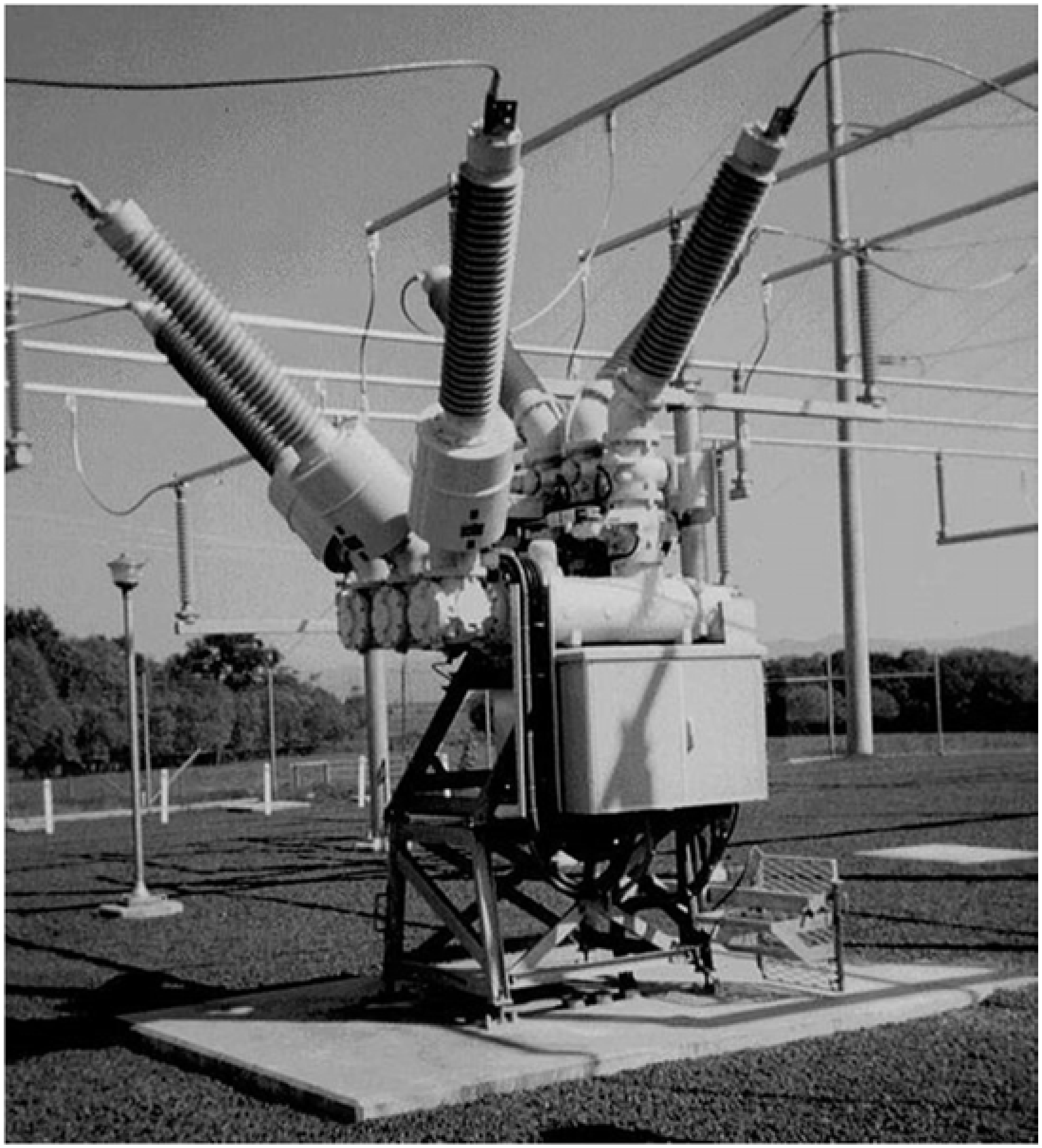



flirthermography.com

Switches & Switchyards

http://www.learnz.org.nz/trips06/images/big/b-switchyard.jpg

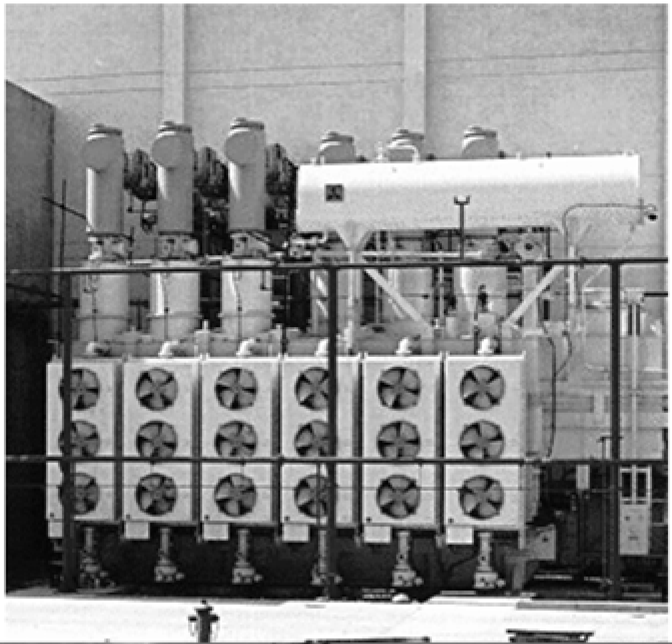
Circuit Breaker Uses Both SF6 And Air As Insulating Gases



High Voltage Circuit Breaker

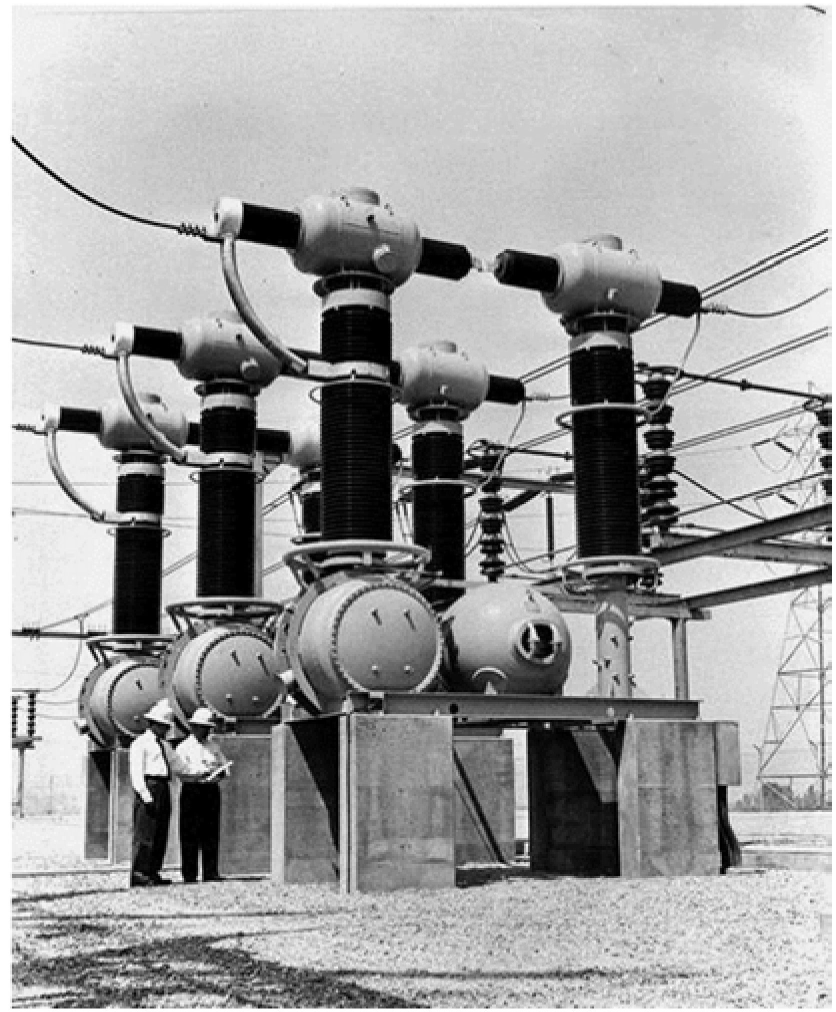
Transformers

- PURPOSE: to change the voltage
  – increase = "step-up"
  – decrease = "step-down"
- Often run hot, must be cooled, prone to explode.
  – oil inside
  – cooling fins and fans
  – blast walls



Circuit Breakers

- PURPOSE: stop the flow of current if too much flows (due to short circuit or excess demand)



230 kV breaker

Capacitor Banks

- Purpose: to smooth out spikes or “glitches” in the line voltage. Used to correct power factor issues, or to mitigate harmonics in filter designs.

Transmission Lines

and the "grid"

Why are High Voltages Used?

- Transmission lines typically carry voltages of 110 kV, 230 kV, or even higher. The wires are not insulated, so they are kept high off the ground and well separated from each other, to prevent arcing (sparks) and injury or people or animals.

- Why use such high voltages? Using very high voltages on the transmission lines reduces the amount of energy wasted heating up the wires.

- And why is that so? Transformers cannot add energy, so if the voltage is increased, the current (in amps) must decrease. The charges flowing through the wires constantly collide with the atoms, losing energy and heating the wire. We call this resistance. Recall that the power (energy per time) lost to that heating is given by the equation $P=I^2R$. If the current is reduced, the power used in heating the wire is reduced.

Transformer Sub-Station

Purpose:

- to reduce the very high voltages from the transmission lines (>100kV) to intermediate voltages used to serve an individual town or section of a city (typically 66 kV or 33 kV)

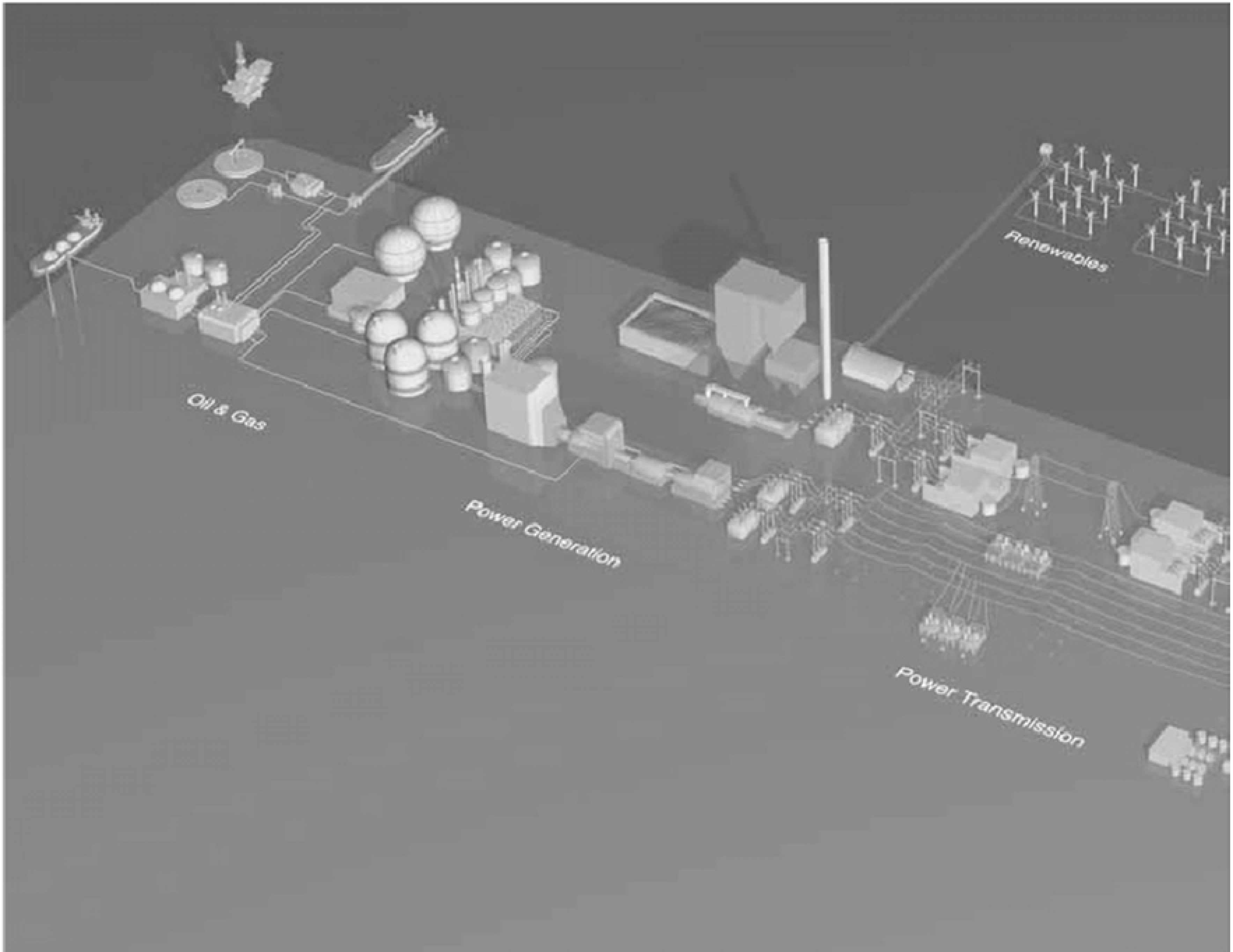
To your house...

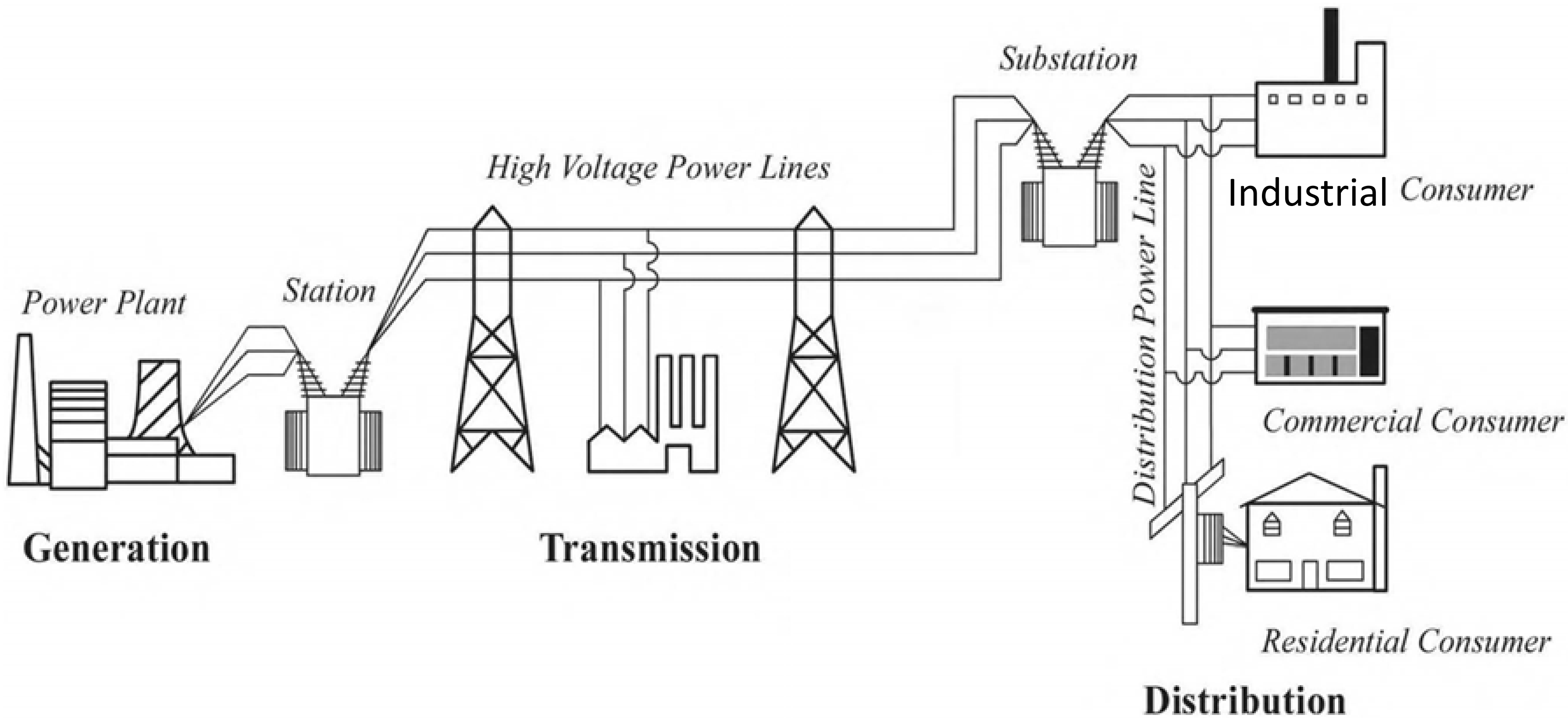
smaller transformers (on power line poles or green boxes on the ground) reduce the voltage further to the 240V delivered to individual homes

Understanding Power Concepts

Part 1

- Introduction
- ***<u>Formulas (AC/DC Basics)</u>***
- Standards
- Codes/Personal Safety
- Grounding

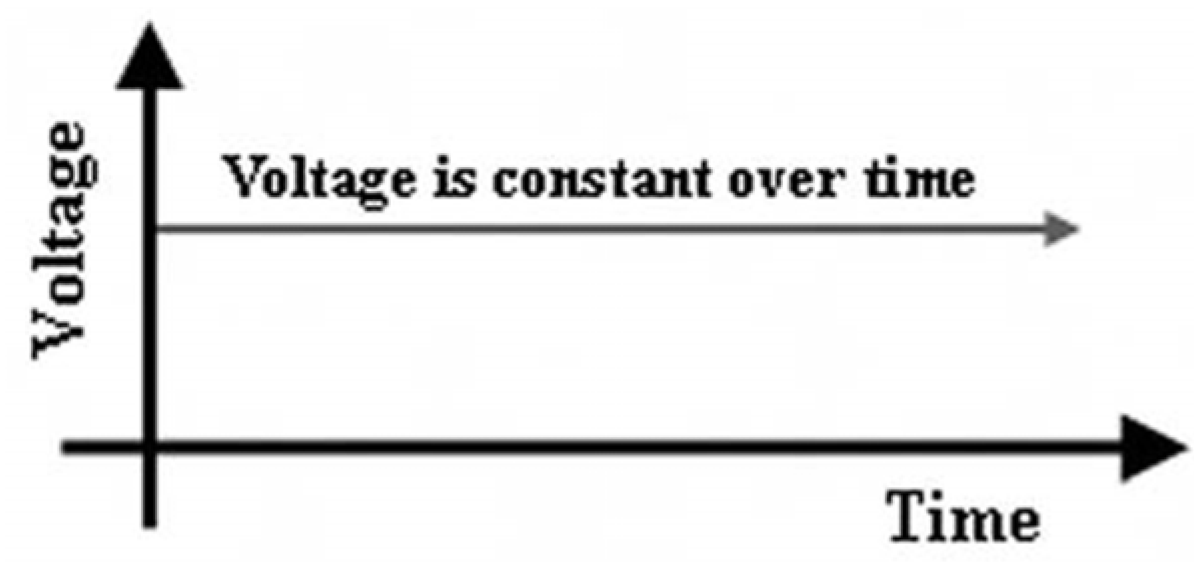

Oil & Gas
Power Generation
Renewables
Power Transmission


Substation
High Voltage Power Lines
Industrial Consumer
Distribution Power Line
Power Plant
Station
Commercial Consumer
Residential Consumer
Generation
Transmission
Distribution

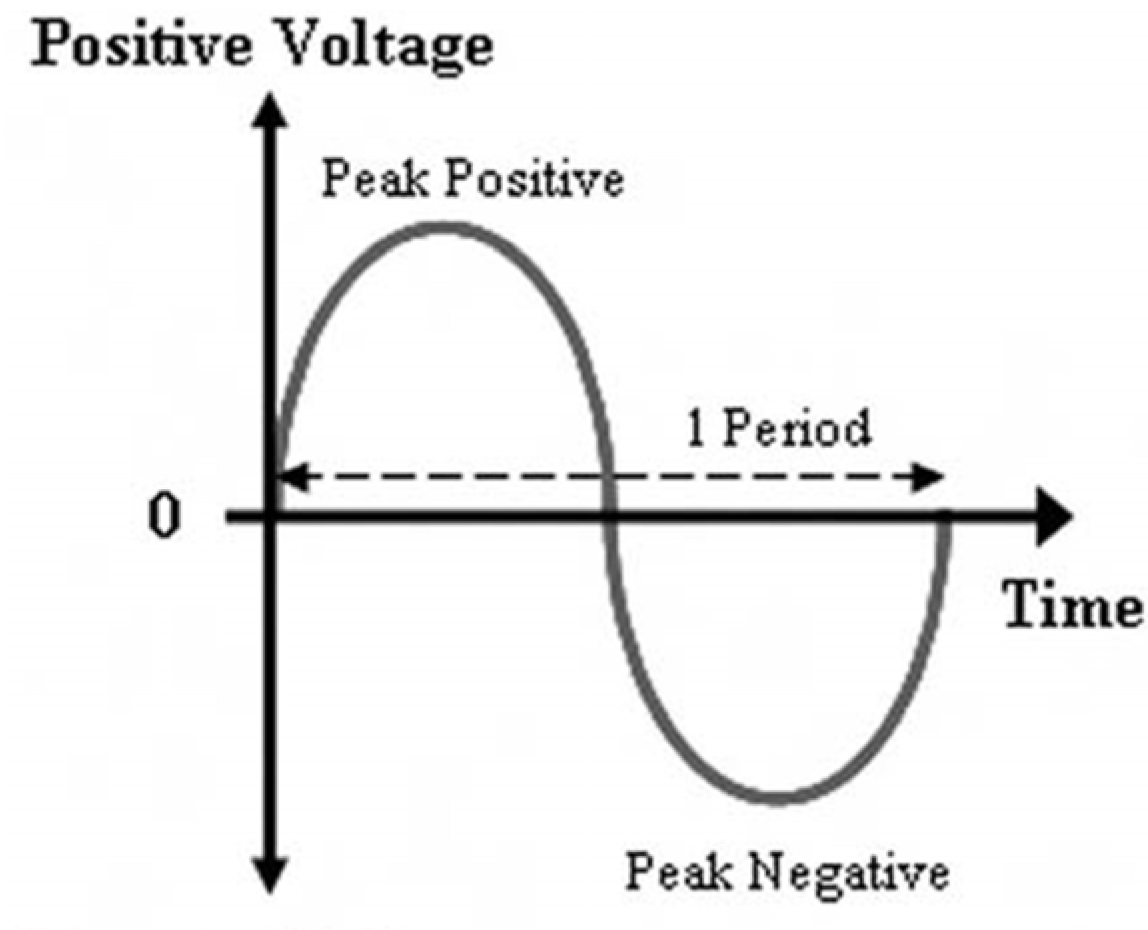
Basic Electricity for Industry

- Ohm’s law
- Impedance
- Power (kW)
- Reactive power (kVAR)
- Apparent power (kVA)
- Power factor (cos theta)
- Efficiency
- Work problems.
- Survey the industry.

DC Voltage



AC Voltage

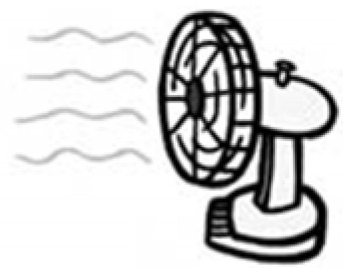

Positive Voltage
Peak Positive
1 Period
0
Time
Peak Negative

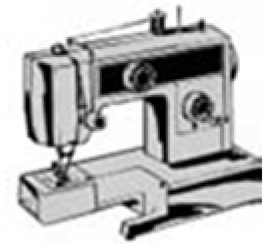
Resistive Load

Resistive
(Ohms)

Inductive Load

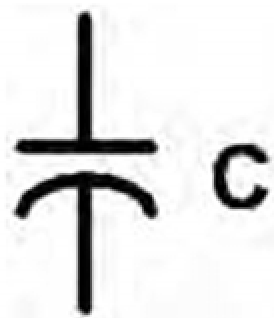
Inductive
(Henrys)

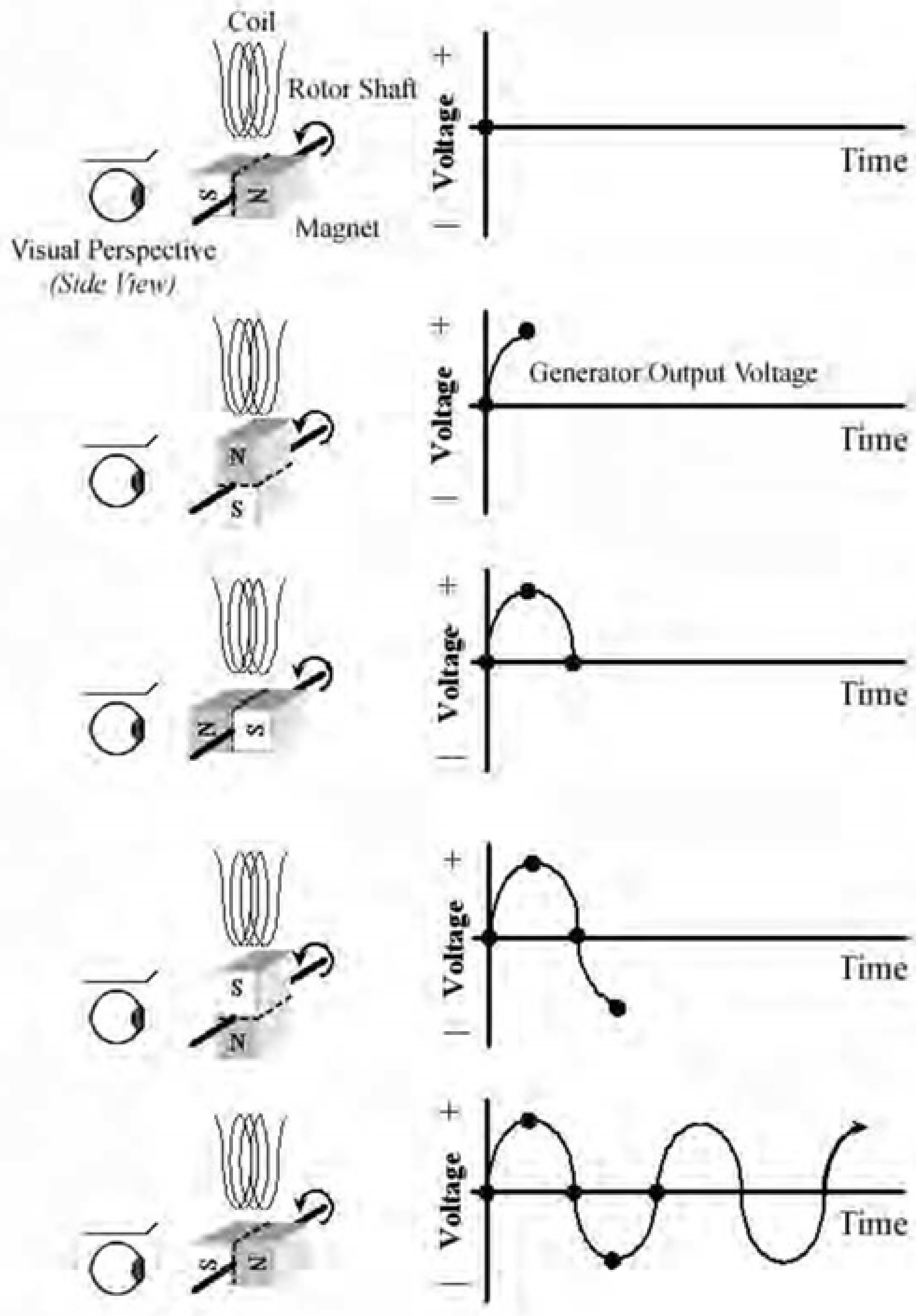




Capacitive Load

Capacitive
(Farads)



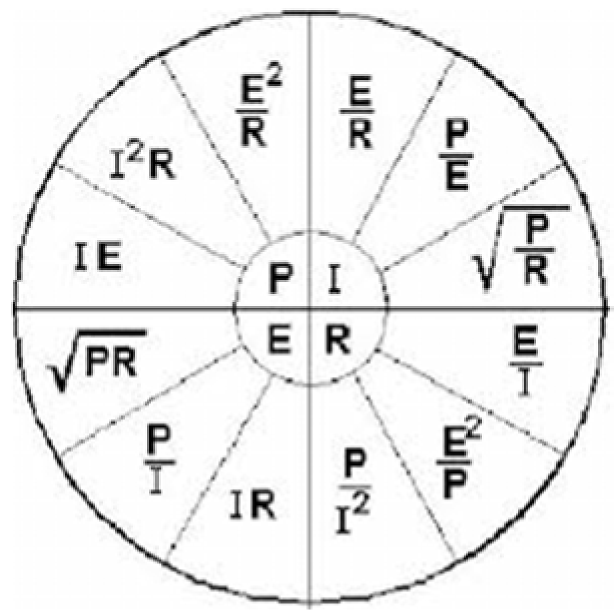


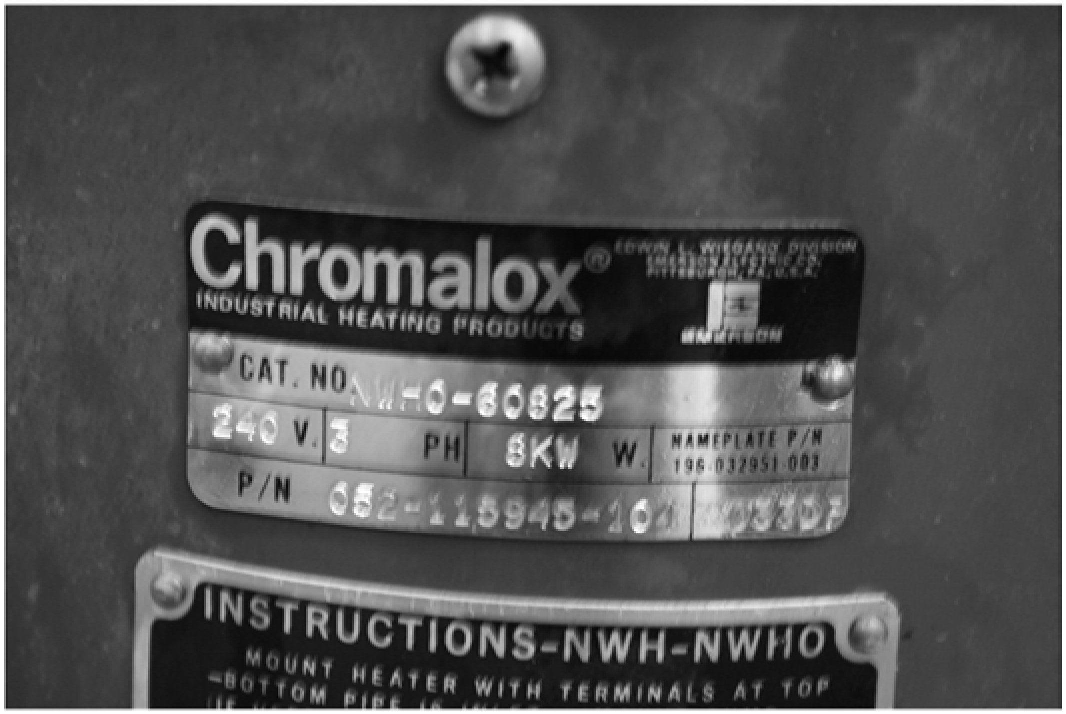
Coil
Rotor Shaft
Magnet
Visual Perspective
(Side View)
Voltage
Time
Generator Output Voltage

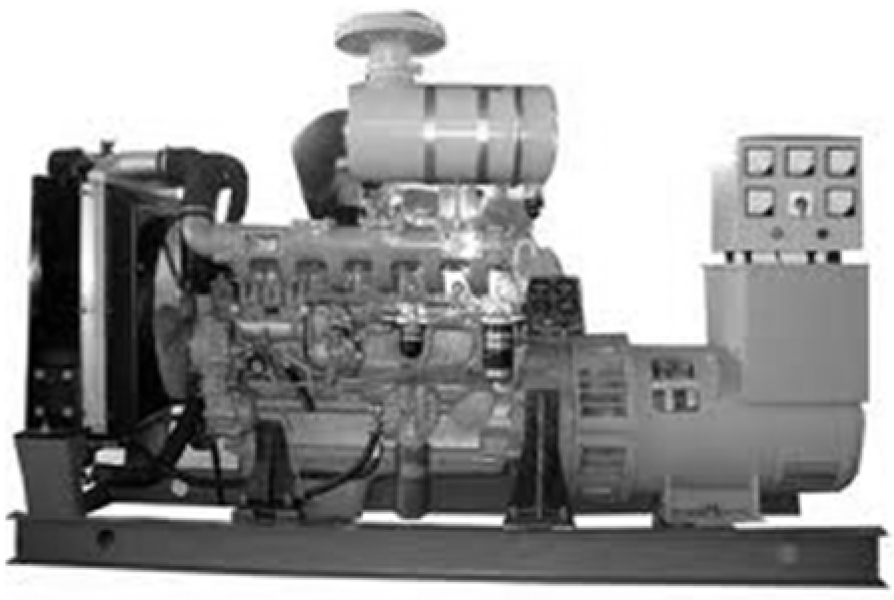
Ohm’s Law

- E: Electromotive force or Voltage; Volts, V
- I: Electric Current; Amperes, A
- R: Resistance of heater; Ohms, omega
- P: Power; watts

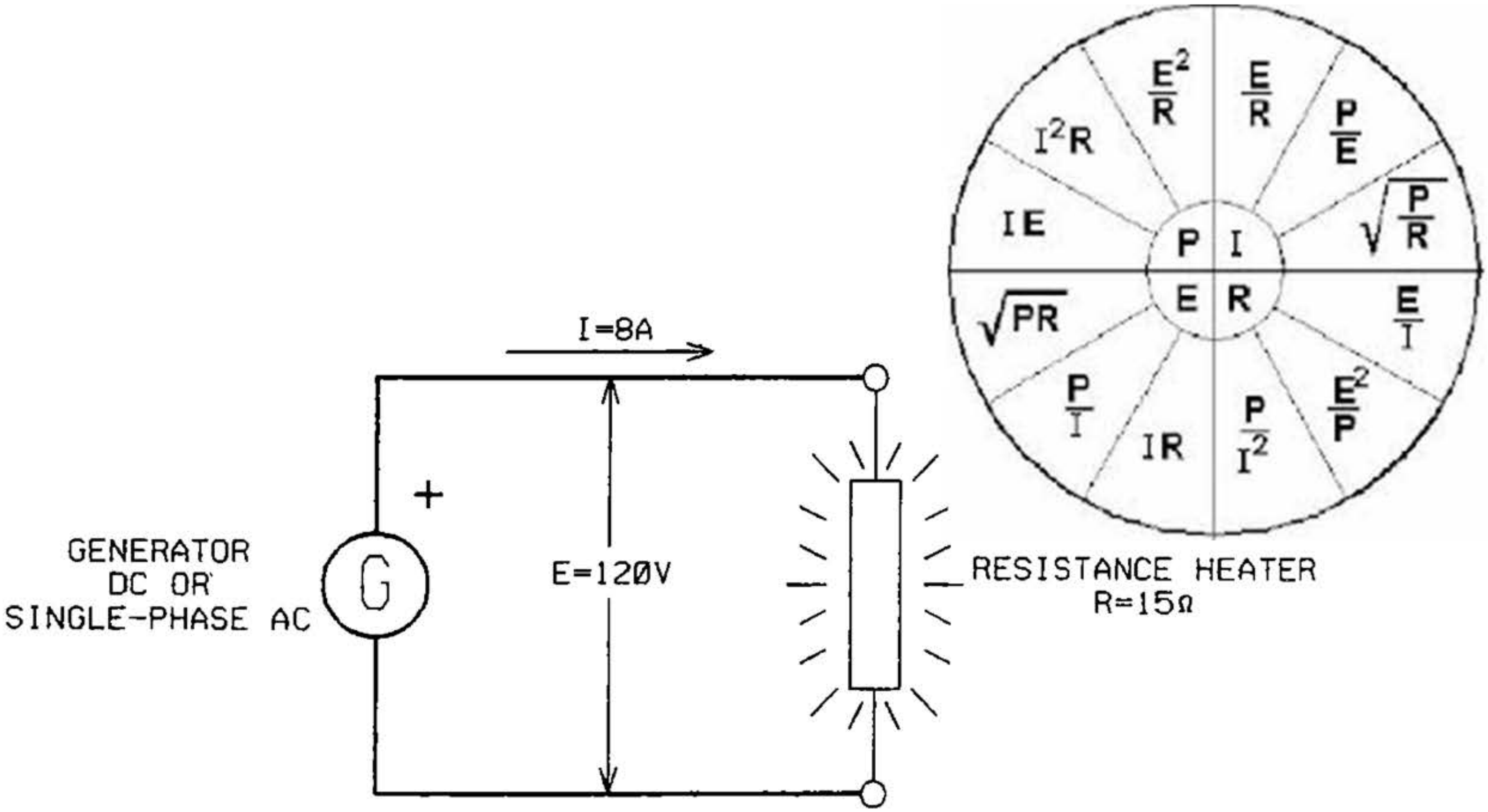
- Example solving resistance space heater element connected to the terminal of an AC generator or other AC source.







http://www.chromalox.com/productcatalog/Component+Technologies/Strip+and+Ring+Heaters/product-family-router.aspx?f=64



$$E = I \times R = 8 \times 15 = 120 \text{ V}$$

$$I = E/R = 120/15 = 8\text{A}$$

$$R = E/I = 120/8 = 15\Omega$$

http://www.chromalox.com/resource-center/calculators/ohms-law.aspx#

Ohm's Law Calculator

There's no need to guess at Ohm's Law calculations with this handy tool. Just plug in two known parameters and let our calculator do the rest.

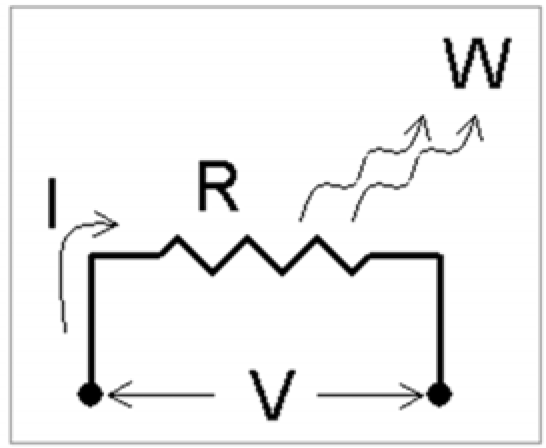
OHM'S LAW CALCULATOR | ROOM HEATING CALCULATOR

Enter only two of the following values to calculate the remaining two:

Voltage (V):	120	Volts
Heat Output (W):	960	Watts
Resistance (R):	15	Ohms
Current (I):	8	Amps

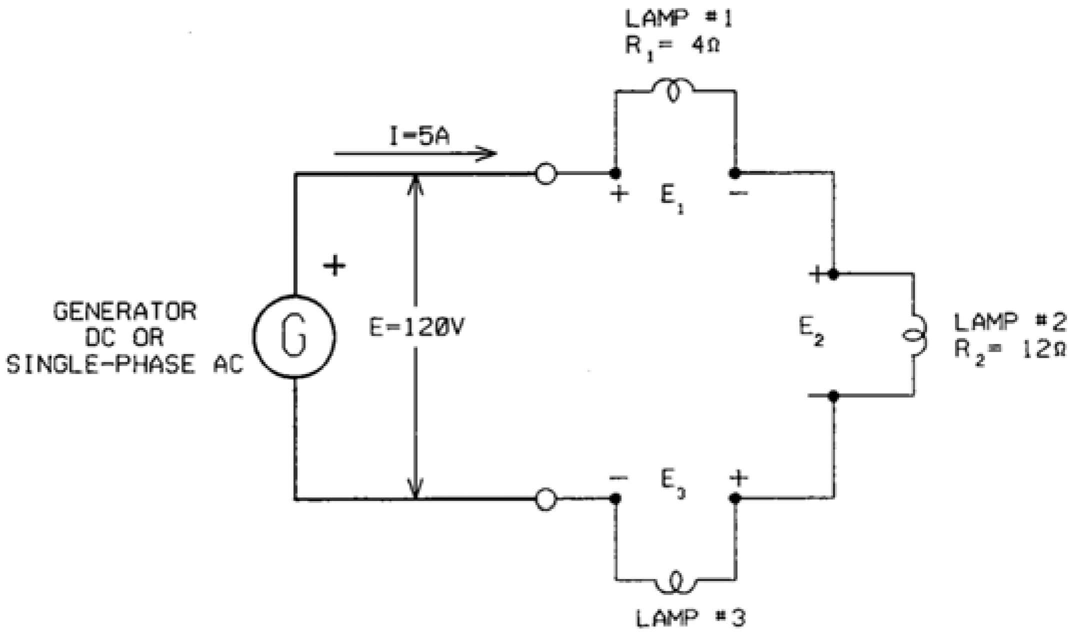
Calculate Now

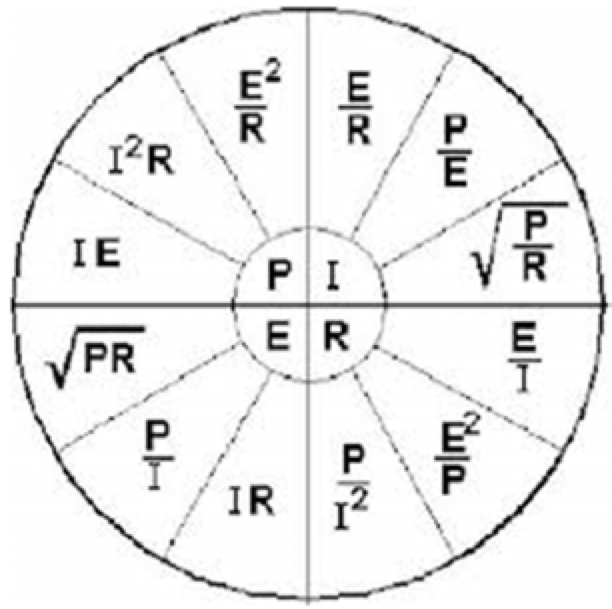
Reset Form



- (•) Single Phase
- ( ) Three Phase Delta
- ( ) Three Phase Wye

Let’s consider three resistive elements. (series circuit)





VOLTAGE DROP ACROSS EACH LAMP (OHM'S LAW)

$E_1 = IR_1 = 5 \times 4 = 20V$

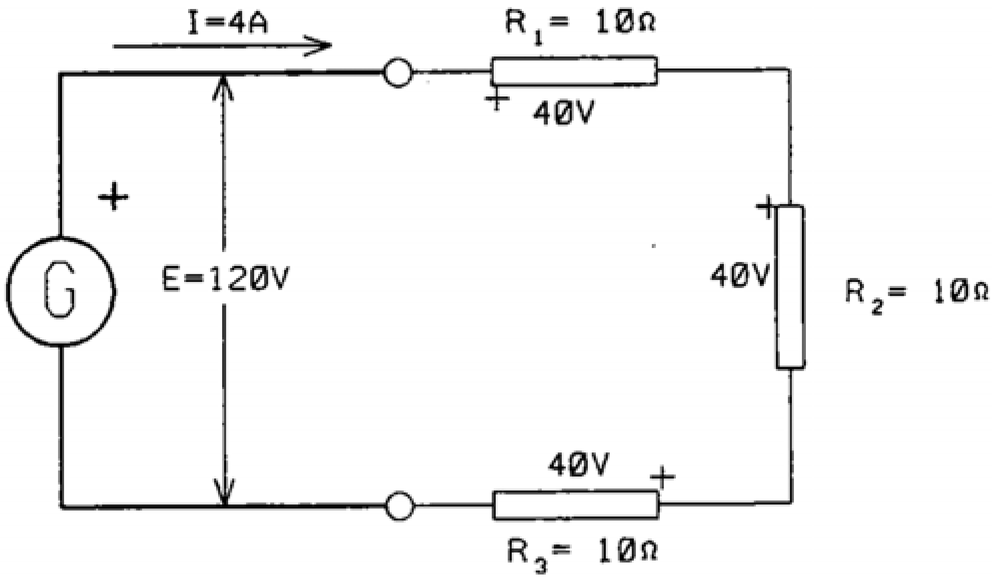
$E_2 = IR_2 = 5 \times 12 = 60V$

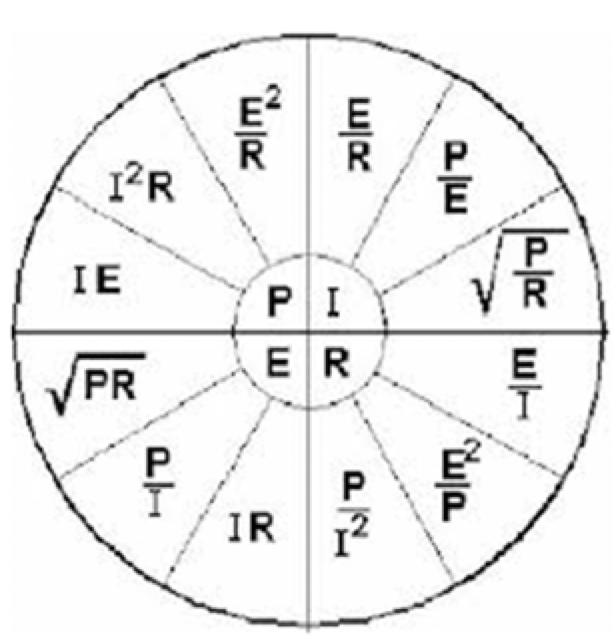
$E_3 = IR_3 = 5 \times 8 = 40V$

SUM OF VOLTAGE DROPS = GENERATOR VOLTAGE, E.

$E = E_1 + E_2 + E_3 = 20+60+40=120V$

Equivalent Circuits

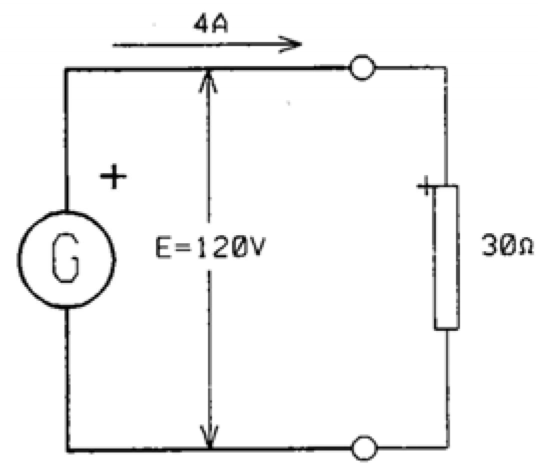




$$R_T = R_1 + R_2 + R_3$$

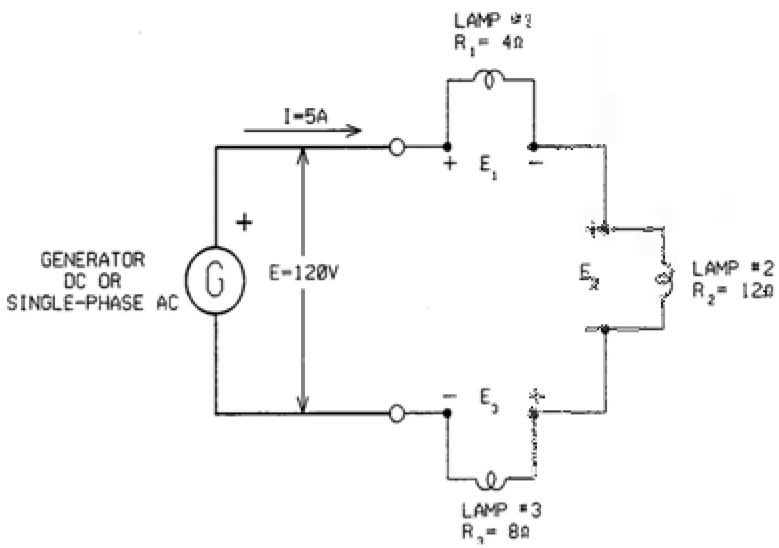
$$R_1 = R_2 = R_3 = 10\Omega$$

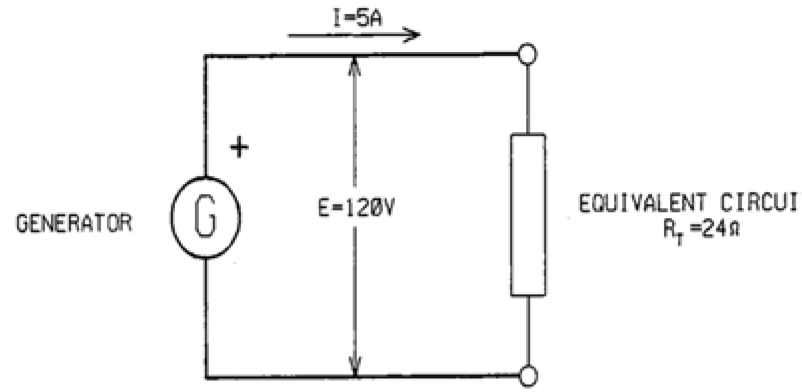
$$\therefore R_T = 10 + 10 + 10 = 3 \times 10 = 30\Omega$$



EQUIVALENT CIRCUIT

Equivalent Circuit



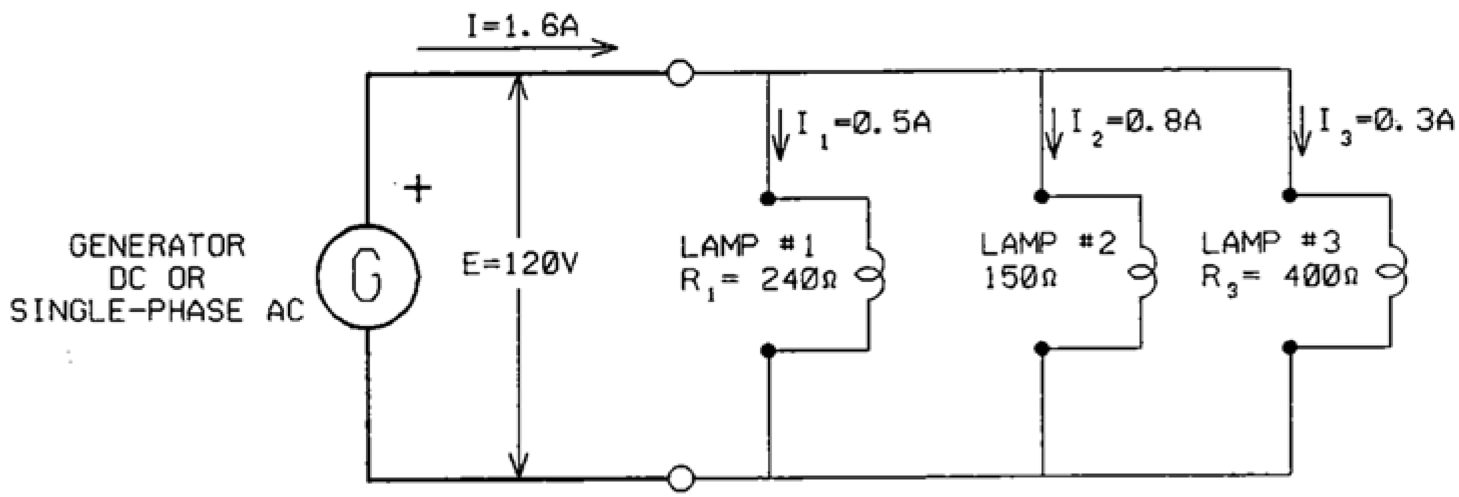


SUM RESISTANCES TO OBTAIN R_T:

$R_T = R_1 + R_2 + R_3 = 4+12+8=24\Omega$

ALSO NOTE THAT $R_T = E/I = 120/5 = 24\Omega$

Parallel Circuit



CURRENT THROUGH EACH LAMP (OHM'S LAW)

$I_1 = E/R_1 = 120/240 = 0.5A$

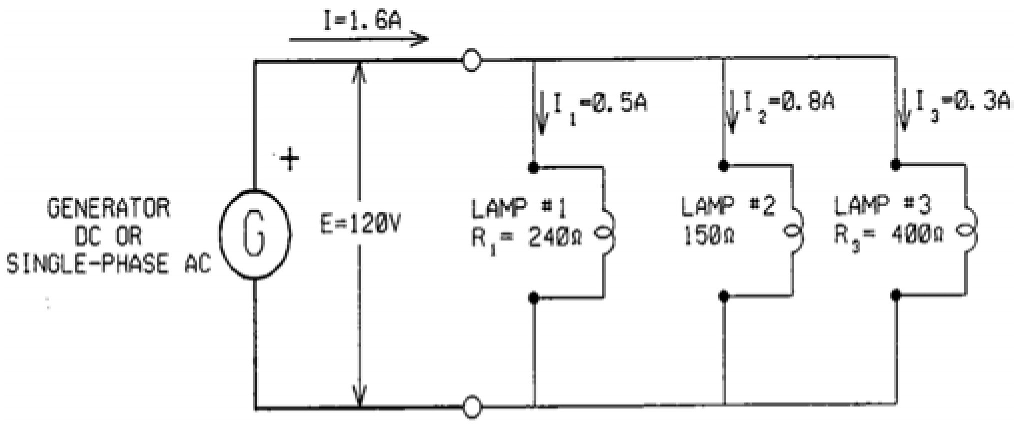
$I_2 = E/R_2 = 120/150 = 0.8A$

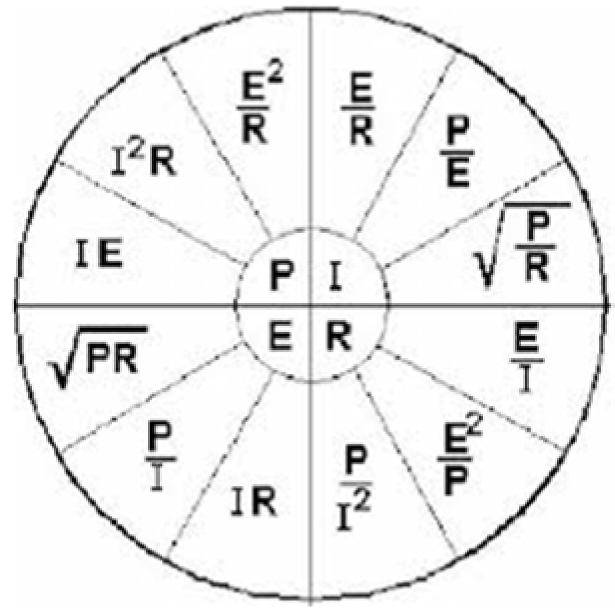
$I_3 = E/R_3 = 120/400 = 0.3A$

SUM OF BRANCH CURRENTS = GENERATOR CURRENT, I.

$I = I_1 + I_2 + I_3 = 0.5+0.8+0.3=1.6A$

Parallel Circuit



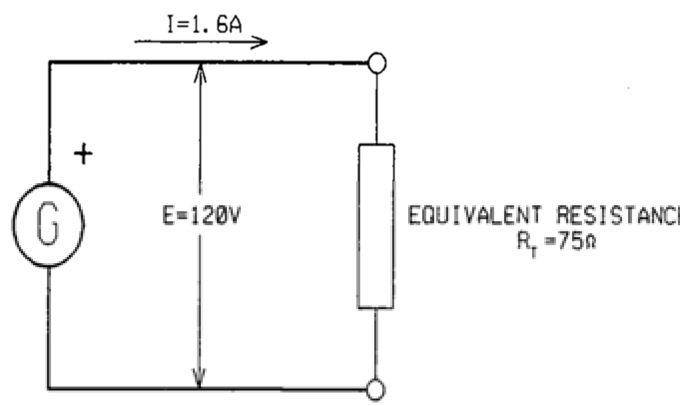


COMPUTATION OF R_T USING:

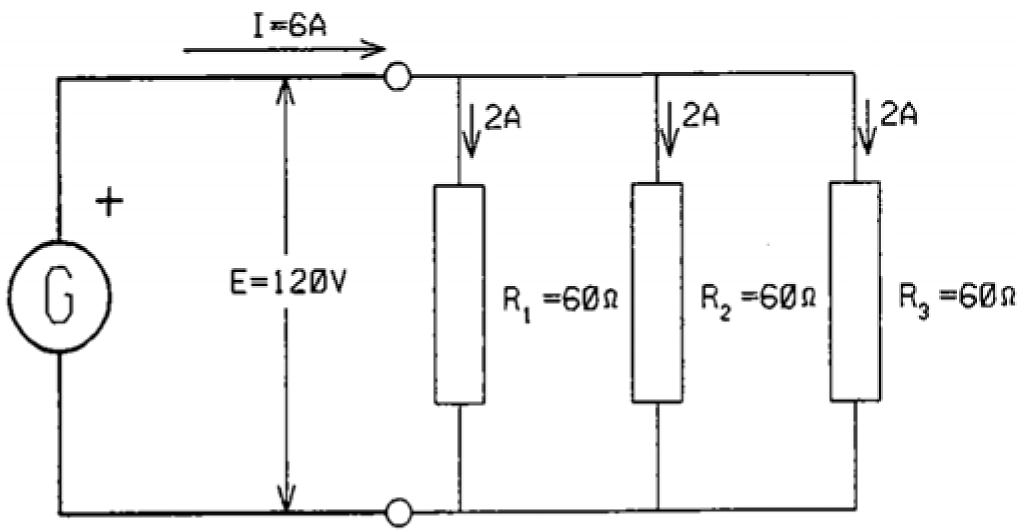
$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{240} + \frac{1}{150} + \frac{1}{400}}$$

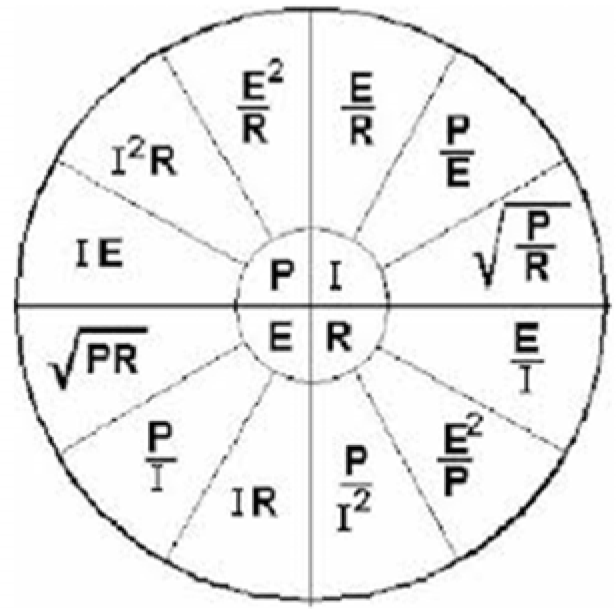
$R_T = 1/0.0133 = 75\Omega$

ALSO NOTE THAT $R_T = E/I = 120/1.6 = 75\Omega$



Parallel Circuit

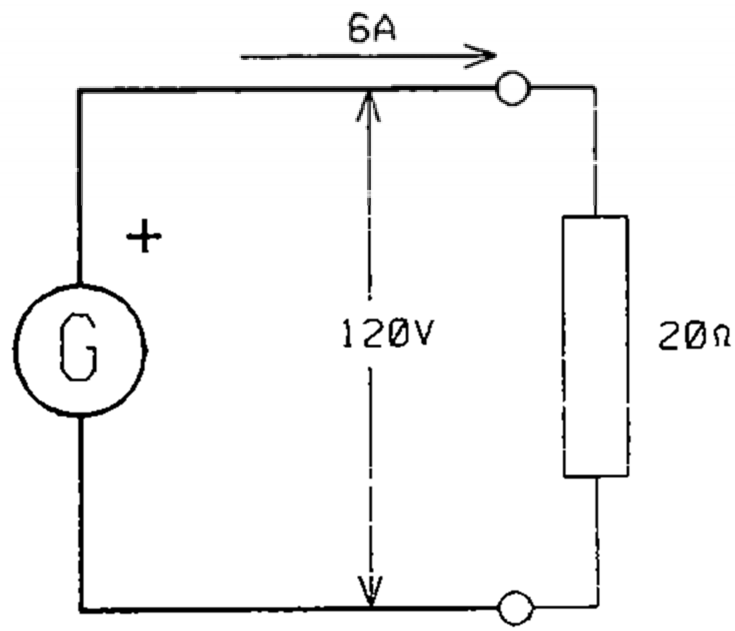


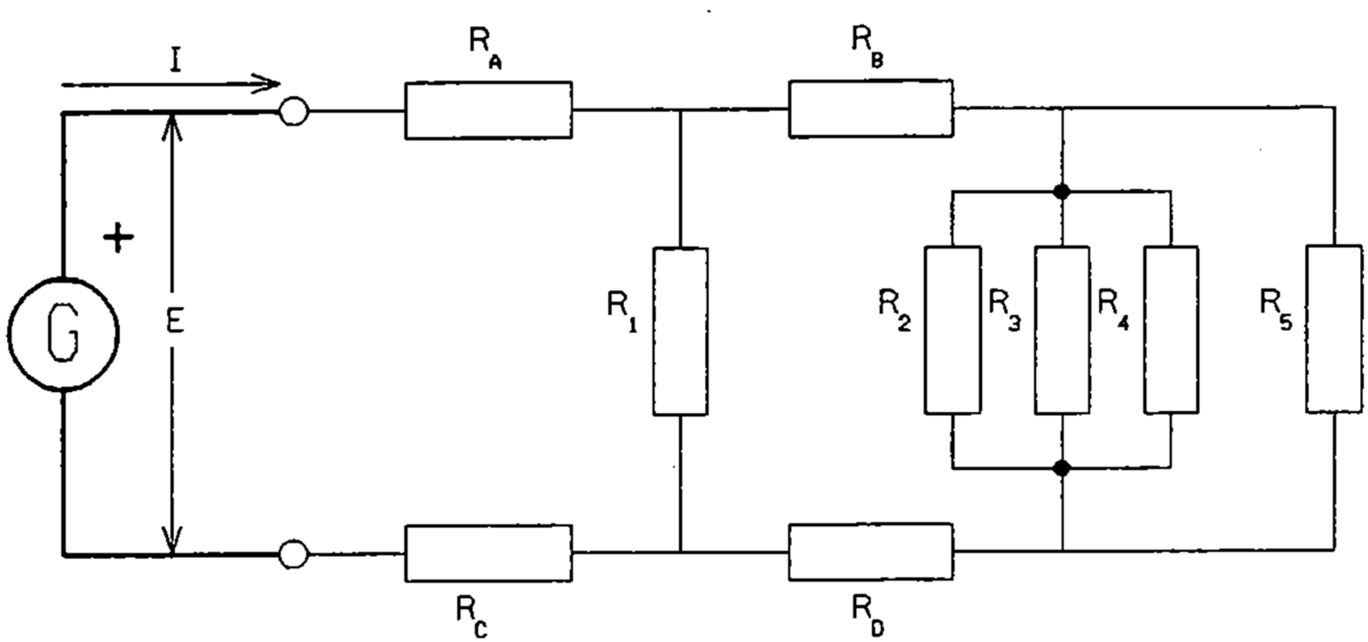


$$R_1 = R_2 = R_3 = 60\Omega$$

$$R_T = \frac{1}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} = \frac{1}{\frac{1}{60} + \frac{1}{60} + \frac{1}{60}}$$

$$R_T = \frac{1}{\frac{3}{60}} = \frac{60}{3} = 20\Omega$$





E = 120V DC OR 120V RMS, SINGLE-PHASE AC

$R_A = R_B = R_C = R_D = 0.1\Omega$; LINE RESISTANCE

$R_1 = 24\Omega$; HEATER

$R_2 = R_3 = R_4 = 144\Omega$; LAMPS

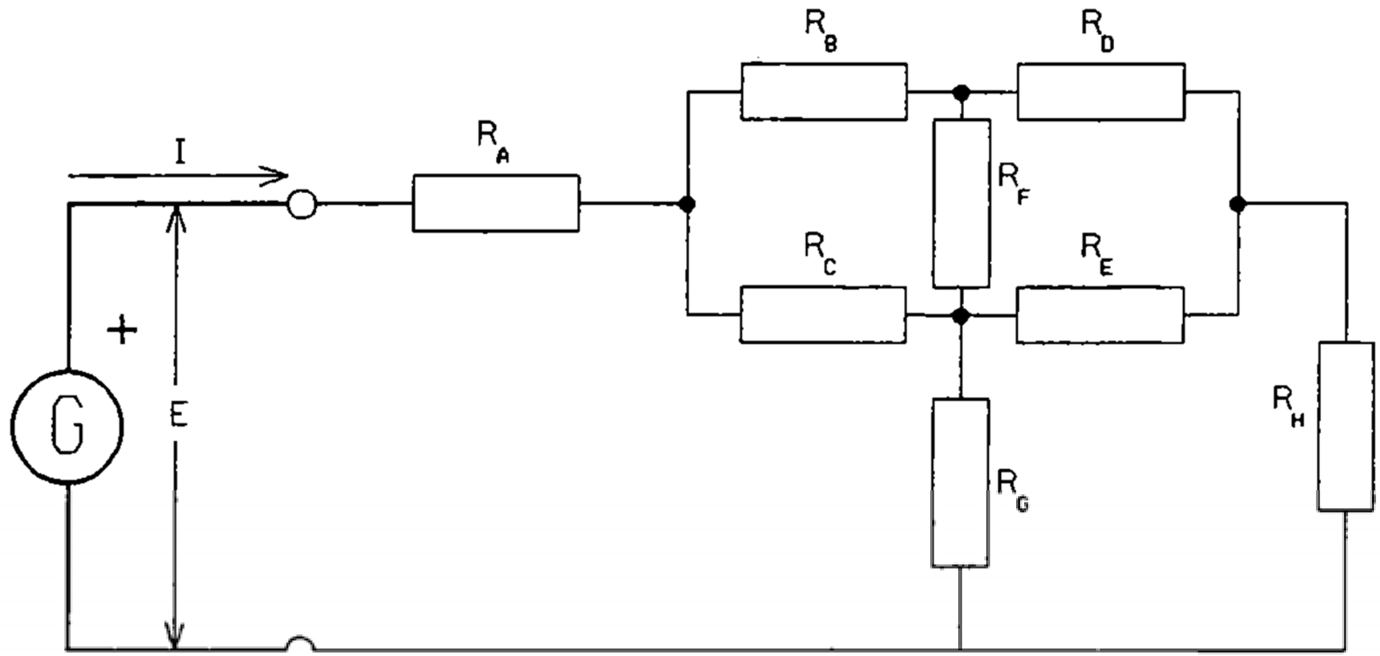
$R_5 = 72\Omega$; HEATER

FIND:

A) EQUIVALENT CIRCUIT RESISTANCE, R_T

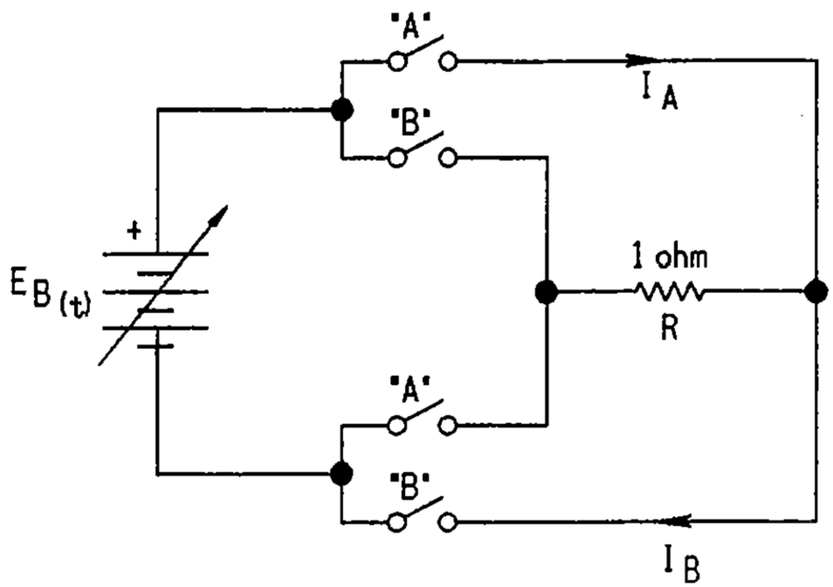
B) GENERATOR CURRENT, I

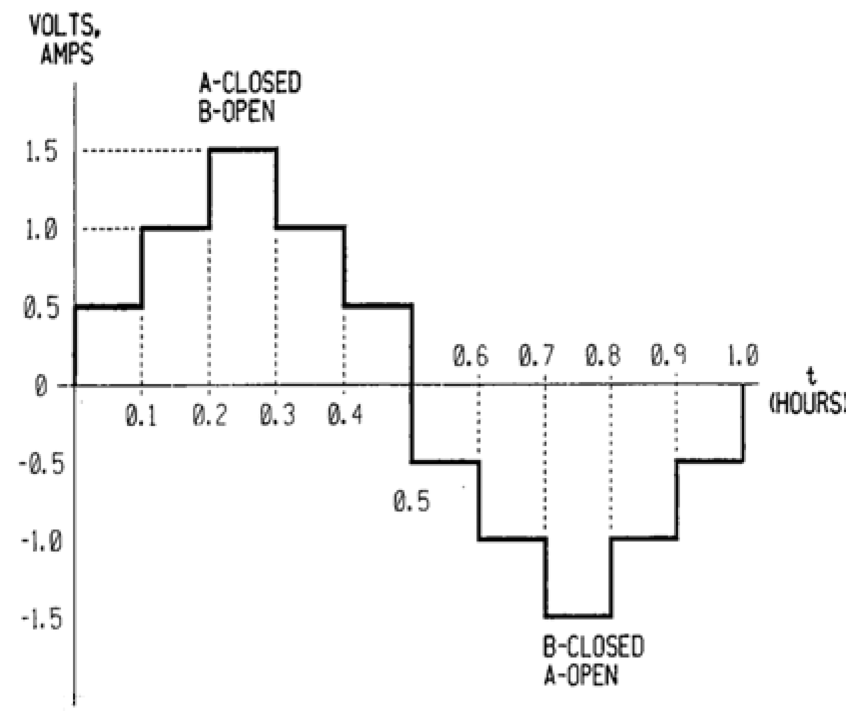
Networks are electrical transmission/distribution systems

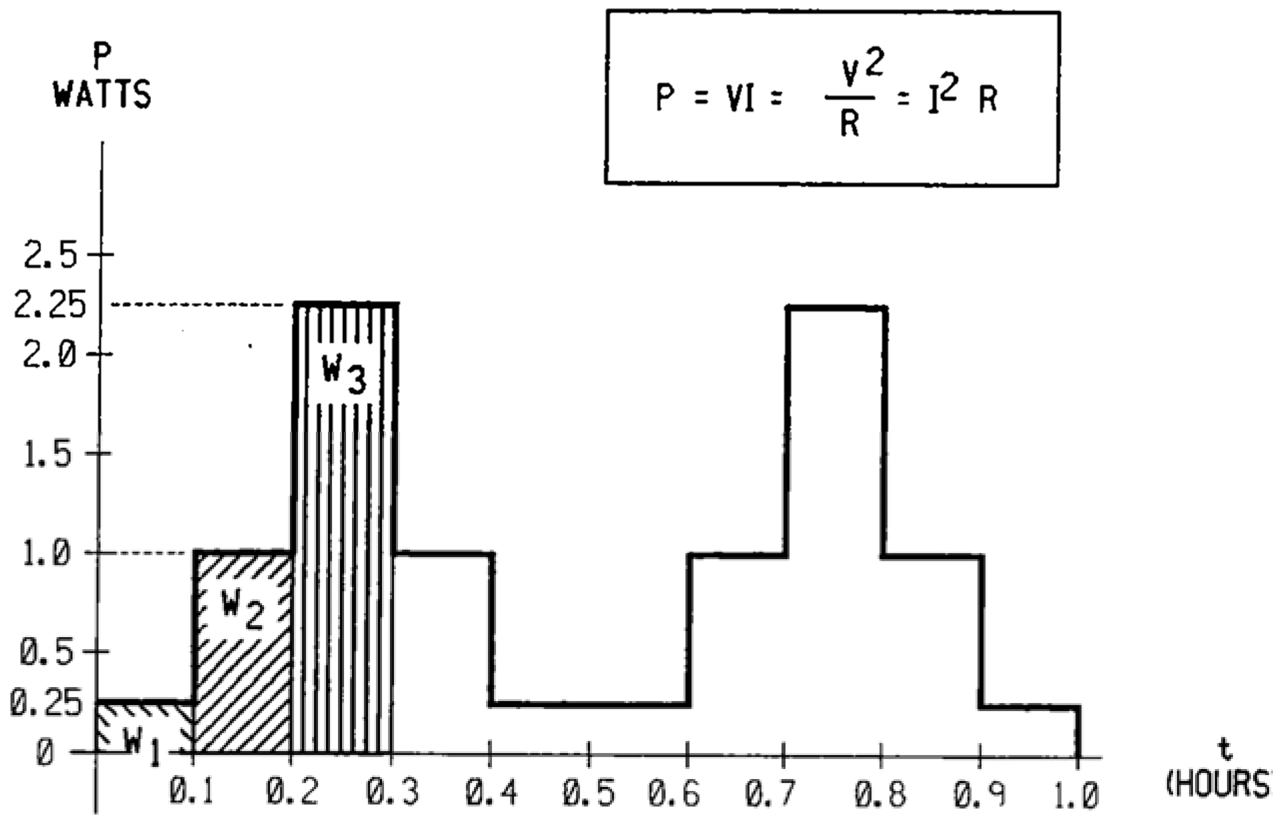


TYPICALLY, $R_A \rightarrow R_F$ REPRESENT TRANSMISSION AND/OR DISTRIBUTION ELEMENTS. R_G AND R_H REPRESENT LOADS. NOTE THE NUMBER OF DIFFERENT PATHS FROM THE GENERATOR TO EACH OF THE LOAD ELEMENTS.

Cyclic Voltage and Current







$W_1 = (0.25) \times (0.1) = 0.025$ WATT-HOURS (4)

$W_2 = (1.0) \times (0.1) = 0.100$ WATT-HOURS (4)

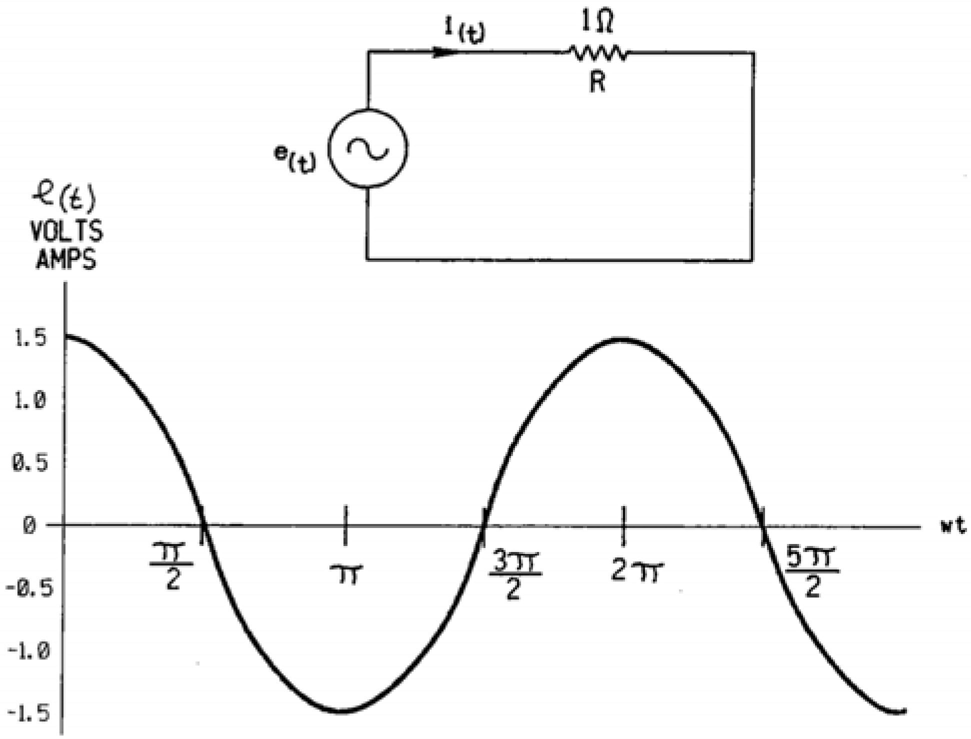
$W_3 = (2.25) \times (0.1) = 0.225$ WATT-HOURS (2)

$W_T = 4W_1 + 4W_2 + 2W_3 = 4(W_1 + W_2) + 2W_3$

$W_T = 4(0.125) + 2(0.225) = 0.95$ WATT-HRS.

$$P_{AVG} = \frac{0.95 \text{ WATT-HRS.}}{1.0 \text{ HR}} = 0.95 \text{ WATTS}$$

Sinusoidal Voltage and Current



$$v_{(t)_R} = V_{MAX} \cos wt = e_{(t)}$$

$$i_{(t)} = I_{MAX} \cos wt$$

$$p_{(t)_R} = v_{(t)}\, i_{(t)} = V_{MAX}\, I_{MAX} \cos^2 wt$$

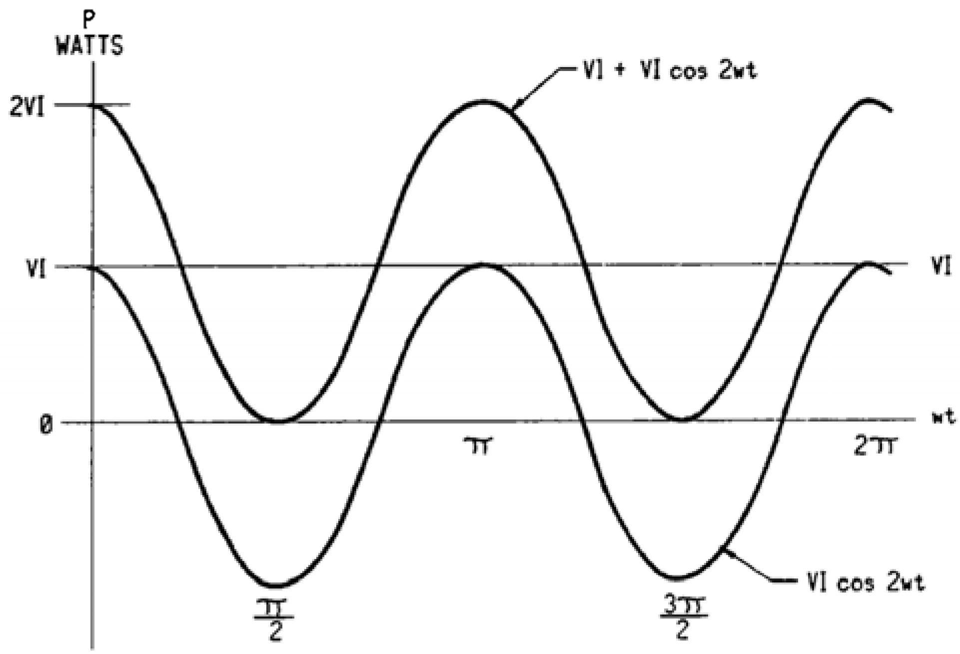
$$P_{(t)} = V_{MAX}\, I_{MAX} \left(\frac{1 + \cos 2wt}{2} \right)$$

$$= \frac{V_{MAX}\; I_{MAX}}{2} + \frac{V_{MAX}\; I_{MAX}}{2} \cos 2wt$$

LET $$\frac{V_{MAX}\; I_{MAX}}{2} = V_{EFF}\; I_{EFF} = VI$$

THEN $$V_{EFF} = \frac{V_{MAX}}{\sqrt{2}} = V \quad , \quad I_{EFF} = \frac{I_{MAX}}{\sqrt{2}} = I$$

SO $$P_{(t)} = VI + VI \cos 2wt$$



EFFECTIVE VALUES ARE ALSO CALLED "RMS" OR ROOT-MEAN-SQUARE VALUES.

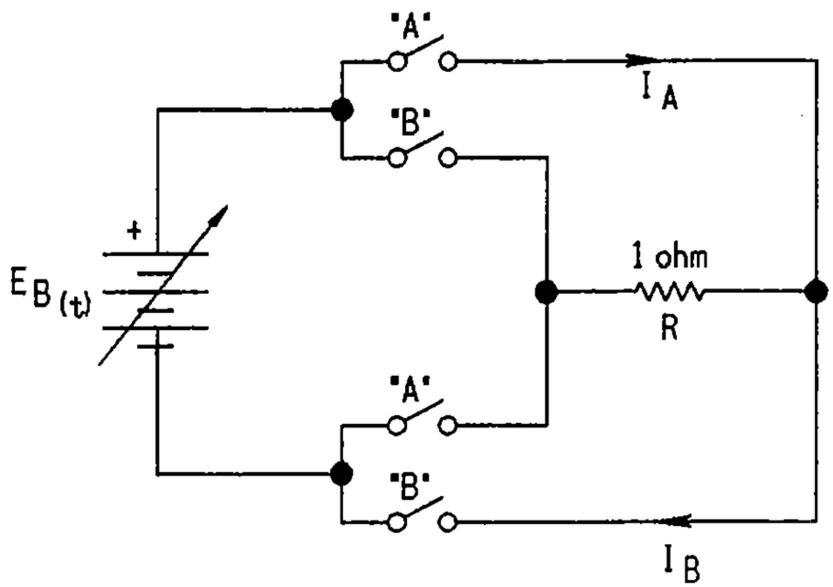
$$\therefore \quad V_{eff} = \sqrt{(V_{(t)}^2)_{AVG}}$$

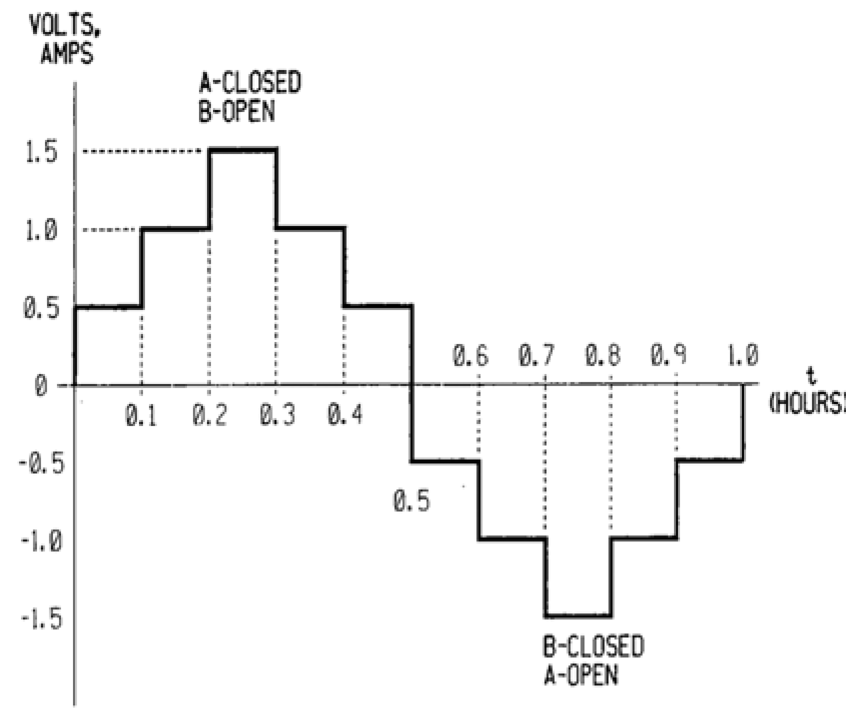
$$V \equiv V_{EFF} \equiv V_{RMS} \qquad\qquad I \equiv I_{EFF} \equiv I_{RMS}$$

Cyclic Voltage and Current

EFFECTIVE VALUES ARE ALSO CALLED "RMS" OR ROOT-MEAN-SQUARE VALUES.

$$\therefore \quad V_{eff} = \sqrt{(V_{(t)}^2)_{AVG}}$$





$$V_{RMS} = \sqrt{\frac{0.5^2 + 1.0^2 + 1.5^2 + 1.0^2 + 0.5^2}{5}}$$

$$= \sqrt{0.95} = \underline{0.9747} \text{ VOLTS RMS}$$

Basic Electrical Quantities

Quantity Measured		Unit of Measure	
Name	Symbol	Name	Symbol
Quantities Used for Both Alternating Current (ac) and Direct Current (dc)			
Electrical pressure (voltage)	E	Volt	V
Flow of electricity (current)	I	Ampere	A
Resistance	R	Ohm	Ω
Inductance	L	Henry	H
Capacitance	C	Farad	F
Power	P	Watt	W
Energy	-	Watthour	Wh
Temperature	T	Degree Celsius	°C
Quantities Used for Alternating Current (ac) Only			
Frequency	f	Hertz	Hz
Power Factor	PF	Percent	%
Inductive Reactance	X_L	Ohm	Ω
Capacitive Reactance	X_C	Ohm	Ω
Impedance	Z	Ohm	Ω
Apparent Power	-	Voltampere	VA
Reactive Power	-	Var	var
Power Factor Angle	θ	Degree	°

Basic Electrical Formulas

Ohm's Law (dc): $I = \frac{E}{R}$, $E = IR$, $R = \frac{E}{I}$

Ohm's Law (ac): $I = \frac{E}{Z}$, $E = IZ$, $Z = \frac{E}{I}$

Power (dc): $P = EI$, $P = I^2R$, $P = \frac{E^2}{R}$

Power (single phase ac): $P = EI \cos\theta$

Power (three phase ac): $P = \sqrt{3}\, E_{L\text{-}L} I_L \cos\theta$

Inductive Reactance (ac): $X_L = 2\pi f L$

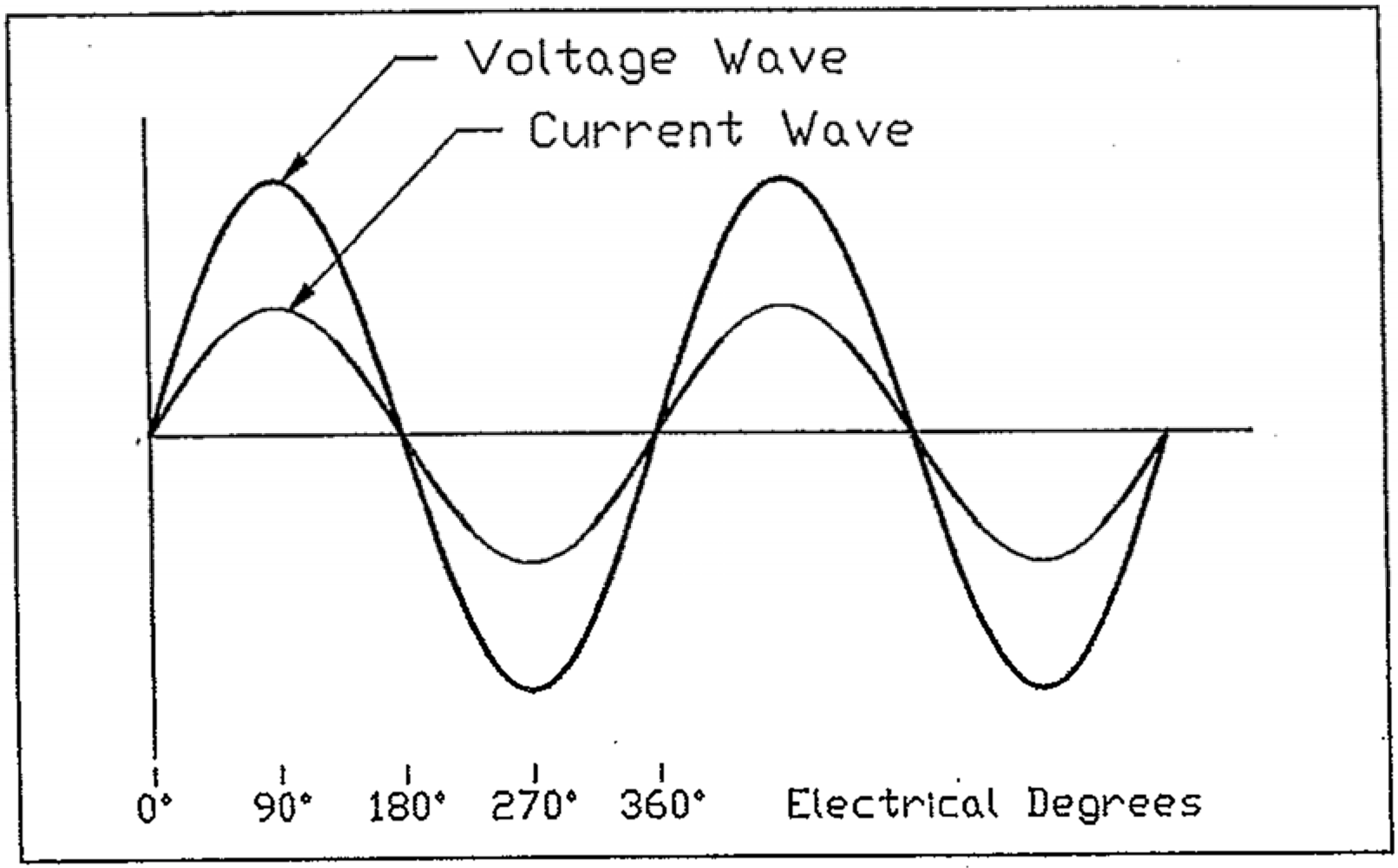
Capacitive Reactance (ac): $X_C = \frac{1}{2\pi f C}$

Impedance (ac): $Z = \sqrt{R^2 + (X_L - X_C)^2}$

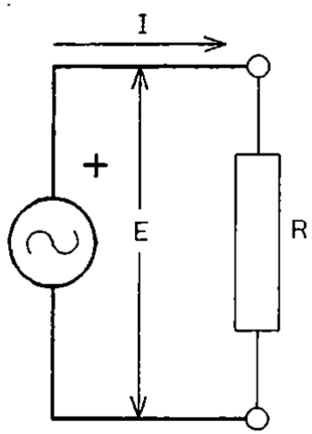
Decimal Multiples and Submultiples

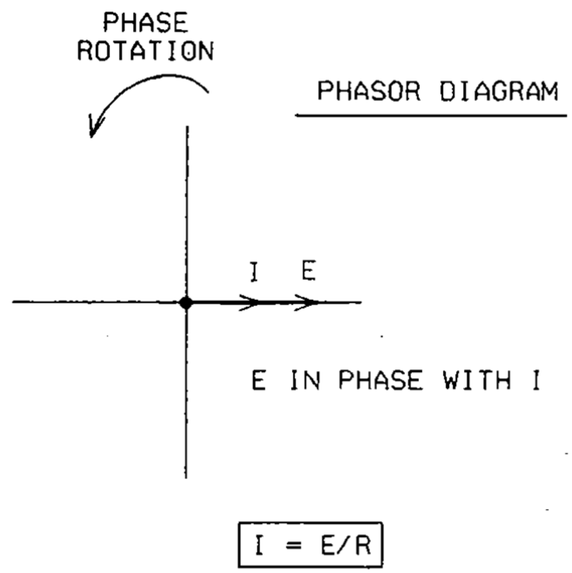
Number	Prefix	Symbol	Numerical Multiplier	Power of 10
One Trillion	tera	T	1 000 000 000 000.0	10^{12}
One Billion	giga	G	1 000 000 000.0	10^{9}
One Million	mega	M	1 000 000.0	10^{6}
One Thousand	kilo	k	1 000.0	10^{3}
One	--	-	1.0	10^{0}
One Thousandth	milli	m	0.001	10^{-3}
One Millionth	micro	μ	0.000 001	10^{-6}
One Billionth	nano	n	0.000 000 001	10^{-9}
One Trillionth	pico	p	0.000 000 000 001	10^{-12}

Current in phase with voltage

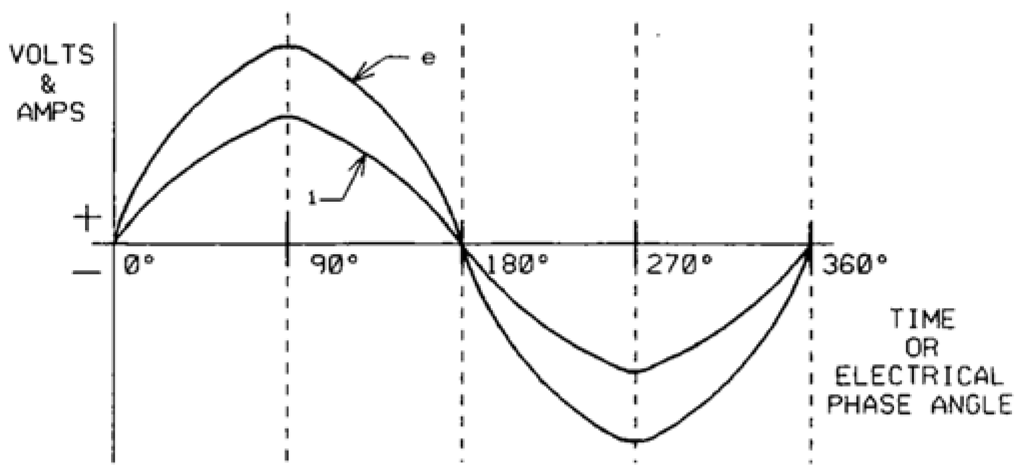


AC Voltage and Current in a resistance



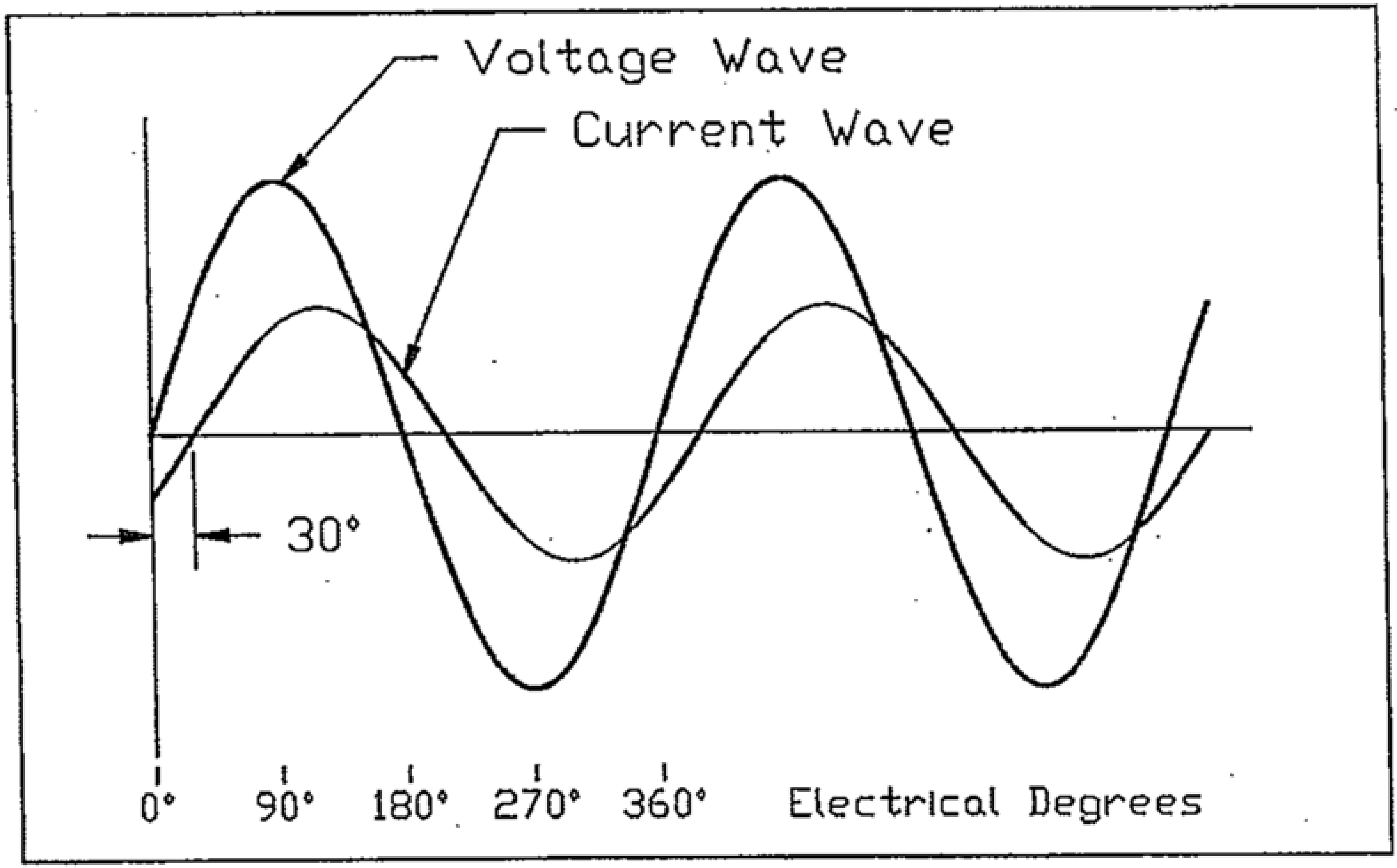


NOTE: E AND I REPRESENT RMS VALUES OF VOLTAGE AND CURRENT RESPECTIVELY.

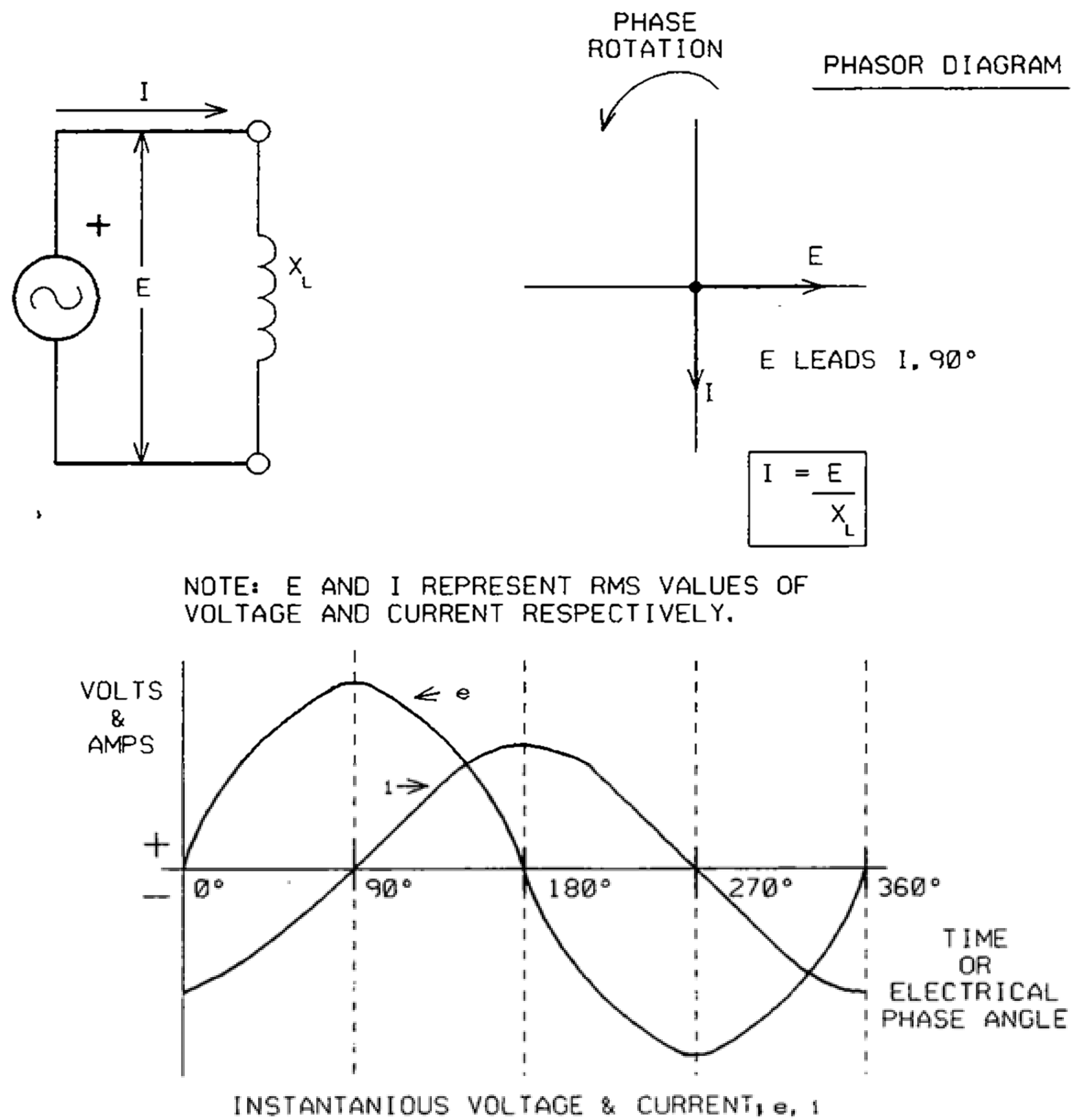


INSTANTANIOUS VOLTAGE & CURRENT; e, i

Current lagging voltage by 30 deg.

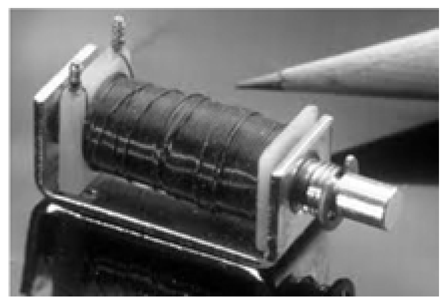


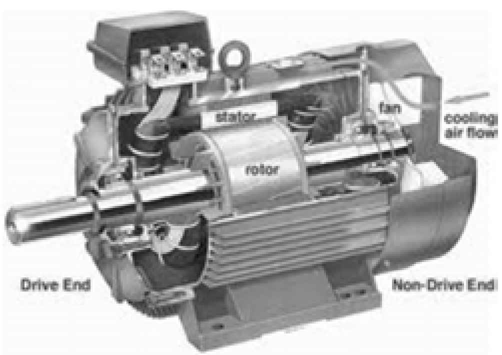
AC Voltage and current in an inductive



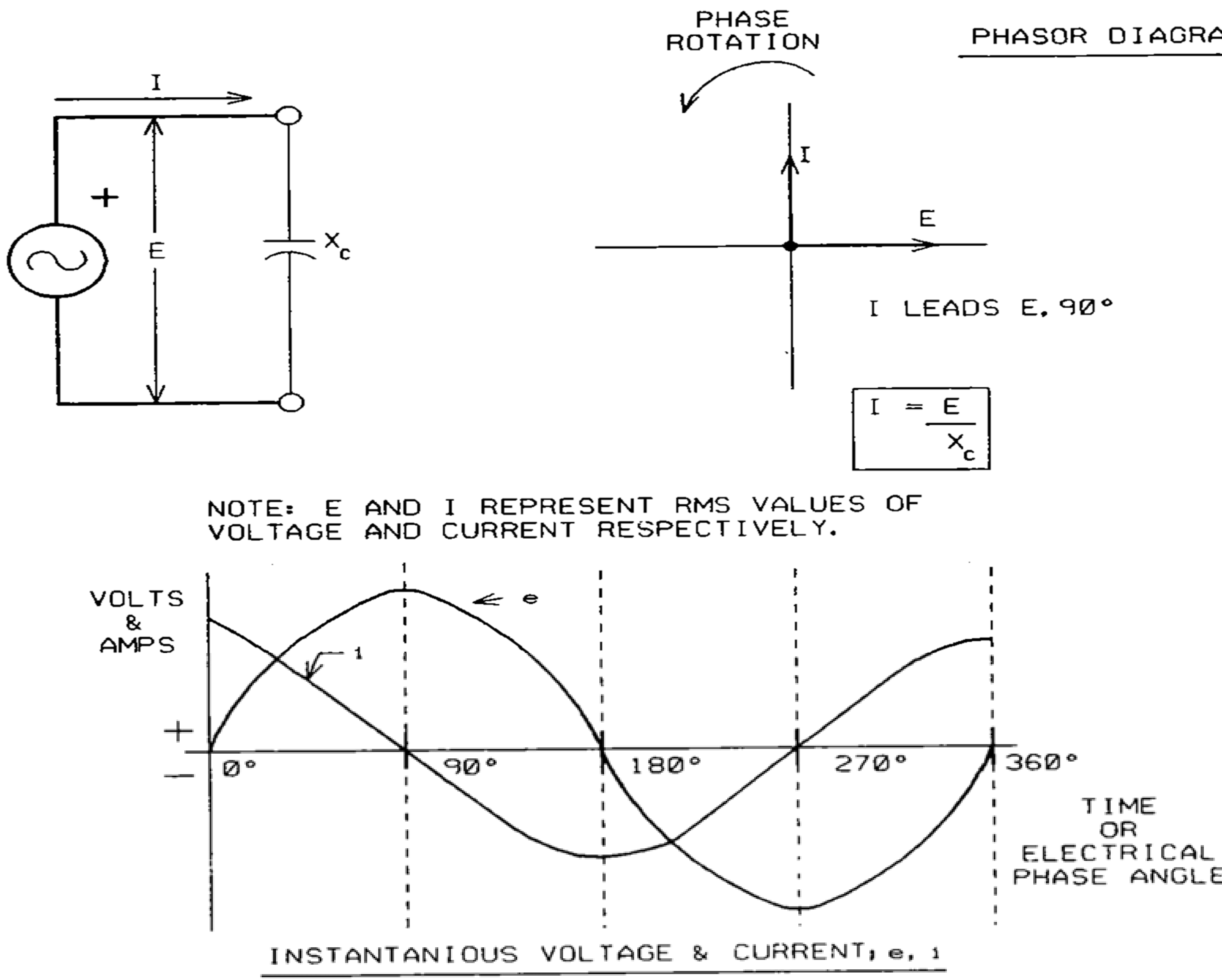
Inductive Equipment Used in Industry

- Transformers
- Solenoids
- Variable Transformers
- Relays
- Fluorescent light ballasts
- Motors

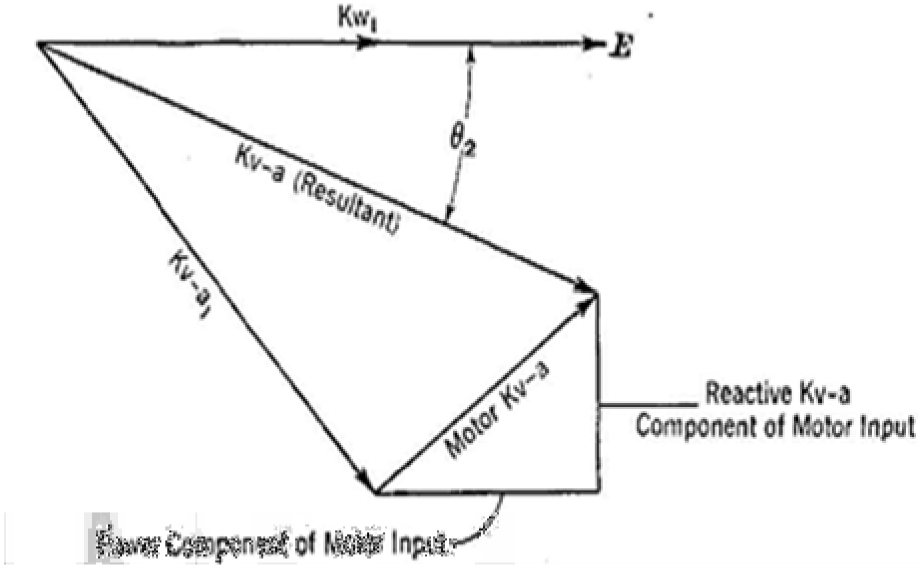




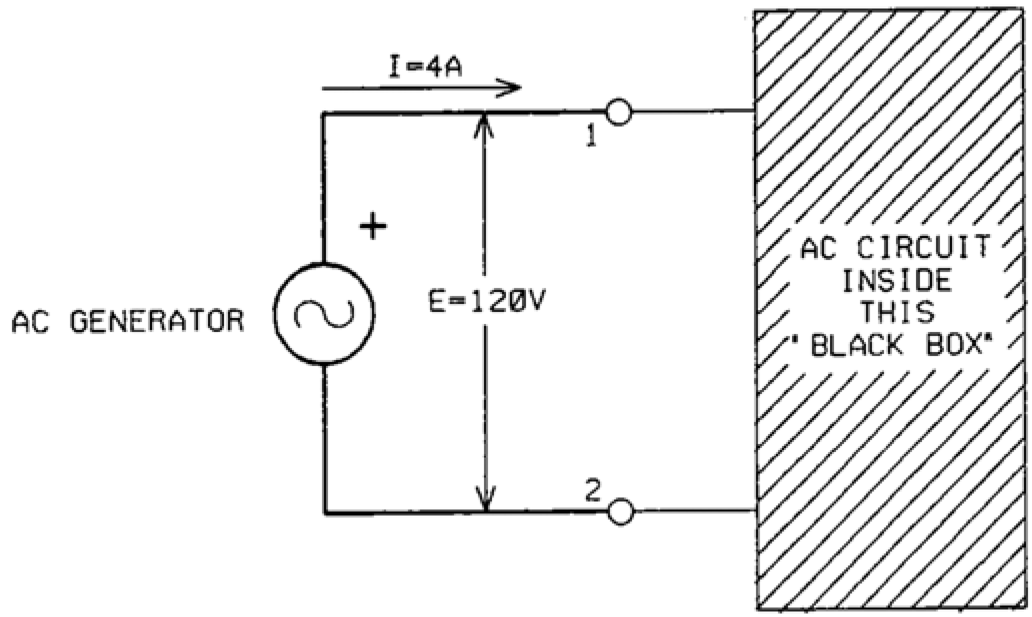
AC Voltage and Current in a capacitive



Capacitor Equipment Used in Industry



Impedance of an ac circuit



IMPEDANCE OF THE CIRCUIT IS DEFINED AS:

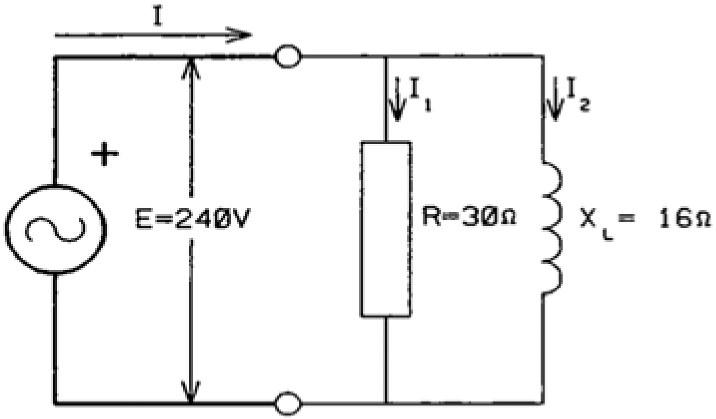
$Z = E/I$ OHMS

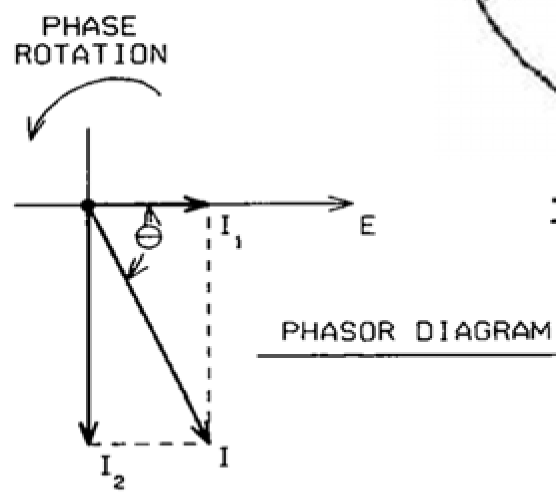
$Z = 120/4 = 30\Omega$

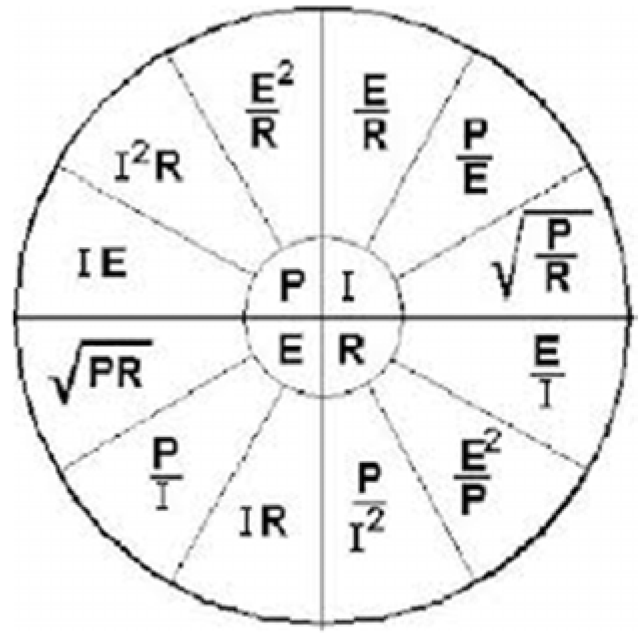
$E = I \times Z = 4 \times 30 = 120V$

$I = E/Z = 120/30 = 4A$

Parallel R-L circuit







$I = E/X_C \qquad I = E/X_L$

$X_C = 1/2\pi \times F \times C$

$X_L = 2\pi \times f \times L,$

a) $I_1 = E/R_1 = 240/30 = 8A$

$I_2 = E/X_L = 240/16 = 15A$

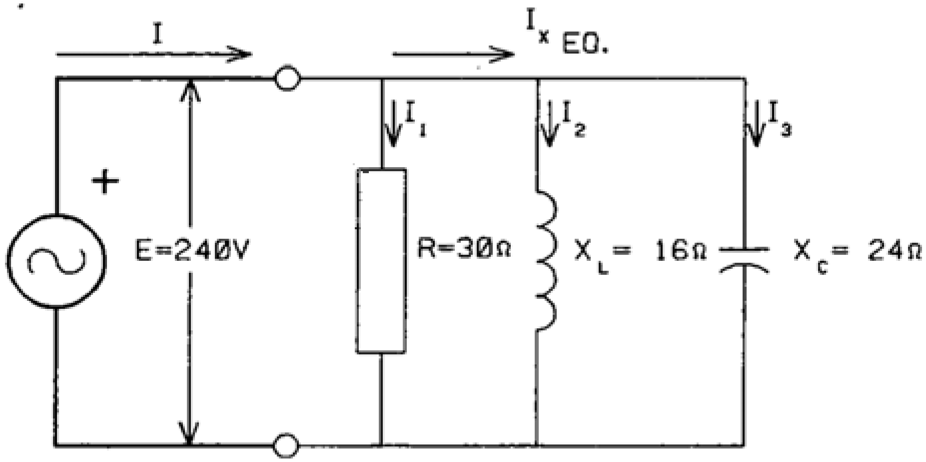
$I = \sqrt{I_1^2 + I_2^2} = \sqrt{8^2 + 15^2} = \sqrt{289} = 17A$

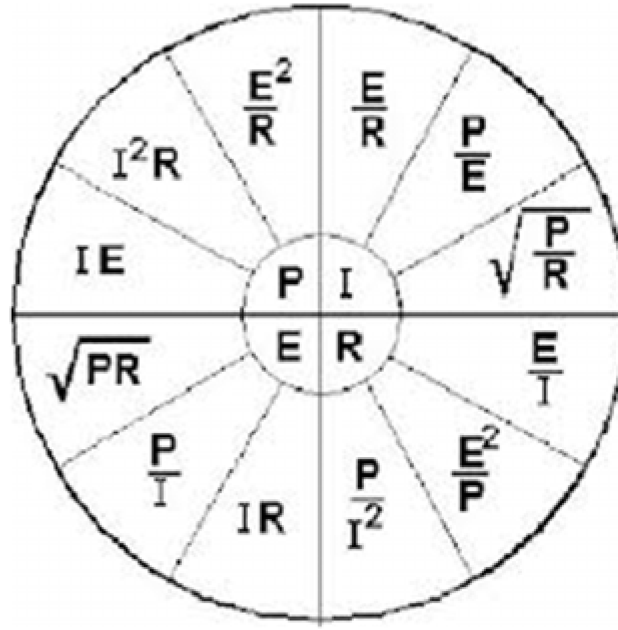
$\cos\Theta = I_1/I = 8/17 = 0.471$

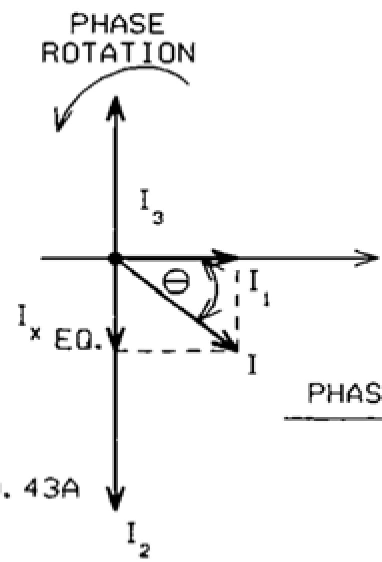
$\therefore \Theta = 61.9°$ LAGGING

b) $Z = E/I = 240/17 = 14.1\ \Omega$

Parallel R,L,C circuit







PHASOR DIAGRAM

$I = E/X_C$ $\quad I = E/X_L$

($X_C = 1/2\pi \times F \times C$

$X_L = 2\pi \times f \times L,$

c) $I_1 = E/R = 240/30 = 8A$

$I_2 = E/X_L = 240/16 = 15A$

$I_3 = E/X_c = 240/24 = 10A$

$I_{xEQ.} = I_2 - I_3 = 15 - 10 = 5A$

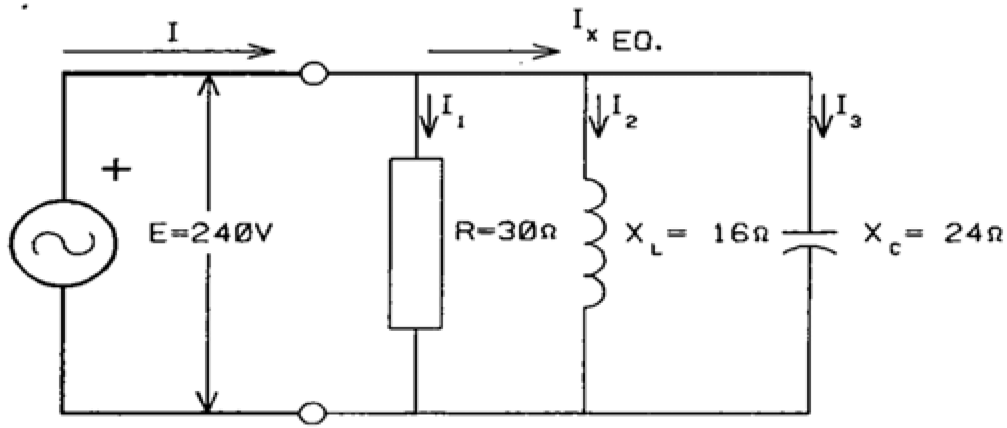
$I = \sqrt{I_1^2 + I_{x_{EQ.}}^2} = \sqrt{8^2 + 5^2} = \sqrt{89} = 9.43A$

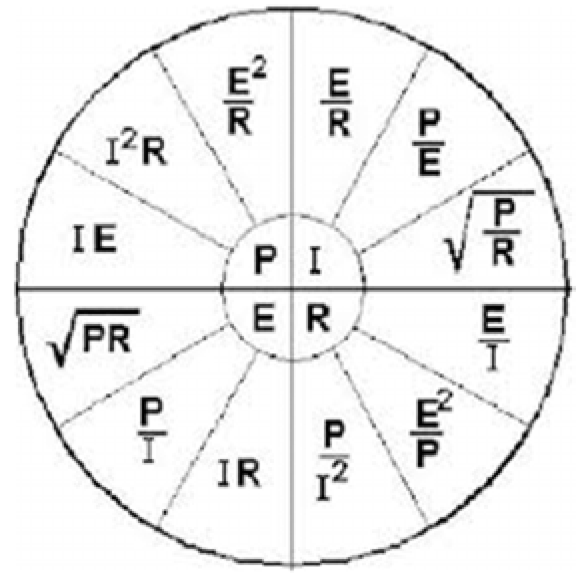
$\cos \Theta = I_1/I = 8/9.43 = 0.848$

$\therefore \Theta = 32°$ LAGGING

$Z = E/I = 240/9.43 = 25.45\ \Omega$

Impedance Formula Parallel-Connected Elements





$I = E/X_C$ $\quad$ $I = E/X_L$

$X_C = 1/2\pi \times F \times C$

$X_L = 2\pi \times f \times L,$

$I_1 = E/R = 240/30 = 8A$

$I_2 = E/X_L = 240/16 = 15A$

$I_3 = E/X_C = 240/24 = 10A$

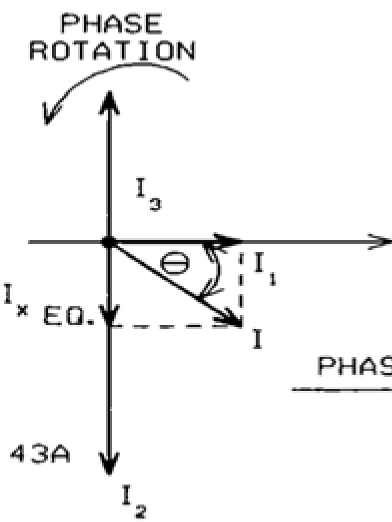
$I_{x\,EQ.} = I_2 - I_3 = 15 - 10 = 5A$

$I = \sqrt{I_1^2 + I_{x\,EQ.}^2} = \sqrt{8^2 + 5^2} = \sqrt{89} = 9.43A$

$\cos\theta = I_1/I = 8/9.43 = 0.848$

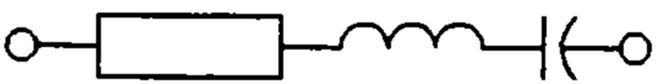
$\therefore \theta = 32°$ LAGGING

$Z = E/I = 240/9.43 = 25.45\ \Omega$

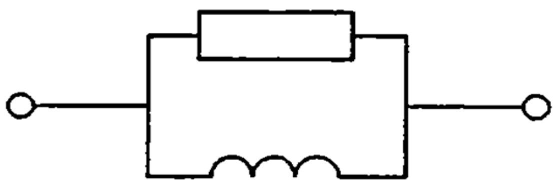
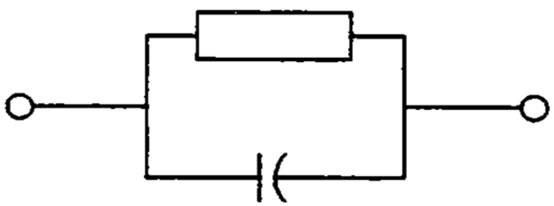
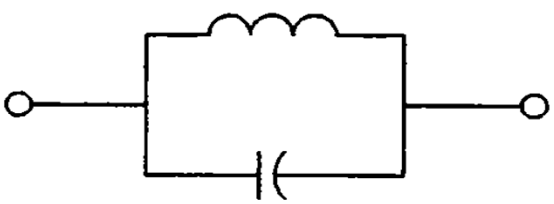
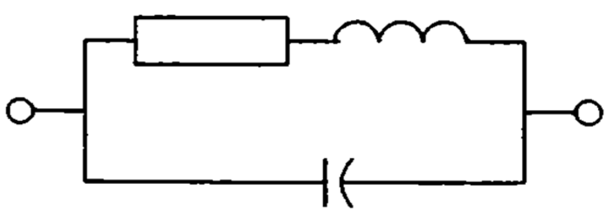


PHASOR DIAGRAM

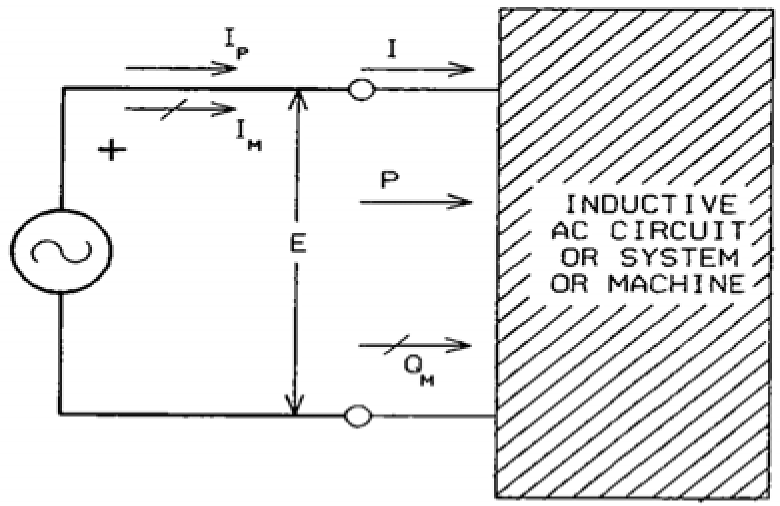
Impedance formula series connected elements

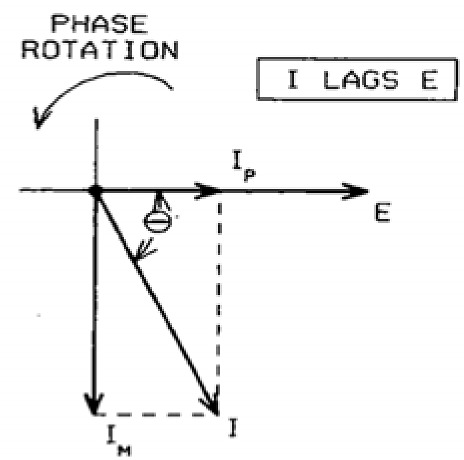
CIRCUIT	ELEMENTS IN SERIES	RESULTING IMPEDANCE
	R, X_L	$Z_S = \sqrt{R^2 + X_L^2}$
	R, X_C	$Z_S = \sqrt{R^2 + X_C^2}$
	X_L, X_C	$Z_S = X_L - X_C$
	R, X_L, X_C	$Z_S = \sqrt{R^2 + (X_L - X_C)^2}$

Impedance Formula Parallel-Connected Elements

CIRCUIT	ELEMENTS IN PARALLEL	RESULTING IMPEDANCE
	R, X_L	$Z_P = \frac{R\ X_L}{\sqrt{R^2 + X_L^2}}$
	R, X_C	$Z_P = \frac{R\ X_C}{\sqrt{R^2 + X_C^2}}$
	X_L, X_C	$Z_P = \frac{X_L, X_C}{X_L - X_C}$
	(R, X_L), X_C (SERIES)	$Z_P = \frac{X_C \sqrt{R^2 + X_L^2}}{\sqrt{R^2 + (X_L - X_C)^2}}$

Power in AC circuits and systems (inductive)



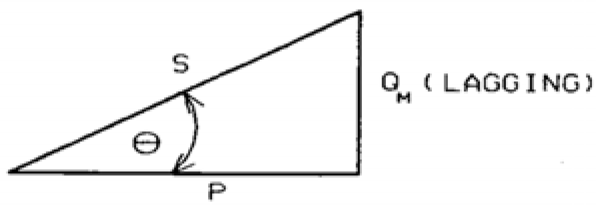


PHASOR DIAGRAM

$$I = \sqrt{I_P^2 + I_M^2}$$

$$I_P = \sqrt{I^2 - I_M^2}$$

$$I_M = \sqrt{I^2 - I_P^2}$$



LOAD DIAGRAM

$S = E \times I$ VOLT-AMPS → APPARENT POWER

$P = E \times I_P = E \times I \times \cos\Theta = S \times \cos\Theta$ → POWER

$Q_M = E \times I_M = E \times I \times \sin\Theta = S \times \sin\Theta$ → REACTIVE POWER

$P/S = \cos\Theta$ → POWER FACTOR

$Q_M/S = \sin\Theta$ → REACTIVE FACTOR

$Q_M/P = \tan\Theta$

$Q_M = P \times \tan\Theta$

$$S = \sqrt{P^2 + Q_M^2}$$

$$P = \sqrt{S^2 - Q_M^2}$$

$$Q_M = \sqrt{S^2 - P^2}$$

$I_P/I = \cos\Theta$

$I_P = I \times \cos\Theta$

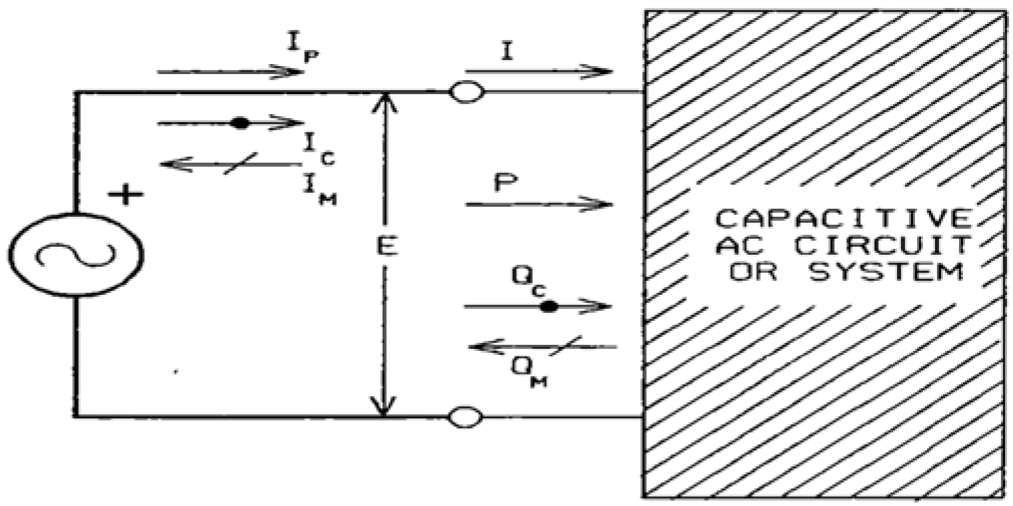
$I_M/I = \sin\Theta$

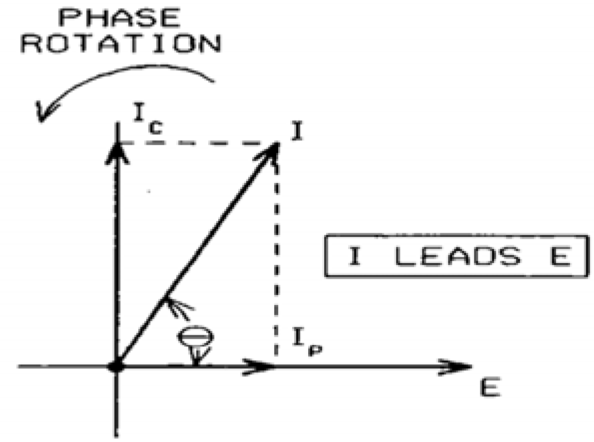
$I_M = I \times \sin\Theta$

$I_M/I_P = \tan\Theta$

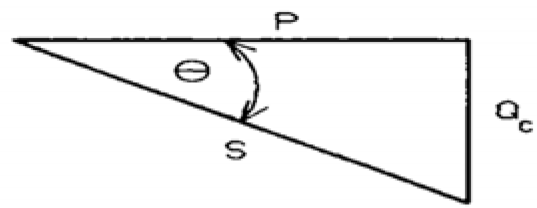
$I_M = I_P \times \tan\Theta$

Power in AC circuits and systems (capacitive)





PHASOR DIAGRAM



NOTE: I_M & Q_M ARE SHOWN IN TERMS OF POWER SYSTEM CONVENTION

LOAD DIAGRAM

$I = \sqrt{I_P^2 + I_C^2}$

$I_P = \sqrt{I^2 - I_C^2}$

$I_C = \sqrt{I^2 - I_P^2}$

$S = E \times I$ VOLT-AMPS → APPARENT POWER

$P = E \times I_P = E \times I \times \cos\Theta = S \times \cos\Theta$ → POWER

$Q_C = E \times I_M = E \times I \times \sin\Theta = S \times \sin\Theta$ → REACTIVE POWER

$P/S = \cos\Theta$ → POWER FACTOR

$Q_C/S = \sin\Theta$ → REACTIVE FACTOR

$Q_C/P = \tan\Theta$

$Q_C = P \times \tan\Theta$

$S = \sqrt{P^2 + Q_C^2}$

$P = \sqrt{S^2 - Q_C^2}$

$Q_C = \sqrt{S^2 - P^2}$

$I_P/I = \cos\Theta$

$I_P = I \times \cos\Theta$

$I_C/I = \sin\Theta$

$I_C = I \times \sin\Theta$

$I_C/I_P = \tan\Theta$

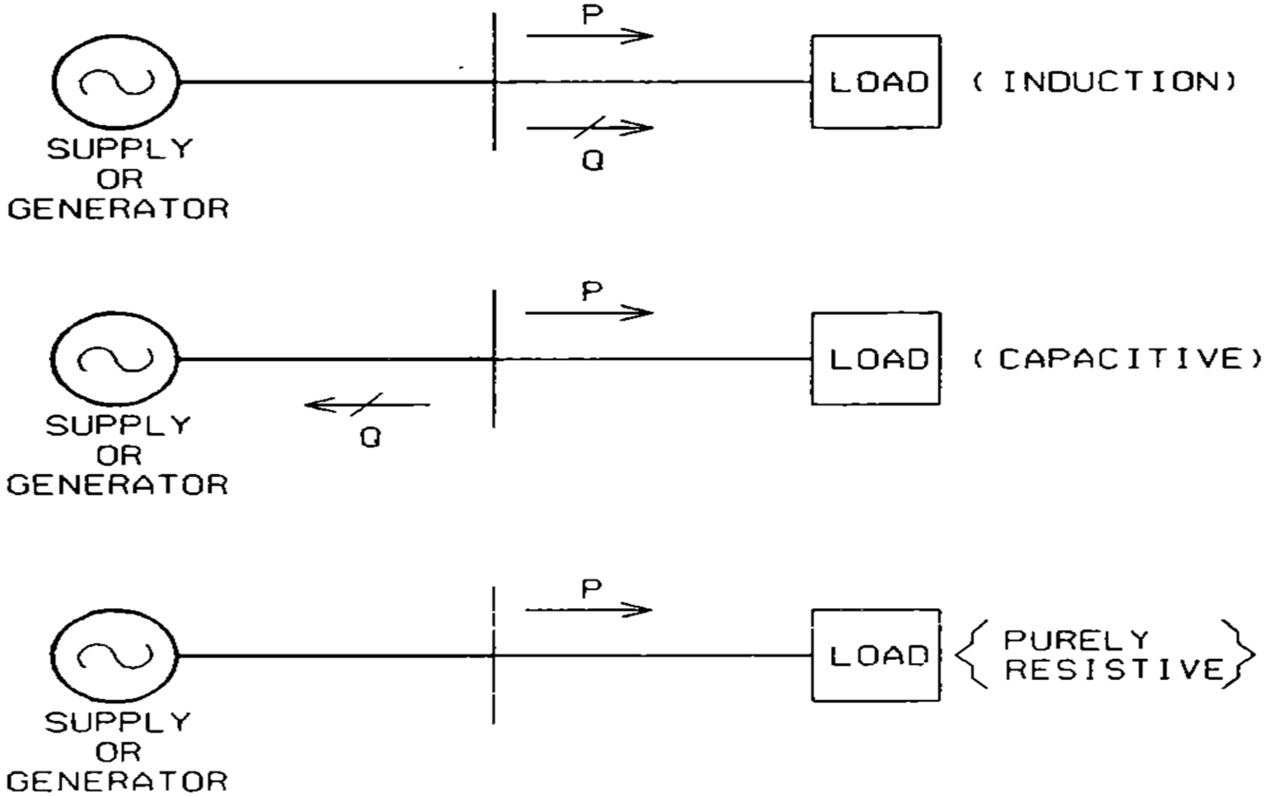
$I_C = I_P \times \tan\Theta$

Typical users of power and their characteristics.

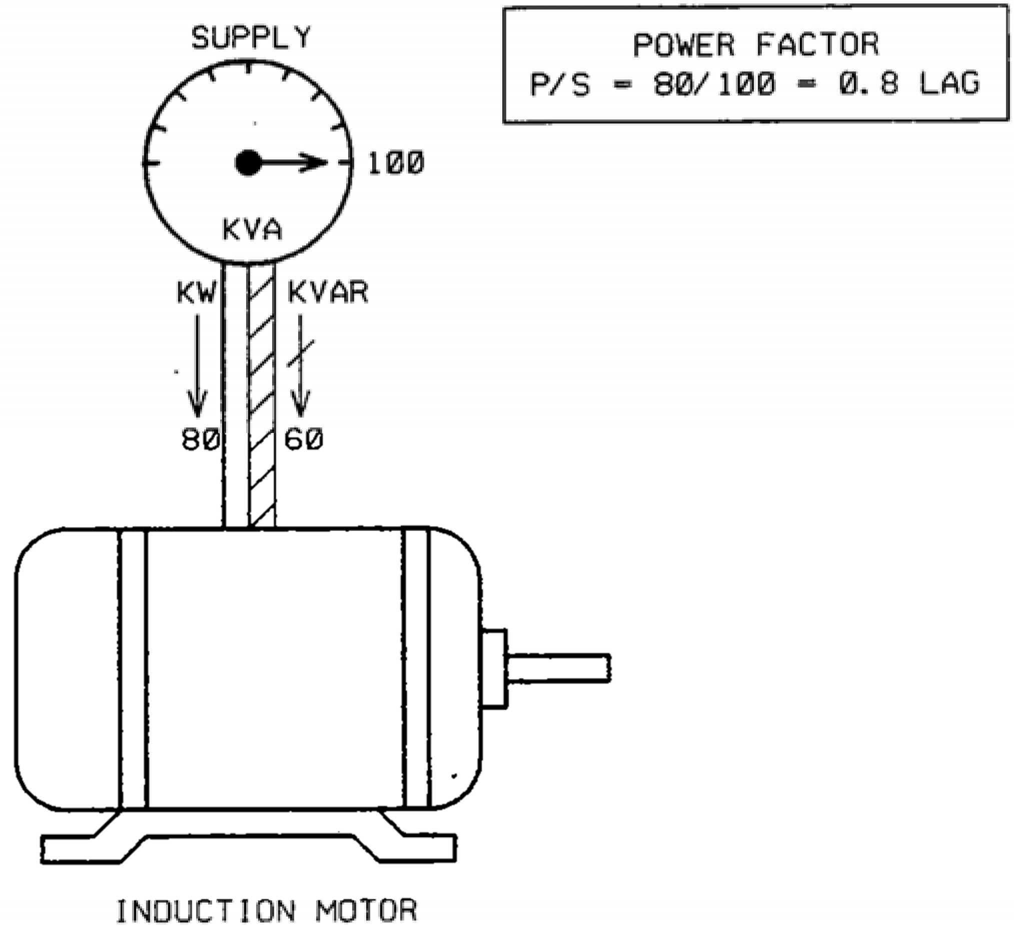
Equipment	Impedance	Power Factor
Motor		
- Running	largely resistive	0.8 - 0.9 lag
- Starting	largely inductive	0.2 - 0.3 lag
Lighting (fluorescent)	mixed resistive/ reactive	0.7 lag
	with power factor correction	0.9 lag
Electrical tracing	resistive	1.0

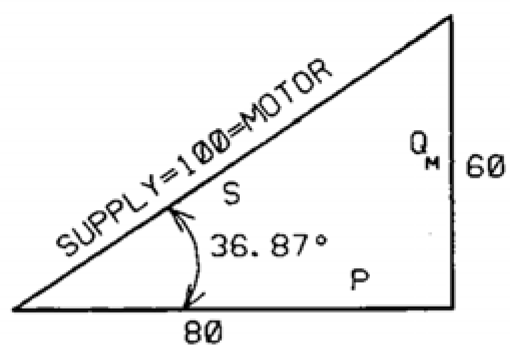
Power Factor or load and supply

DIRECTION OF 'FLOW'						
	REFERRED TO LOAD			REFERRED TO SUPPLY		
TYPE OF LOAD	POWER (KW)	REACTIVE (KVAR)	POWER FACTOR	POWER (KW)	REACTIVE (KVAR)	POWER FACTOR
INDUCTION	IN	IN	LAGGING	OUT	OUT	LAGGING
CAPACITIVE	IN	OUT	LEADING	OUT	IN	LEADING
PURELY RESISTIVE	IN	Ø	UNITY	OUT	Ø	UNITY



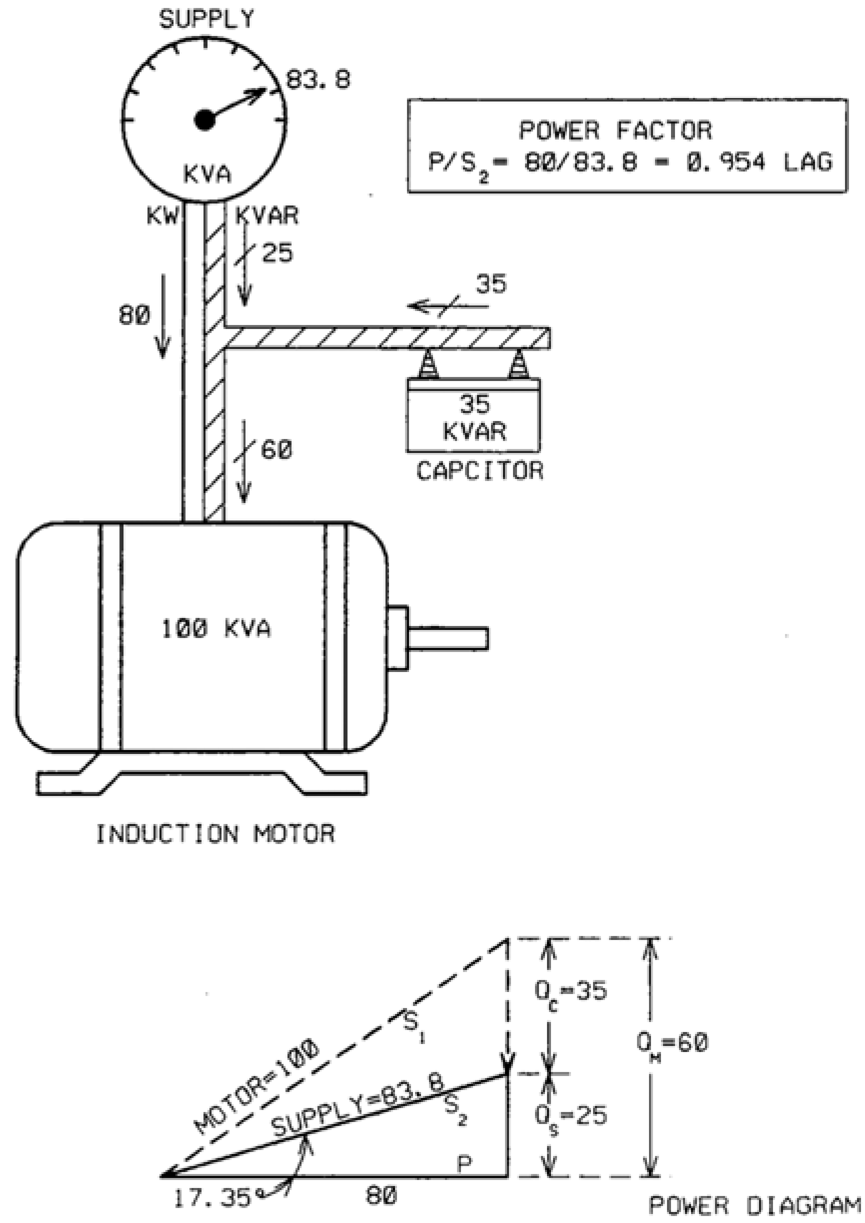
Power and Power Factor in an induction load



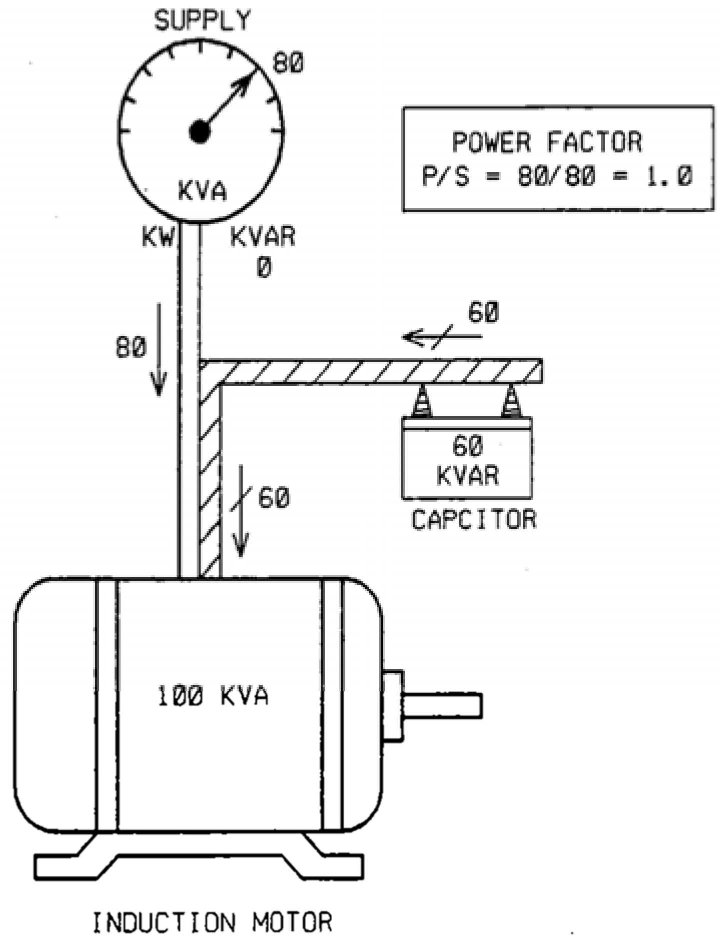


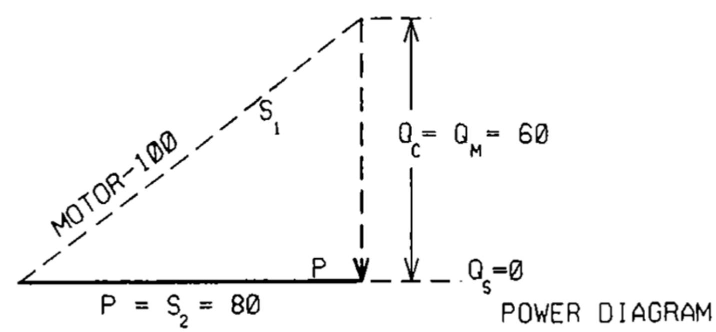
POWER DIAGRAM

Power Capacitor connected to Motor

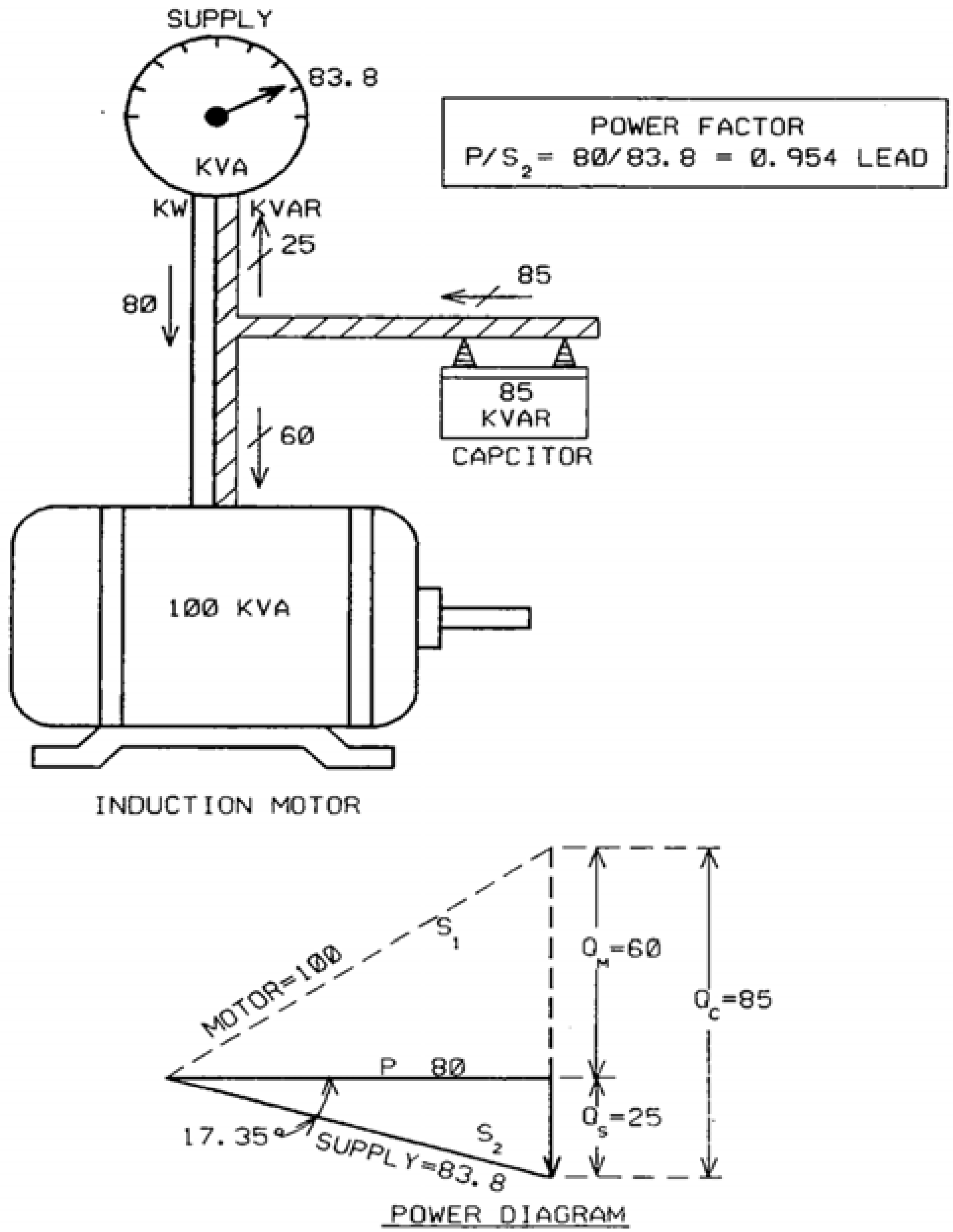


Power Capacitor connected to Motor

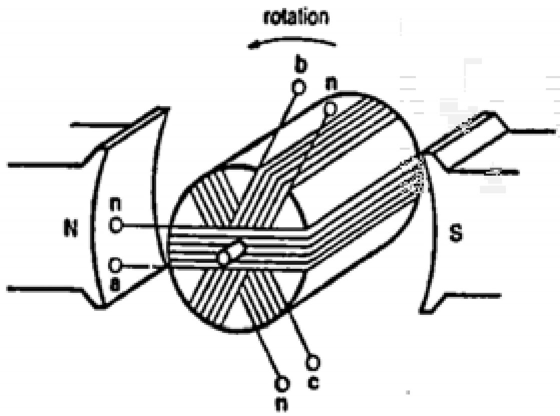




Power Capacitor connected to Motor

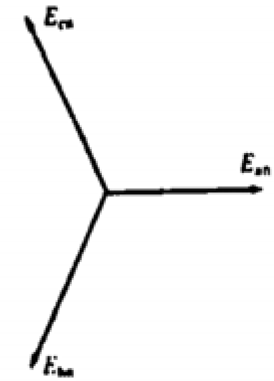


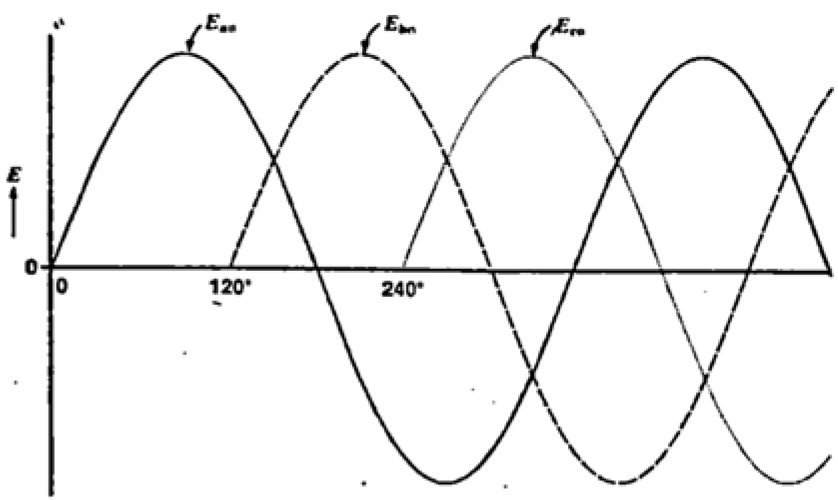
Generation of three phase voltage



A
SIMPLE THREE-PHASE GENERATOR

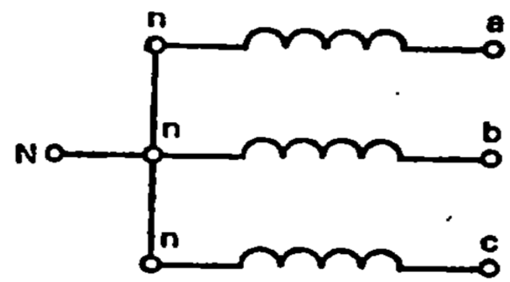
C
PHASOR DIAGRAM





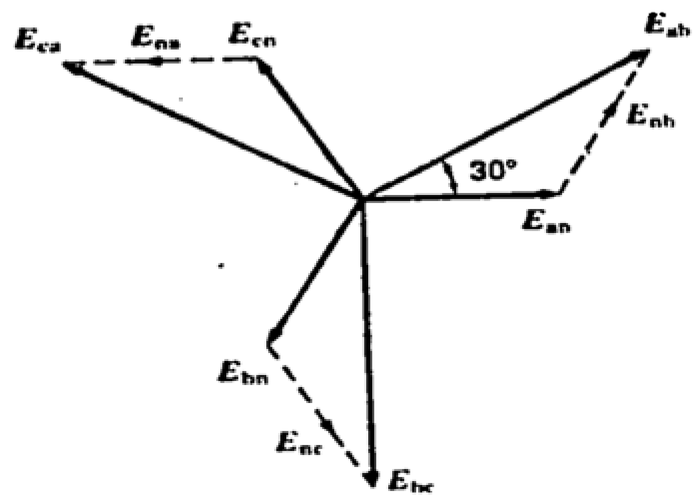
B
VOLTAGE WAVEFORMS

Line voltages and line to neutral



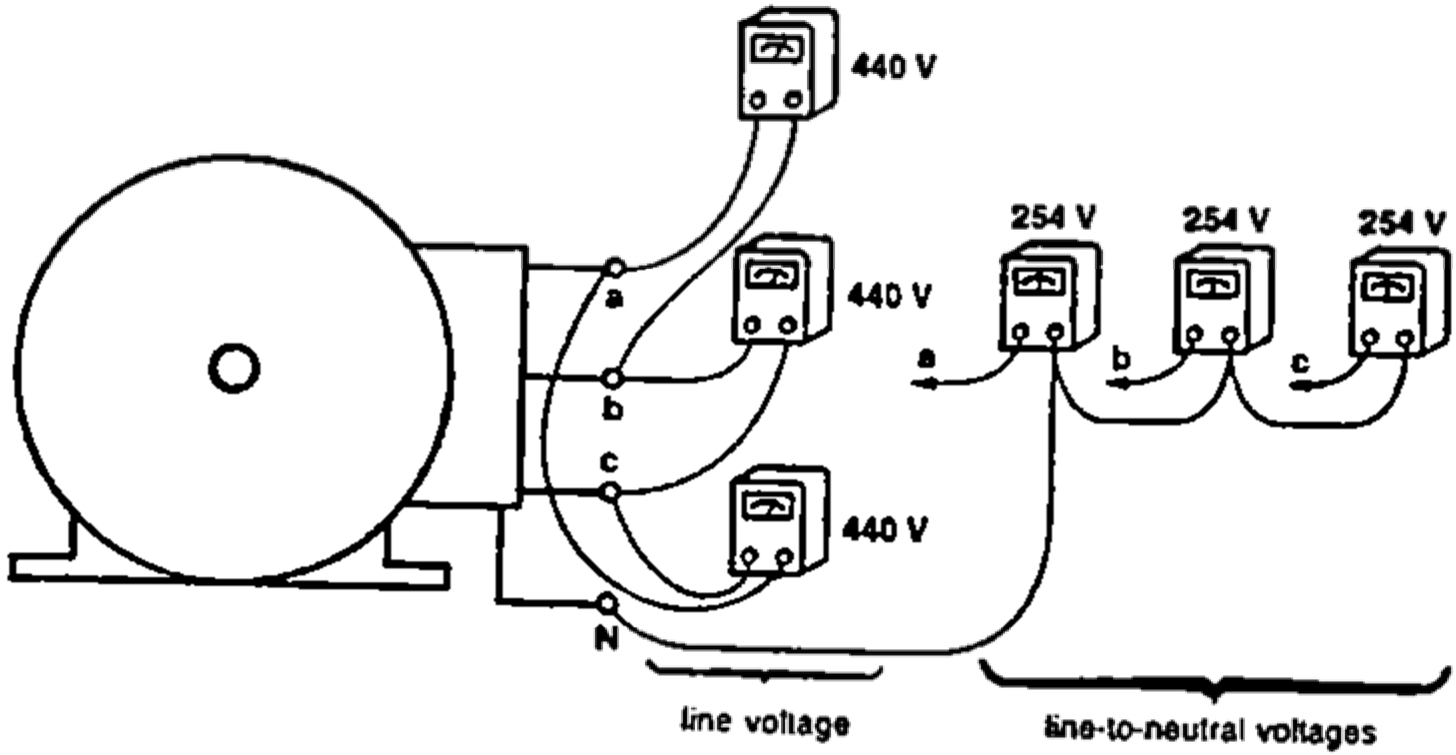
A
GENERATOR WINDING
CONNECTION DIAGRAM

$$440/\sqrt{3} = 254 \text{ V.}$$



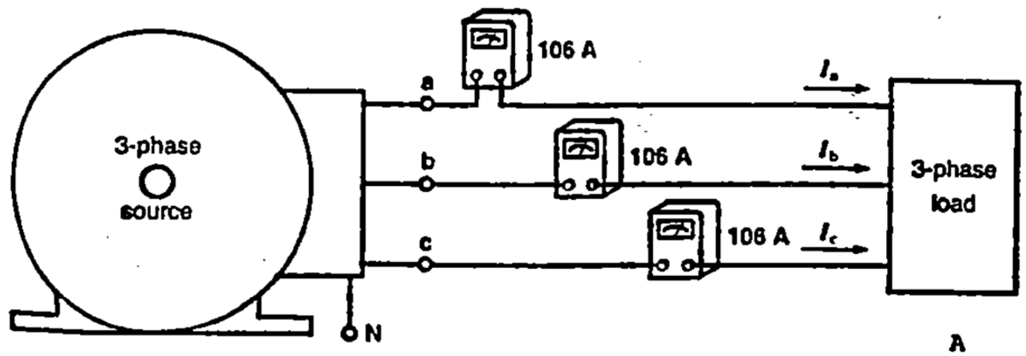
B
TERMINAL VOLTAGE
RELATIONSHIPS
PHASOR DIAGRAM

Voltages generated by a 3-phase 440 volt AC generator.

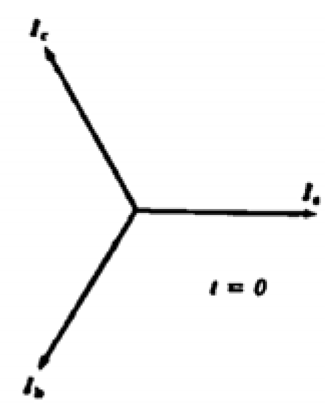


$$440/\sqrt{3} = 254 \text{ V.}$$

Line currents in a balanced 3-phase

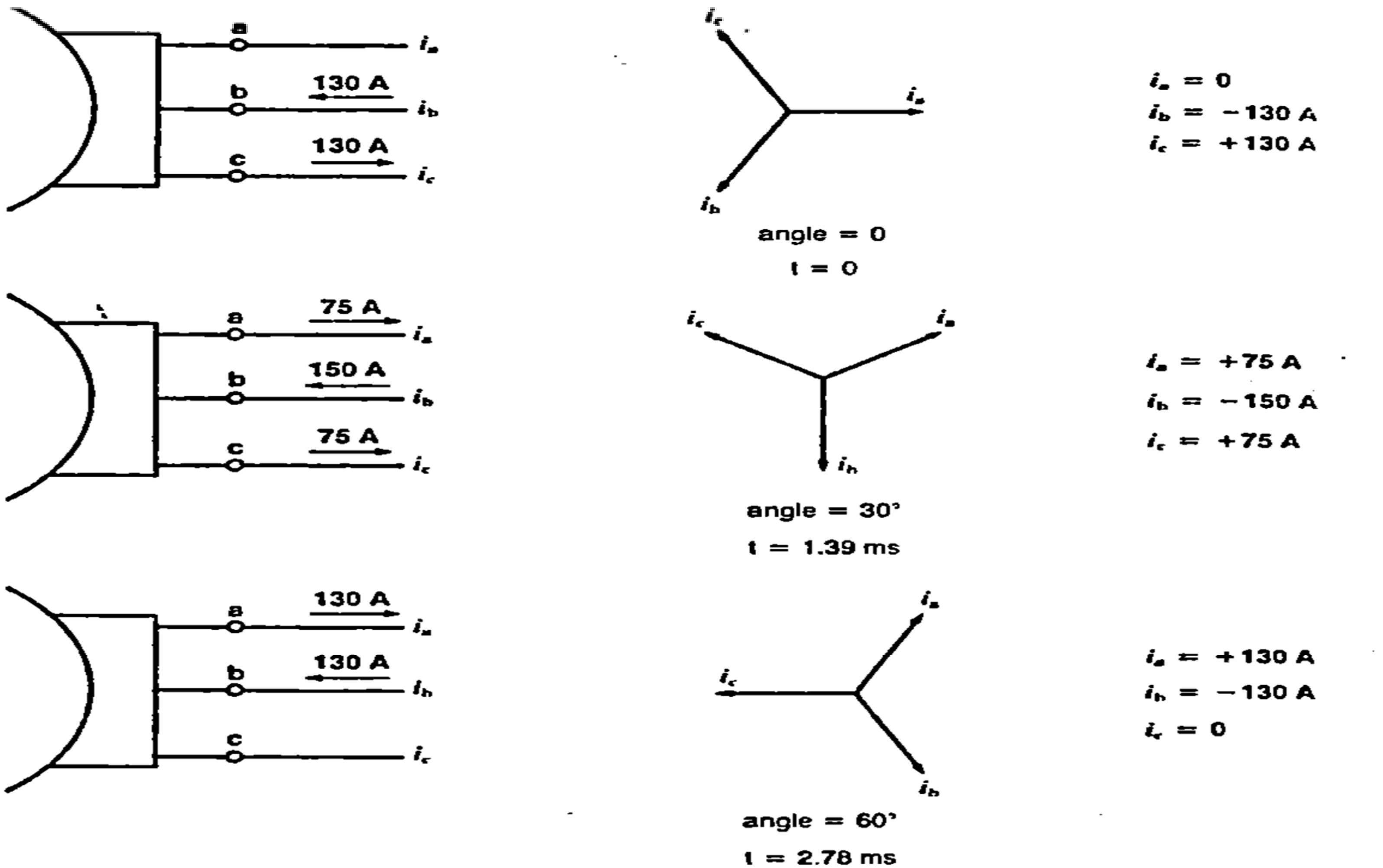


A
LINE CURRENTS
EQUAL rms
VALVES



B
PHASOR DIAGRAM

The magnitude and direction of the currents in the three lines change continually. The magnitudes of the instantanious currents can be visualized by assuming that the rotating phasors are projected on a screen at the right. The magnitudes are given at three instants, separated by intervals of 30^{o}.

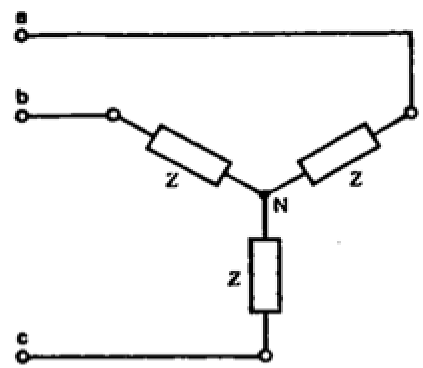


actual instantaneous line current

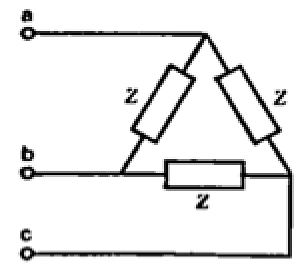
rotating phasors having a peak value of 150 A

magnitude of the currents projected on the screen

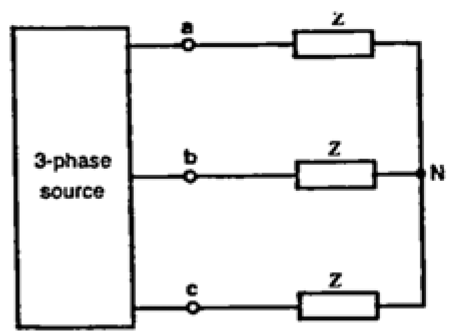
Delta and Wye connected loads



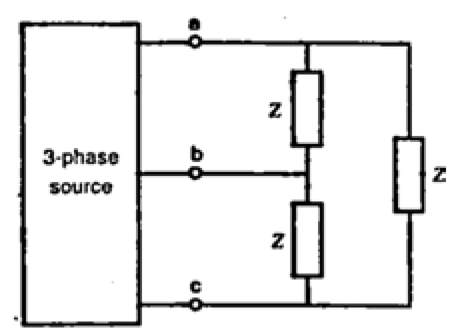
A Three single-phase loads connected in wye.



B Three single-phase loads connected in delta.

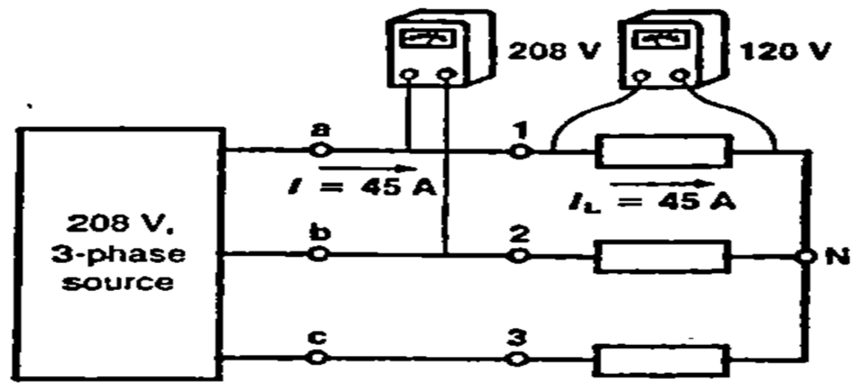


C Alternative method of showing a wye connection.

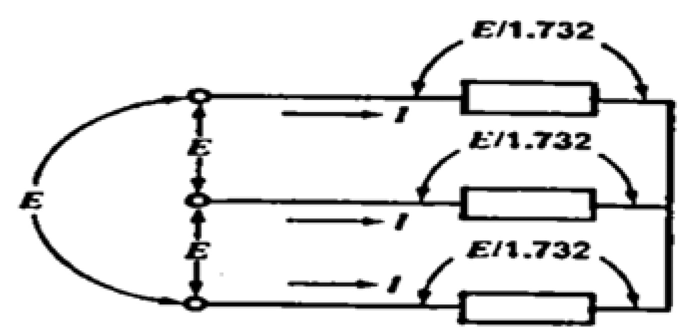


D Alternative method of showing a delta connection.

Current and voltage in a wye connection

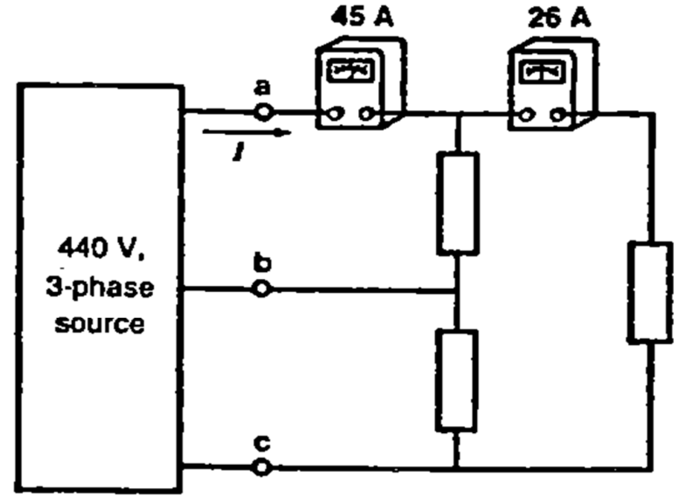


A Currents and voltages in a 208 V 3-phase line and a wye-connected load.

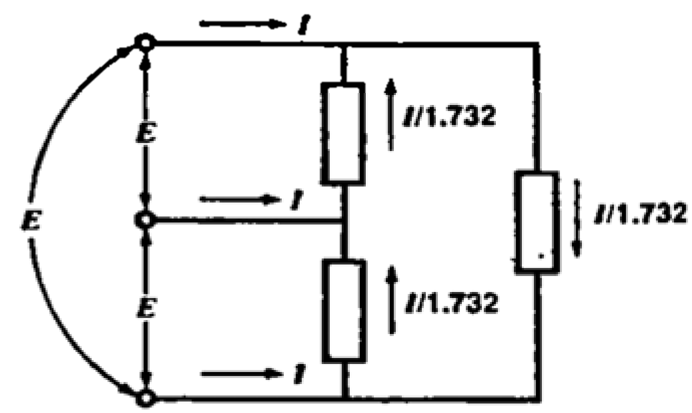


B General current and voltage relationships in a balanced wye-connected load.

Current and voltage in a delta connection

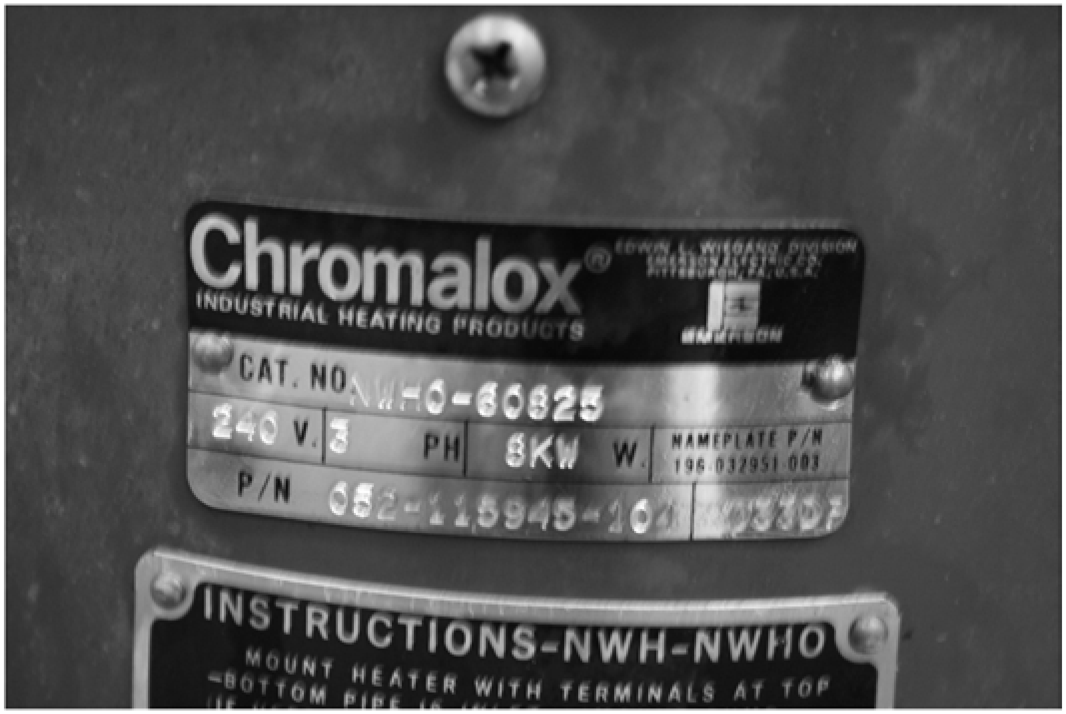


A Currents and voltages in a 440 V, 3-phase line and delta-connected load.



The above relationships can be applied to any three-phase balanced load or line.

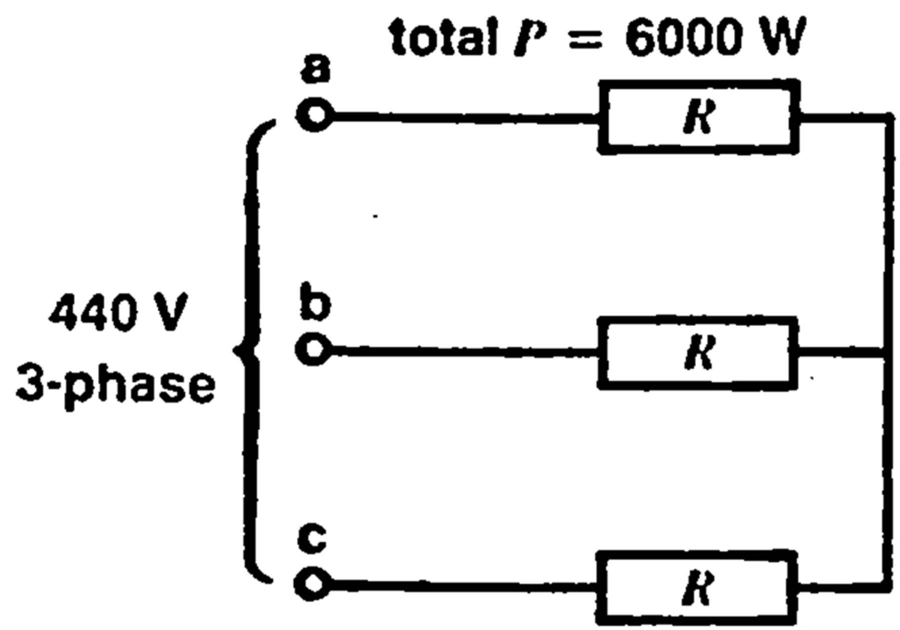
The load may be connected in any way as long as it is balanced.

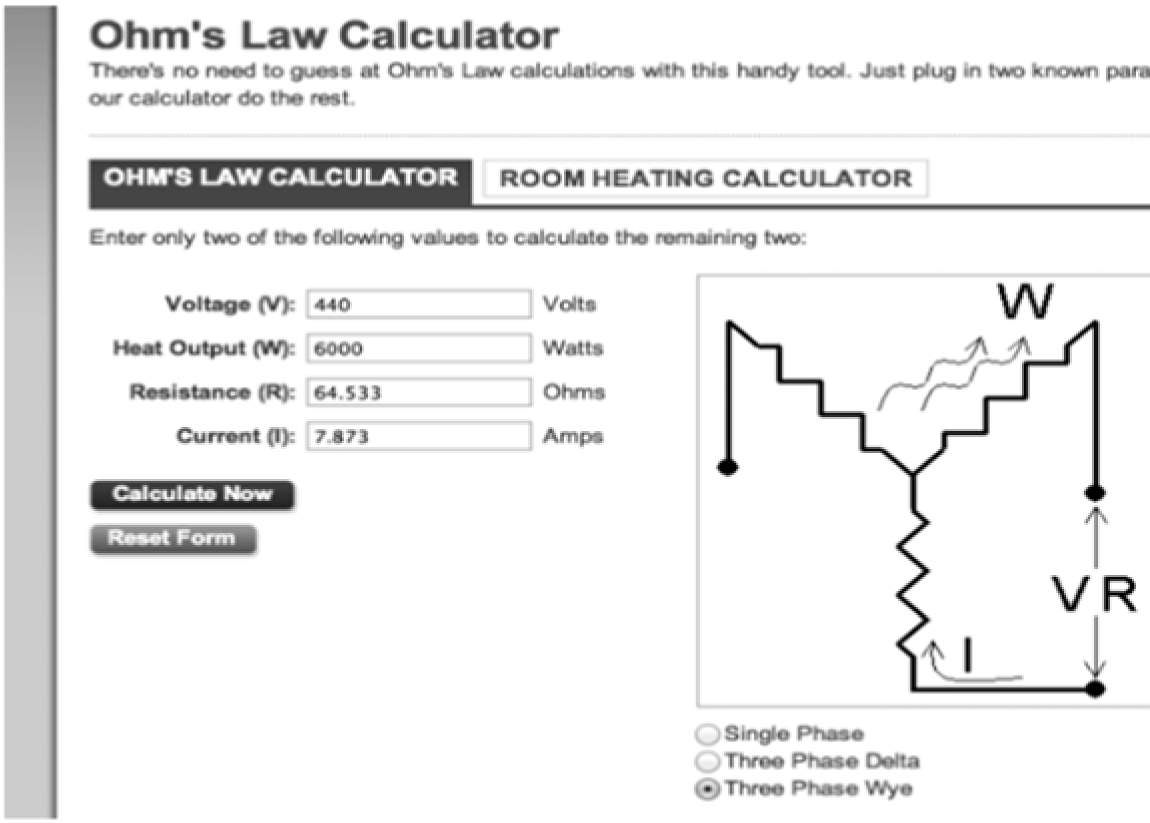


http://www.chromalox.com/productcatalog/Component+Technologies/Strip+and+Ring+Heaters/product-family-router.aspx?f=64

Three resistors are connected in a wye across a 440V 3-phase line. If they dissipated a total of 6000 W, or 6kW, calculate:

1) Calculate the line current.
2) Calculate the resistor values.





1) First, we make a sketch of the circuit (Figure 26).

2) Next, we make a list of everything we know about the single-phase load:

   a) the power dissipated by one resistor is P = 6000/3 = 2000 W

   b) the voltage across the resistor is E = 440/1.732 = 254 V

   c) the current in the resistor is I = P/E = 2000/254 = 7.87 A

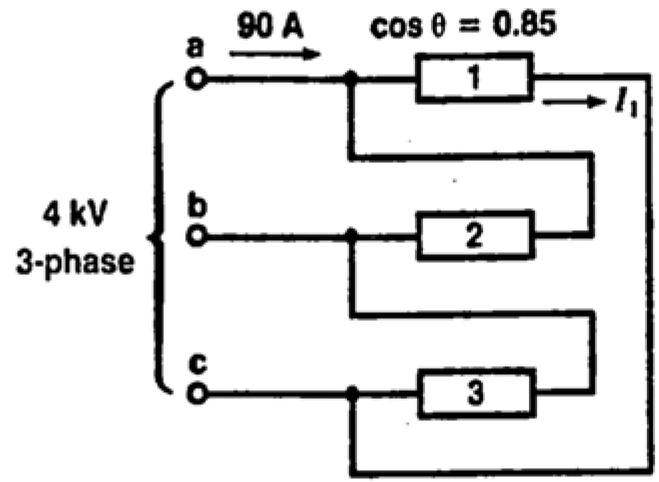
   d) the line current = 7.87 A

   e) the resistance of the resistor is R = E/I = 254/7.87 = 32.3 Ω

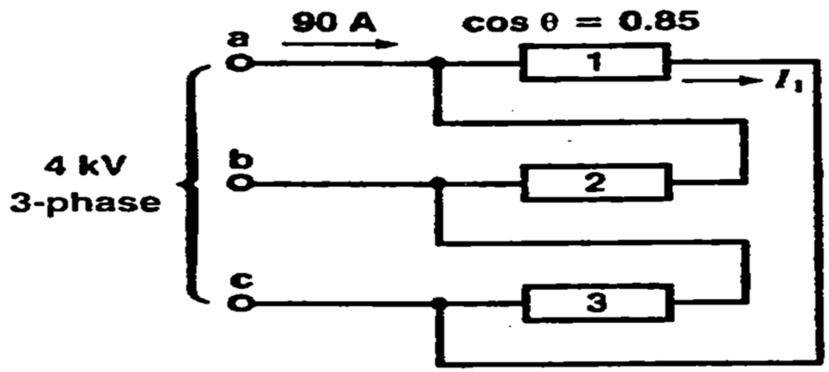
A 4kV 3-phase line carries a line current of 90A. The power factor is 0.85 lagging, and the load is connected in delta.

Calculate:

1) The impedance of the load, per phase.
2) The reactive power, per phase.



THREE IDENTICAL
DELTA-CONNECTED
IMPEDANCES



THREE IDENTICAL
DELTA-CONNECTED
IMPEDANCES

Next, we make a list of everything we know about the single-phase loads, taking load 1 as a sample.

a) the current in load 1 is $I_1 = 90/1.732 = 52$ A

b) the voltage across load 1 is $E = 4000$ V

c) Impedance of load 1 is $Z = E/I = 4000/52 = 76.9\ \Omega$

d) Apparent power of load 1 is

$$S = EI = 4000 \times 52 = 208{,}000 = 208 \text{ kVA}$$

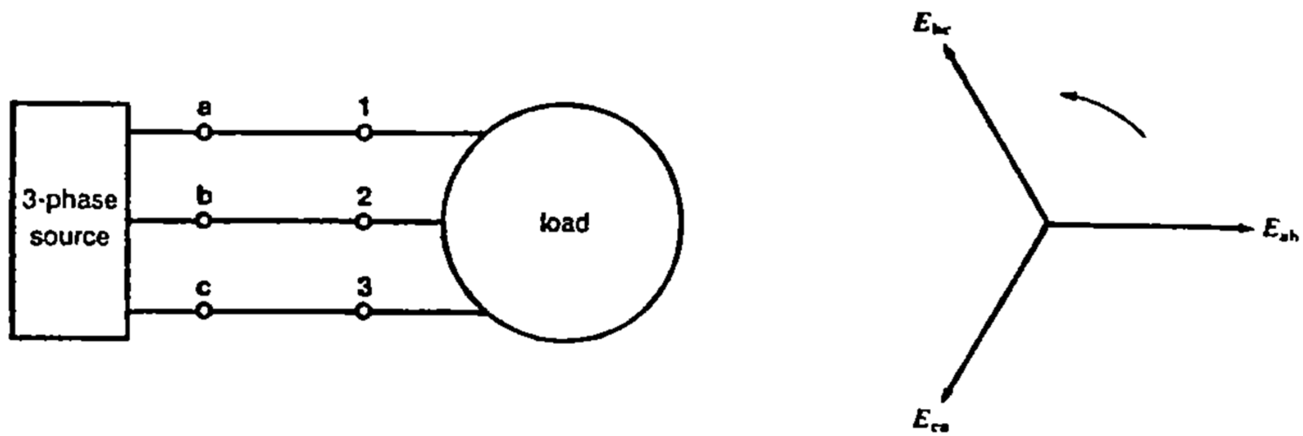
e) Active power of load 1 is

$$P = S \cos\theta = 208 \times 0.85 = 176.8 \text{ kW}$$

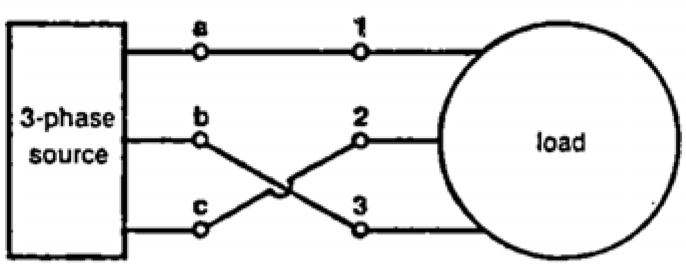
f) Reactive power is

$$Q = \sqrt{S^2 - P^2} = \sqrt{208^2 - 176.8^2} = 109.6 \text{ kvar}$$

Phase sequence



A Load terminals 1, 2, 3 have the same phase sequence as line terminals a, b, c.



B Load terminals 1, 2, 3 have the reverse phase sequence of line terminals a, b, c.

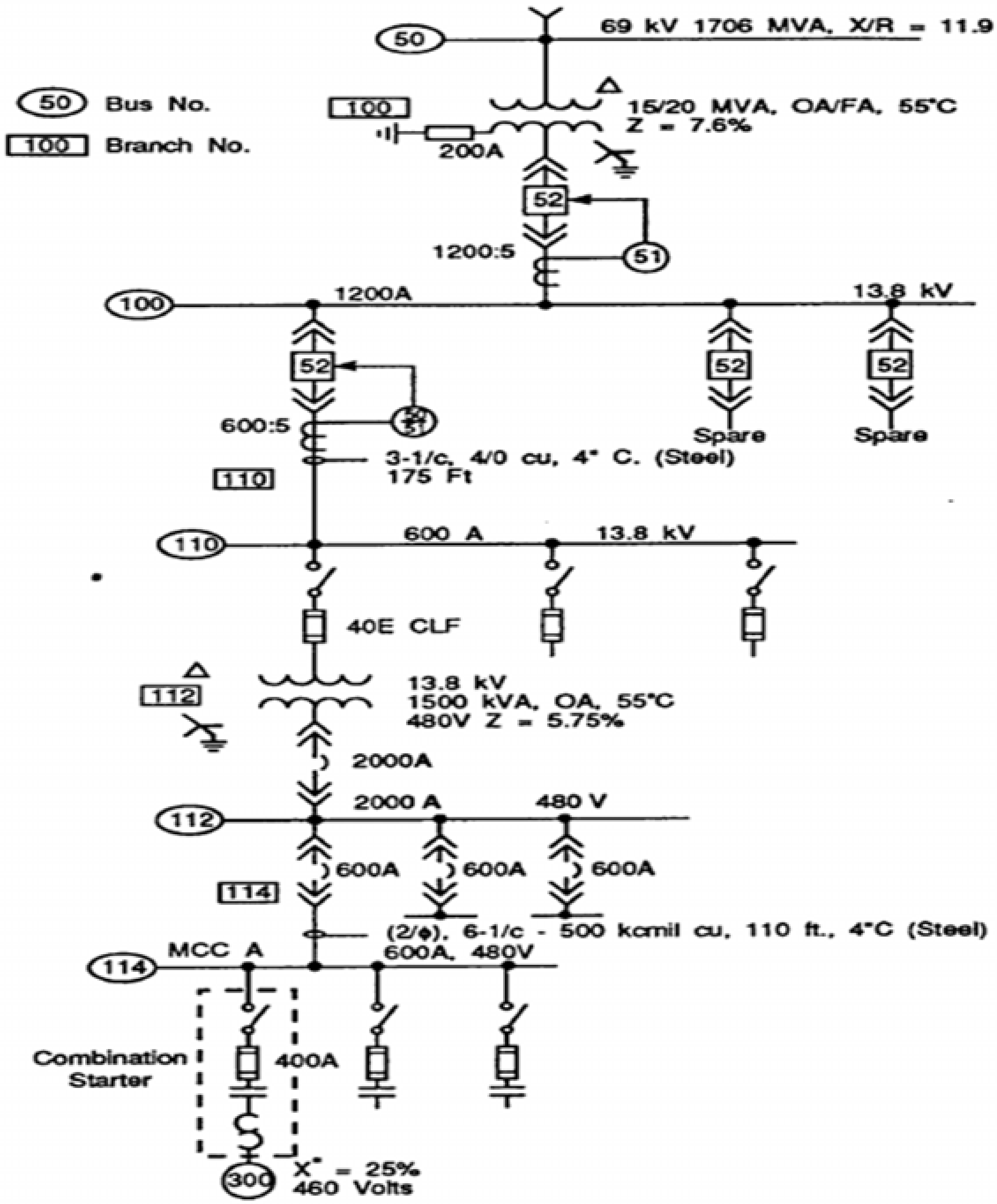
Does the equipment used to transmit the power to the load have a large impact on the power factor?

Typical equipment would be cables and transformers

- These components do not dictate power factor, but only have a small effect on it under normal steady state conditions.
- Under fault conditions their effect is very large.

The most commonly used electrical diagrams, schedules, and drawings are:

- one-line diagrams.
- elementary three-line diagrams.
- schematic wiring diagrams.
- circuit breaker schedules.
- motor control center schedules.
- lighting panel board schedules.
- loading schedules.
- conduit schedules.
- wiring schedules.
- switchgear layout drawings.
- motor control center (MCC) layout drawings.
- riser conduit/stub-up diagrams.
- circuit wiring layout diagrams.

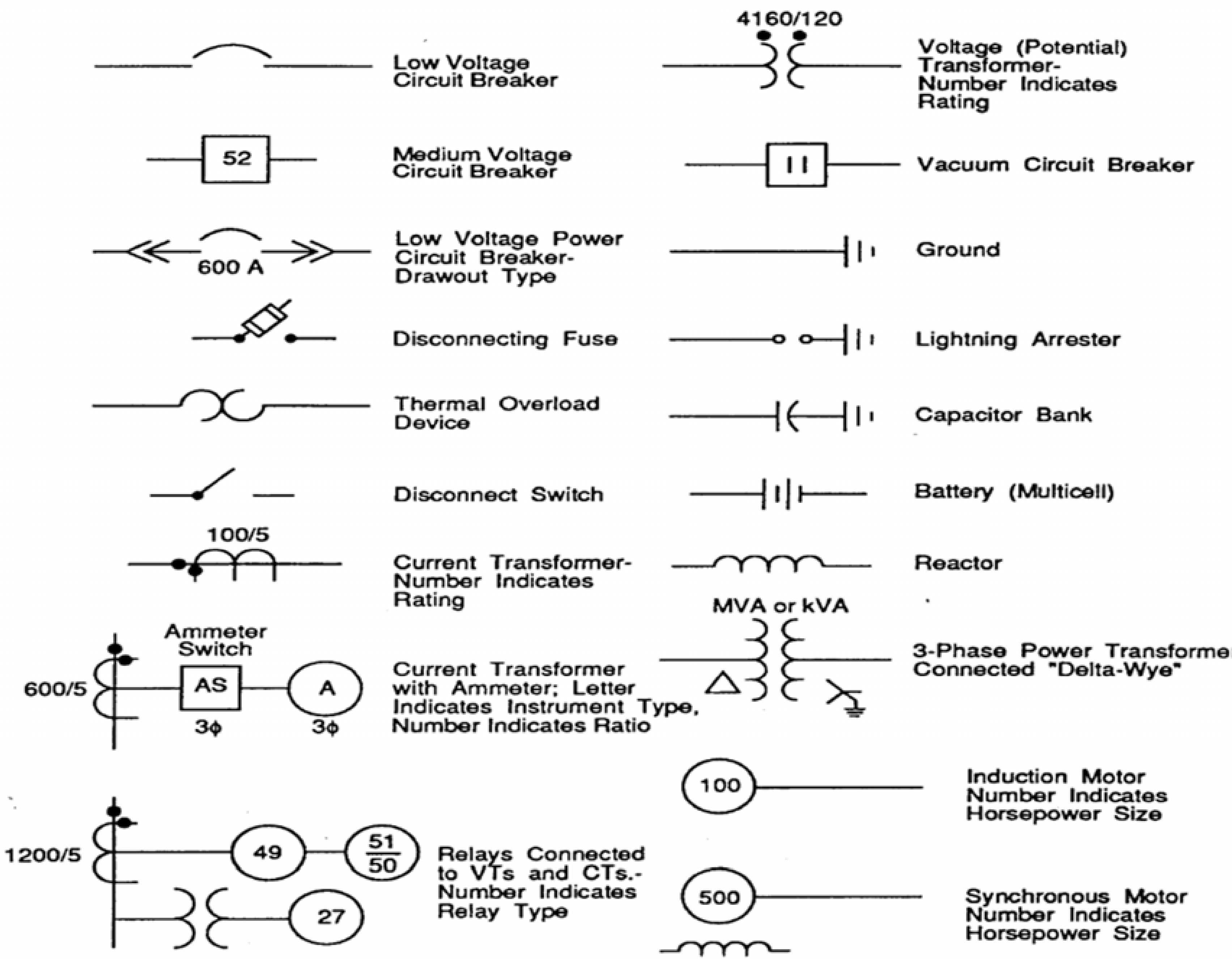

50
69 kV 1706 MVA, X/R = 11.9
50 Bus No.
100 Branch No.
100
15/20 MVA, OA/FA, 55°C
Z = 7.6%
200A
52
1200:5
51
100
1200A
13.8 kV
52
52
52
600:5
Spare
Spare
3-1/c, 4/0 cu, 4" C. (Steel)
175 Ft
110
110
600 A
13.8 kV
40E CLF
13.8 kV
1500 kVA, OA, 55°C
480V Z = 5.75%
112
2000A
112
2000 A
480 V
600A
600A
600A
114
(2/ϕ), 6-1/c - 500 kcmil cu, 110 ft., 4"C (Steel)
MCC A
600A, 480V
114
Combination
Starter
400A
300
X" = 25%
460 Volts

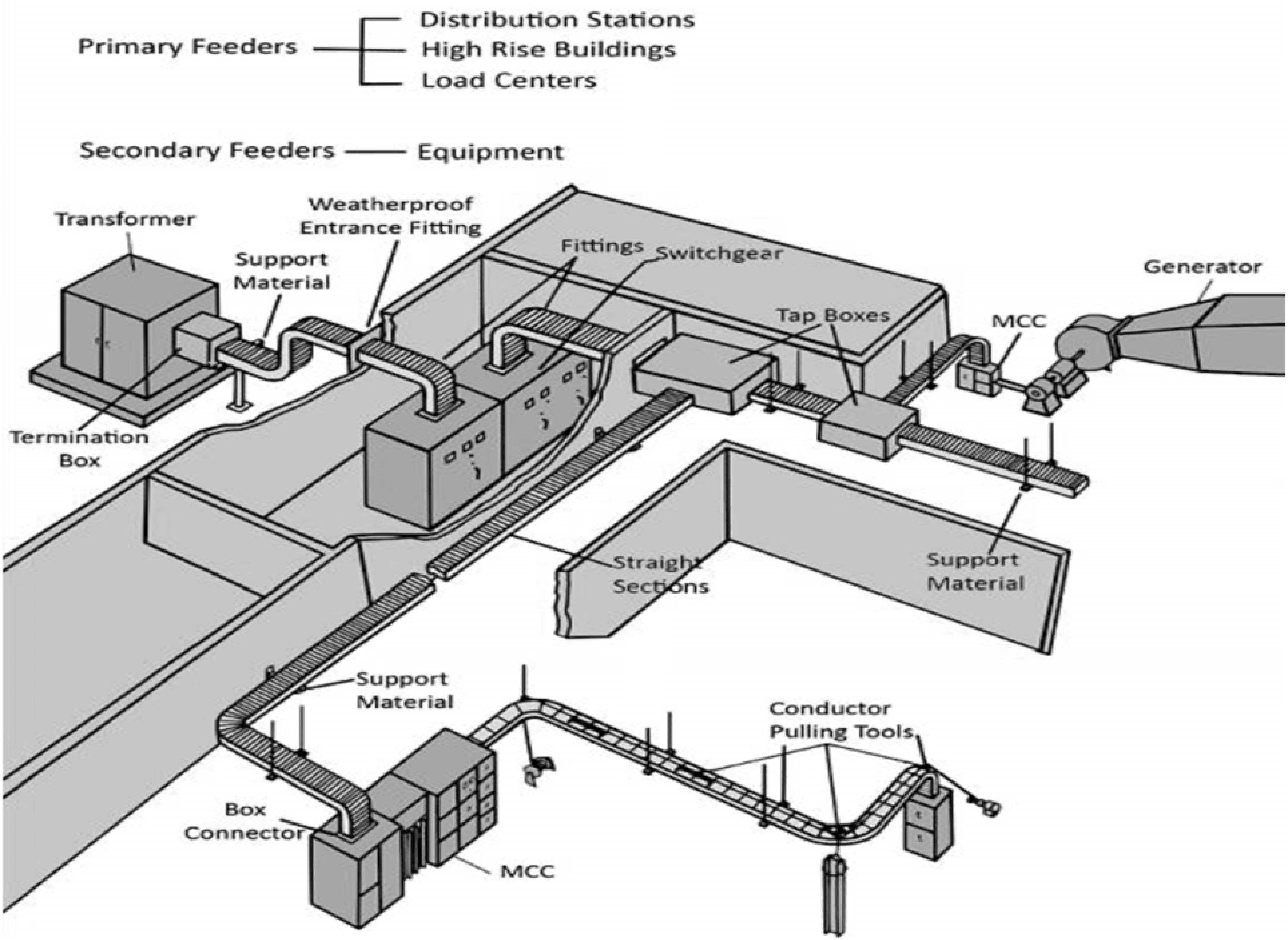
Power Systems Study

- The one-line diagram is most commonly used in the performance of power systems studies. The following information should be provided, as a minimum, on the one-line diagram, regardless of the type of power system study being performed.

  - bus current and voltage ratings
  - short-circuit current available (optional)
  - voltage and current ratios of instrument transformers
  - protective device (circuit breakers, fuses) ratings
  - functions of relays indicated by device numbers
  - ratings, type, and impedance of motors and transformers
  - connections (i.e. delta or wye) of transformers
  - number, length, size, and type of conductors and conduit

- The final application of the drawing (short-circuit study, coordination study, construction, etc.) will determine the exact information on the one-line diagram. For example, impedance of a motor is required for a short-circuit study but not for a coordination study. Relay and adjustable settings of circuit breakers are required for a coordination study but are not required for a short-circuit study.


Low Voltage Circuit Breaker
52
Medium Voltage Circuit Breaker
600 A
Low Voltage Power Circuit Breaker-Drawout Type
Disconnecting Fuse
Thermal Overload Device
Disconnect Switch
100/5
Current Transformer-Number Indicates Rating
Ammeter Switch
600/5
AS
A
3ϕ
3ϕ
Current Transformer with Ammeter; Letter Indicates Instrument Type, Number Indicates Ratio
1200/5
49
51/50
27
Relays Connected to VTs and CTs.-Number Indicates Relay Type
4160/120
Voltage (Potential) Transformer-Number Indicates Rating
Vacuum Circuit Breaker
Ground
Lightning Arrester
Capacitor Bank
Battery (Multicell)
Reactor
MVA or kVA
3-Phase Power Transformer Connected "Delta-Wye"
100
Induction Motor Number Indicates Horsepower Size
500
Synchronous Motor Number Indicates Horsepower Size

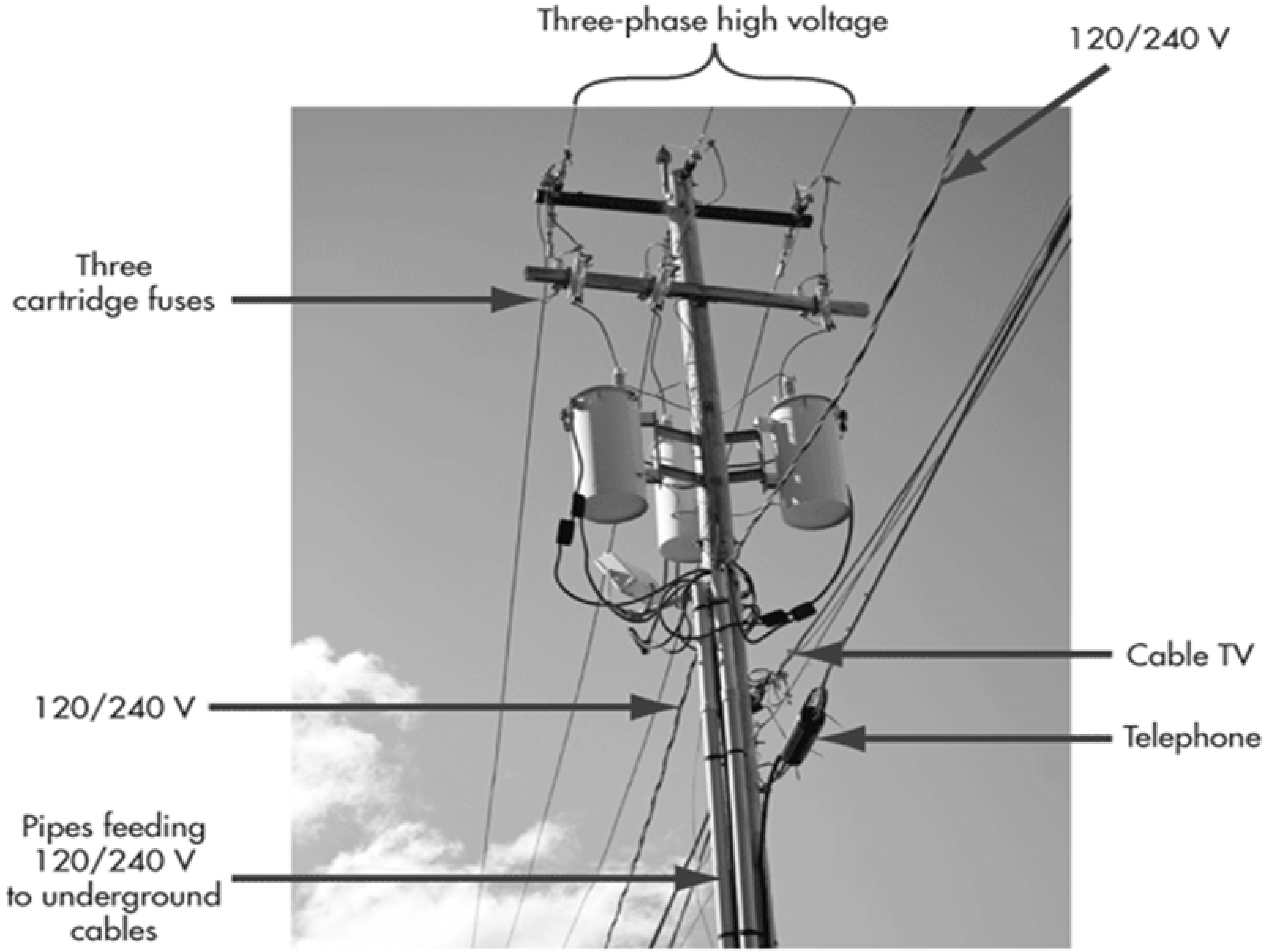


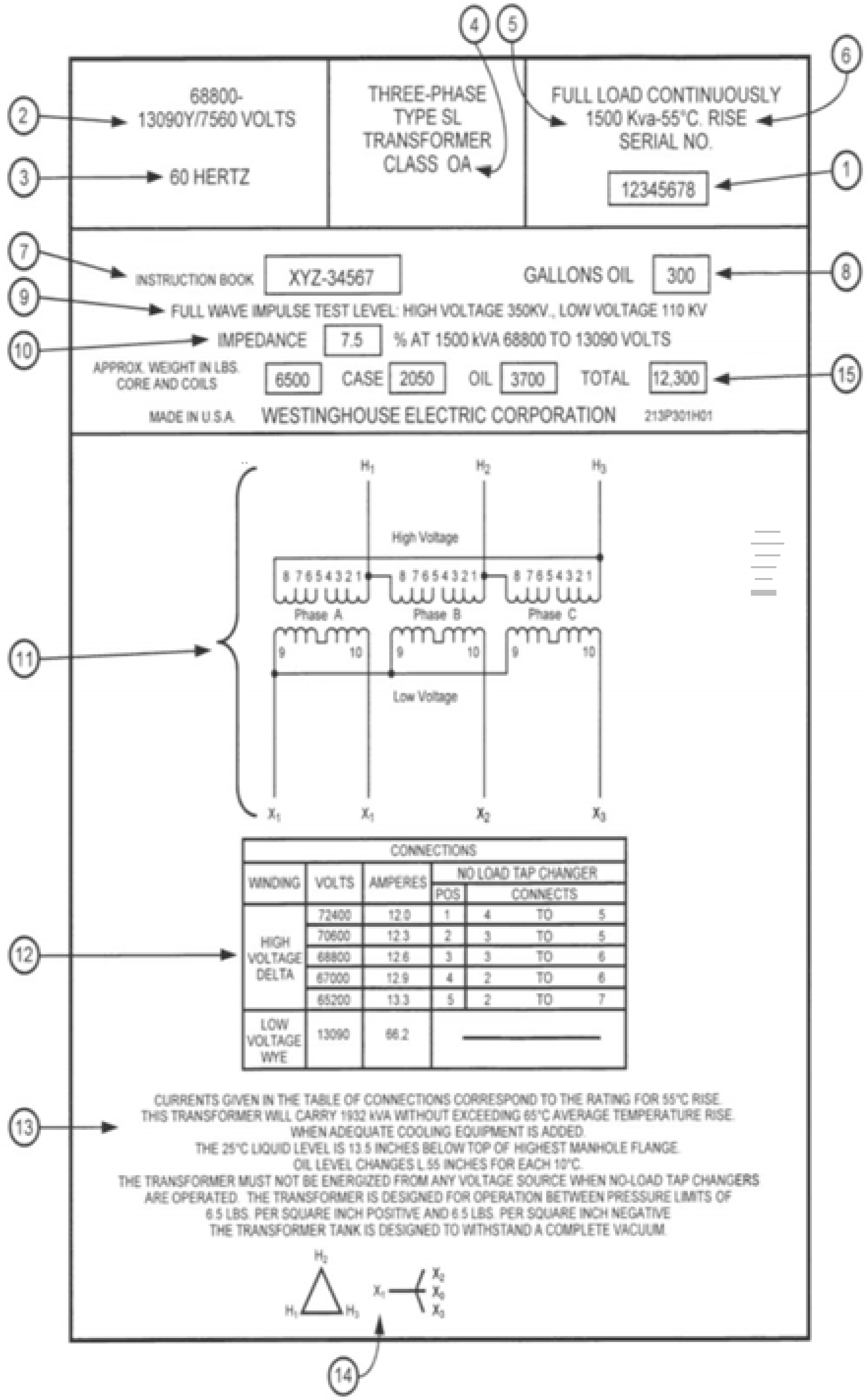
Primary Feeders
Distribution Stations
High Rise Buildings
Load Centers
Secondary Feeders
Equipment
Transformer
Weatherproof Entrance Fitting
Support Material
Fittings
Switchgear
Generator
Tap Boxes
MCC
Termination Box
Straight Sections
Support Material
Support Material
Conductor Pulling Tools
Box Connector
MCC

Main equipment used:

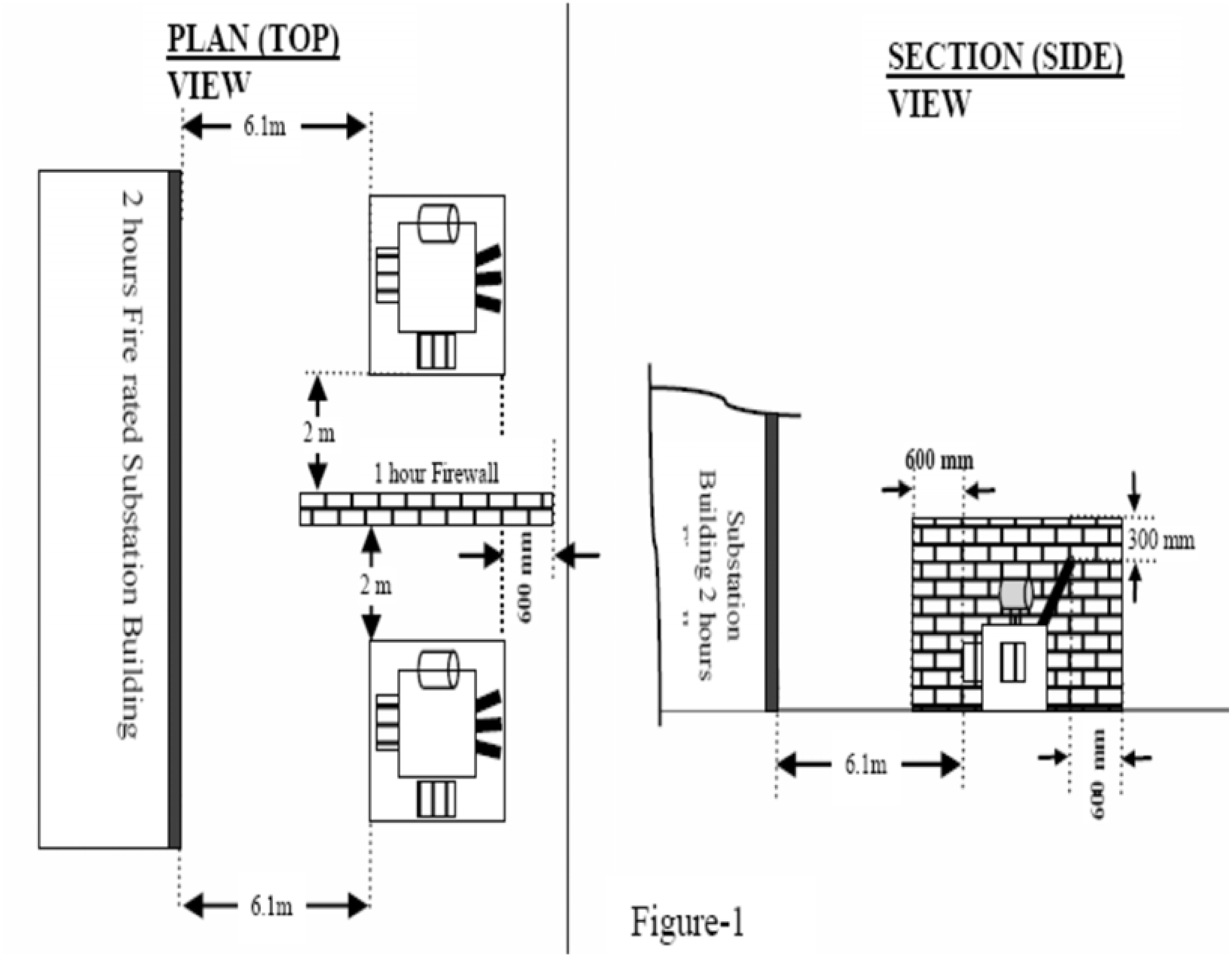
<u>Transformers</u> :

- Usually oil cooled with radiators, plus oil conservator
- Use fans to give extra rating
- Sized in KVA, primary and secondary voltages, impedance.
- Taps used to adjust output voltage either by manual or automatic control.
- Typically have high efficiency, 97 to 99% depending on size.
- Windings can be copper or aluminum


Three-phase high voltage
120/240 V
Three cartridge fuses
Cable TV
120/240 V
Telephone
Pipes feeding 120/240 V to underground cables



Item No.	Item	Item Description
1	Serial Number	Identifies specific transformer
2	Voltage	Rated terminal-to-terminal voltage for the primary and secondary windings
3	Frequency	Frequency at which transformer is designed to operate
4	Cooling Class	Method used to dissipate the heat generated during operation
5	kVA	The kVA capacity transformer can transmit without exceeding stated temperature rise
6	Temperature Rise	Average winding rise above ambient temperature at rated kVA
7	Instruction Book	Instruction book that applies to the specific transformer
8	Gallons of Fluid	Liquid volume of oil in transformer
9	Impulse Levels	Full wave FIL (basic insulation level) in kilovolts of line and neutral terminals
10	Impedance	Percent impedance measured by test
11	Winding Connection Diagram	Winding connection diagram to show relative location of bushings and internal terminals
12	Connection Chart	Chart showing voltage, current, and connection of each tap changer position
13	Notes	Contains valuable information about operation and maintenance of transformer
14	Phase Relation	Phase rotation and phase angle shift between high voltage and low voltage windings
15	Approximate Weights	Information itemized to facilitate untanking and shipping



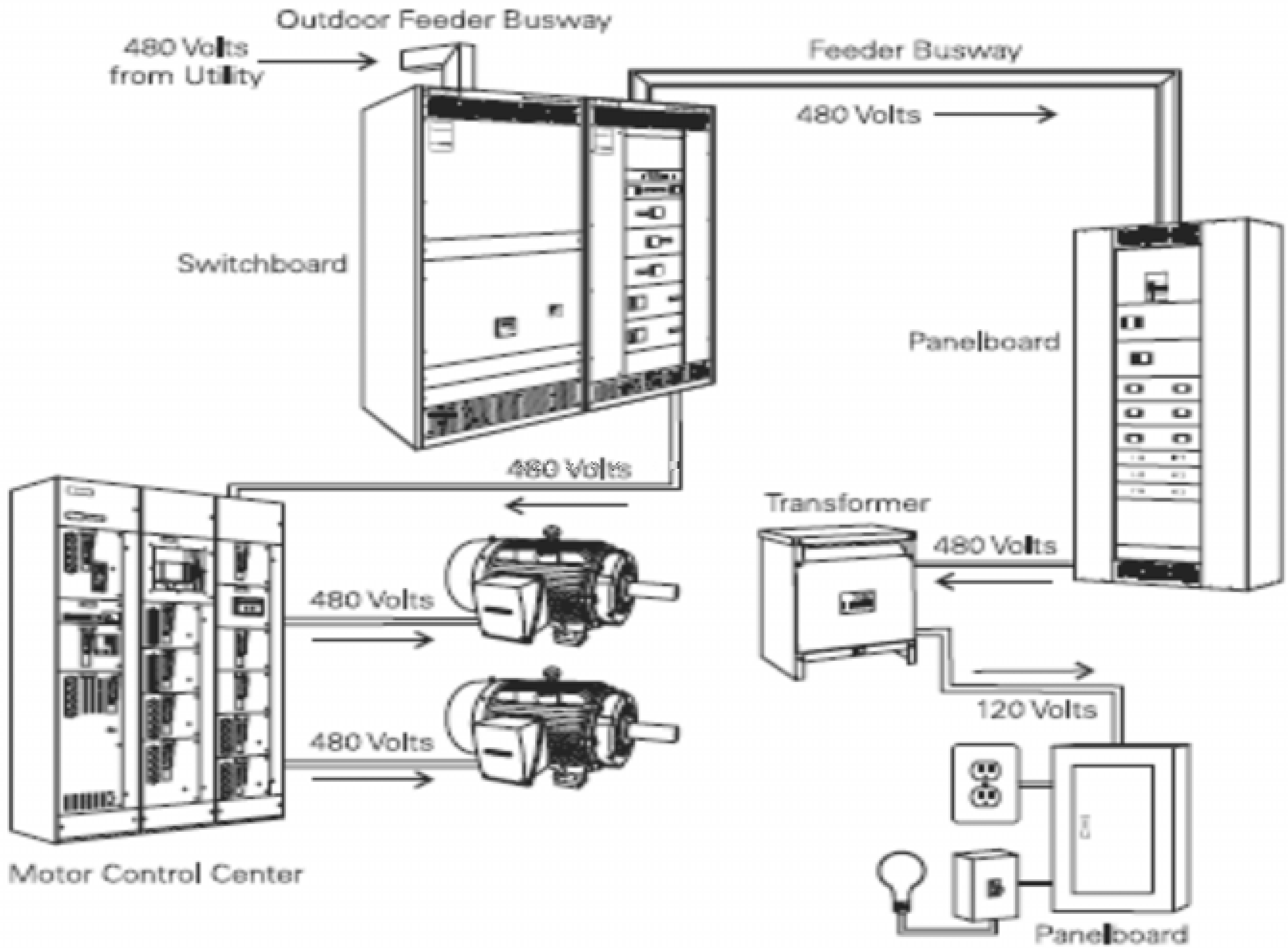
PLAN (TOP) VIEW
6.1m
2 hours Fire rated Substation Building
2 m
1 hour Firewall
2 m
600 mm
6.1m
SECTION (SIDE) VIEW
Substation Building 2 hours
600 mm
300 mm
6.1m
600 mm

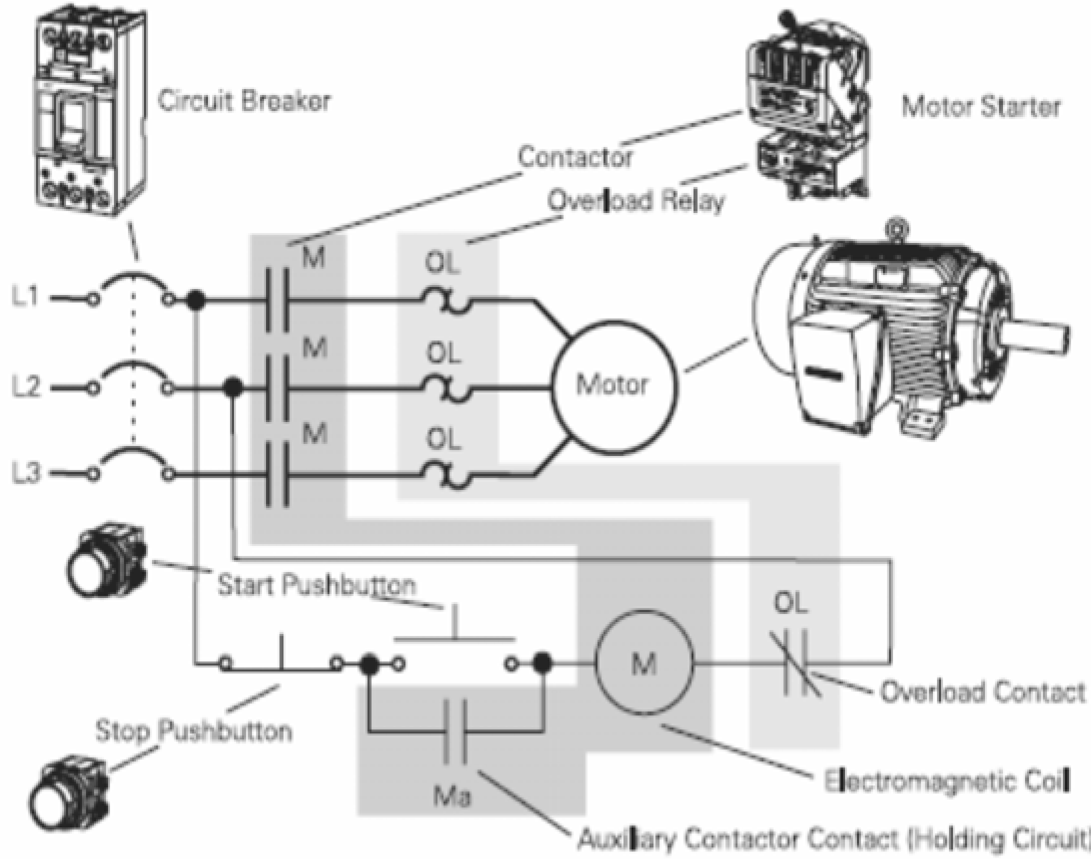
Figure-1

Main equipment used:

Motors :

- Mainly squirrel cage induction motors, occasionally use synchronous motors, or DC motors and variable frequency driver where speed control is required.
- Type of enclosure chosen to suit conditions. IEC standard enclosure type, IP series used when choosing.
- Rating in HP or KW refers to power available at rotor shaft. The efficiency and power factor of motor are needed before calculating motor current.
- Comparison of squirrel cage induction, synchronous and DC motors shows up main differences.
- Bought in standard frame sizes which allow interchangeability between different manufacturers.
- Motors should be run around full load to obtain maximum power factor and efficiency.


Outdoor Feeder Busway
480 Volts
from Utility
Feeder Busway
480 Volts
Switchboard
Panelboard
480 Volts
Transformer
480 Volts
480 Volts
480 Volts
120 Volts
Motor Control Center
Panelboard


Circuit Breaker
Motor Starter
Contactor
Overload Relay
M
M
M
OL
OL
OL
L1
L2
L3
Motor
Start Pushbutton
Stop Pushbutton
M
OL
Overload Contact
Electromagnetic Coil
Ma
Auxiliary Contactor Contact (Holding Circuit)

Motor Control Centers MCC

Main equipment used:

Motor Control Centers (MCC) :

a) Motor starters grouped together in a "metal clad" arrangement similar to switchgear, and usually are withdrawable.

b) Usually mounted inside substation, but sometimes in the plant close to a group of motors to avoid excessive cabling costs.

c) Circuit breakers used either for a main incoming feeder or to supply a large motor.

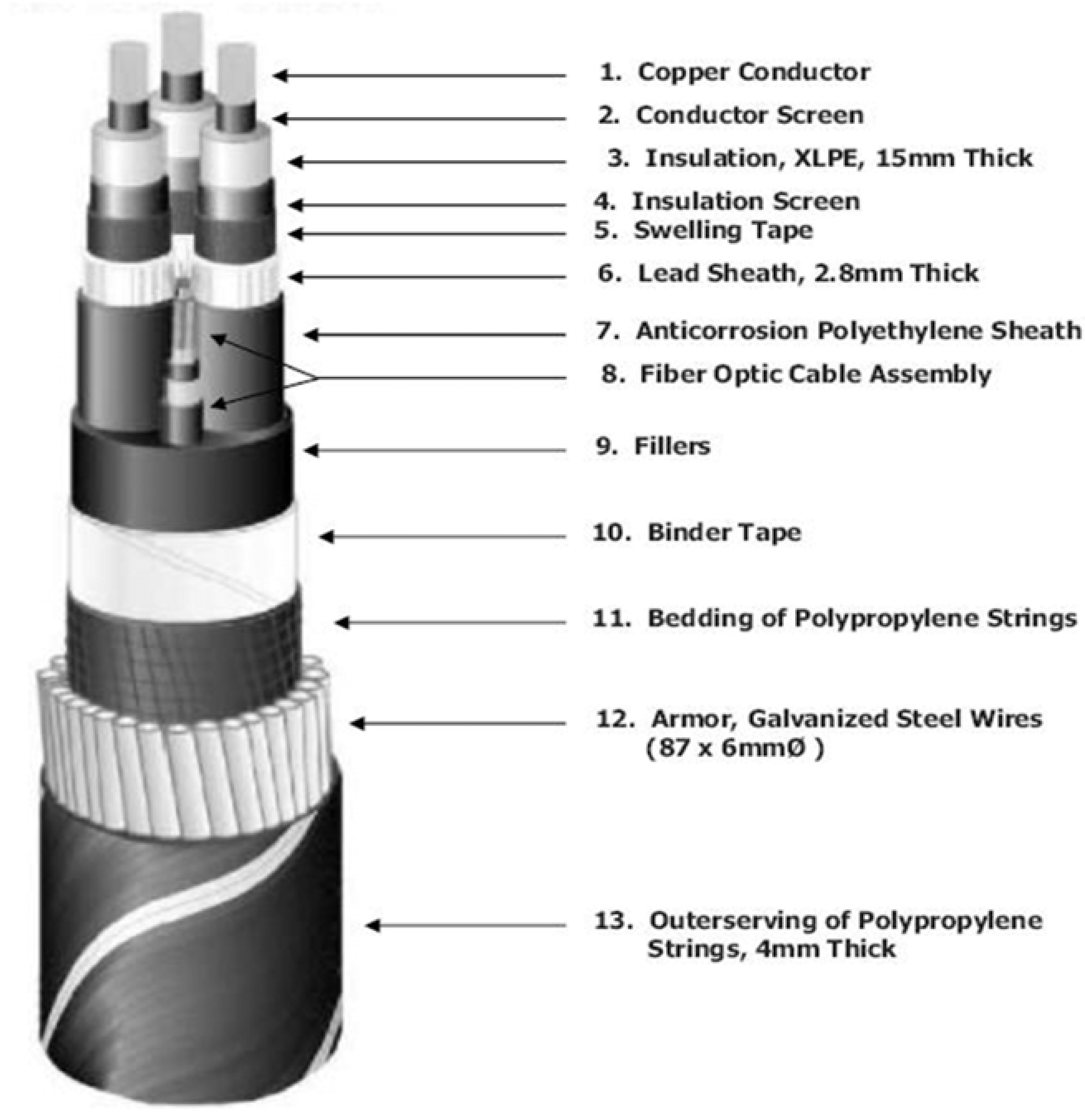
d) Contactors used for starting and stopping of motors. Contactors can be air type, vacuum or SF 6. They are not built to clear fault currents.

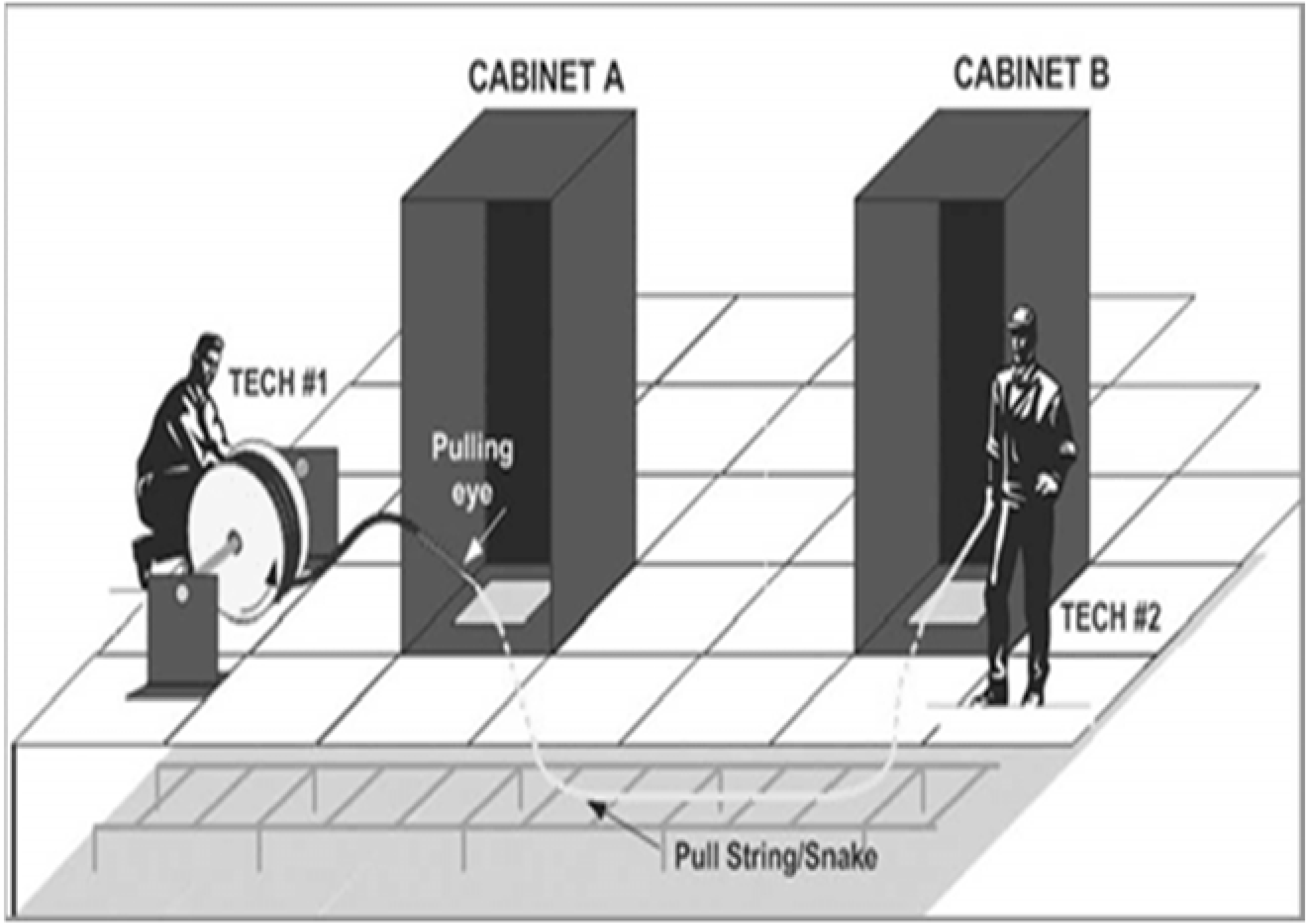
e) Contactors are rated based on

- maximum continuous burrent, or motor size, that can be switched.
- the frequency of operation.

f) Fuses are used to clear fault currents and must be sized relative to

g) Isolators often used to isolate the circuit, and should be rated to be able to break motor locked rotor current.


1. Copper Conductor
2. Conductor Screen
3. Insulation, XLPE, 15mm Thick
4. Insulation Screen
5. Swelling Tape
6. Lead Sheath, 2.8mm Thick
7. Anticorrosion Polyethylene Sheath
8. Fiber Optic Cable Assembly
9. Fillers
10. Binder Tape
11. Bedding of Polypropylene Strings
12. Armor, Galvanized Steel Wires (87 x 6mmØ)
13. Outerserving of Polypropylene Strings, 4mm Thick



CABINET A
CABINET B
TECH #1
Pulling
eye
TECH #2
Pull String/Snake

Main equipment used:

<u>Cables</u> :

a) Cables need to be chosen with the following considerations

- Operating voltage
- Operating current
- Maximum fault current versus time
- Mechanical protection
- Corrosion protection
- Method of installation, above or below ground

Main equipment used:

b) Type of insulation used are often as follows :

Low voltage (0 - 600 v)	PVC, Rubber
Medium voltage (3 and 6 KV)	Paper/oil insulated (PILC) PVC Rubber PE, or XLPE
High voltage	Paper/Oil insulated PE or XLPE

Main equipment used:

c) Mechanical protection is provided by

- Metal sheath e.g. steel wire armour
- Install cables in conduits
- Above ground cables on trays will need extra protection close to ground level.

d) Corrosion protection provided by lead sheath, if external PVC sheath is not sufficient.

Main equipment used:

d) Underground cable installations can be either :

- direct buried
- in conduits

e) Heat tracing cables

- mineral insulated system - needs thermostats
- tape system - needs thermostats
- self regulating system - thermostats may or may not be needed.

Typical Low Voltage Switchgear


SIEMENS

Main equipment used:

Switchgear :

a) Equipment mounted inside cubicles hence name of "metal clad" switchgear with a draw out arrangement.

b) Usually inside substation building, occasionally outdoor type used.

c) Connection between transformer and switchgear can be by "bus duct" or by cable.

d) Circuit breakers used can be oil (bulk or minimum), air or air blast type, vacuum or SF6. Function is to clear faults, and switch on and off circuits.

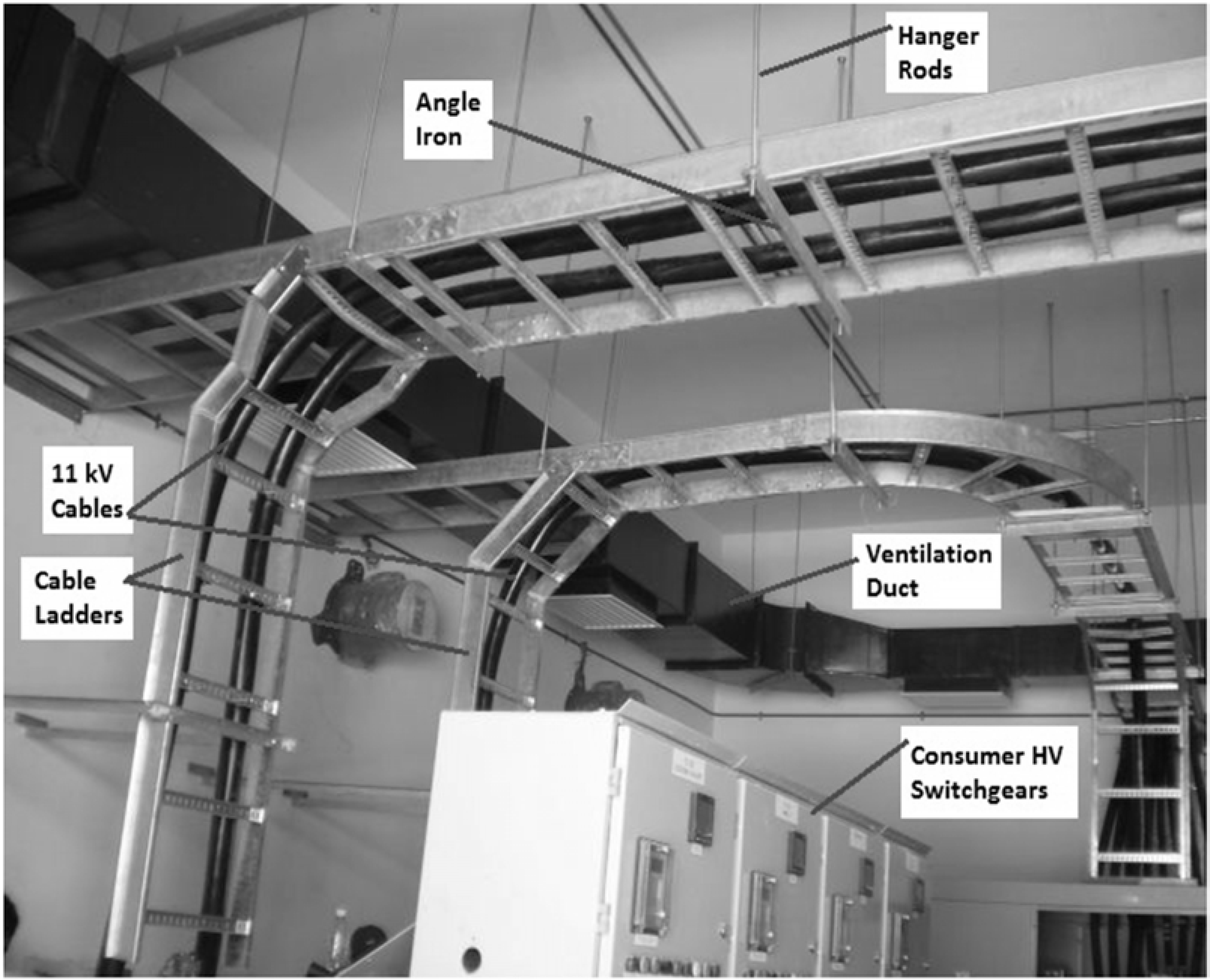
e) Circuit breakers are rated based on

- the maximum continuous current permitted under steady state conditions

and
- the maximum fault currents it can clear electrically and mechanically.

f) Bus bars are rated on

- maximum continuous current permitted
- plus maximum fault current that can pass through it without mechanical damage.


Hanger
Rods
Angle
Iron
11 kV
Cables
Cable
Ladders
Ventilation
Duct
Consumer HV
Switchgears

Main equipment used:

Miscellaneous :

a) Lighting types depending on requirements such as :

- fluorescent often used in plants as well as in offices
- sodium or fluorescent types used for street lighting
- Mercury vapour and high pressure sodium used for area or flood lighting.

Correct choice of type also leads to efficient operation.

b) Pushbuttons used for local control of motors

c) Above ground cable installations supported by means of

- cable trays
- conduits
- cable ladders

Mechanical protection needs to be provided in addition, if necessary.

General Causes of failure of electrical equipment.

a) Excessive heat destroys the electrical insulation. This can be caused by

- Overloads
- High ambient temperatures
- Localised hot spots in equipment
- Undervoltage on motors leading to overload
- Dirt and contamination on insulation
- Insufficient ventilation

b) Overvoltages result in a breakdown of the electrical insulation, aided perhaps by heat.

c) Mechanical causes such as excessive vibrations etc. can lead to damage to the insulation and eventually failure.

d) The above can be short term transient conditions, or long term situations.

Cost of Power

Typical utility contracts are broken up as follows:

- KWHRS — covers cost of fuel required for generation
- KW — covers cost of installed capacity held available for use
- COS Ø — covers extra generation needed because of poor utilisation of power

Understanding Power Concepts

Part 1

- Introduction
- Formulas (AC/DC Basics)
- **Standards**
- Codes/Personal Safety
- Grounding

Electrical Codes

- NFPA 70 (National Electrical Code)
- NESC (The National Electrical Safety Code)
- OSHA (Occupational Safety and Health Act)
- API RP-14F
- API RP-500

National Electrical Code

- The National Electrical Code (NEC) establishes the minimum requirements necessary to provide practical safeguarding of persons and property from hazards arising from the use of electricity.
- It should not be considered a design guide since it does not consider efficiency, convenience, or expandability for future service in its requirements.

National Electrical Safety Code

- The National Electrical Safety Code (NESC) covers basic provisions for safeguarding people from hazards arising from the installation, operation, or maintenance of
- 1) conductors and equipment in electric supply stations,
- 2) overhead and underground electric supply and communication lines.
- It also includes work rules for the construction, maintenance, and operation of electric supply and communication lines and equipment.

National Electrical Safety Code

- The document is published by the American National Standards Institute (ANSI) which requires it's standards to be reviewed and/or revised on at least a 5 year cycle.

- However, the NESC closely follows NEC requirements and therefore is updated on a three year cycle to match that of the NEC.

1) The minimum size THWN copper conductors rated at 75 degC installed in conduit required to serve a 230-V 10-hp induction motor and non-continuous 1-kW resistance heater on a circuit operating at 240-V single phase are:

(A) 4/0 AWG
(B) 2/0 AWG
(C) 4 AWG
(D) 6 AWG

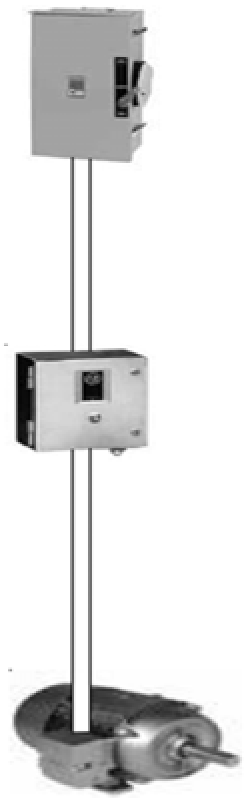
230V 10HP motor 50AMPS

240V 1kW heater 1000W/240V = 4.17 AMPS

54.17AMPS

Motor Schedules - 75° C Conductors

Listed in this section are 170 motor schedules with 19 calculations each. These schedules provide 3,230 calculations to determine the conduit and wiring configuration of a given installation. The schedules include both single phase and three phase motors.



Disconnect

The disconnect size is based on 115% of the motor full load amps per NEC Article 430-110. Note: Disconnect size may have to be increased if a fused disconnect is installed. When this condition exists an "@" proceeds the ampacity of the switch size shown in column 15 of the motor schedules.

Short Circuit Protection

The short circuit ground fault protection is based on 175% of the motor full load amps. The fuse/breaker size selected is the largest size not exceeding the 175% . This method of calculation assures compliance to NEC Article 430-52.

Conductors

Conductors are sized to carry 125% of the motor full load amps per NEC Article 430-22. Conductor ampacity is based on NEC Table 310-15(b)(16) copper.

Conductor Length (Voltage Drop)

The maximum conductor length is indicated in column 6 of the motor schedules. This number represents the maximum one-way conductor length before 3% voltage drop is exceeded.

Equipment Grounding Conductor

The equipment grounding conductor(s) size is based on the ampacity of the short circuit ground fault protection per NEC Article 250-122.

Motor Starter Size

The motor starter size is based on the motor full load amps and NEMA standard sizes.

Motor Overload Protection

The motor overload protection is based on 125% of the motor full load amps. The fuse size selected is the largest size not exceeding the 125% . This method of calculation assures compliance to NEC Article 430-32.

Raceway Size

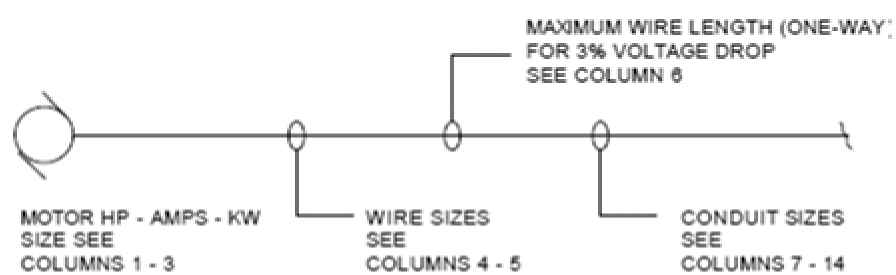
Raceway sizes are based on Standard Conduit Area Tables #1 and #2 located in Section #1 of this manual.

Motor Schedules - 75° C Conductors

1	2	3	4	5	6	7	8	9	10
						CONDUIT SIZE 2-WIRE (31% FILL)			
HP	FLA	KW	WIRE SIZE AWG	GND WIRE SIZE AWG	MAX WIRE LENGTH FEET NOTE #1	THW	RHH RHW NOTE #2	THWN THHN	XHHW
230 Volt Single Phase									
1/6	2.2	0.5	14	14	506'	1/2"	1/2"	1/2"	1/2"
1/4	2.9	0.7	14	14	384'	1/2"	1/2"	1/2"	1/2"
1/3	3.6	0.8	14	14	309'	1/2"	1/2"	1/2"	1/2"
1/2	4.9	1.1	14	14	227'	1/2"	1/2"	1/2"	1/2"
3/4	6.9	1.6	14	14	161'	1/2"	1/2"	1/2"	1/2"
1	8	1.8	14	14	139'	1/2"	1/2"	1/2"	1/2"
1 1/2	10	2.3	14	14	111'	1/2"	1/2"	1/2"	1/2"
2	12	2.8	14	14	93'	1/2"	1/2"	1/2"	1/2"
3	17	3.9	10	10	169'	1/2"	1/2"	1/2"	1/2"
5	28	6.4	8	10	158'	1/2"	3/4"	1/2"	1/2"
7 1/2	40	9.2	8	8	111'	3/4"	3/4"	1/2"	1/2"
10	50	11.5	6	8	141'	3/4"	1"	3/4"	3/4"

NOTES:

1. Maximum wire length (one-way) for 3% voltage drop.
2. RHW and RHH conductor fill with outer covering.
3. Disconnects must be horsepower rated.
4. @ May require larger size if fused switch is used.



VOLTAGE DROP CALCULATOR

(SINGLE PHASE CIRCUITS)

Project No.	??
Circuit No.	XXXX
System Voltage	240
Motor H.P.	L.O. PANEL FEED
Conductor Length	25
Power Factor	0.8

Note: Green text refers to NEC

Minimum Conductor Capacity

Circuit FLA	X	125%	=	Min. Conductor Capacity (amps)
Table 430-150				See Table 310-16
54.17				67.7125

Minimum Conductor Capacity (w/multiconductor derate and ambient temp. factors)

Motor Full Load Amps X 125% X (1/Derate Factor) X (1/Ambient Temperature Correction Factor) = Min. Condutor Capacity (amps)

Mtr. FLA			Derate Factor		Amb.Temp. Factor		Min. Capacity
			Article 310, Note 8		See Table 310-16		See Table 310-16
54.17	X 125%	X [(1/	1	) X (1/	1	)] =	67.7

Maximum Voltage Drop = 3%

%Vd = [((2 x Length x I x Eff. Z)/ (System Voltage x 1000)) x 100]

Motor H.P.	System Voltage	Full Load Amps	Conductor Length	Conductor Size	Cond. Ampacity	Cond. Effective Z	P.F.	Voltage Drop
		Table 430-150			Table 310-16 (Based on 75C)	Table 8 (Based on Coated Copper Wire)		
L.O. PANEL FEE	240	54.17	25	14	20	2.628	0.8	2.97%
L.O. PANEL FEE	240	54.17	25	12	25	1.660	0.8	1.87%
L.O. PANEL FEE	240	54.17	25	10	35	1.051	0.8	1.19%
L.O. PANEL FEE	240	54.17	25	8	50	0.666	0.8	0.75%
L.O. PANEL FEE	240	54.17	25	6	65	0.427	0.8	0.48%
L.O. PANEL FEE	240	54.17	25	4	85	0.275	0.8	0.31%
L.O. PANEL FEE	240	54.17	25	2	115	0.178	0.8	0.20%
L.O. PANEL FEE	240	54.17	25	1	130	0.145	0.8	0.16%

1) The minimum size THWN copper conductors rated at 75 degC installed in conduit required to serve a 230-V 10-hp induction motor and non-continuous 1-kW resistance heater on a circuit operating at 240-V single phase are:

According to table 430.248, this motor has a FLA of 50 A. 430.22(A) specifies 125% for the size of the conductor. 50 x 1.25 = 62.5 A.

The heater is 1kW. 1000W / 240V = 4.17A This load is rated noncontinuous so the current is taken as is.

The conductor required must carry 62.5 + 4.17 = 66.67 A. Table 310.15(B)(16) shows that a 4 AWG THWN has an Ampacity of 85 A. Remember, the conductor must carry the full current calculated. The next size up is not permitted for conductors.

(C) 4 AWG

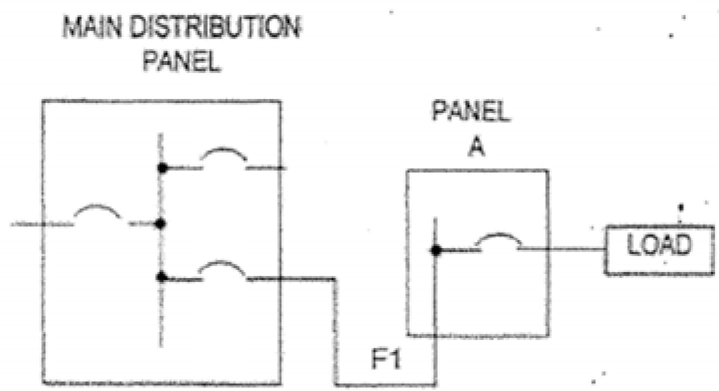
2) Answer this question in accordance with the National Electrical Code. Assume the voltage at the main distribution panel is 480 V, 3-phase. Feeder F1 consists of three 500-kcmil THWN copper phase conductors and a neutral in a steel conduit that runs a distance of 250 feet. Panel A serves a continuous, balanced load of 300 A at .8 lagging pf. The voltage at panel A is most nearly:

(A) 469

(B) 471

(C) 473

(D) 475



1% voltage drop or 480V*.01 = 4.8V; so 480V-4.8V= 475V

NOMENCLATURE FOR FORMULAS

e = line-to-neutral voltage drop

e_S = line-to-neutral voltage at source end

e_R = line-to-neutral voltage at load end

EXACT FORMULAS:

If e_R is known,

Line-to-neutral voltage drop =

$$\sqrt{(e_R \cos\theta + IR)^2 + (e_R \sin\theta + IX)^2} - e_R \qquad (1)$$

If e_S is known,

Line-to-neutral voltage drop =

$$e_S + IR\cos\theta + IX\sin\theta - \sqrt{e_S^2 - (IX\cos\theta - IR\sin\theta)^2} \qquad (2)$$

Equations (1) and (2) were derived from Fig. 1.

The voltage drop can also be obtained by a proportional method. Both the voltage drop and phase shift due to voltage drop can be obtained by

$$\star\ e_R = e_S \left(\frac{Z_L}{Z_S + Z_L} \right) \qquad (3)$$

★ where all quantities are expressed vectorially and Z_L is equivalent load impedance and Z_S is system impedance to the point of load connection.

Voltage drop $= e_S - e_R$, numerically (4)

VOLTAGE DROP CALCULATOR

(3-PHASE CIRCUITS)

Project No.	EX
Circuit No.	**TBD**
System Voltage	480
Motor H.P.	n/a
Conductor Length	250
Power Factor	0.8

Note: Green text refers to NEC

Minimum Conductor Capacity

Circuit FLA	X	**125%**	=	**Min. Conductor Capacity (amps)**
Table 430-150				See Table 310-16
300				375

Minimum Conductor Capacity (w/multiconductor derate and ambient temp. factors)

Motor Full Load Amps X 125% X (1/Derate Factor) X (1/Ambient Temperature Correction Factor) = Min. Condutor Capacity (amps)

Mtr. FLA			**Derate Factor**		**Amb. Temp. Factor**		**Min. Capacity**
			Article 310, Note 8		See Table 310-16		See Table 310-16
300	X 125%	X [(1/	1	) X (1/	1	)] =	375.0

Maximum Voltage Drop = 3%

%Vd = [((1.732 x Length x I x Eff. Z)/ (System Voltage x 1000)) x 100]

	Motor H.P.	System Voltage	Full Load Amps	Conductor Length	Conductor Size	Cond. Ampacity	Cond. Effective Z	P.F.	Voltage Drop
			Table 430-150			Table 310-16 (Based on 75C)	Table 8 (Based on Coated Copper Wire)		
	n/a	480	300	250	14	20	2.628	0.8	71.11%
	n/a	480	300	250	12	25	1.660	0.8	44.92%
	n/a	480	300	250	10	35	1.051	0.8	28.45%
*	n/a	480	300	250	8	50	0.666	0.8	18.03%
	n/a	480	300	250	6	65	0.427	0.8	11.54%
	n/a	480	300	250	4	85	0.275	0.8	7.45%
	n/a	480	300	250	2	115	0.178	0.8	4.82%
	n/a	480	300	250	1	130	0.145	0.8	3.92%
	n/a	480	300	250	1/0	150	0.118	0.8	3.19%
	n/a	480	300	250	2/0	175	0.097	0.8	2.63%
	n/a	480	300	250	3/0	200	0.079	0.8	2.15%
	n/a	480	300	250	4/0	230	0.066	0.8	1.78%
	n/a	480	300	250	250MCM	255	0.058	0.8	1.58%
	n/a	480	300	250	300MCM	285	0.051	0.8	1.39%
	n/a	480	300	250	350MCM	310	0.046	0.8	1.25%
	n/a	480	300	250	500MCM	380	0.037	0.8	1.00%
	n/a	480	300	250	600MCM	420	0.033	0.8	0.89%
	n/a	480	300	250	750MCM	475	0.029	0.8	0.77%

Notes:

1. These values are based on the following constants: UL-Type RHH wires with Class B stranding, in cradled configuration. Wire conductivities are 100 percent IACS copper and 61 percent IACS aluminum, and aluminum conduit is 45 percent IACS. Capacitive reactance is ignored, since it is negligible at these voltages. These resistance values are valid only at 75°C (167°F) and for the parameters as given, but are representative for 600-volt wire types operating at 60 Hz.

2. *Effective* Z is defined as *R* cos(θ) + X sin(θ), where θ is the power factor angle of the circuit. Multiplying current by effective impedance gives a good approximation for line-to-neutral voltage drop. Effective impedance values shown in this table are valid only at 0.85 power factor. For another circuit power factor (*PF*), effective impedance (*Ze*) can be calculated from *R* and *XL* values given in this table as follows: *Ze* = *R* × *PF* + *XL* sin[arccos(*PF*)].

Table 9 **Alternating-Current Resistance and Reactance for 600-Volt Cables, 3-Phase, 60 Hz, 75°C (167°F) — Three Single Conductors in Conduit**

Size (AWG or kcmil)	Ohms to Neutral per Kilometer Ohms to Neutral per 1000 Feet6														Size (AWG or kcmil)
	XL (Reactance) for All Wires		Alternating-Current Resistance for Uncoated Copper Wires			Alternating-Current Resistance for Aluminum Wires			Effective *Z* at 0.85 *PF* for Uncoated Copper Wires			Effective *Z* at 0.85 *PF* for Aluminum Wires			
	PVC, Aluminum Conduits	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	PVC Conduit	Aluminum Conduit	Steel Conduit	
500	0.128	0.157	0.089	0.105	0.095	0.141	0.157	0.148	0.141	0.157	0.164	0.187	0.200	0.210	500
0.039	0.048	0.027	0.032	0.029	0.043	0.048	0.045	0.043	0.048	0.050	0.057	0.061	0.064		

The Z of these conductors are found in Table 9. For steel conduit, Table 9 shows a Resistance of .029 Ohms/kft and a Reactance of .048 Ohms/kft. The general equation is given in note 2 of the Table. Effective Z = Rcos(theta) + Xsin(theta)

Therefore Z = [(.029)(.8) + (.048)(.6)] /kft, or .052/kft

Since this circuit is 250 feet, this number must be divided by 4.

Z = .052 / 4 = .013

2) *The Z of these conductors are found in Table 9. For steel conduit, Table 9 shows a Resistance of .029 Ohms/kft and a Reactance of .048 Ohms/kft. The general equation is given in note 2 of the Table. Effective Z = Rcos(theta) + Xsin(theta)*

Therefore Z = [(.029)(.8) + (.048)(.6)] /kft, or .052/kft

Since this circuit is 250 feet, this number must be divided by 4.

Z = .052 / 4 = .013

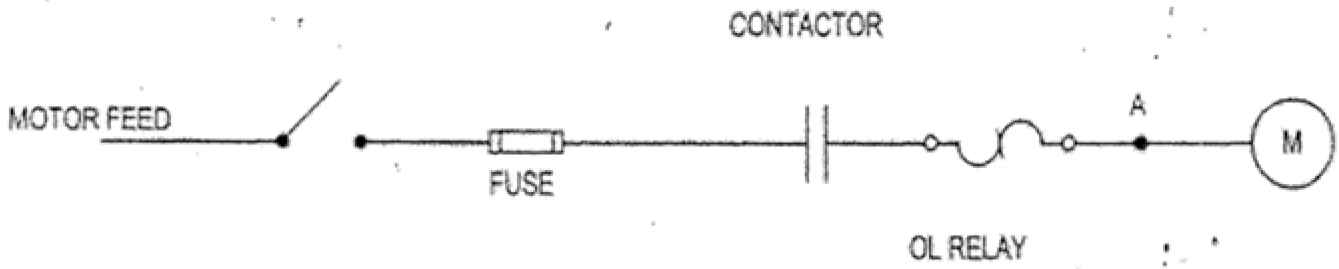
E=I*R

E = (300) * (.013) = 3.9 V *Caution! This is a line-to-neutral voltage. It must be multiplied by the sqrt(3) if it is to be compared with a line-to-line voltage!*

3.9V * sqrt(3) = 6.8 V   480 - 6.8 = 473 V

(B) 473

3) To correct power factor, a capacitor is proposed to be connected to Point A in the 3-phase induction motor circuit shown in the figure below.



After the addition of the capacitor, which of the following statements is most likely correct?

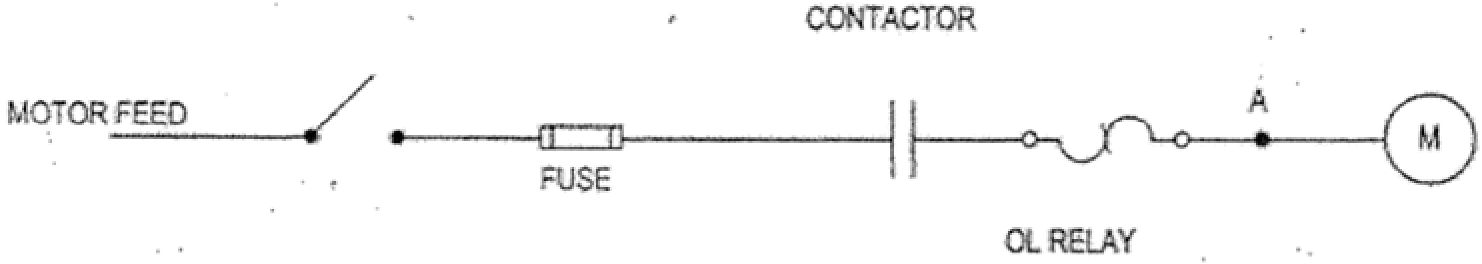
(A) The full-load current at motor M will be significantly reduced

(B) The motor overload trip settings should be reduced

(C) The NEC requires that the capacitor be connected through a separate disconnect switch

(D) The motor feed conductors may be sized for a reduced ampacity

3)



(A) The full-load current at motor M will be significantly reduced

Be careful here! The current "at the motor" is not changed at all. It is only the current before point A that is changed

(B) The motor overload trip settings should be reduced

Yes. If the Overloads are not adjusted down, an actual overload condition could occur that might not be protected.

(C) The NEC requires that the capacitor be connected through a separate disconnect switch

Generally, this is true. This is covered in Article 460. 460.8(C)Exception states that a disconnect is not required on the load side of a motor controller

(D) The motor feed conductors may be sized for a reduced ampacity

This is a total violation of the spirit of the Code. If the capacitor became disconnected, the conductors would still have to be able to carry the load.

Answer is B

4) An unknown wire gauge must be determined during an electrical inspection. The wire diameter is measured as .2591 cm. What is the AWG standard designation?

(A) 4/0 AWG

(B) 4 AWG

(C) 8 AWG

(D) 10 AWG

Table 8 **Conductor Properties**

Size (AWG or kcmil)	Area		Conductors							Direct-Current Resistance at 75°C (167°F)					
			Stranding			Overall				Copper				Aluminum	
			Quantity	Diameter		Diameter		Area		Uncoated		Coated			
	mm2	Circular mils		mm	in.	mm	in.	mm2	in.2	ohm/km	ohm/kFT	ohm/km	ohm/kFT	ohm/km	ohm/kFT
18	0.823	1620	1	—	—	1.02	0.040	0.823	0.001	25.5	7.77	26.5	8.08	42.0	12.8
18	0.823	1620	7	0.39	0.015	1.16	0.046	1.06	0.002	26.1	7.95	27.7	8.45	42.8	13.1
16	1.31	2580	1	—	—	1.29	0.051	1.31	0.002	16.0	4.89	16.7	5.08	26.4	8.05
16	1.31	2580	7	0.49	0.019	1.46	0.058	1.68	0.003	16.4	4.99	17.3	5.29	26.9	8.21
14	2.08	4110	1	—	—	1.63	0.064	2.08	0.003	10.1	3.07	10.4	3.19	16.6	5.06
14	2.08	4110	7	0.62	0.024	1.85	0.073	2.68	0.004	10.3	3.14	10.7	3.26	16.9	5.17
12	3.31	6530	1	—	—	2.05	0.081	3.31	0.005	6.34	1.93	6.57	2.01	10.45	3.18
12	3.31	6530	7	0.78	0.030	2.32	0.092	4.25	0.006	6.50	1.98	6.73	2.05	10.69	3.25
10	5.261	10380	1	—	—	2.588	0.102	5.26	0.008	3.984	1.21	4.148	1.26	6.561	2.00
10	5.261	10380	7	0.98	0.038	2.95	0.116	6.76	0.011	4.070	1.24	4.226	1.29	6.679	2.04
8	8.367	16510	1	—	—	3.264	0.128	8.37	0.013	2.506	0.764	2.579	0.786	4.125	1.26
8	8.367	16510	7	1.23	0.049	3.71	0.146	10.76	0.017	2.551	0.778	2.653	0.809	4.204	1.28
6	13.30	26240	7	1.56	0.061	4.67	0.184	17.09	0.027	1.608	0.491	1.671	0.510	2.652	0.808
4	21.15	41740	7	1.96	0.077	5.89	0.232	27.19	0.042	1.010	0.308	1.053	0.321	1.666	0.508
3	26.67	52620	7	2.20	0.087	6.60	0.260	34.28	0.053	0.802	0.245	0.833	0.254	1.320	0.403
2	33.62	66360	7	2.47	0.097	7.42	0.292	43.23	0.067	0.634	0.194	0.661	0.201	1.045	0.319

4) An unknown wire gauge must be determined during an electrical inspection. The wire diameter is measured as .2591 cm. What is the AWG standard designation?

Table 8 in Chapter 9 "Conductor Properties" shows the applicable information. The overall diameter of a conductor is given in column 7 (in mm.). The problem gives the diameter as .2591 cm. This is 2.591 mm. Column 7 shows a conductor with an overall diameter of 2.588 mm. Following this to the left shows a conductor size of 10 AWG Solid.

(D) 10 AWG

6) A branch circuit is to supply 20 A of continuous load and 5 A of noncontinuous load. What minimum conductor ampacity is required?

(A) 20 A

(B) 25 A

(C) 36 A

(D) 30 A

20A * 1.25 =25A
5A *1.00 = 5A
So the total amps should be 25+5 = 30A

6) A branch circuit is to supply 20 A of continuous load and 5 A of noncontinuous load. What minimum conductor ampacity is required?

"Branch Circuits" are covered in Article 210 and "Branch Circuit Calculations" are covered in Article 220. Section 210.19 (A)(1) states that "...the minimum branch-circuit conductor size, before the application of any adjustment or correction factors, shall have an allowable ampacity not less than the noncontinuous load plus 125% of the continuous load."

Therefore, (20 A x 1.25) + (5 x 1.00) = 30 Amps

(D) 30 A

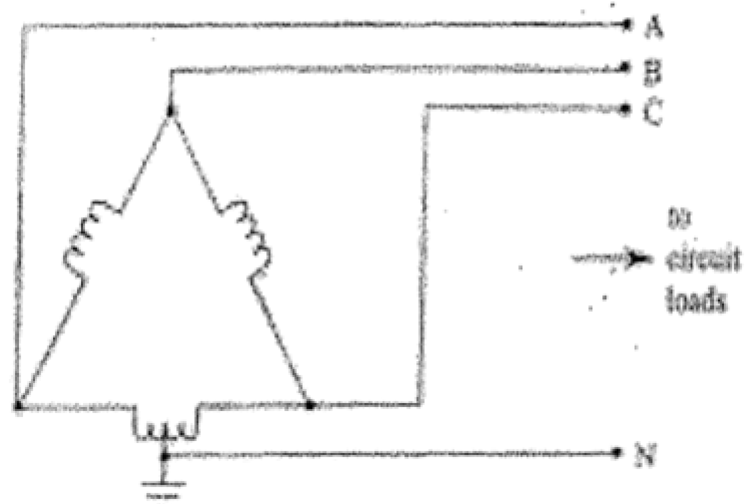
7) A four-wire, 240/120 V delta-connected secondary is used as a feeder for a variety of downstream circuits. Upon investigation, phase B is noted to be orange in colour. This colour, prescribed by NEC Art. 110.15, indicates what magnitude of voltage in this case?

(A) 120 V

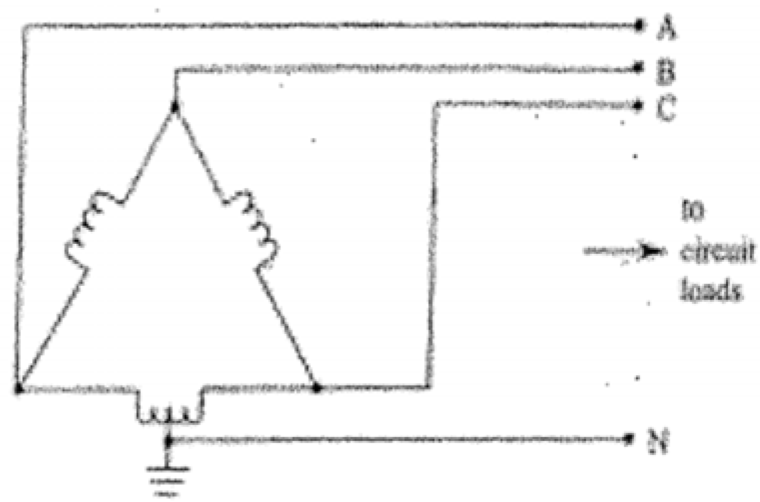
(B) 208 V

(C) 240 V

(D) 277 V



7) A four-wire, 240/120 V delta-connected secondary is used as a feeder for a variety of downstream circuits. Upon investigation, phase B is noted to be orange in colour. This colour, prescribed by NEC Art. 110.15, indicates what magnitude of voltage in this case?



The appropriate Code reference is given in the problem statement. If you draw a line from the top of the triangle to the middle of the base, you will find that each half is a 30/60/90 right triangle. The long leg is sqrt(3) times the short leg. The short leg is given as 120 V. This gives the long leg (Phase B to reference) as 120 V x sqrt(3), or 208 V.

(B) 208 V

9) A 200 hp, 460 V, three-phase, continuous-duty, squirrel-cage induction motor is designed to operate at a .85 power factor. The supplying branch circuit is 30.5 m long and utilizes THHN copper conductors in a steel conduit. The voltage drop is limited to 3% in the branch circuit, leaving 2% for the feeder circuit. NEC Table 430.250 and Table 9 list the applicable data. What size cable should be used to meet the voltage drop recommendations and current requirements of the load?

(A) 4/0 AWG

(B) 250 kcmil

(C) 300 kcmil

(D) 350 kcmil

Motor FLA = 240A

Table 430.250 Full-Load Current, Three-Phase Alternating-Current Motors

The following values of full-load currents are typical for motors running at speeds usual for belted motors and motors with normal torque characteristics.

The voltages listed are rated motor voltages. The currents listed shall be permitted for system voltage ranges of 110 to 120, 220 to 240, 440 to 480, and 550 to 600 volts.

	Induction-Type Squirrel Cage and Wound Rotor (Amperes)							Synchronous-Type Unity Power Factor* (Amperes)			
Horsepower	115 Volts	200 Volts	208 Volts	230 Volts	460 Volts	575 Volts	2300 Volts	230 Volts	460 Volts	575 Volts	2300 Volts
½	4.4	2.5	2.4	2.2	1.1	0.9	—	—	—	—	—
¾	6.4	3.7	3.5	3.2	1.6	1.3	—	—	—	—	—
1	8.4	4.8	4.6	4.2	2.1	1.7	—	—	—	—	—
1½	12.0	6.9	6.6	6.0	3.0	2.4	—	—	—	—	—
2	13.6	7.8	7.5	6.8	3.4	2.7	—	—	—	—	—
3	—	11.0	10.6	9.6	4.8	3.9	—	—	—	—	—
5	—	17.5	16.7	15.2	7.6	6.1	—	—	—	—	—
7½	—	25.3	24.2	22	11	9	—	—	—	—	—
10	—	32.2	30.8	28	14	11	—	—	—	—	—
15	—	48.3	46.2	42	21	17	—	—	—	—	—
20	—	62.1	59.4	54	27	22	—	—	—	—	—
25	—	78.2	74.8	68	34	27	—	53	26	21	—
30	—	92	88	80	40	32	—	63	32	26	—
40	—	120	114	104	52	41	—	83	41	33	—
50	—	150	143	130	65	52	—	104	52	42	—
60	—	177	169	154	77	62	16	123	61	49	12
75	—	221	211	192	96	77	20	155	78	62	15
100	—	285	273	248	124	99	26	202	101	81	20
125	—	359	343	312	156	125	31	253	126	101	25
150	—	414	396	360	180	144	37	302	151	121	30
200		552	528	480	240	192	49	400	201	161	40
250	—	—	—	—	302	242	60	—	—	—	—
300	—	—	—	—	361	289	72	—	—	—	—
350	—	—	—	—	414	336	83	—	—	—	—
400	—	—	—	—	477	382	95	—	—	—	—
450	—	—	—	—	515	412	103	—	—	—	—
500	—	—	—	—	590	472	118	—	—	—	—

*For 90 and 80 percent power factor, the figures shall be multiplied by 1.1 and 1.25, respectively.

Table 430.251(A) Conversion Table of Single-Phase Locked-Rotor Currents for Selection of Disconnecting Means and Controllers as Determined from Horsepower and Voltage Rating

For use only with 430.110, 440.12, 440.41, and 455.8(C).

Maximum Locked-Rotor Current in

VOLTAGE DROP CALCULATOR

(3-PHASE CIRCUITS)

Project No.	EX
Circuit No.	TBD
System Voltage	460
Motor H.P.	n/a
Conductor Length	100
Power Factor	0.85

Note: Green text refers to NEC

Minimum Conductor Capacity

Circuit FLA	X	125%	=	Min. Conductor Capacity (amps)
Table 430-150				See Table 310-16
240				300

Minimum Conductor Capacity (w/multiconductor derate and ambient temp. factors)

Motor Full Load Amps X 125% X (1/Derate Factor) X (1/Ambient Temperature Correction Factor) = Min. Condutor Capacity (amps)

Mtr. FLA		Derate Factor		Amb.Temp. Factor		Min. Capacity
		Article 310, Note 8		See Table 310-16		See Table 310-16
240	X 125%	X [(1/ 1	) X (1/	1	)] =	300.0

Maximum Voltage Drop = 3%

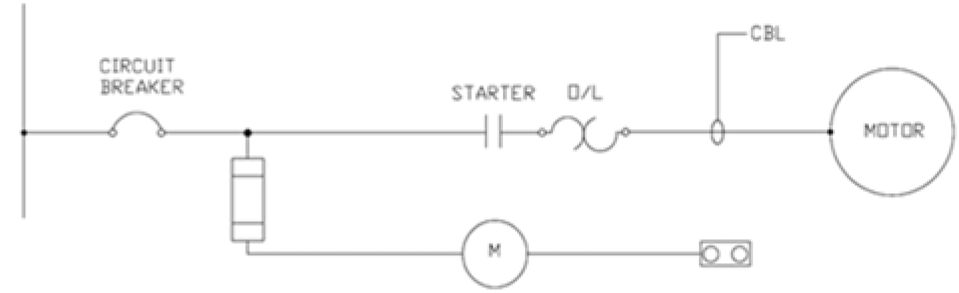
%Vd = [((1.732 x Length x I x Eff. Z)/ (System Voltage x 1000)) x 100]

	Motor H.P.	System Voltage	Full Load Amps	Conductor Length	Conductor Size	Cond. Ampacity	Cond. Effective Z	P.F.	Voltage Drop
			Table 430-150			Table 310-16 (Based on 75C)	Table 8 (Based on Coated Copper Wire)		
	n/a	460	240	100	14	20	2.788	0.85	25.20%
	n/a	460	240	100	12	25	1.760	0.85	15.90%
	n/a	460	240	100	10	35	1.113	0.85	10.06%
*	n/a	460	240	100	8	50	0.705	0.85	6.37%
	n/a	460	240	100	6	65	0.450	0.85	4.06%
	n/a	460	240	100	4	85	0.289	0.85	2.61%
	n/a	460	240	100	2	115	0.186	0.85	1.68%
	n/a	460	240	100	1	130	0.151	0.85	1.36%
	n/a	460	240	100	1/0	150	0.122	0.85	1.10%
	n/a	460	240	100	2/0	175	0.100	0.85	0.90%
	n/a	460	240	100	3/0	200	0.081	0.85	0.74%
	n/a	460	240	100	4/0	230	0.067	0.85	0.60%
	n/a	460	240	100	250MCM	255	0.059	0.85	0.53%
	n/a	460	240	100	300MCM	285	0.052	0.85	0.47%
	n/a	460	240	100	350MCM	310	0.046	0.85	0.42%
	n/a	460	240	100	500MCM	380	0.036	0.85	0.33%

9) A 200 hp, 460 V, three-phase, continuous-duty, squirrel-cage induction motor is designed to operate at a .85 power factor. The supplying branch circuit is 30.5 m long and utilizes THHN copper conductors in a steel conduit. The voltage drop is limited to 3% in the branch circuit, leaving 2% for the feeder circuit. NEC Table 430.250 and Table 9 list the applicable data. What size cable should be used to meet the voltage drop and current requirements of the load?

*This problem is a direct attempt at trying to get the test-taker to waste valuable time. Look at the answers first, before you start calculating. First of all, this motor, according to Table 430.250, has a FLC of 240 Amps. 240 * 1.25 = 300. Of the answer choices, 350 kcmil is the only one that is rated for this much current. Plus, the rule of thumb is about "a foot per volt." Since this is a 480 V circuit, we don't get into appreciable voltage drop problems until the circuit is over 500 feet. This circuit is only 100 feet in length. There are no voltage drop considerations here.*

(D) 350 kcmil



200 HP MOTOR - 460V (3PH-4W) (SEE NOTE 7)

MOTOR HP	MOTOR VOLTAGE	MOTOR FLC (AMPS) (1)	NEMA STARTER SIZE	BREAKER SIZE (AMPS) (6)	O/L SIZE (AMPS) (8)	SPACE HEATER (WATTS) (7)	SPACE HEATER MAX CURRENT (A) (7)
200	460	240	5	400	276.000	400	3.33

POWER CABLES (4W)

MOTOR HP	POWER CABLE SIZE (AWG) (4)	MAX. DISTANCE (FEET)	VOLTAGE DROP PERCENT (5)	RMC CONDUIT SIZE (INCHES) (2)	PVC CONDUIT SIZE (INCHES) (2)	FLEX METAL CONDUIT SIZE (2)	MINIMUM CABLE BENDING RADIUS (8 x OD)
200	#350	675	2.7	3.5	4	3.5	17.52
200	#500	850	2.67	4	5	4	20

CONTROL CABLES (4W)

BASED OFF NEMA COIL DATA	CTRL CABLE SIZE (AWG) (4)	MAX. DISTANCE (FEET) (10)	VOLTAGE DROP PERCENT (5)(10)	RMC CONDUIT SIZE (INCHES) (2)	PVC CONDUIT SIZE (INCHES) (2)	FLEX METAL CONDUIT SIZE (2)	MINIMUM CABLE BENDING RADIUS (8 x OD)
	#12	100	2.83	0.75	1	0.75	3.36
	#10	150	2.69	1	1	1	4.64

SPACE HEATER CABLE (2W)

MOTOR HEATER (W) (7)	HEATER CABLE SIZE (AWG) (4)	(SEE NOTE 7) MAX. DISTANCE (FEET)	(SEE NOTE 7) VOLTAGE DROP PERCENT (5)	RMC CONDUIT SIZE (INCHES) (2)	PVC CONDUIT SIZE (INCHES) (2)	FLEX METAL CONDUIT SIZE (2)	MINIMUM CABLE BENDING RADIUS (8 x OD)
400	#12	275	2.69	0.75	0.75	0.75	3.36
	#10	425	2.63	0.75	1	0.75	4.64
	#8	675	2.64	1	1.25	1.25	5.76
	#6	1075	2.68	1.25	1.25	1.25	6.48

POWER AND CONTROL CABLES

	PWR CABLE SIZE (AWG) (4)	CTRL CABLE SIZE (AWG) (4)		RMC CONDUIT SIZE (INCHES) (2)	PVC CONDUIT SIZE (INCHES) (2)	FLEX METAL CONDUIT SIZE (2)	MINIMUM CABLE BENDING RADIUS (8 x OD)
	#350	#12		3.5	4	4	17.52
	#350	#10		4	4	4	17.52
	#500	#12		4	5		20
	#500	#10		5	5		20

NOTES:

1) Based on NEC Table 430.150 Full-Load Current, Three Phase Alternating-Current Motors
2) All conduit fills are based on 40% fill with individual conductors. Okonite-FMR Okoseal Type TC Cable was used to size conduits. Product Data Section 3: Sheet 15
If EMT conduit is required refer to PVC sch. 80 for proper conduit sizing.
3) Based on NEC Table 250.66 Grounding Electrode Conductor for Alternating Systems.
4) Conductor sizing is based on 40 deg C ambient. Max. 60 deg C for conductors less than 100A and 75 deg C for conductors greater than 100A; as well as voltage drop due to cable distances.
5) Voltage drop calculation is based on 0.85 pF
*Engineer should make sure equipment and protective devices can handle large cables and termination lugs.
6) Based on NEC Table 430.52, Breaker size shall not exceed 250% of the Full Load Current.
7) Motor manufacture typically sizes space heaters depending on motor size and environmental conditions. For the purpose of sizing conduit a space heater range between 25-400 watt using 1-2/C was specified. Max current based off 400 watt heater and 120 volts was used to calculate voltage drop and max distance for heater.
8) Based on NEC 430.32(A)(1) O/L device shall be rated no more than 115% of the motor nameplate FLC rating.
9) Class 10 O/L heaters = fast trip, Class 20 O/L heaters = standard trip
10) Voltage drop calculations due to control cable distance based of Eaton product data sheet (31.3-3) inrush current. Coil must maintain 85% of rated voltage.

11) Find the ampacity of a 4/0 THWN Cu. conductor routed in a conduit. The conductor is one of six current carrying conductors in the same conduit (two per phase). The conduit is routed through an ambient temperature of 43 degC.

(A) 132 A

(B) 151 A

(C) 184 A

(D) 230 A

#4/0 75deg C column 230A * 0.80 (six conductors) * .82 (43 deg C) = 230*.8*.82 = 150.88A or (B) 151 A

Table 310.15(B)(16) (formerly Table 310.16) Allowable Ampacities of Insulated Conductors Rated Up to and Including 2000 Volts, 60°C Through 90°C (140°F Through 194°F), Not More Than Three Current-Carrying Conductors in Raceway, Cable, or Earth (Directly Buried), Based on Ambient Temperature of 30°C (86°F)*

	Temperature Rating of Conductor [See Table 310.104(A).]						
	60°C (140°F)	75°C (167°F)	90°C (194°F)	60°C (140°F)	75°C (167°F)	90°C (194°F)	
Size AWG or kcmil	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE, ZW	Types TBS, SA, SIS, FEP, FEPB, MI, RHH, RHW-2, THHN, THHW, THW-2, THWN-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	Types TW, UF	Types RHW, THHW, THW, THWN, XHHW, USE	Types TBS, SA, SIS, THHN, THHW, THW-2, THWN-2, RHH, RHW-2, USE-2, XHH, XHHW, XHHW-2, ZW-2	
	COPPER			ALUMINUM OR COPPER-CLAD ALUMINUM			Size AWG or kcmil
18	—	—	14	—	—	—	—
16	—	—	18	—	—	—	—
14**	15	20	25	—	—	—	—
12**	20	25	30	15	20	25	12**
10**	30	35	40	25	30	35	10**
8	40	50	55	35	40	45	8
6	55	65	75	40	50	55	6
4	70	85	95	55	65	75	4
3	85	100	115	65	75	85	3
2	95	115	130	75	90	100	2
1	110	130	145	85	100	115	1
1/0	125	150	170	100	120	135	1/0
2/0	145	175	195	115	135	150	2/0
3/0	165	200	225	130	155	175	3/0
4/0	195	230	260	150	180	205	4/0
250	215	255	290	170	205	230	250
300	240	285	320	195	230	260	300
350	260	310	350	210	250	280	350
400	280	335	380	225	270	305	400
500	320	380	430	260	310	350	500
600	350	420	475	285	340	385	600
700	385	460	520	315	375	425	700
750	400	475	535	320	385	435	750
800	410	490	555	330	395	445	800
900	435	520	585	355	425	480	900
1000	455	545	615	375	445	500	1000
1250	495	590	665	405	485	545	1250
1500	525	625	705	435	520	585	1500
1750	545	650	735	455	545	615	1750
2000	555	665	750	470	560	630	2000

*Refer to 310.15(B)(2) for the ampacity correction factors where the ambient temperature is other than 30°C (86°F).

**Refer to 240.4(D) for conductor overcurrent protection limitations.

Table 310.15(B)(3)(a) Adjustment Factors for More Than Three Current-Carrying Conductors in a Raceway or Cable

Number of Conductors[1]	Percent of Values in Table 310.15(B)(16) through Table 310.15(B)(19) as Adjusted for Ambient Temperature if Necessary
4–6	80
7–9	70
10–20	50
21–30	45
31–40	40
41 and above	35

[1]Number of conductors is the total number of conductors in the raceway or cable adjusted in accordance with 310.15(B)(5) and (6).

Informational Note No. 2: See 366.23(A) for adjustment factors for conductors in sheet metal auxiliary gutters and 376.22(B) for adjustment factors for conductors in metal wireways.

(1) Where conductors are installed in cable trays, the provisions of 392.80 shall apply.

(2) Adjustment factors shall not apply to conductors in raceways having a length not exceeding 600 mm (24 in.).

(3) Adjustment factors shall not apply to underground conductors entering or leaving an outdoor trench if those conductors have physical protection in the form of rigid metal conduit, intermediate metal conduit, rigid polyvinyl chloride conduit (PVC), or reinforced thermosetting resin conduit (RTRC) having a length not exceeding 3.05 m (10 ft), and if the number of conductors does not exceed four.

(4) Adjustment factors shall not apply to Type AC cable or to Type MC cable under the following conditions:

a. The cables do not have an overall outer jacket.
b. Each cable has not more than three current-carrying conductors.
c. The conductors are 12 AWG copper.
d. Not more than 20 current-carrying conductors are installed without maintaining spacing, are stacked, or are supported on"bridle rings."

(5) An adjustment factor of 60 percent shall be applied to Type AC cable or Type MC cable under the following conditions:

a. The cables do not have an overall outer jacket.
b. The number of current carrying conductors exceeds 20.
c. The cables are stacked or bundled longer that 600 mm (24 in) without spacing being maintained.

(b) *More Than One Conduit, Tube, or Raceway.* Spacing between conduits, tubing, or raceways shall be maintained.

(c) *Circular Raceways Exposed to Sunlight on Rooftops.* Where conductors or cables are installed in circular raceways exposed to direct sunlight on or above rooftops, the adjustments shown in Table 310.15(B)(3)(c) shall be added to the outdoor temperature to determine the applicable ambient temperature for application of the correction factors in Table 310.15(B)(2)(a) or Table 310.15(B)(2)(b).

Informational Note: One source for the average ambient temperatures in various locations is the ASHRAE *Handbook — Fundamentals*.

Table 310.15(B)(3)(c) Ambient Temperature Adjustment for Circular Raceways Exposed to Sunlight on or Above Rooftops

Distance Above Roof to Bottom of Conduit	Temperature Adder	
	°C	°F
0–13 mm (½ in.)	33	60
Above 13 mm (½ in.)–90 mm (3½ in.)	22	40
Above 90 mm (3½ in.)–300 mm (12 in.)	17	30
Above 300 mm (12 in.)–900 mm (36 in.)	14	25

Informational Note to Table 310.15(B)(3)(c): The temperature adders in Table 310.15(B)(3)(c) are based on the results of averaging the ambient temperatures.

(4) Bare or Covered Conductors. Where bare or covered conductors are installed with insulated conductors, the temperature rating of the bare or covered conductor shall be equal to the lowest temperature rating of the insulated conductors for the purpose of determining ampacity.

(5) Neutral Conductor.

(a) A neutral conductor that carries only the unbalanced current from other conductors of the same circuit shall not be required to be counted when applying the provisions of 310.15(B)(3)(a).

(b) In a 3-wire circuit consisting of two phase conductors and the neutral conductor of a 4-wire, 3-phase, wye-connected system, a common conductor carries approximately the same current as the line-to-neutral load currents of the other conductors and shall be counted when applying the provisions of 310.15(B)(3)(a).

(c) On a 4-wire, 3-phase wye circuit where the major portion of the load consists of nonlinear loads, harmonic currents are present in the neutral conductor; the neutral conductor shall therefore be considered a current-carrying conductor.

(6) Grounding or Bonding Conductor. A grounding or bonding conductor shall not be counted when applying the provisions of 310.15(B)(3)(a).

(3) The rate at which generated heat dissipates into the ambient medium. Thermal insulation that covers or surrounds conductors affects the rate of heat dissipation.
(4) Adjacent load-carrying conductors — adjacent conductors have the dual effect of raising the ambient temperature and impeding heat dissipation.

Informational Note No. 2: Refer to 110.14(C) for the temperature limitation of terminations.

(B) Tables. Ampacities for conductors rated 0 to 2000 volts shall be as specified in the Allowable Ampacity Table 310.15(B)(16) through Table 310.15(B)(19), and Ampacity Table 310.15(B)(20) and Table 310.15(B)(21) as modified by 310.15(B)(1) through (B)(7).

The temperature correction and adjustment factors shall be permitted to be applied to the ampacity for the temperature rating of the conductor, if the corrected and adjusted ampacity does not exceed the ampacity for the temperature rating of the termination in accordance with the provisions of 110.14(C).

Informational Note: Table 310.15(B)(16) through Table 310.15(B)(19) are application tables for use in determining conductor sizes on loads calculated in accordance with Article 220. Allowable ampacities result from consideration of one or more of the following:

(1) Temperature compatibility with connected equipment, especially the connection points.
(2) Coordination with circuit and system overcurrent protection.
(3) Compliance with the requirements of product listings or certifications. See 110.3(B).
(4) Preservation of the safety benefits of established industry practices and standardized procedures.

(1) General. For explanation of type letters used in tables

Table 310.15(B)(2)(a) Ambient Temperature Correction Factors Based on 30°C (86°F)

For ambient temperatures other than 30°C (86°F), multiply the allowable ampacities specified in the ampacity tables by the appropriate correction factor shown below.

Ambient Temperature (°C)	Temperature Rating of Conductor			Ambient Temperature (°F)
	60°C	75°C	90°C	
10 or less	1.29	1.20	1.15	50 or less
11–15	1.22	1.15	1.12	51–59
16–20	1.15	1.11	1.08	60–68
21–25	1.08	1.05	1.04	69–77
26–30	1.00	1.00	1.00	78–86
31–35	0.91	0.94	0.96	87–95
36–40	0.82	0.88	0.91	96–104
41–45	0.71	0.82	0.87	105–113
46–50	0.58	0.75	0.82	114–122
51–55	0.41	0.67	0.76	123–131
56–60	—	0.58	0.71	132–140
61–65	—	0.47	0.65	141–149
66–70	—	0.33	0.58	150–158
71–75	—	—	0.50	159–167
76–80	—	—	0.41	168–176
81–85	—	—	0.29	177–185

11) Find the ampacity of a 4/0 THWN Cu. conductor routed in a conduit. The conductor is one of six current carrying conductors in the same conduit (two per phase). The conduit is routed through an ambient temperature of 43 degC.

Table 310.15(B)(16) gives the basic ampacity of this conductor as 230 Amps. First, six current-carrying conductors are in the same conduit. Table 310.15(B)(3)(a) indicates that we must multiply the conductor ampacity by .8. Second, the temperature is higher than normal. Table 310.15(B)(2)(a) shows a temperature derating multiplier of .82 for this situation.

Therefore, 230 A x .8 x .82 = 150.88 Amps

(B) 151 A

OSHA 1910 Subpart S

- The Occupational Safety and Health Administration (OSHA) has overall responsibility for the safety and health of industrial workers in the United States.
- However, their authority may sometimes be delegated to another agency such as the United States Coast Guard as explained above in Section 1. 3.
- Regardless of whether they delegate the authority, their regulations are still applicable to industries operating either onshore or offshore in the United States.
- For electrical systems, the applicable regulations are contained in 1910 subpart S. In addition, various state agencies may also exercise jurisdiction over some facilities, and where this is done, the National Electrical Code is typically the enforcing document.

API RP-l4F

- "The API Recommended Practice for Design and Installation of Electrical Systems for Offshore Production Platforms" is referred to as API RP-14F.

- The document recommends minimum requirements, and guidelines for the design and installation of electrical systems on fixed production platforms located *offshore,*

- and is intended to bring together in one place a brief description of basic desirable electrical practices for offshore electrical systems.

API RP-500

- The API document titled "Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities" is referred to as API RP-500.

- That document applies to the classification of locations for both temporarily and permanently installed electrical equipment.

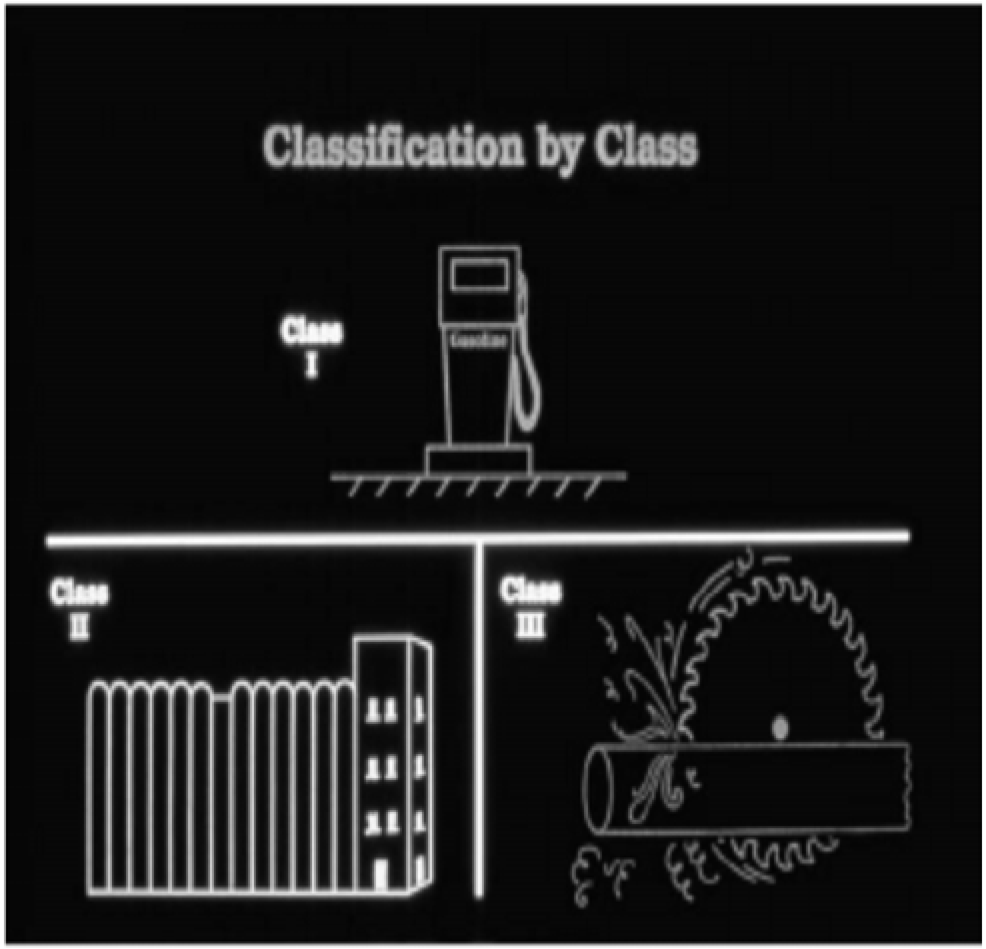
- The suitability of locations for the placement of non-electrical equipment is not covered.

- In addition, the recommendations do not address possible catastrophic conditions such as a well blowout or a process vessel rupture since such extreme conditions require emergency measures at the time of occurrence.

N.E.C. Article 500 Code Sections

- Article 500 Hazardous Locations
- Article 501 Class I Locations
- Article 502 Class II Locations
- Article 503 Class III Locations
- Article 504 Intrinsically Safe Systems
- Article 505 Class 1, Zone 0, 1, and 2 Locations
- Article 510 Hazardous Location -Specific
- Article 511 Commercial Garages
- Article 513 Aircraft Hangars
- Article 514 Gasoline Service Stations
- Article 515 Bulk Storage Plants
- Article 516 Paint Spray Application

Class Locations

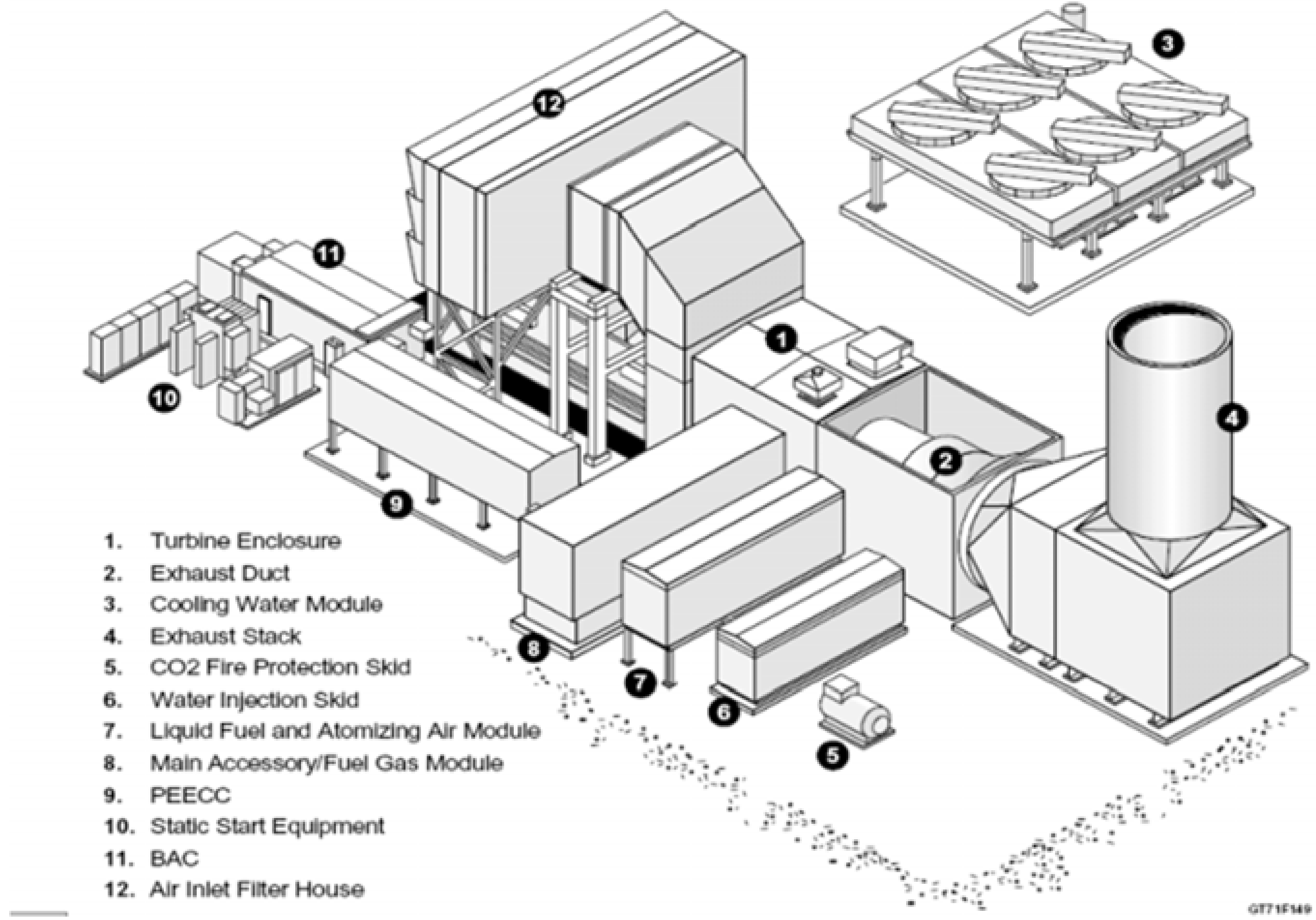


- N.E.C. Article 500.5 (B)
- An area where FLAMMABLE GASES or VAPORS are or may be present in the air in sufficient quantities to produce explosive or ignitable mixtures.

Class I Locations (Gases)

- N.E.C. Article 500.5 (B)
- An area where FLAMMABLE GASES or VAPORS are or may be present in the air in sufficient quantities to produce explosive or ignitable mixtures.

Class I Locations (Gases)
7FA GE Turbine Installation



Class I Locations (Gases)
7FA GE Turbine Installation

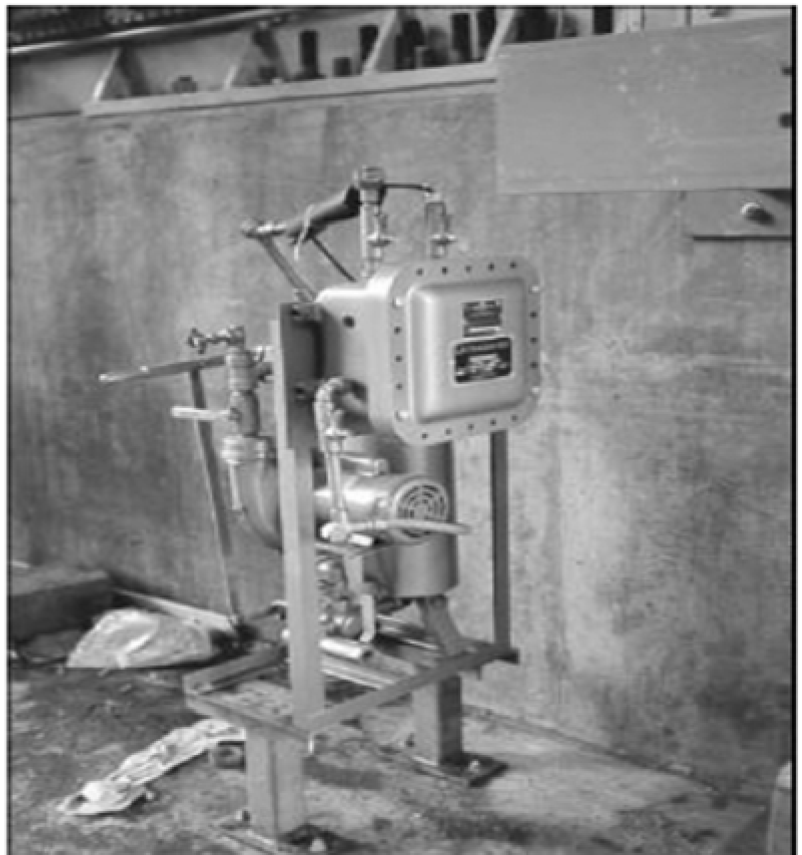


Figure 44. Hydrogen Dryer Used For 7FH2 Generator

Class I Locations (Gases)

CLASS I INDUSTRIES AND APPLICATIONS

- Natural or liquefied gas storage facilities
- Chemical plants
- Petroleum refineries
- Bulk handling or storage facilities for gasoline
- Dip tanks
- Storage tanks for flammable liquids or gas
- Spraying areas for paints or plastics
- Aircraft fuel servicing areas or hangers
- Well drilling (oil and gas), offshore or on
- Pipeline pumping areas
- Printing machine areas

Class II Locations (Dust)

- N.E.C. Article 500.5 (C)
- An area where presence of COMBUSTIBLE DUST presents a fire or explosion hazard.

Class II Locations (Dust)

CLASS II INDUSTRIES AND APPLICATIONS

- Grain storage, handling or processing plants
- Coal storage, handling or processing facilities
- Metal grinding or metal powder producing facilities
- Gunpowder or explosive (fireworks) plants
- Sugar, cocoa, spice or starch production or handling facilities

Class III Locations (Fibers)

- NEC Article 500.5 (D)
- An area made hazardous because of the presence of easily ignitable FIBERS or FLYINGS, but in which such fibers or flying's are not likely to be in suspension in the air in quantities sufficient to produce ignitable mixtures.

Class III Locations (Fibers)

- CLASS III INDUSTRIES AND APPLICATIONS
- Cotton, textile or flax producing or handling facilities
- Wood cutting, pulverizing or shaping plants
- Clothing manufacturing facilities

Locations

- Division 1
- Division 2

Division 1 Location

- NEC Articles 500.5(B)(1), 500.5(C)(1) and 500.5(D)(1)
- An area where the HAZARD EXIST UNDER NORMALOPERATING CONDITIONS. This also includes locations where the hazard is caused by frequent maintenance or repair work or frequent equipment failure.

Division 1 Location

- Consider that there are 8,760 hours in a year. It is proposed that a Division I location would be one that is within the flammable range more than 0.1% of the time, that is more than 8.76 hrs/yr.

- From a practical viewpoint on this basis, we would suggest that any area in the flammable range 10 hrs/yr. or more should be classified as Division 1.

Division 2 Location

- NEC Articles 500.5(B)(2) , 500.5(C)(2), and 500.5(D)(2)
- An area where ignitable gases, vapors, dust, or fibers are handled, processed, or used, but which EXIST ONLY UNDER ABNORMAL CONDITIONS, such as containers or closed systems from which they can only escape through accidental rupture or breakdown.
- Note: No electrically conductive dust are included in Class II, Division 2 atmospheres.

Division 2 Location

- A Division 2 location would be one that is within the range more than 0.01% and up to 0.1 % of the time (0.876 hours to 8.76 hours).

- From a practical viewpoint on this basis, we would suggest that any area in the flammable range classified as Division 2, would be in the range between 1-10 hrs/yr.

Comparison of Div 1 and Div 2 for Gases

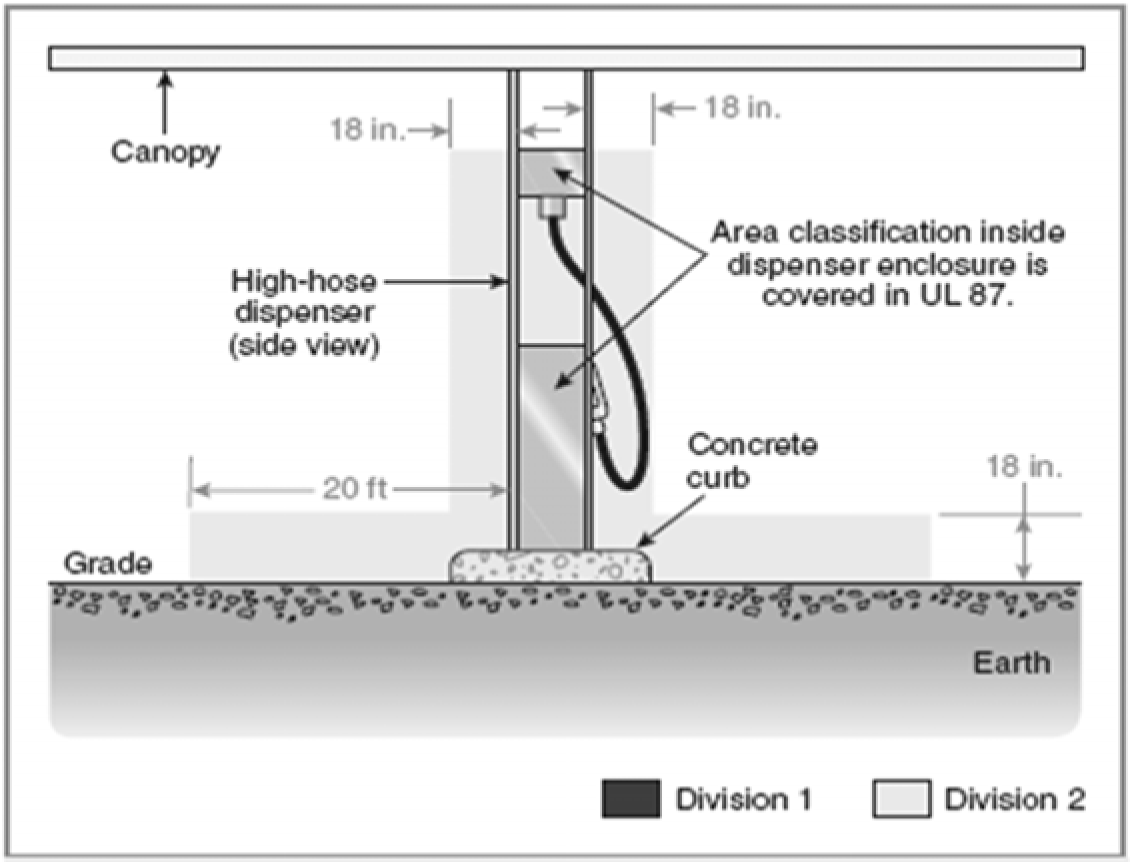
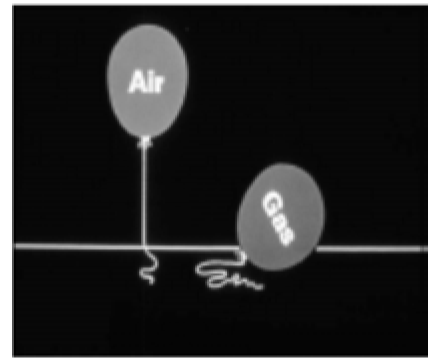
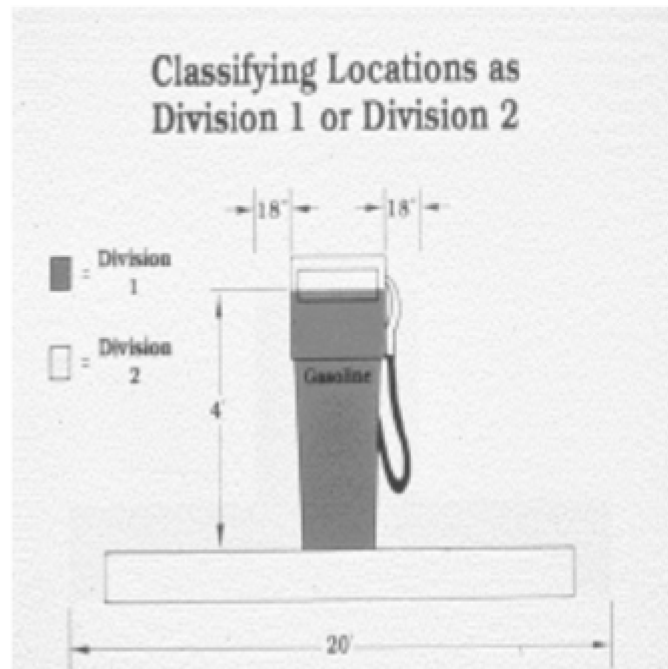


Exhibit 514.1 Extent of Class I location around overhead motor fuel dispensing units, in accordance with Table 514.3(B)(1).





Groups A, B, C, and D (Gases)

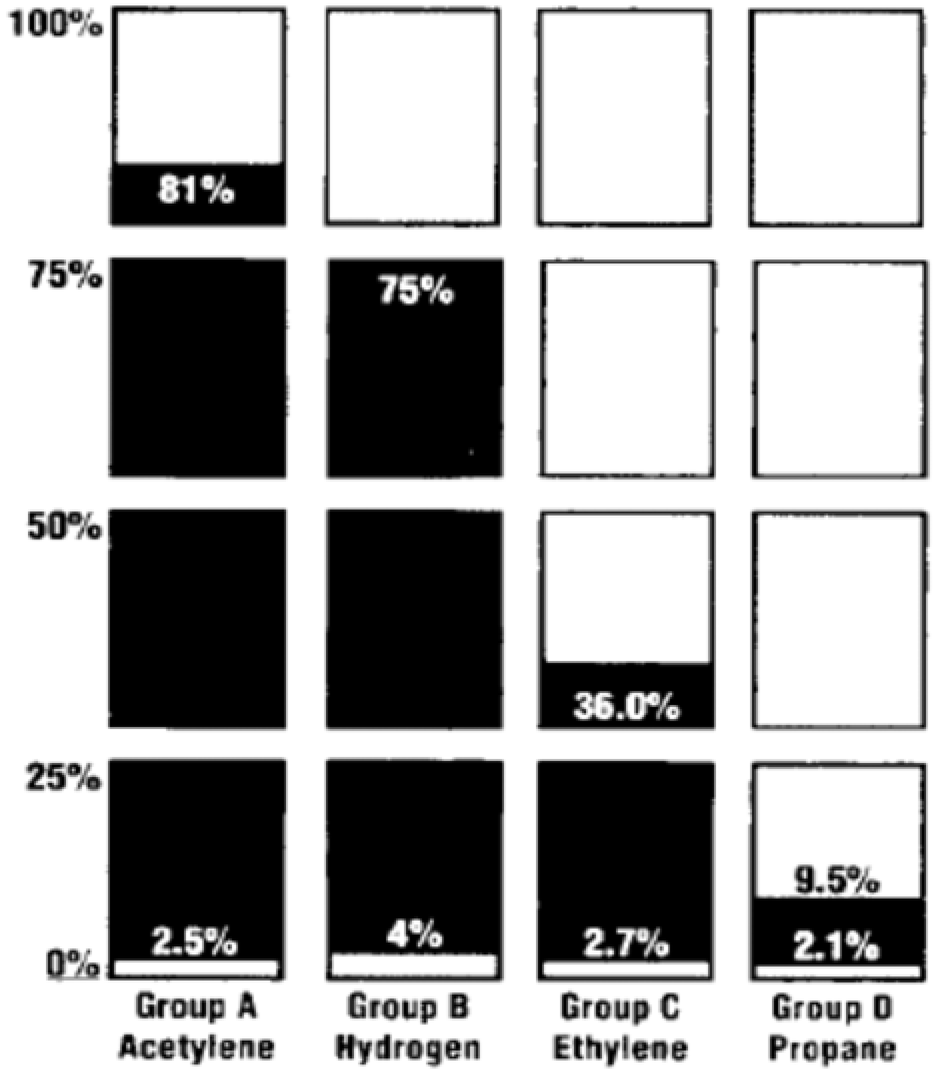
NEC Article 500.6(A)

- Groups indicates the DEGREE OF THE HAZARD.

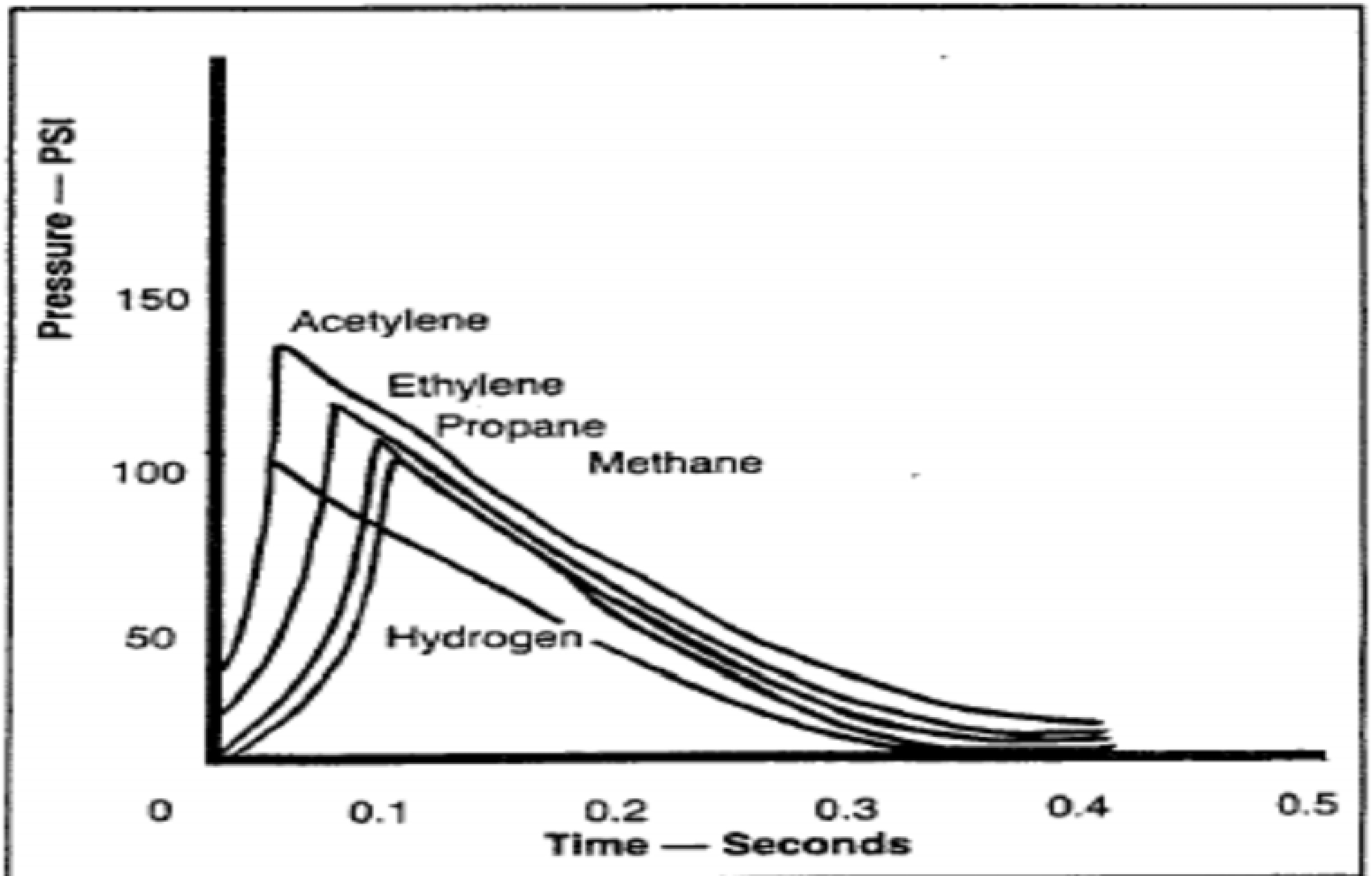
- GROUPS A, B, C and D are classified by chemical families as shown in NFPA 497M-1986 and 325M-1984.

- The important factor in classifying a gas or vapor by Group is how much PRESSURE is created during an explosion. Group A (Acetylene) creates the most pressure, with Group B (Hydrogen) next.

Groups A, B, C, and D (Gases)



Groups A, B, C, and D (Gases)

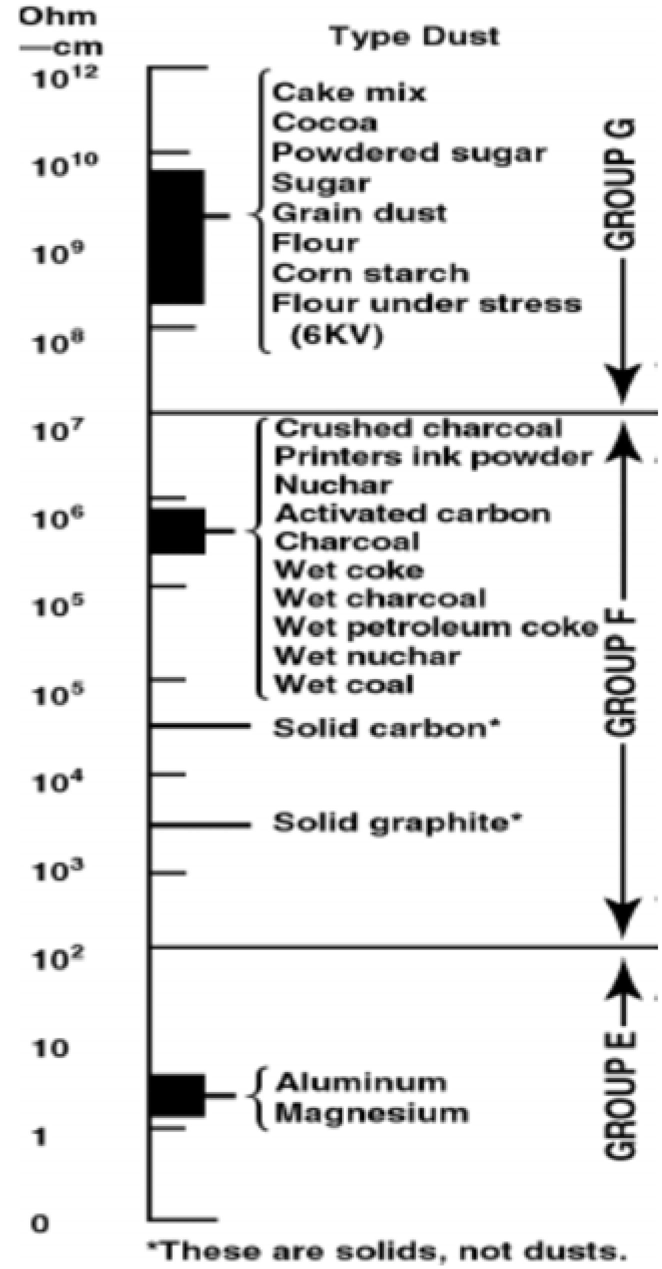


Relative speed and maximum pressure of five test gases: acetylene, hydrogen, ethylene, propane, and methane.

Groups E, F and G (Dust)

NEC Article 500.6(B)

- Groups indicates the DEGREE OF THE HAZARD, based on Electrical Resistivity from Table on right (Source: ANSI/ISA-S12.10-1988)
- GROUP E -Atmospheres containing combustible METAL DUST.
- GROUP F -Atmospheres containing CARBON BLACK, CHARCOAL, COAL, or COKE DUST.
- GROUP G -Atmospheres containing AGRICULTURAL and other dusts



Summary of Classes and Groups

CLASS I:FLAMMABLE VAPORS & GASSES (Volatile gas or vapor present in sufficient quantity to produce ignition or explosion).

GROUP A: ACETYLENE

GROUP B: HYDROGEN

GROUP C: ETHYLENE

GROUP D: GASOLINE

CLASS II:COMBUSTIBLE DUSTS (Combustible dusts present in sufficient quantity to present a fire or explosion hazard).

GROUP E: METAL DUSTS

GROUP F: CARBON DUSTS -COAL

GROUP G: GRAIN DUSTS

CLASS III:FIBERS & FLYINGS (Easily ignitable fibers or flyings present but not likely to be suspended in the air).

Understanding Power Concepts

Part 1

- Introduction
- Formulas (AC/DC Basics)
- Standards
- ***<u>Codes/Personal Safety</u>***
- Grounding

REFERENCES

- IEEE PES (Presentation Material)
- NFPA 70E
- IEEE 1584
- NEC
- OSHA
- SEL Arc Flash Seminar Material

- This presentation does not qualify the person to perform the calculation (a licensed professional engineer in the State the analysis is being conducted) shall perform the study.

- This presentation is for educational purposes.

ELECTRICAL HAZARDS

- Electrical shock
- Electrical arc-flash
- Electrical arc-blast

TYPICAL ELECTRICAL RESISTANCES

HUMAN BODY:

DRY SKIN - 100,000 TO 500,000 OHMS

WET SKIN (PERSPIRING) - DOWN TO 1,000 OHMS

IN WATER - DOWN TO 150 OHMS

FROM HAND TO A FOOT - 400 TO 600 OHMS

THROUGH THE HEAD, FROM EAR TO EAR, APPROXIMATELY 100 OHMS

BODY EFFECTS FROM ELECTRIC CURRENT VALUES

	CURRENT VALUES (Milliamperes)	EFFECTS
NON-LETHAL RANGE	1 OR LESS	NO SENSATION - PROBABLY NOT EVEN FELT.
	1 TO 8	SHOCK IS FELT BUT NOT PAINFUL. INDIVIDUAL CAN LET GO AT WILL. MUSCULAR CONTROL IS NOT LOST.
	8 TO 15	PAINFUL SHOCK. INDIVIDUAL CAN LET GO AT WILL BECAUSE MUSCULAR CONTROL IS NOT LOST.
	15 TO 20	PAINFUL SHOCK. MUSCULAR CONTROL IS LOST. CANNOT LET GO.
	20 TO 50	PAINFUL. SEVERE MUSCULAR CONTRACTIONS. CANNOT LET GO.
LETHAL RANGE	50 TO 200	POSSIBLE VENTRICULAR FIBRILLATION. (A HEART CONDITION THAT RESULTS IN DEATH - NO KNOWN EMERGENCY REMEDY AVAILABLE ON THE JOB.) MUSCULAR CONTRACTION AND NERVE DAMAGE
	OVER 200	SEVERE BURNS AND SEVERE MUSCULAR CONTRACTIONS - SO SEVERE THAT CHEST MUSCLES CLAMP HEART AND STOP IT FOR DURATION OF THE SHOCK.

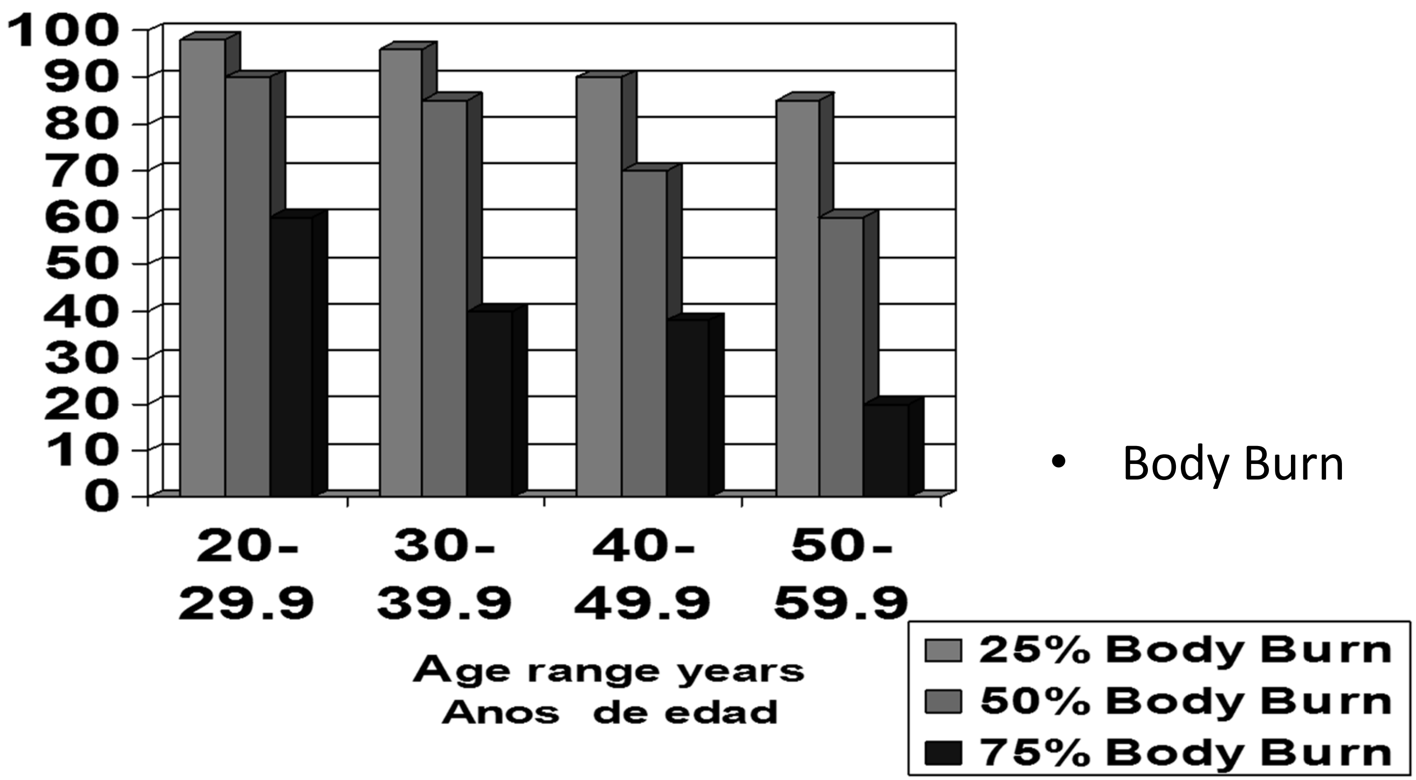
ELECTRICAL SHOCK

- Body resistance
- Wet or dry skins are major factors of resistance
- Circuit voltage
- Amount of current flowing through the body
- Current through the body
- Area of contact
- Duration of contact

ELECTRICAL ARC-FLASH

Arco electric-flash

Burn Injury - Probability of Survival



- Body Burn

American Burn Association (1991-1993 Study)

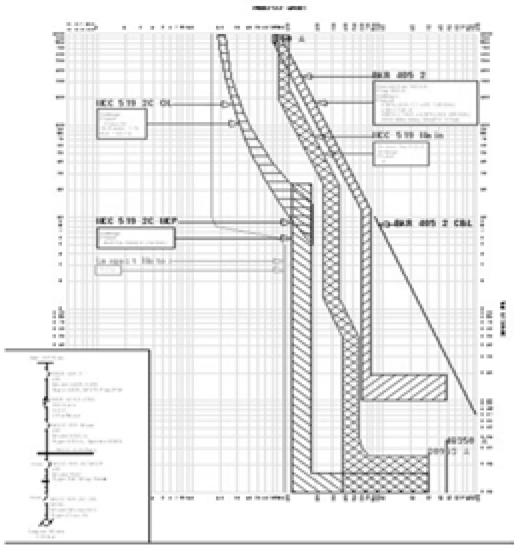
ELECTRICAL Arc-Blast

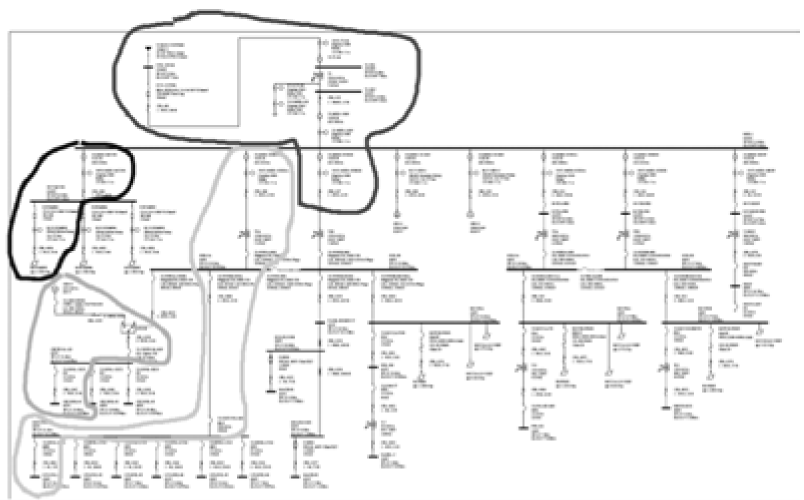
- Rapid expansion of the air caused by an electrical arc, referred to as an electrical arc-blast or explosion

CONTRIBUTING FACTORS TO ELECTRICAL ACCIDENTS

- Faulty Insulation
- Improper grounding
- Loose connections
- Defective Parts
- Ground faults in equipment
- Unguarded live parts
- Failure to de-energize electrical equipment when it is being repaired or inspected
- Intentional use of obviously defective and unsafe tools
- Use of tools or equipment too close to energized parts
- Tools left in electrical cubicle

An Introduction to Arc Flash

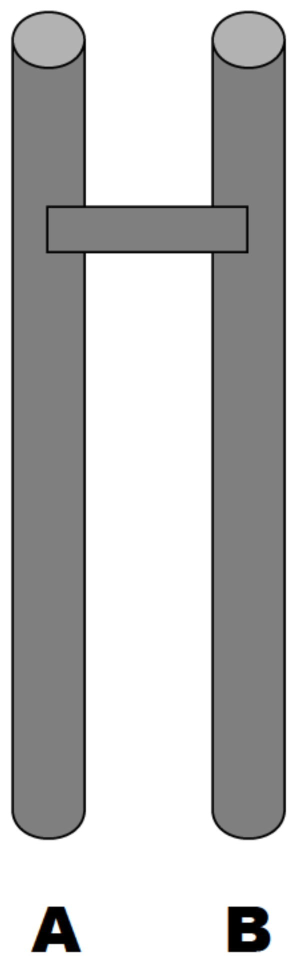




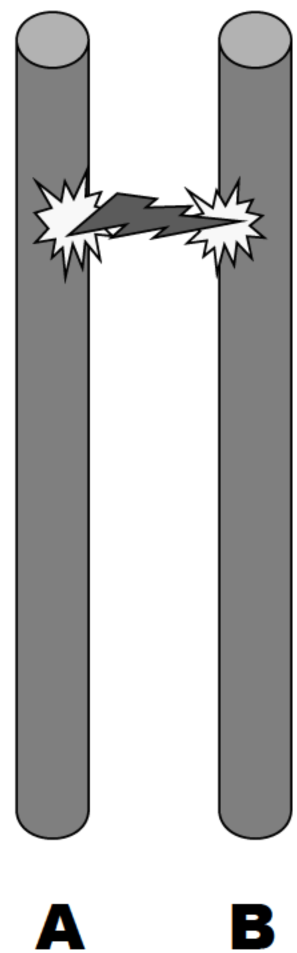
AGENDA

- Standards Related to Safety
- What is the purpose of an arc flash study?
- Approach to Arc Flash
- Preparing to Work Safely
- Discussion/Path Forward

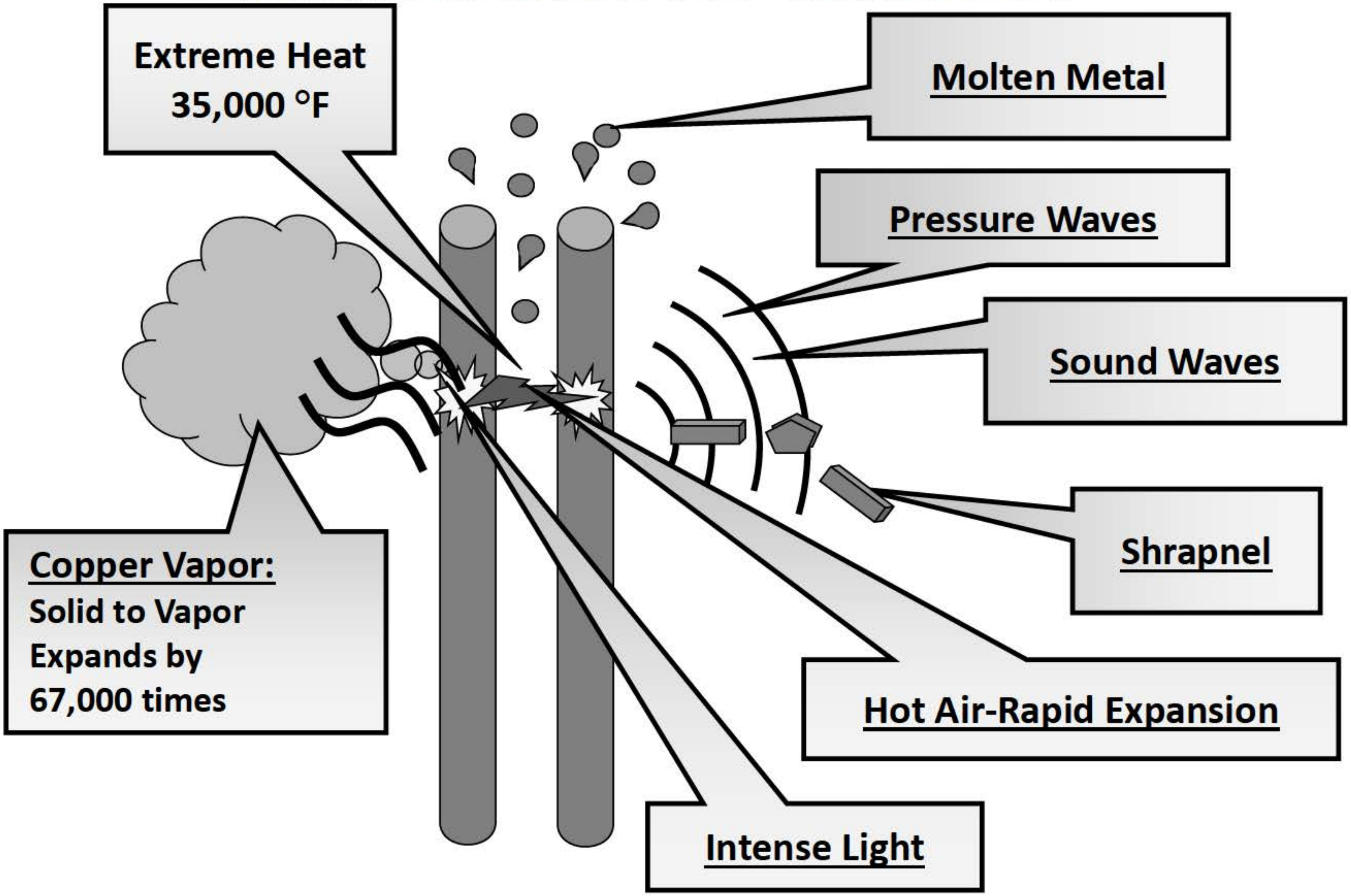
Bolted Short Circuit



Arcing Short Circuit



ARCING SHORT CIRCUIT



WHAT CAUSES ARC FAULTS?

– Human error
– Unintentional grounds
– Equipment failure (Poles welded shut)
– Forgotten tools lying on or near energized parts
– Undetected overheating
– Dielectric failure of the switchgear
– Small animals such as rat or snakes coming in contact with energized parts

AGENDA

- **Standards Related to Safety**
- What is the purpose of an arc flash study?
- Approach to Arc Flash
- Preparing to Work Safely
- Discussion/Path Forward

STANDARDS RELATED TO SAFETY

NFPA 70E

IEEE Standard 1584

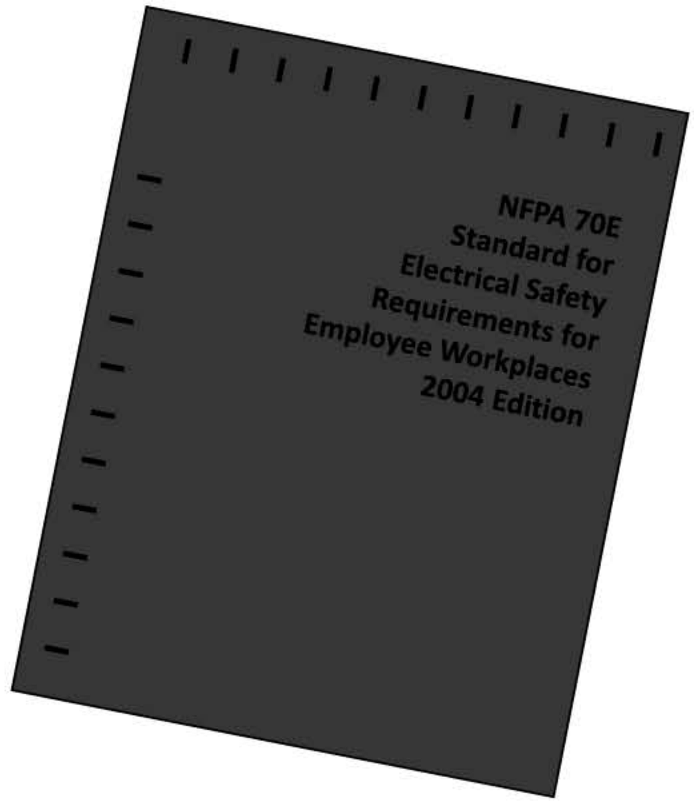
NEC 110.16

OSHA

NFPA 70E

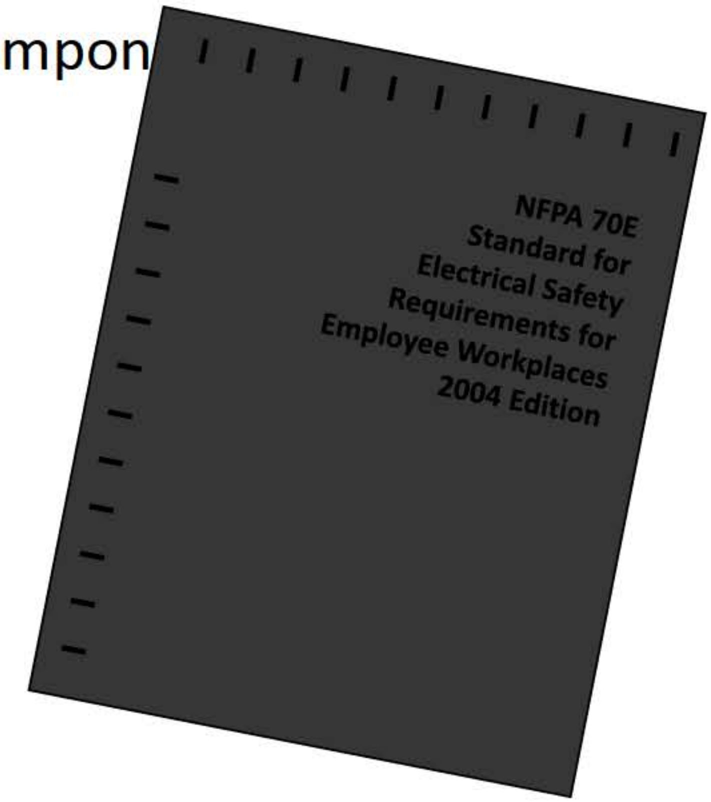
Safety of Employee Workplaces

- Part I – Installation Safety Requirements
- Part II – Safety Related Work Practices
- Part III – Safety Related Maintenance Requirements
- Part IV – Safety Requirements for Special Equipment



NFPA 70E

- Requirements for safe work practices
- Working on or near live electrical compon
- Addresses hazards:
  - Shock
  - Arc Flash
- Shock and arc flash boundaries
- Personal protective equipment
- Incident Energy and flash boundary calculations (<1000V, 5kA-106kA)



NFPA 70E - 2004

Appropriate safety-related work practices shall be determined before any person approaches exposed live parts within the Limited Approach Boundary by using both shock hazard analysis and flash hazard analysis.

NFPA 70E - 2004

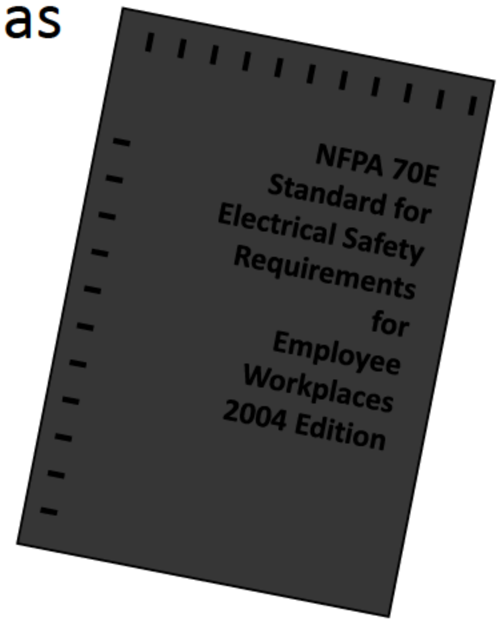
If live parts are not placed in an **electrically safe work conditions** (i.e., for the reasons of increased or additional hazards or infeasibility per 130.1) work to be performed shall be considered energized electrical work and shall be performed by written permit only.

NFPA 70E – 2009
130.3(C) – Equipment shall be filled marked with a label containing the available incident energy or required level of PPE

NFPA 70E - 2000

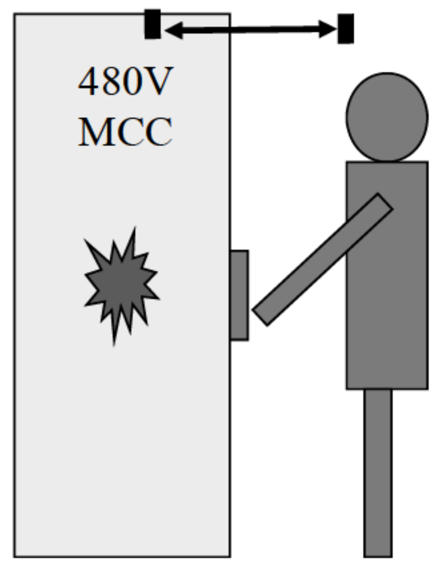
2-1.3.3 Flash Hazard Analysis

Flash hazard analysis shall be done before a person approaches any exposed electrical conductor or circuit part that has not been placed in an electrically safe work condition.



NFPA 70E

The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed.



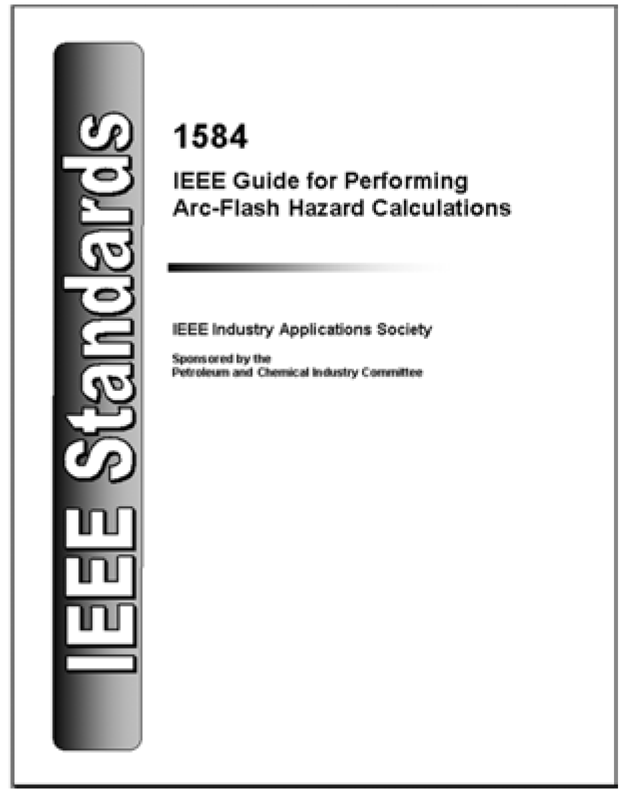
NFPA 70E

(B) Protective Clothing and Personal Protective Equipment for Application with a Flash Hazard Analysis. Where it has been determined that work will be performed within the Flash Protection Boundary by 130.3(A), the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker (in calories per square centimeter). The incident energy exposure level shall be based on the working distance of the employee's face and chest areas from a prospective arc source for the specific task to be performed. Flame-resistant (FR) clothing and personal protective equipment (PPE) shall be used by the employee based on the incident energy exposure associated with the specific task. Recognizing that incident energy increases as the distance from the arc flash decreases, additional PPE shall be used for any parts of the body that are closer than the distance at which the incident energy was determined As an alternative, the PPE requirements of 130.7(C)(9) shall be permitted to be used in lieu of the detailed flash hazard analysis approach described in 130.3(A).

FPN: For information on estimating the incident energy, see Appendix D.

IEEE Std 1584 - 2002

- Addresses Arc Flash Calculations:
  - Arcing Fault
  - Incident energy
  - Flash boundary
- Valid Ranges
  - 208 V to 15 kV
  - 700A to 106kA
  - Gap 13mm to 153mm
- Out of Range
  - Use Lee Equation



NEC® 2002 Article 110.16

NEC 2011 changed occupancies to units.

NEC 2008 added

110.16 Flash Protection. Electrical equipment, such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling ~~occupancies~~, and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

NEC® 2005 Article 110.16

<u>FPN No. 1: NFPA 70E-2004</u>, Standard for Electrical Safety in the Workplace, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

FPN No. 2: ANSI Z535.4 – 1998, Product Safety Signs and Labels for application to products.

AGENDA

- Standards Related to Safety
- **<u>What is the purpose of an arc flash study?</u>**
- Approach to Arc Flash
- Preparing to Work Safely
- Discussion/Path Forward

ARC-FLASH STUDIES

Purpose

To examine the incident energy and arc-flash boundary at each electrical equipment location in the electrical system.

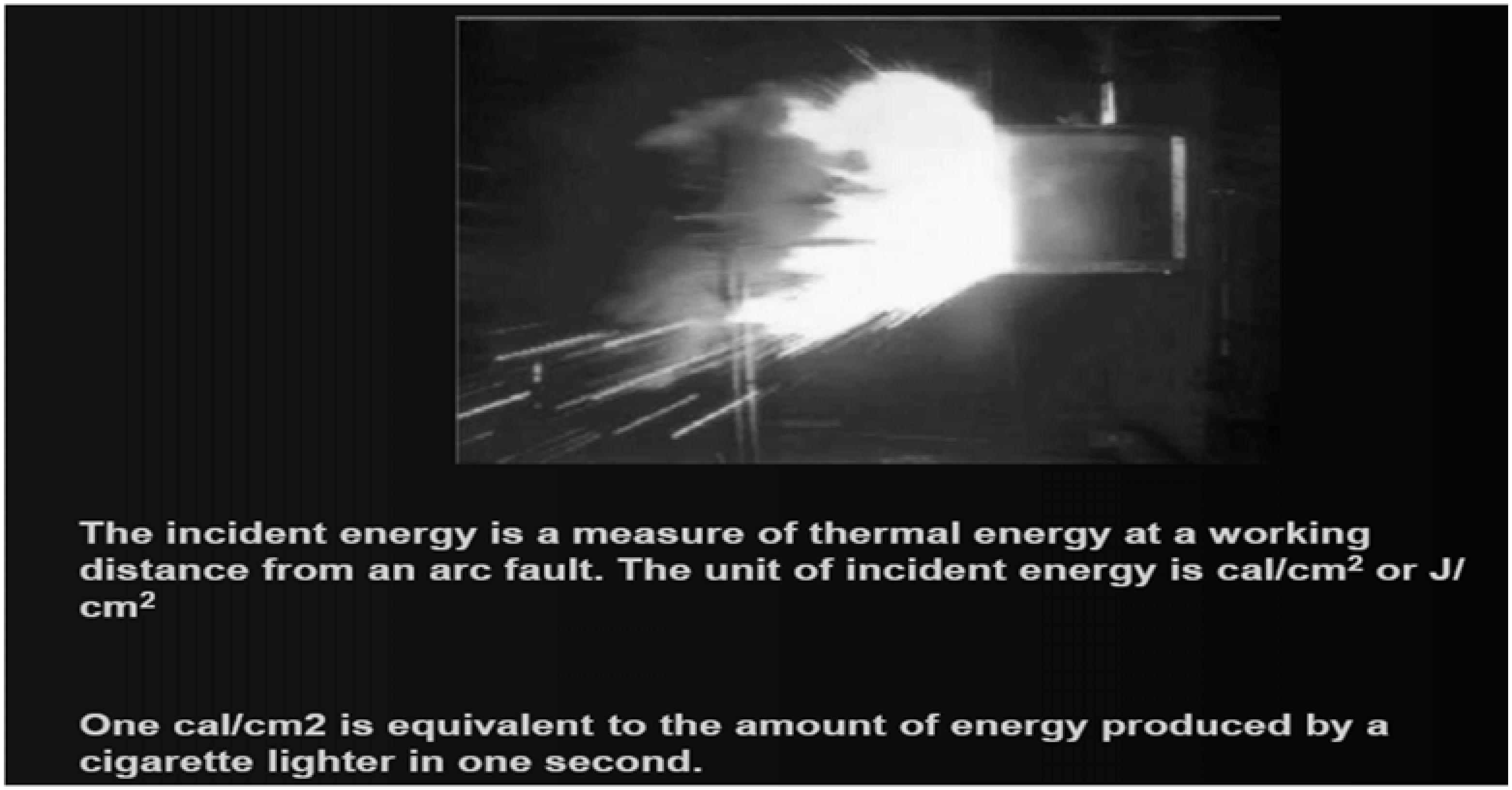
Study Used to Determine:

- Incident energy
- Arc-Flash Boundary
- Personal Protective Equipment (PPE)

Goals

- Introduce operating procedures to avoid exposure.
- Keep incident energy under 40-cal/cm^2 if possible.

INCIDENT ENERGY



Energy Per Unit of Area Received On A Surface Located A Specific Distance Away From The Electric Arc, Both Radiant And Convective, in Units of cal/cm^2.

Use IEEE 1584 Calculations

Preliminary IEEE 1584 work used in NFPA 70E

NFPA 70E equations limited to < 1000V

IEEE 1584 equations expanded to 15,000V

NFPA 70E 38% Arcing Fault Current is overly conservative and doesn't guarantee worst case incident energy.

INCIDENT ENERGY

$$\log(En) = K1 + K2 + 1.081 \log(Ia) + 0.0011\,G$$

En	*Incident energy (J/cm^2) normalized for 0.2s arcing duration and 610mm working distance*
K1	*–0.792 for open configuration* *–0.555 for box configuration (switchgear, panel)*
K2	*0 for ungrounded and high resistance grounded systems* *-0.113 for grounded systems*
Ia	*Arcing fault current*
G	*gap between bus bar conductors in mm*

solve $En = 10^{\log En}$

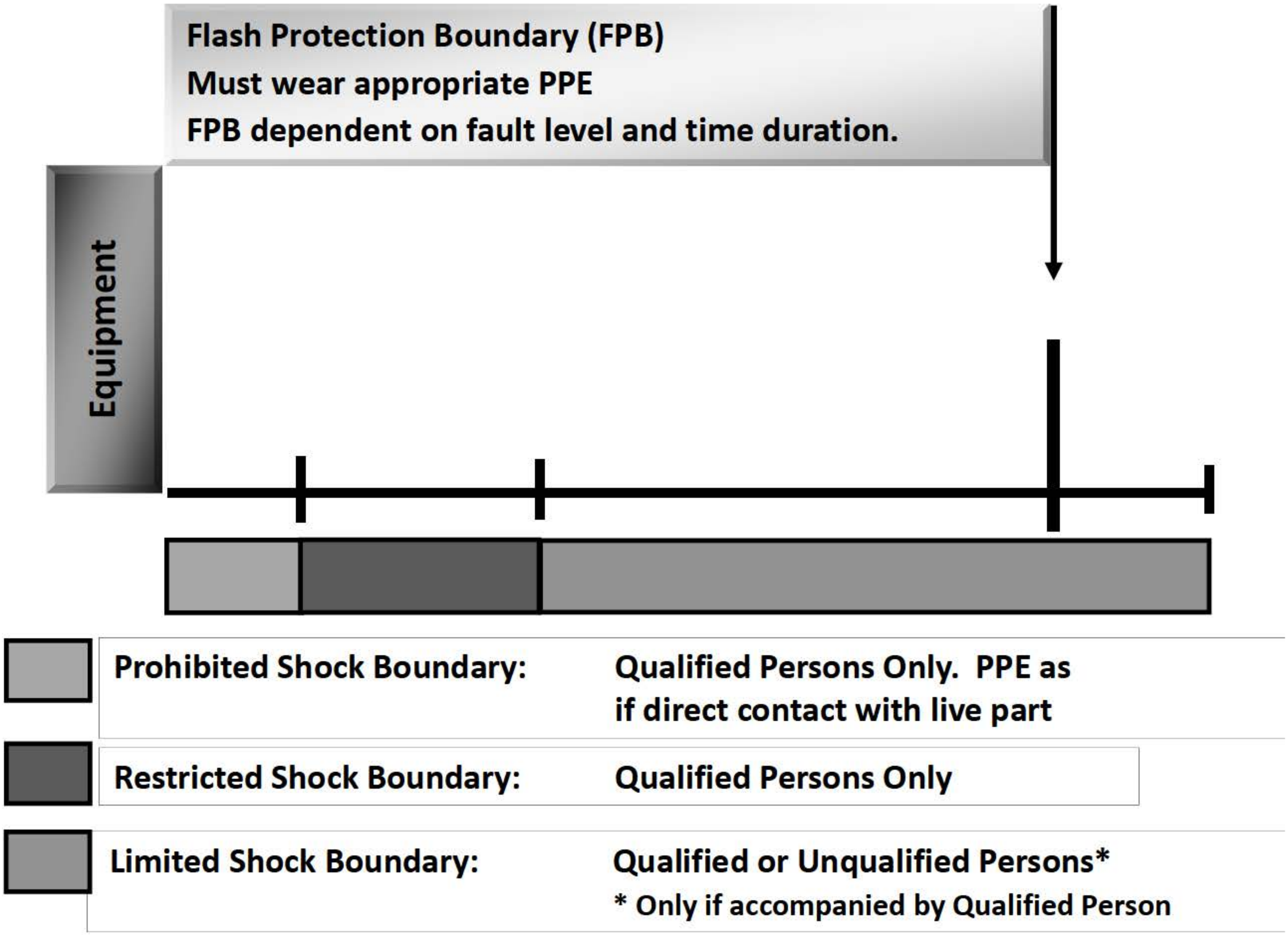
INCIDENT ENERGY

Incident Energy convert from normalized:

$$E = 4.184\ C_f\ En\ (t/0.2)\ (610^X / D^X)$$

E	*incident energy (J/cm^2)*
C_f	*1.0 for voltage above 1 kV and 1.5 for voltage at or below 1 kV*
t	*arcing duration in seconds*
D	*working distance*
x	*distance exponent*

x	*Equipment Type*	*kV*
1.473	*Switchgear*	*<= 1*
1.641	*Panel*	*<= 1*
0.973	*Switchgear*	*> 1*
2	*Cable, Open Air*	



Note: shock boundaries dependent on system voltage level

Flash Boundary

D_B arc flash boundary (mm) at incident energy of 5.0 (J/cm^2)

$$D_B = [\, 4.184\, C_f\, En\, (t/0.2)\, (610^X / E_B)\,]^{1/X}$$

where

E_B incident energy set 5.0 (J/cm^2)
C_f 1.0 for voltage above 1 kV and
1.5 for voltage at or below 1 kV
t arcing duration in seconds
x distance exponent

x	*Equipment Type*		*kV*
1.473	*Switchgear*	*<= 1*	
1.641	*Panel*		*<= 1*
0.973	*Switchgear*	*> 1*	
2	*all others*		

The flash boundary is essentially a reverse calculation to determine the distance where the incident energy is equal to 1.2 calories per square centimeters.

Appropriate PPE

Incident Energy From (cal/cm2)	Incident Energy To (cal/cm2)	Hazard Risk Category	Clothing Description	Clothing Layers	Required Minimum Arc Rating of PPE (cal/cm2)	Notes
0.0	1.2	0	Untreated Cotton	1	N/A	
1.2	4.0	1	FR Shirt & Pants	1	4	
4.0	8.0	2	Cotton Underwear + FR Shirt & Pants	1 or 2	8	
8.0	25.0	3	Cotton Underwear + FR Shirt & Pant + FR Coverall	2 or 3	25	
25.0	40.0	4	Cotton Underwear + FR Shirt & Pant + Multi Layer Flash Suit	3 or more	40	

AGENDA

- Standards Related to Safety
- What is the purpose of an arc flash study?
- **<u>Approach to Arc Flash</u>**
- Preparing to Work Safely
- Discussion/Path Forward

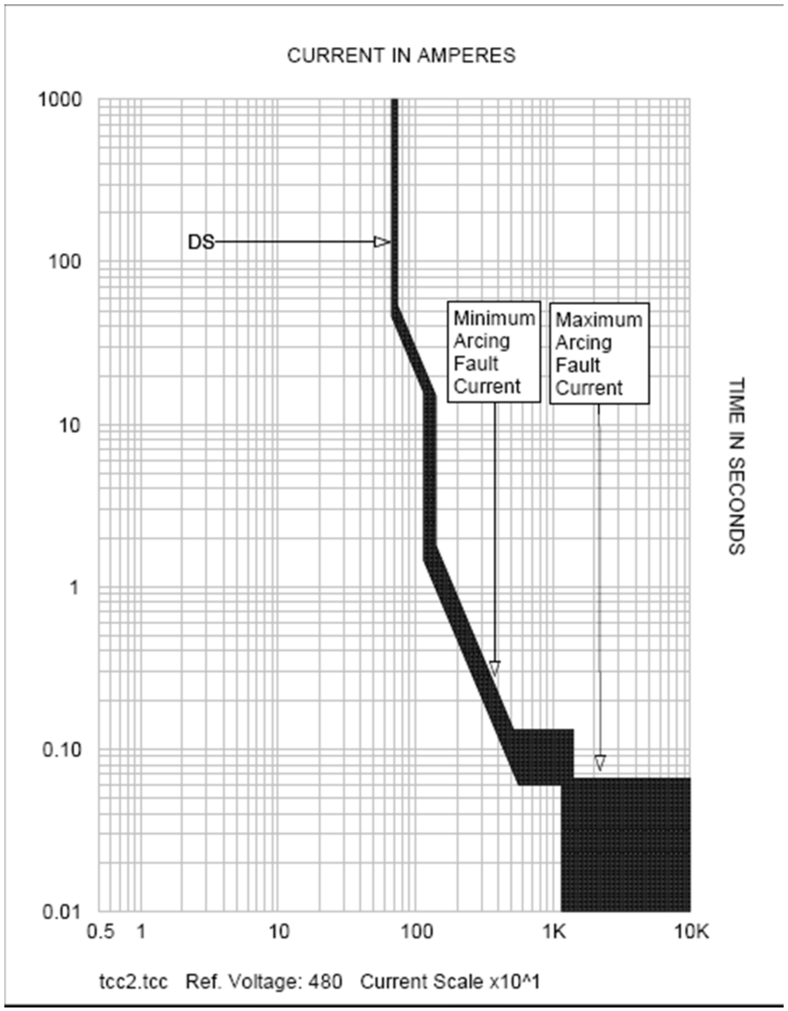
6 Step Approach

1. Project Understanding
2. Build an Electrical System Model
3. Short Circuit Calculations
4. Protective Device Coordination Study
5. Arc-Flash Hazard Analysis
6. Review and Implement the Results

Data Required

- One-Line Diagrams
- Breaker/Switch Positions
- Utility Short-Circuit Contribution
- Transformer Data
- Generator Data
- Reactor Data
- Cable Lengths & Sizes
- Connected Rotating Machinery
- Breaker Clearing Times
- CT Ratios
- Relay/Trip Unit Manufacturer & Models
- Relay/Trip Unit Settings (Phase & Ground)
- Fuse Data

Issues – Arc Fault Tolerance



- **A Small Reduction in Available Fault Current can result in a large increase in incident energy due to longer trip time.**
- **IEEE P1584 suggests to calculate incident energy based on 100% and 85% of the arcing fault.**
- **NFPA 70E suggests to calculate incident energy based on 100% and 38% of the fault current.**

PERFORM AN ARC FLASH ANALYSIS

- Arc Flash Calculation Step Review
  - Determine System Modes of Operation
  - Calculate Bolted Fault Current at each Bus
  - Calculate Arcing Fault Current at each Bus
  - Calculate Arcing Fault Current seen by each Protective Device
  - Determine Trip Time for Each Protective Device based on Arcing Fault Current
  - Calculate Incident Energy at Working Distance
  - Calculate Arc Flash Boundary
  - Determine Required PPE

Deliverables

1. Updated One Lines
2. Arc Flash Data
3. Incident Energy
4. Arc Flash Boundary
5. Personal Protective Equipment
6. Classification of Hazard/Risk Category
7. Working Distances
8. Labels
9. Comprehensive Report

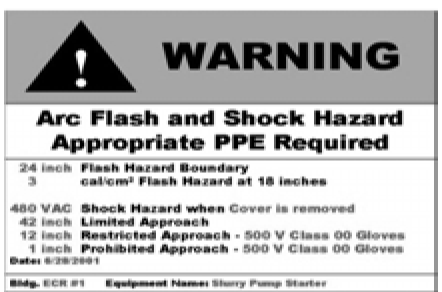


Table 1-3

Incident Energy Calculation Summary

Bus Name	Main Breaker/Bus	Equipment Type	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm^2)	Required Protective FR Clothing Class
400-1B (400-1/16 FU)	Main	SWGR	253.00	18	58.5	Not Defined – Should establish work practices to avoid operating or working on equipment while energized.
400-2A	Bus	SWGR	236.18	18	52.98	Not Defined – Should establish work practices to avoid operating or working on equipment while energized.
400-2A (400-2/2 FU)	Main	SWGR	266.00	18	63.2	Not Defined – Should establish work practices to avoid operating or working on equipment while energized.

Table 1-3

Incident Energy Calculation Summary

Bus Name	Main Breaker/Bus	Equipment Type	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm^2)	Required Protective FR Clothing Class
400-1A	Bus	SWGR	182.63	18	36.28	Category 4 - Cotton Underwear + FR Shirt & Pant + Multi Layer Flash Suit
400-1A (400-1/2 FU)	Main	SWGR	292.00	18	72.4	Not Defined – Should establish work practices to avoid operating or working on equipment while energized.
400-1B	Bus	SWGR	153.62	18	28.12	Category 4 - Cotton Underwear + FR Shirt & Pant + Multi Layer Flash Suit

⚠ WARNING

Arc Flash and Shock Hazard
Appropriate PPE Required

WARNING

Arc Flash and Shock Hazard
Appropriate PPE Required

24 inch Flash Hazard Boundary
3 cal/cm^2 Flash Hazard at 18 inches
1DF PPE Level, 1 Layer 6 oz Nomex ®,
Leather Gloves Faceshield

480 VAC Shock Hazard when Cover is removed
36 inch Limited Approach
12 inch Restricted Approach -500 V Class 00 Gloves
1 inch Prohibited Approach -500 V Class 00 Gloves

Equipment Name: Slurry Pump Starter

AGENDA

- Standards Related to Safety
- What is the purpose of an arc flash study?
- Approach to Arc Flash
- **Preparing to Work Safely**
- Discussion/Path Forward

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
  - Job briefing (written work processes & procedures)
  - Energized work permit

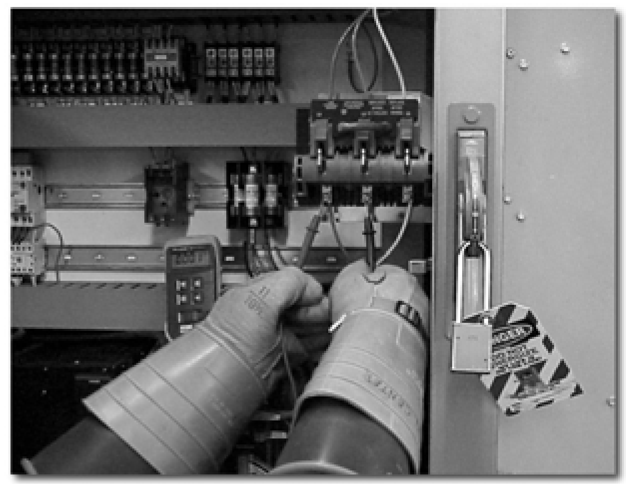
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category

Safe Work Practices

OSHA 1910.333 (a) (1) & NFPA 70E 130.1

not to work "hot" or "live" except when Employer can demonstrate:

1. De-energizing introduces additional or increased hazards
2. Infeasible due to equipment design or operational limitations



PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
  - Bolted Fault
  - Arcing Fault
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
- Know Safe Approach Distance
  - Limits of approach
  - Flash boundary
- Know Hazard Risk Category
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
  - Time current curves
  - Coordination studies
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
  - NFPA 70E Method
  - IEEE 1584 Method
- Know Hazard Risk Category

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Documented Procedures
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category
  - NFPA 70E

PREPARING TO WORK SAFELY
WHAT DO WE NEED TO KNOW OR DO?

- Prepare to work safely
- Know Fault Current Calculations
- Know Safe Approach Distance
- Know Arcing Fault Clearing Time
- Know the Incident Energy Exposure Calculations
- Know Hazard Risk Category

But Why?

Arc Flash Incident

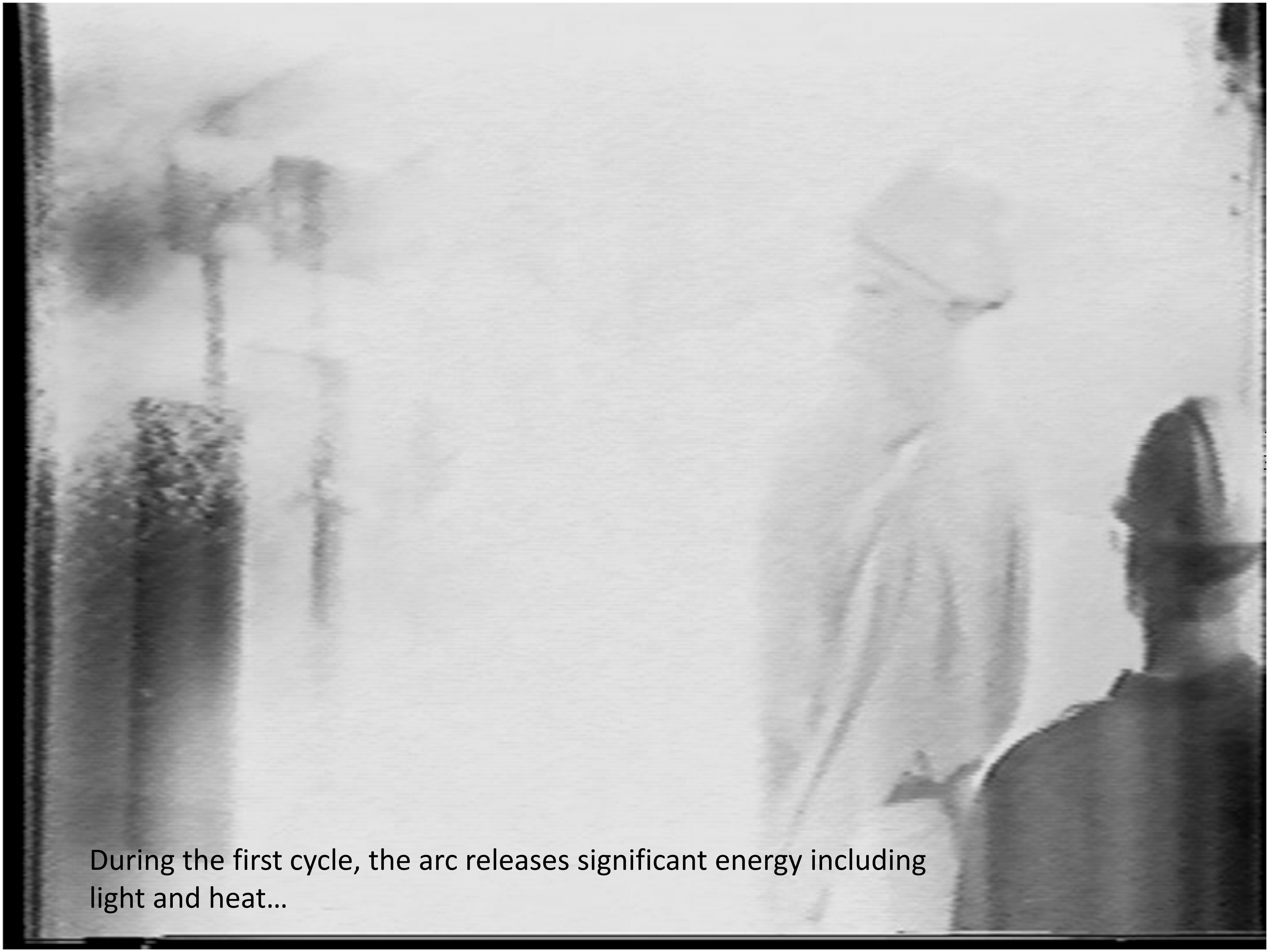
480 Volt System

22,600 Amp Symmetrical Fault

Motor Controller Enclosure

6-Cycle Arcing Fault (0.1 sec)

Each slide represents approximately 1 cycle



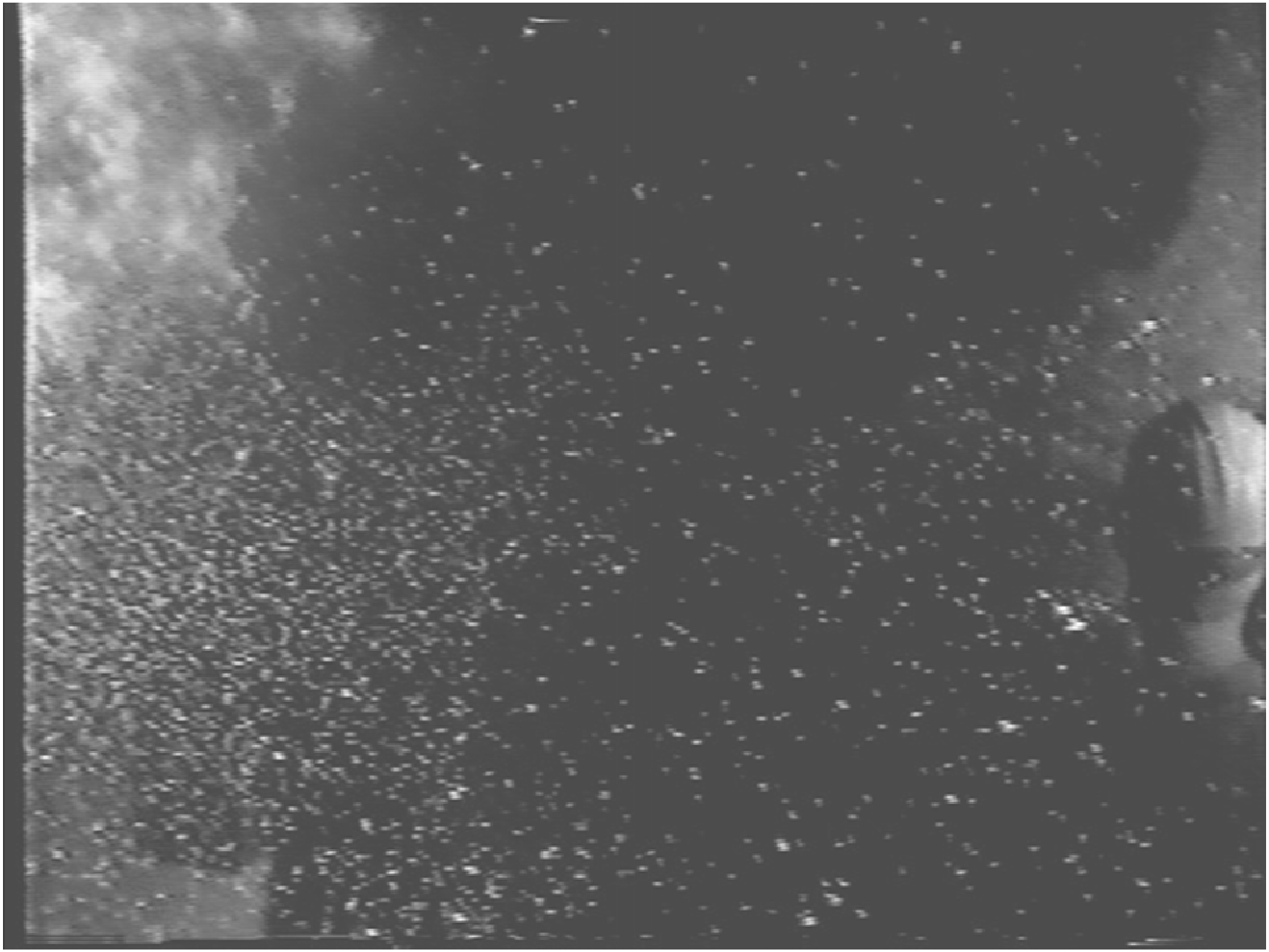
During the first cycle, the arc releases significant energy including light and heat…

At 2 cycles, vapor and debris can be seen.


At 3 cycles, the pressure and sound waves
begin to move the worker.

At 4 cycles, the equipment and worker are engulfed in flame.


At 5 cycles smoke rises from the fire.



Arc Flash Incident

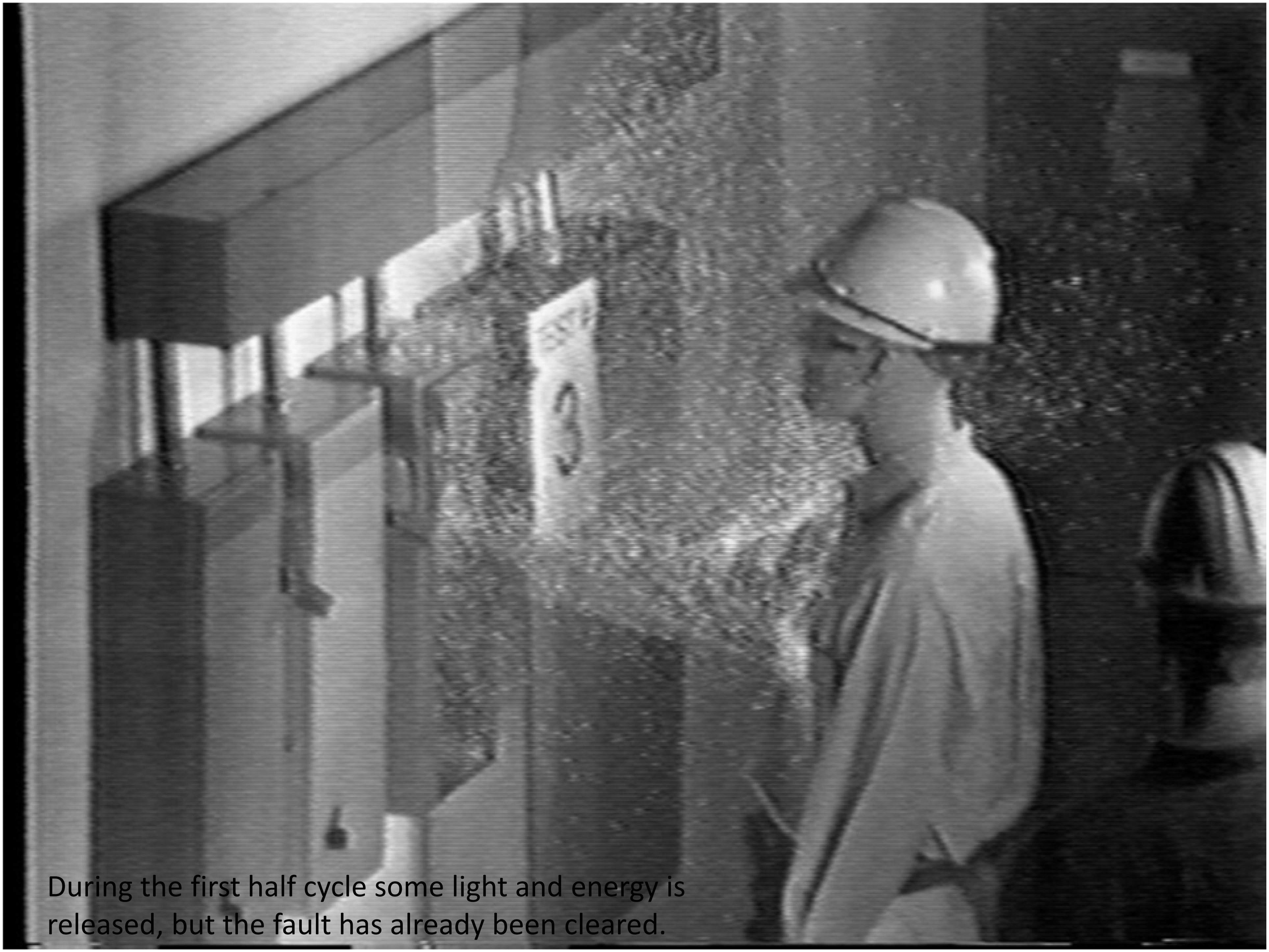
480 Volt System

22,600 Amp Symmetrical Fault

Motor Controller Enclosure

Current Limiting Device with < ½ Cycle operation (.0083 sec). Note that Arcing Fault must be in current limiting range.

Again each slide represents approximately 1 cycle.



During the first half cycle some light and energy is released, but the fault has already been cleared.

At 2 cycles, the environment begins to return to normal.

3 cycles

4 cycles

5 cycles. For this case, by clearing the fault is less than ½ cycle, there is no perceivable damage

Recommendations to Reduce Incident Energy Levels

- Use optical sensors when flash occurs
- Use instantaneous settings when work is being performed (maintenance settings)
- Reactors (current limiting)
- Differential protection (increases complexity an
- Fuses and or breakers (current limiting)
- Block paralleling capabilities (watch for electrical reliability issues)

Arc Protection System REA

Minimizes material damage and allows smooth, safe power restoration

Supplied with a value-adding information package

Enables fail-safe and instantaneous arc detection

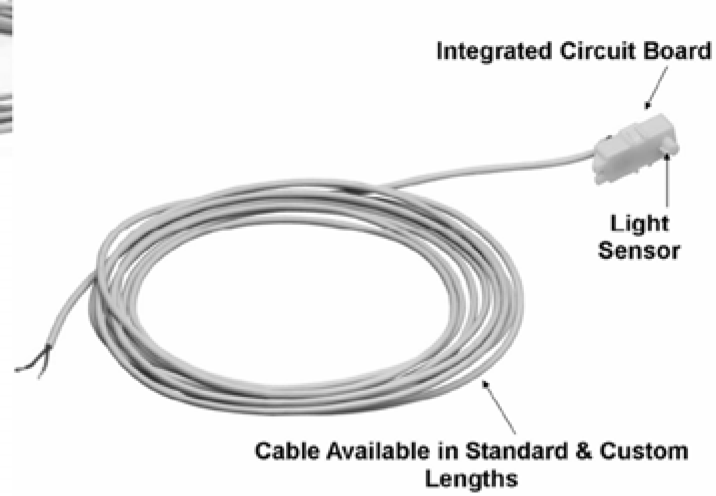
Patented fiber-optic loops and flexible overcurrent monitoring for total protection

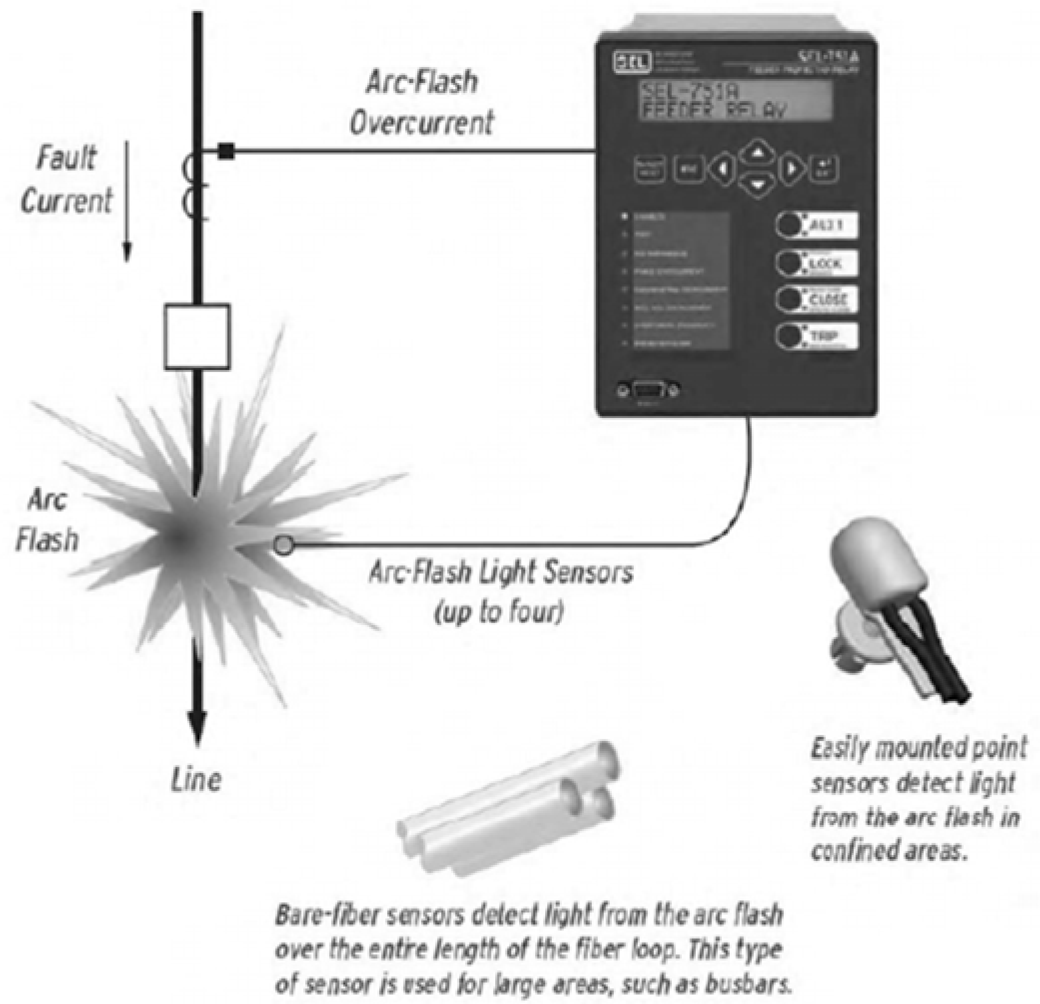
Technology promotes quick reaction and cost-effective installation

VAMP

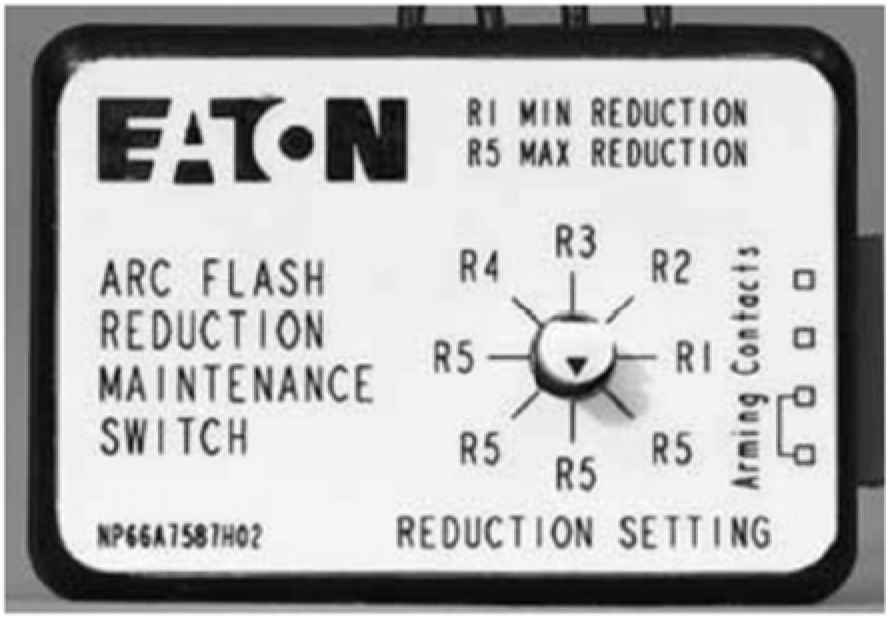
Arc Protection Series
VAMP 121
VAMP 221

Arc Detection Point Sensor



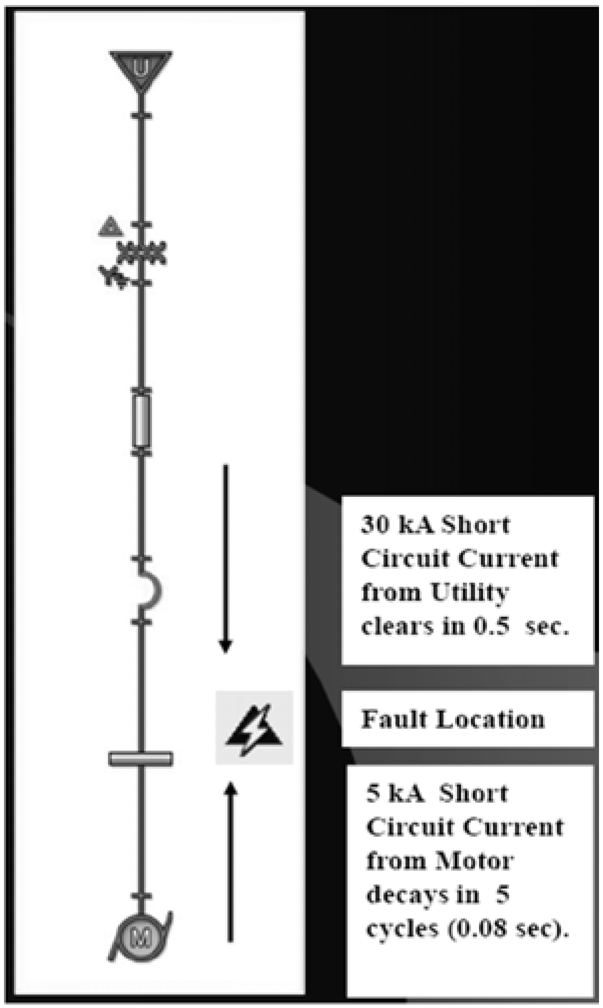

Arc-Flash
Overcurrent
Fault
Current
SEL-751A
FEEDER RELAY
LOCK
CLOSE
TRIP
Arc
Flash
Arc-Flash Light Sensors
(up to four)
Line
Easily mounted point sensors detect light from the arc flash in confined areas.
Bare-fiber sensors detect light from the arc flash over the entire length of the fiber loop. This type of sensor is used for large areas, such as busbars.

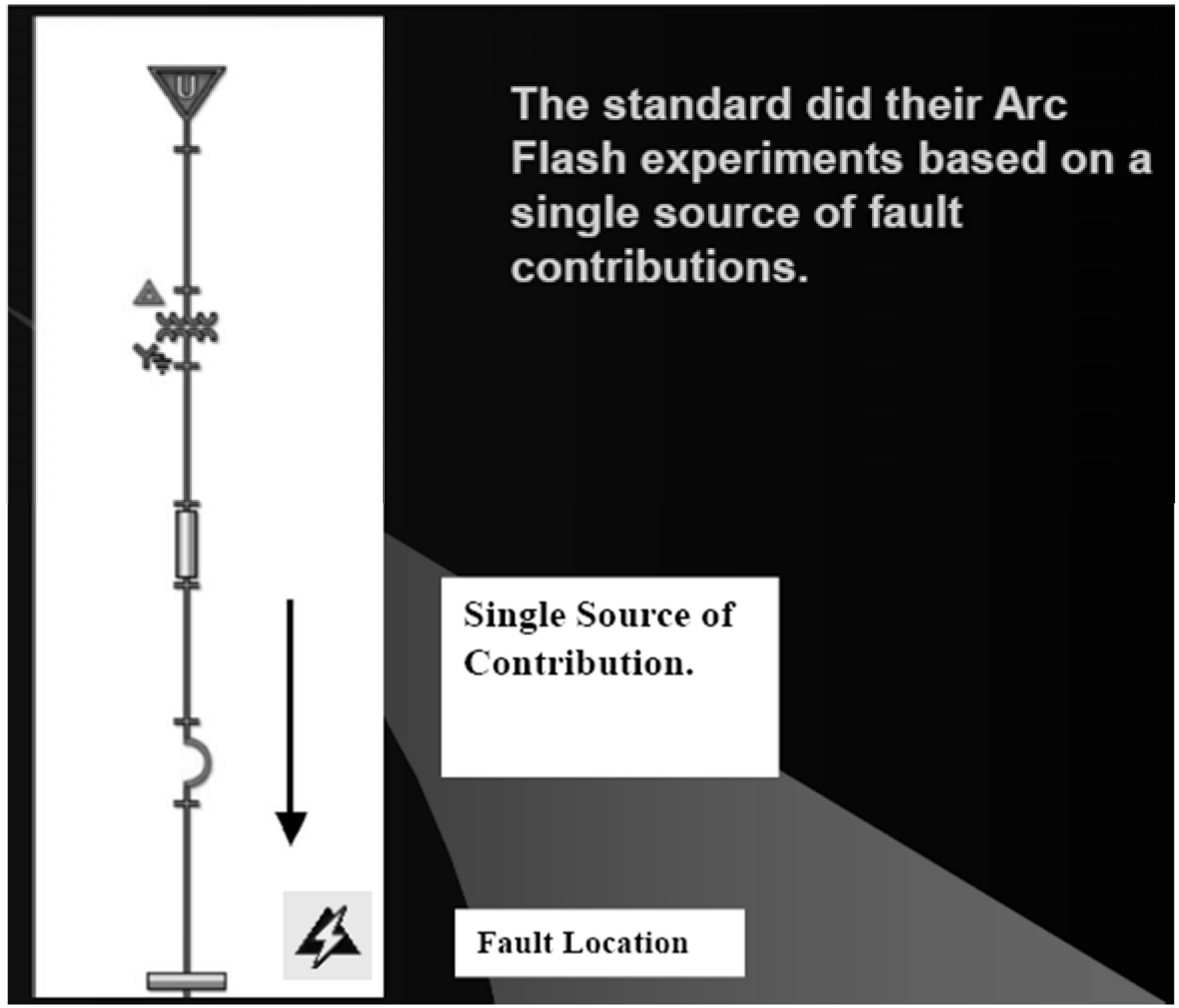
(2.5 ×, 4.0 ×, 5.9 ×, 7.6 × or 9.8 × sensor rating).

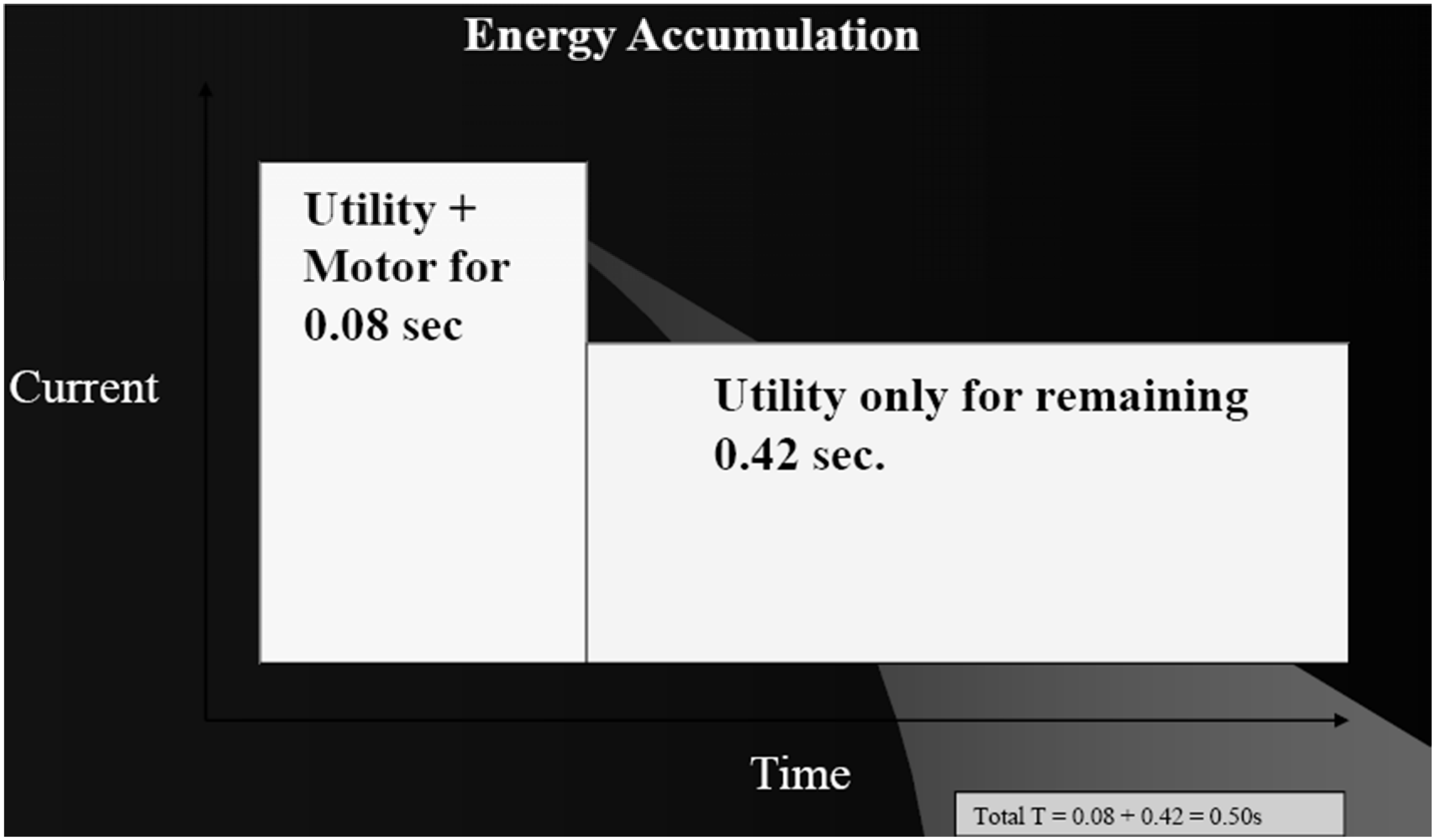


PICK UP SETTINGS	REDUCTION SETTING SWITCH POSITION
9.8	R1
7.6	R2
5.9	R3
4.0	R4
2.5	R5

Figure 1. Arcflash Reduction Maintenance Switch RS.


30 kA Short Circuit Current from Utility clears in 0.5 sec.
Fault Location
5 kA Short Circuit Current from Motor decays in 5 cycles (0.08 sec).


The standard did their Arc Flash experiments based on a single source of fault contributions.
Single Source of Contribution.
Fault Location


Energy Accumulation
Utility + Motor for 0.08 sec
Utility only for remaining 0.42 sec.
Current
Time
Total T = 0.08 + 0.42 = 0.50s

Recommendations to Reduce Incident Energy Levels

- Decrease pickup and delay settings (watch your coordination issues)
- Change relay settings or replacing fuse types to reduce incident energy from arc flash events.
- Reduce fuse sizes (watch your coordination issues)
- Implement instantaneous functions
- Use current-limiting breakers or fuses for high arcing fault currents

Be familiar with the equipment, this will help minimize human error.

PREVENTING ELECTRICAL ACCIDENTS

- Largely preventable through safe work practices
- Examples of some safe work practices
  - De-energizing electrical equipment for inspection and repair
  - Keeping electrical and equipment properly maintained
  - Exercising caution when working near exposed energized lines or equipment
  - Using appropriate personal protective equipment and insulated tools

ELECTRICAL SAFETY

- ENVIRONMENT, SAFETY AND HEALTH PRINCIPLES (used by DOE)
- Plan Work
- Analyze Hazards
- Control Hazards
- Perform Work
- Feedback and improve

ELECTRICAL ACCIDENTS CAUSED BY ONE OF THE FOLLOWING

- Unsafe work practices
- Unsafe equipment or installation
- Unsafe environment

REQUIREMENTS

- Knowledge/Familiarity
- Mechanical Interlocks
- Electrical Interlocks
- Bus Transfer Procedures
- Lock, Tag and Try Procedures

REQUIREMENTS

- Workers: Trained and Qualified
- One Line Diagrams: Up- to- date and attached to procedures
- Test Equipment: Good working condition and calibrated
- PPE(Personal Protective Equipment) Good Working Condition and tested per standards

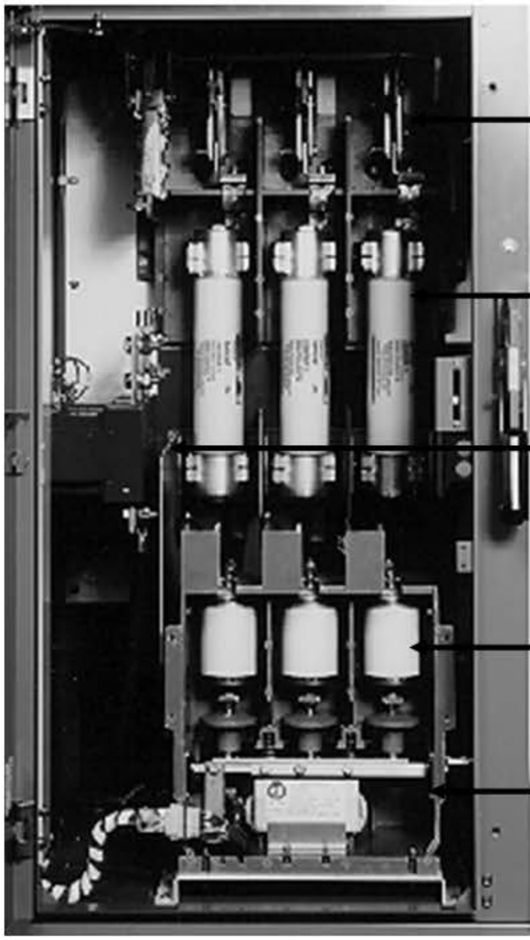
SAFETY INTERLOCKS IN MEDIUM VOLTAGE STARTERS

- Protective Barriers for Safe Operation of MV Starter Isolating Switches

- Design And Function Of Safety Interlocks

- Maintenance of Safety Interlocks in MV Starters

Power Cell MV Compartment



3 Pole, Non-Load Break
Isolation Switch

3 Current Limiting Power Fuses
(Clip-On or Bolted Type)

3 Bar Type
Current Transformers

3 Phase Vacuum Contactor

Control Power Transformer
is located behind the contactor

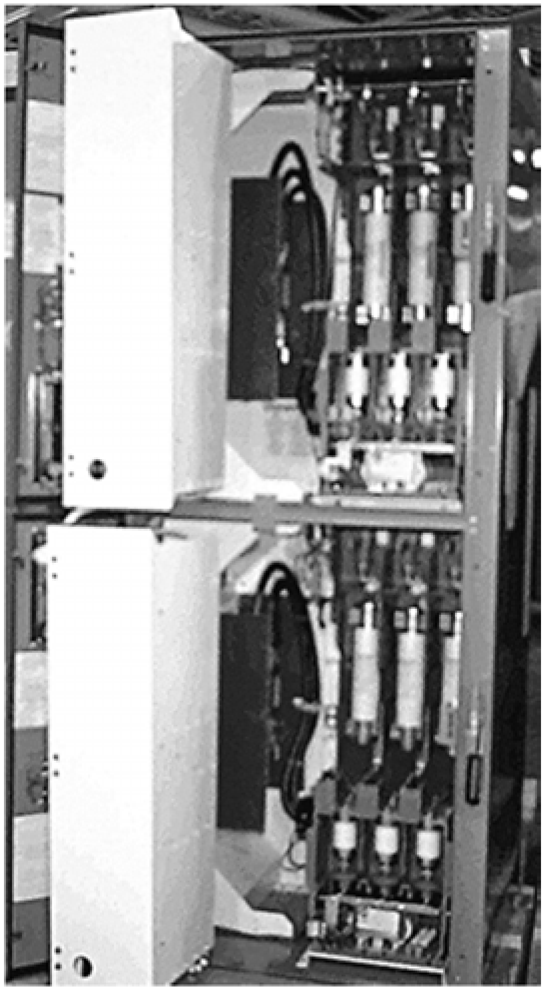
1 High MV Cell

Power Cell MV Compartment

1 High MV Cell

- The power cell is designed to allow easy access without the need to remove components.

Power Cell MV Compartment

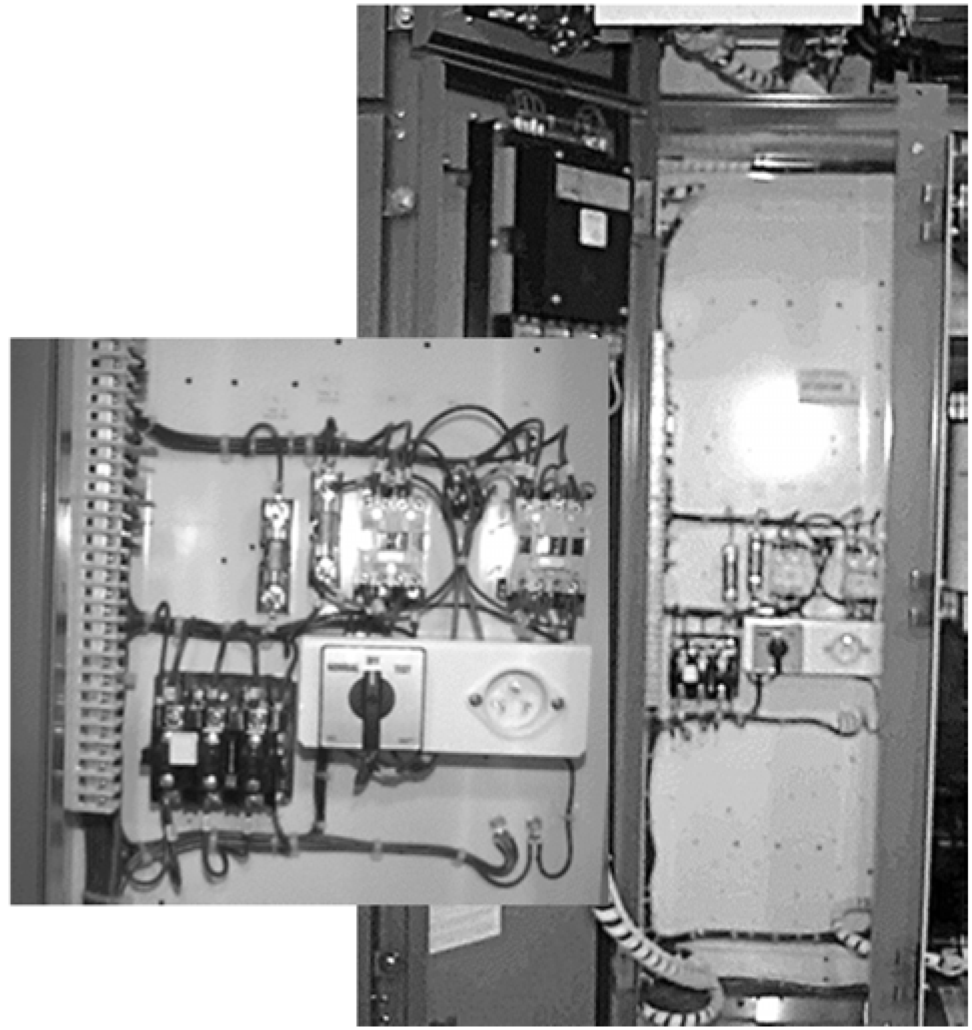


Two High MV Cell

- The power cell in a Two High structure includes, as standard, a swing-out Low Voltage panel, allowing for increased working area.

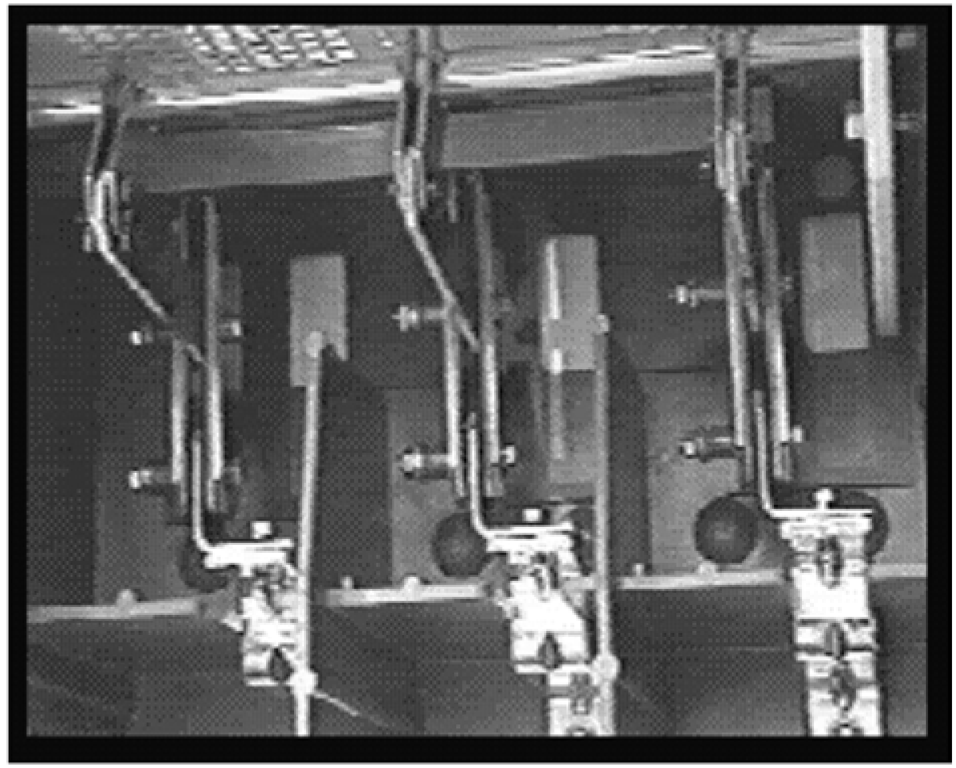
Low Voltage Compartment

- The standard components housed in the panel are:
  - Normal-Off-Test selector switch
  - Male test power receptacle
  - Rectifier Bridge
  - CR1 and CR2 control relays
  - Motor protection relay(s)



Non-load Break Isolation Switch

When in the “OFF” position the isolation switch is connected to “Ground Potential” via grounding pins.



Non-load Break Isolation Switch

- It is mechanically and electrically interlocked with the contactor to ensure it can't open or close when the contactor is closed.
- It is also mechanically interlocked with the power cell door.

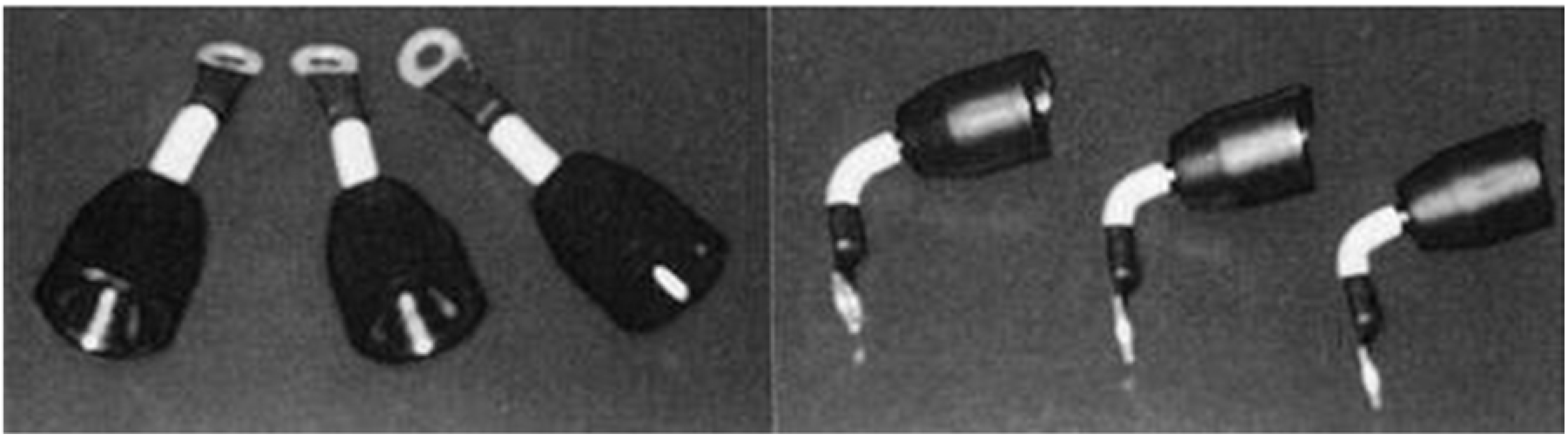
Maintenance Aids

- Voltage detectors
- Viewing windows
- Infrared sight glass
- Grounding balls

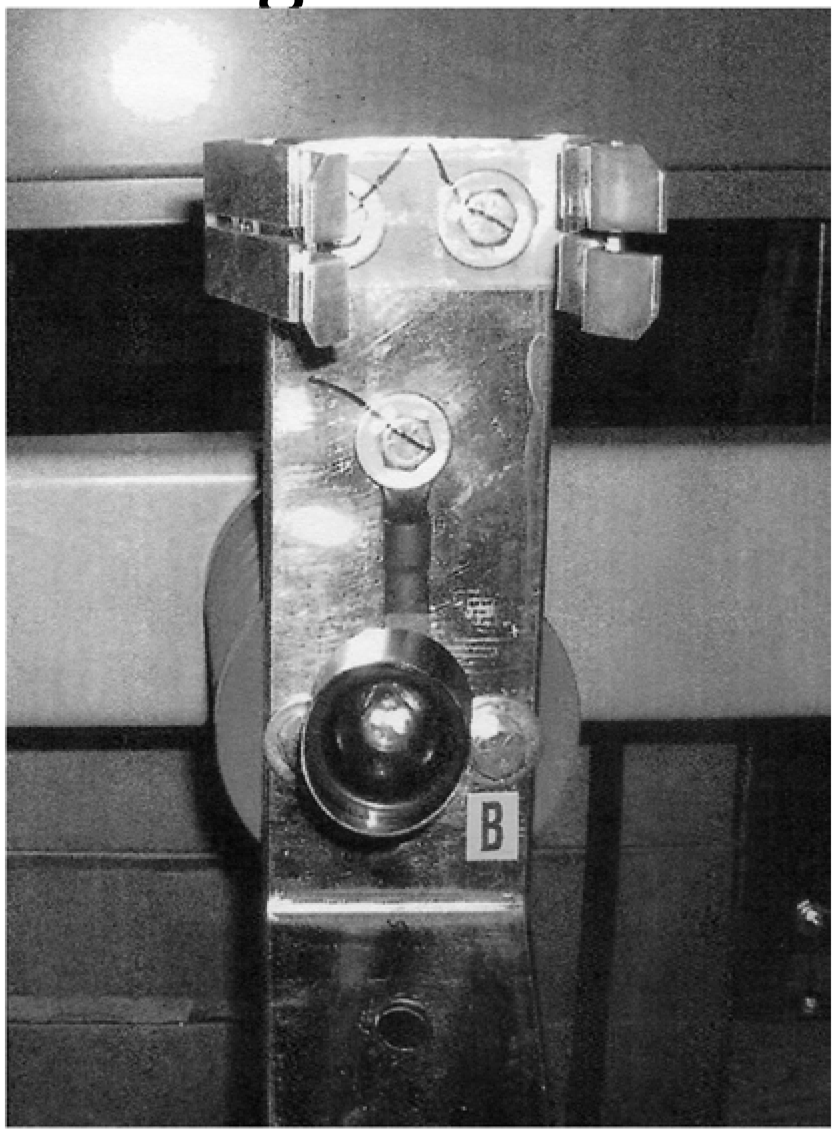
Voltage Checking Devices

- Non Contact Voltage Detectors (NCVD)
- Voltage Indicator (low and high voltage)
- Voltmeters

Voltage Detectors

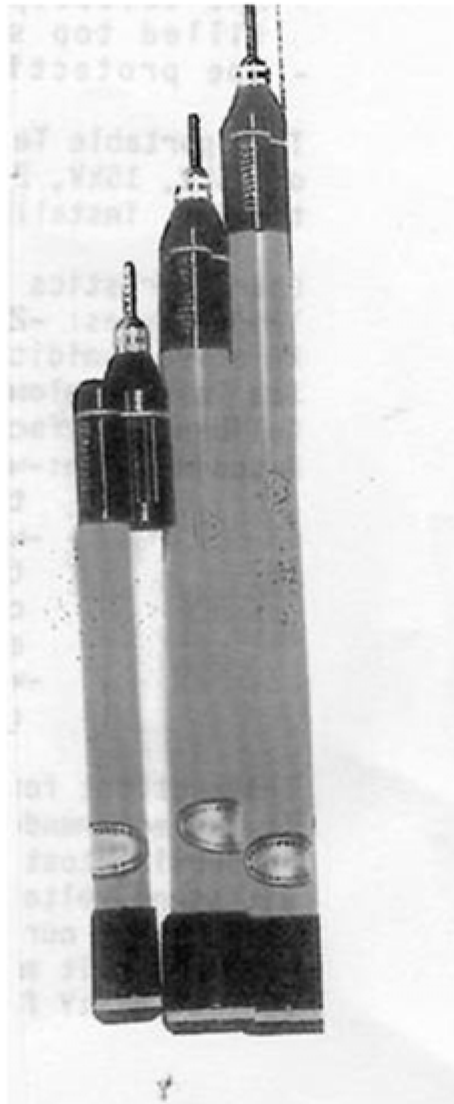


Voltage Detectors

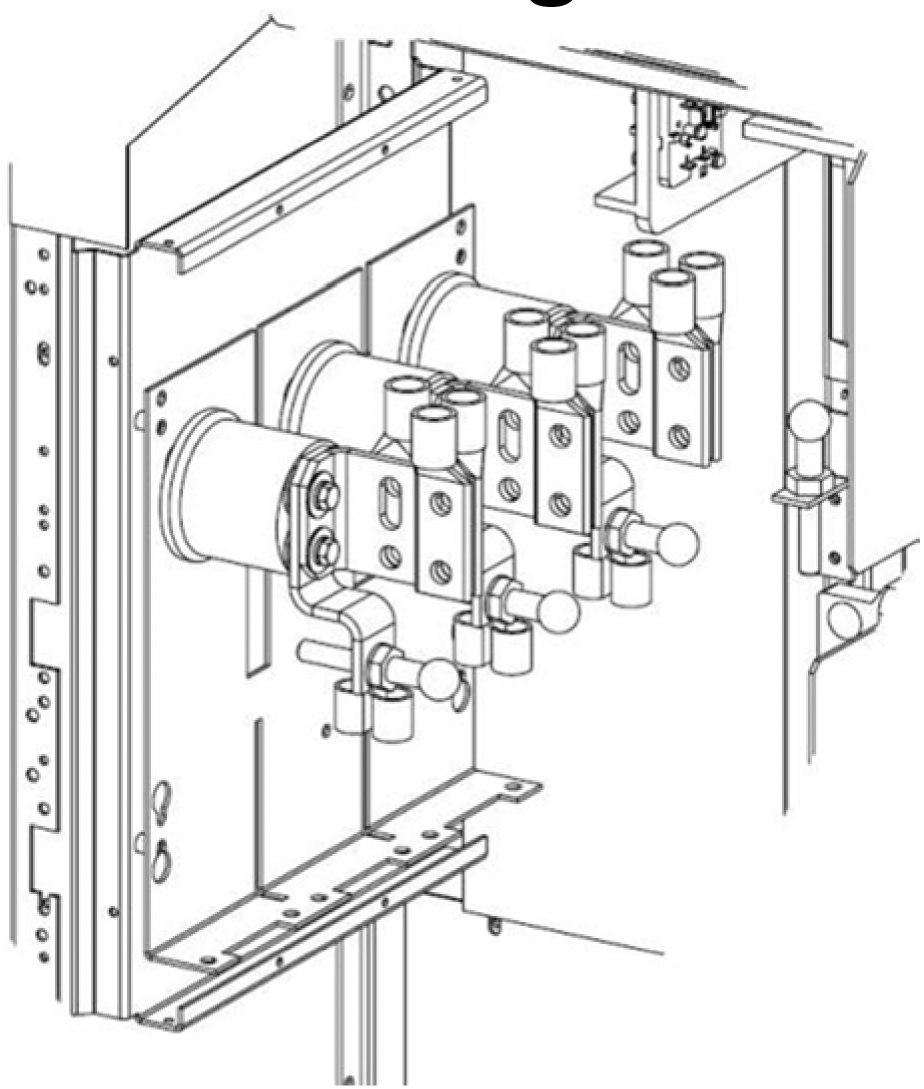


Voltage Detectors

Voltage Detectors

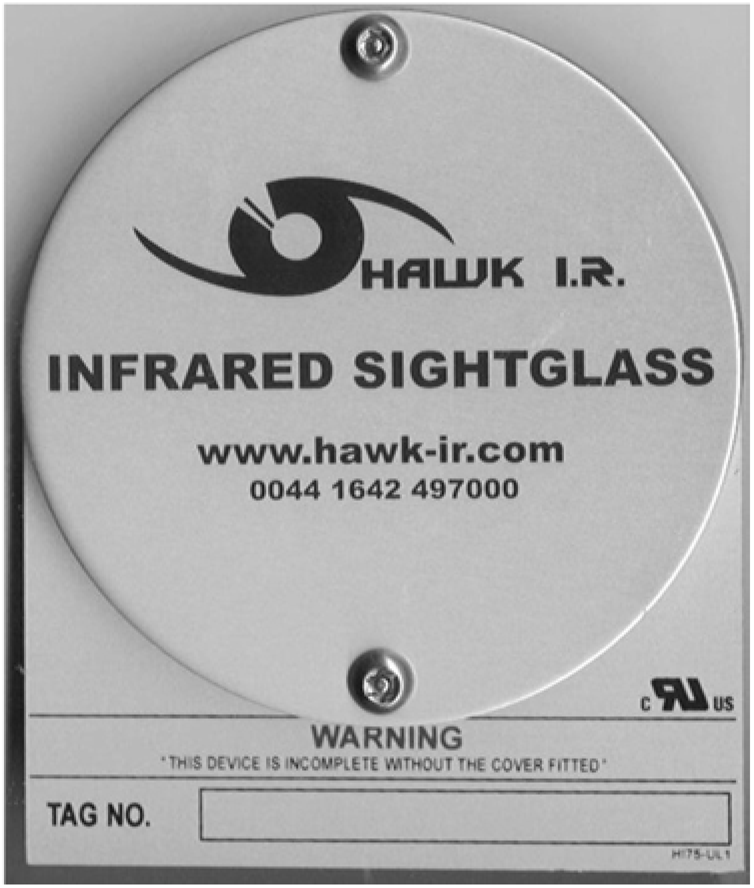


Grounding Balls

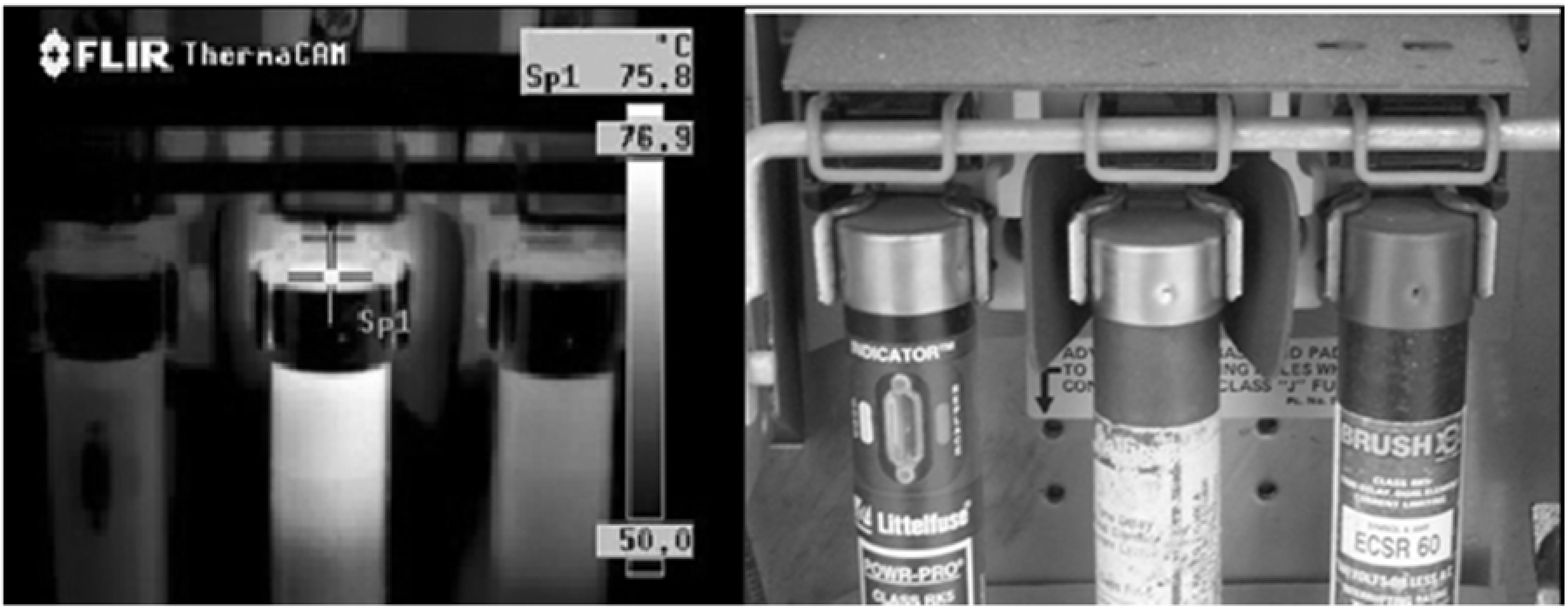


Grounding Cable

Infrared Sight glass



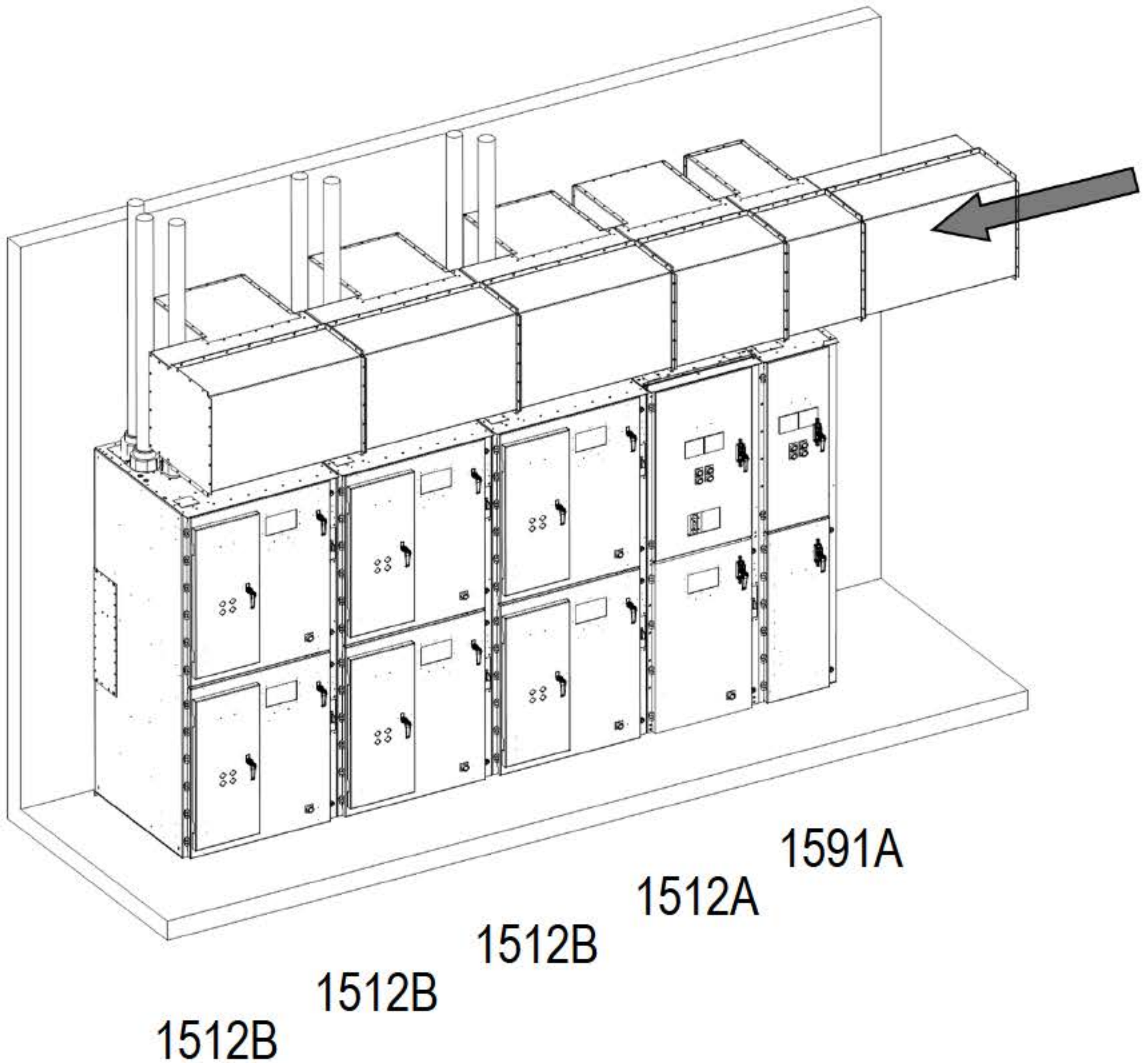
Infrared Scanning



Medium Voltage and Low Voltage

- The higher voltage does not effect the function of the product
  - it only affects the form of the product:
    - size
    - electrical clearances
    - interlocking
    - components

ArcShield Two-High: Top Cable Entry/Exit



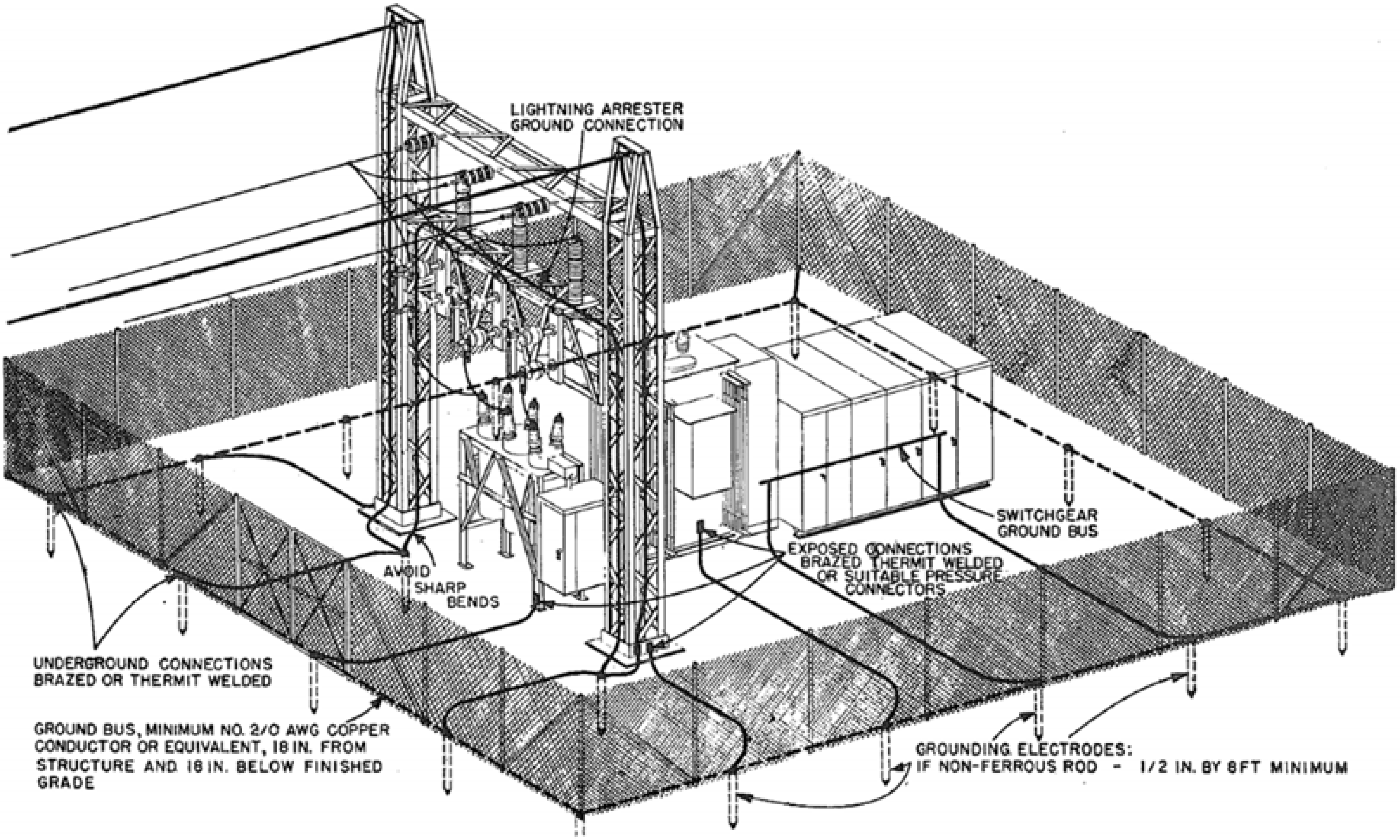
New plenum design enables top cable/conduit connections!

ArcShield Overview

- Arc vent on the unit roof
  - Aluminum plate designed to open under high pressure associated with arc flash conditions
  - Offset to rear of structure (allows use of LV wireways)
  - Installers must not step on this area (suitable warning label is provided)

Understanding Power Concepts

- Part 1
  - Introduction
  - Formulas (AC/DC Basics)
  - Standards
  - Codes/Personal Safety
  - ***<u>Grounding</u>***



(Photo 1100449)

Fig. 1. Typical grounding system for an outdoor substation

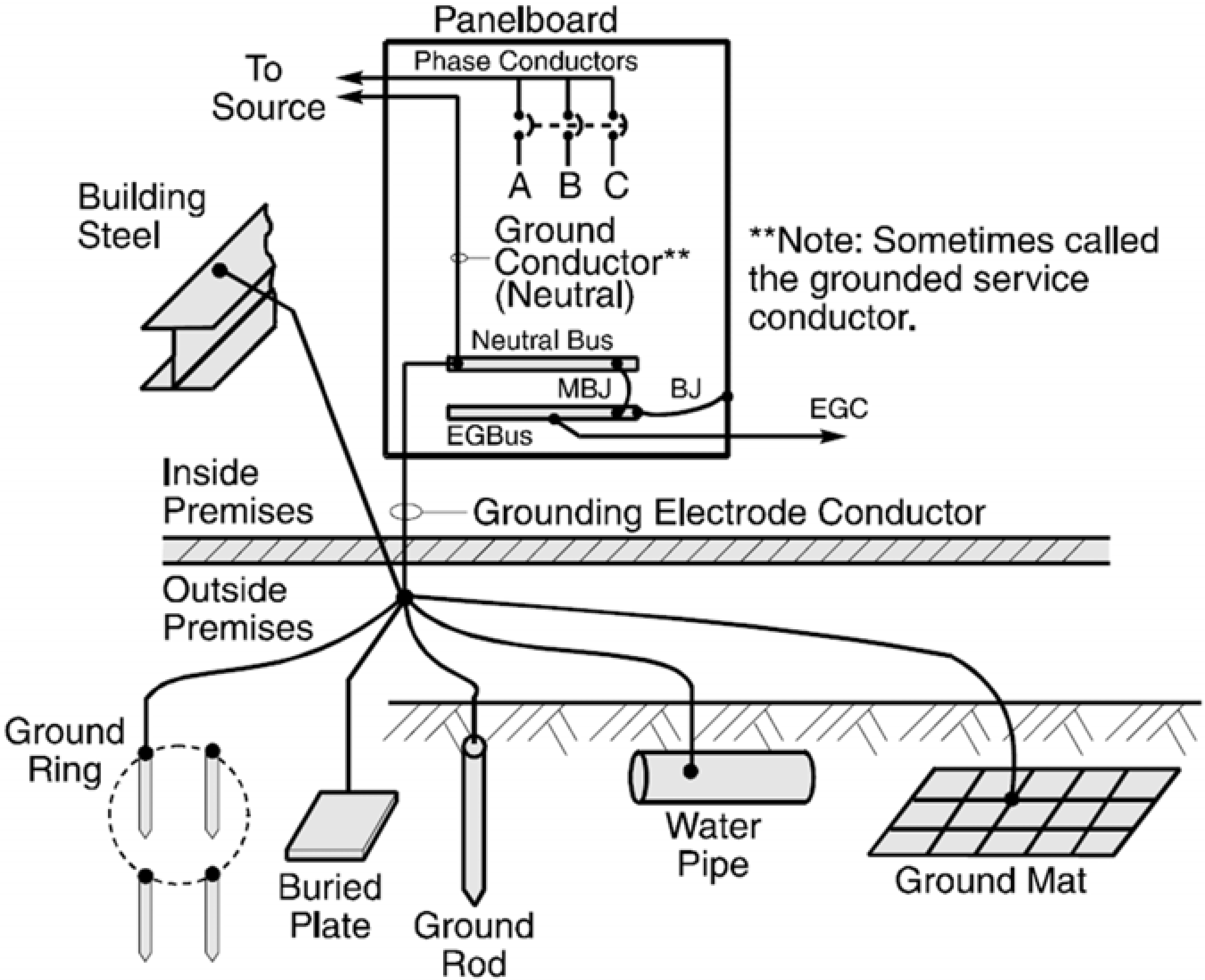
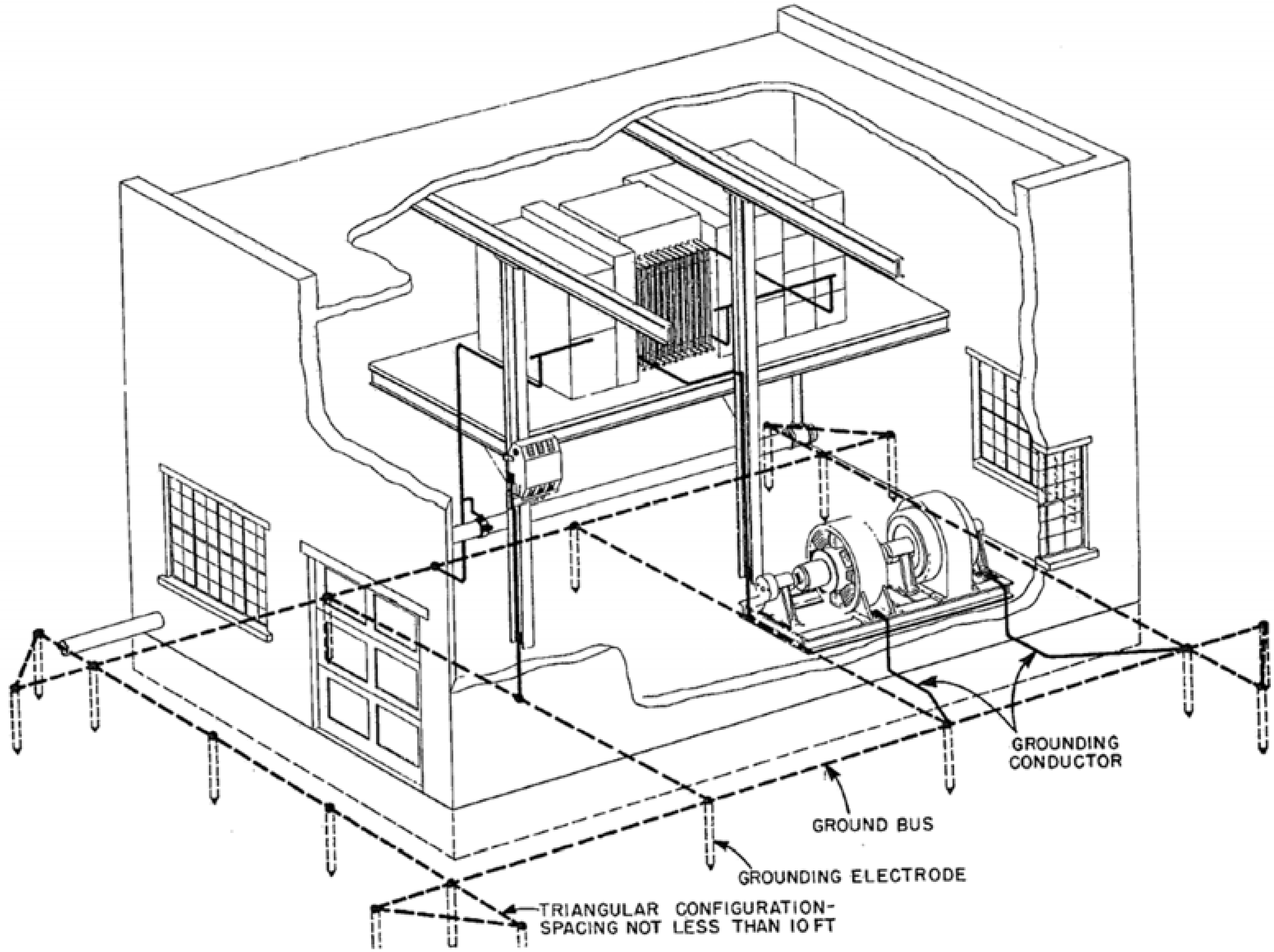
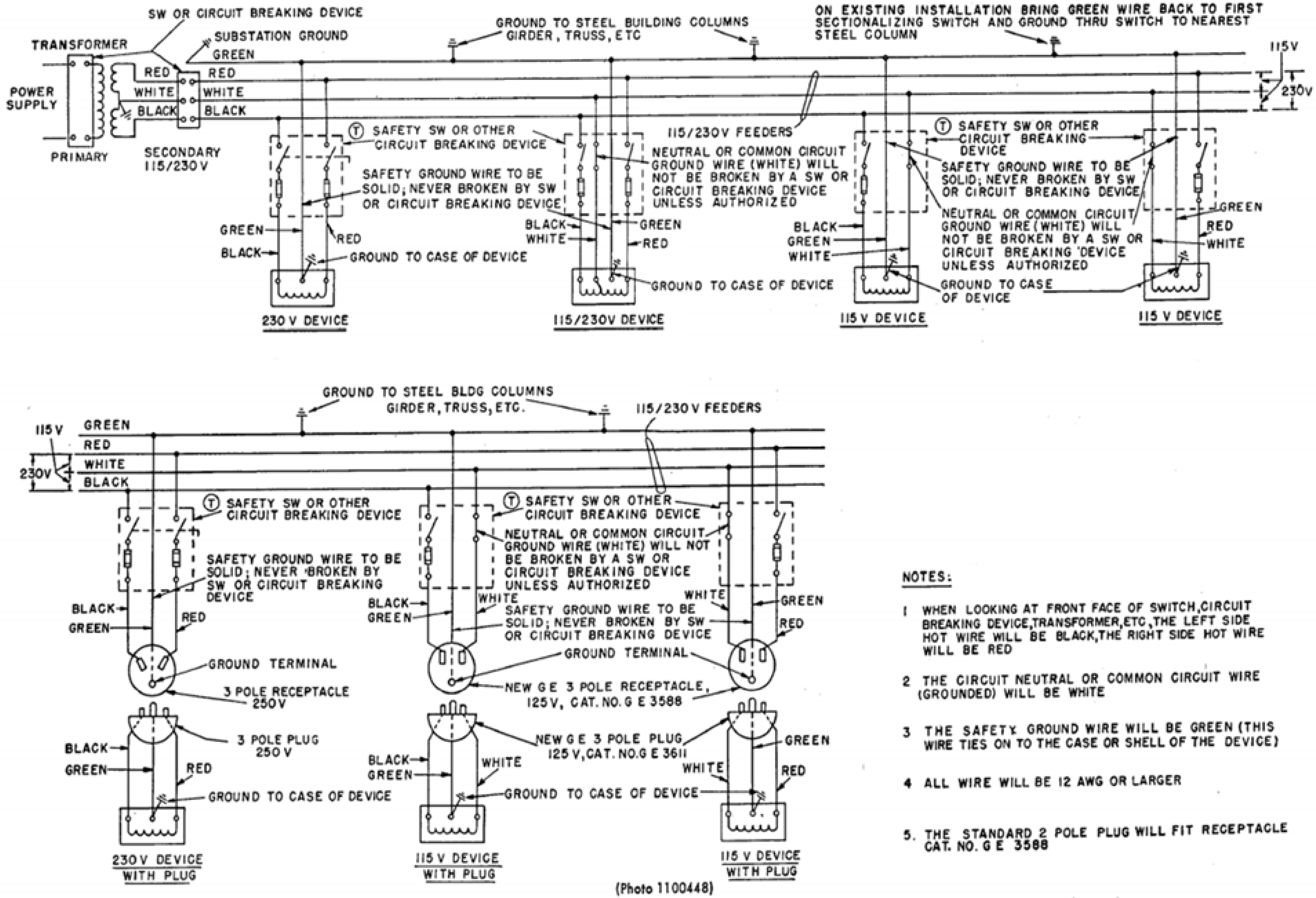


Figure 3. Typical Grounding Electrodes



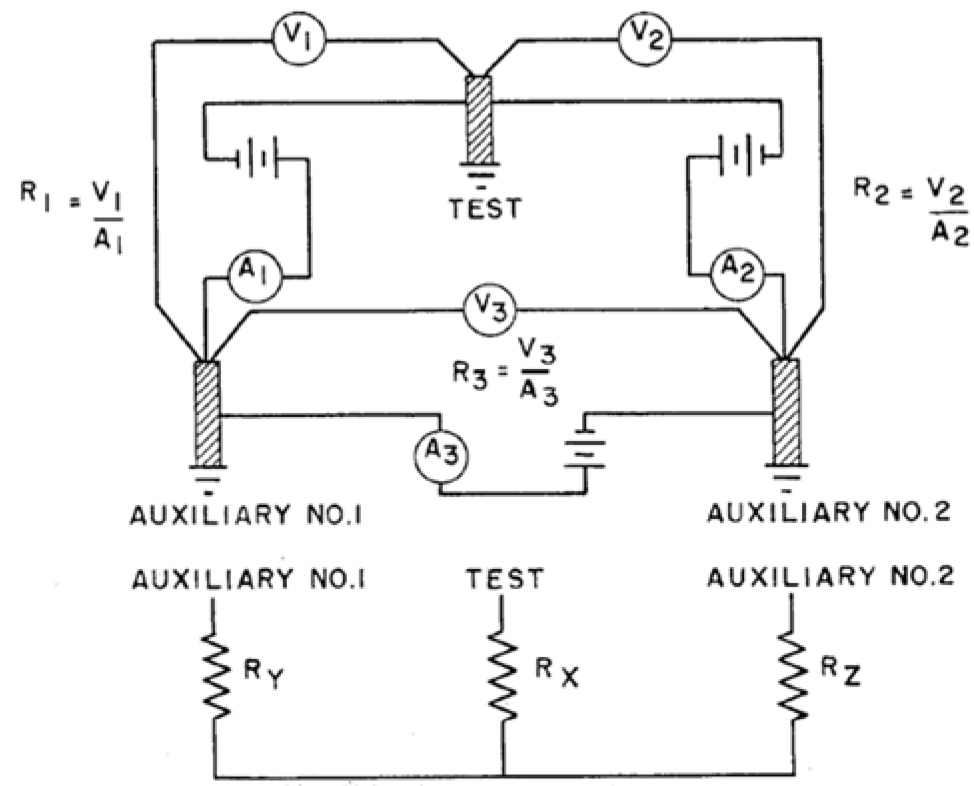
(Photo 1100396)

Fig. 2. Typical grounding system for a building and heavy electrical apparatus in the building



(Photo 1100448)

Fig. 4. Power distribution connections showing distinction between neutral conductor (white) and grounding conductor (green)



$$R_1 = R_X + R_Y$$

$$R_2 = R_X + R_Z$$

$$R_3 = R_Y + R_Z$$

$$R_Y = R_3 - R_Z$$

$$R_X = R_1 - R_Y = R_1 - R_3 + R_Z$$

$$R_X = R_2 - R_Z = R_2 \qquad - R_Z$$

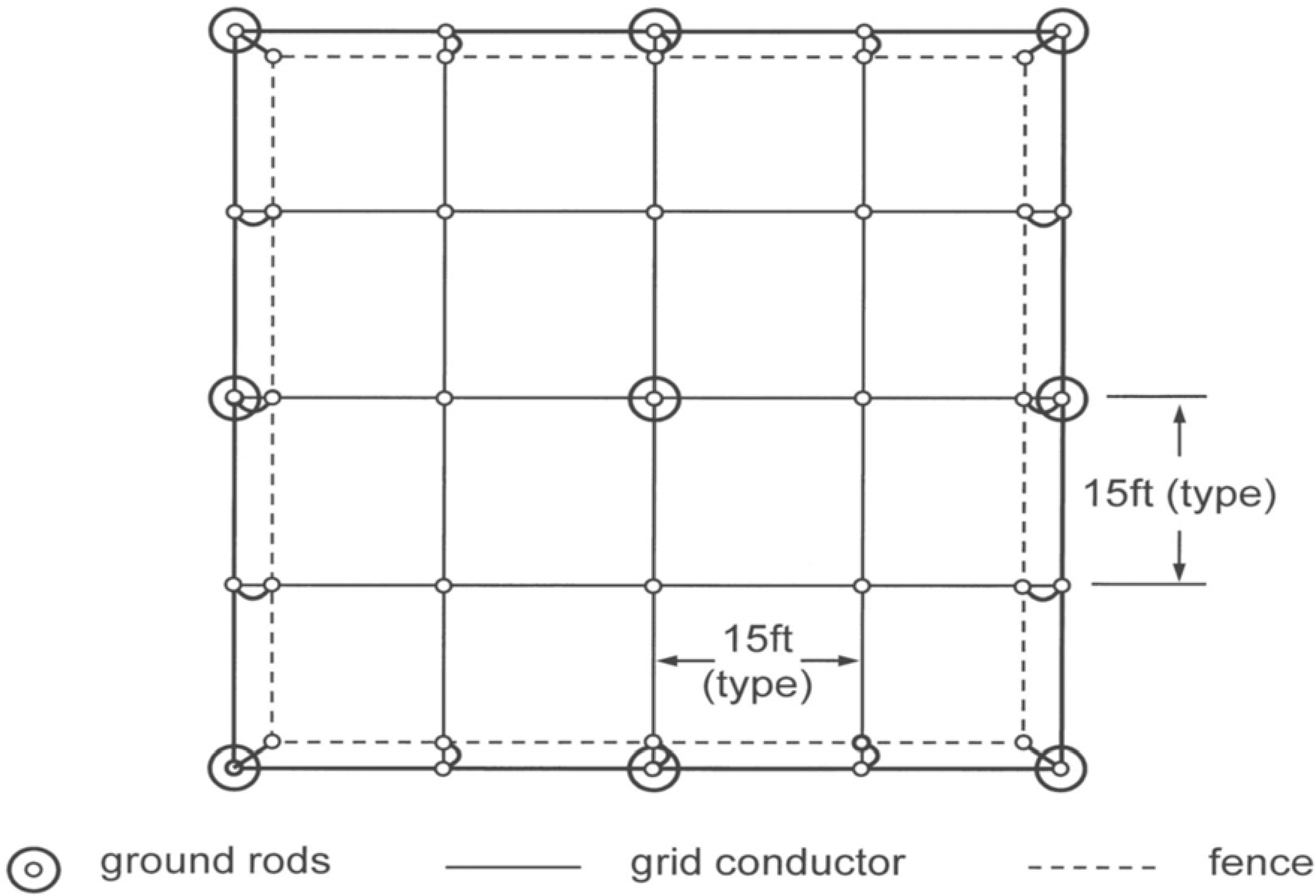
$$2R_X = R_1 + R_2 - R_3$$

$$R_X = \frac{R_1 + R_2 - R_3}{2}$$

(Photo 1100435)

Fig. 15. Three-point method of connection and test for resistance of ground connection

Typical Substation Grounding Grid



Practical Earth Testing

Content

- Principles
- Test Methods
- Practical Measurement
- Summary

Earth / Ground Basics

What is ground?

A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of earth*

Ground is a connection to Earth made either intentionally or accidentally

*NFPA 70-2000 (National Fire Protection Association)

Earth / Ground Basics

Why ground?

To protect people and equipment

By dissipating stray energy from:
Electrical faults (fuses, breakers etc.)
Lightning strikes
Radio Frequency
Static discharges

Real Examples

Why test? – Catch the problem before it happens!

Estimate: at least 15% of power quality problems are related to grounding

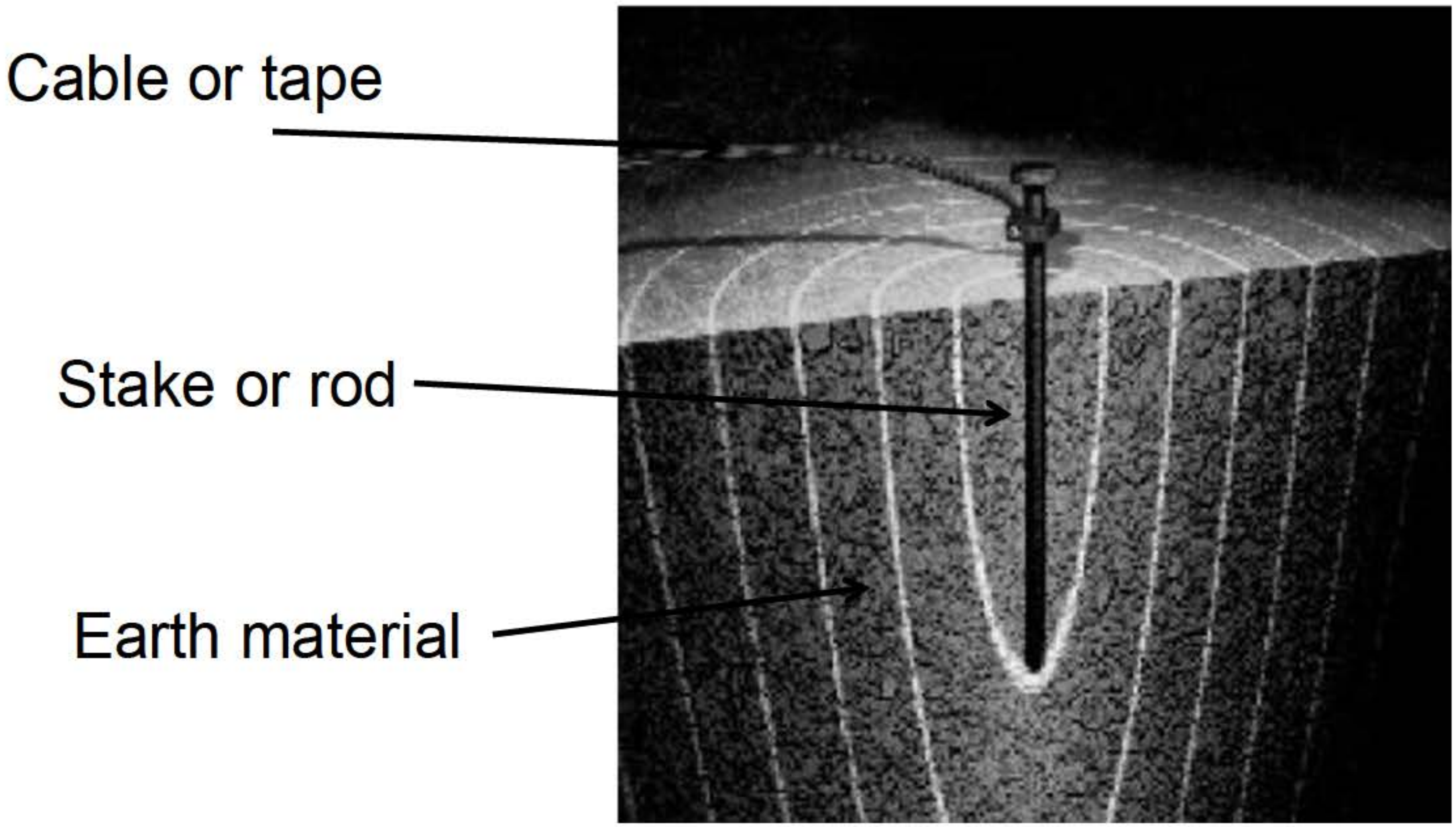
Lightning strikes on equipment with poorly maintained protection systems destroy millions of dollars of equipment and lost production every year

Using ground testing in a PDM protocol will help prevent possible dangerous situations and loss of downtime

(= money)

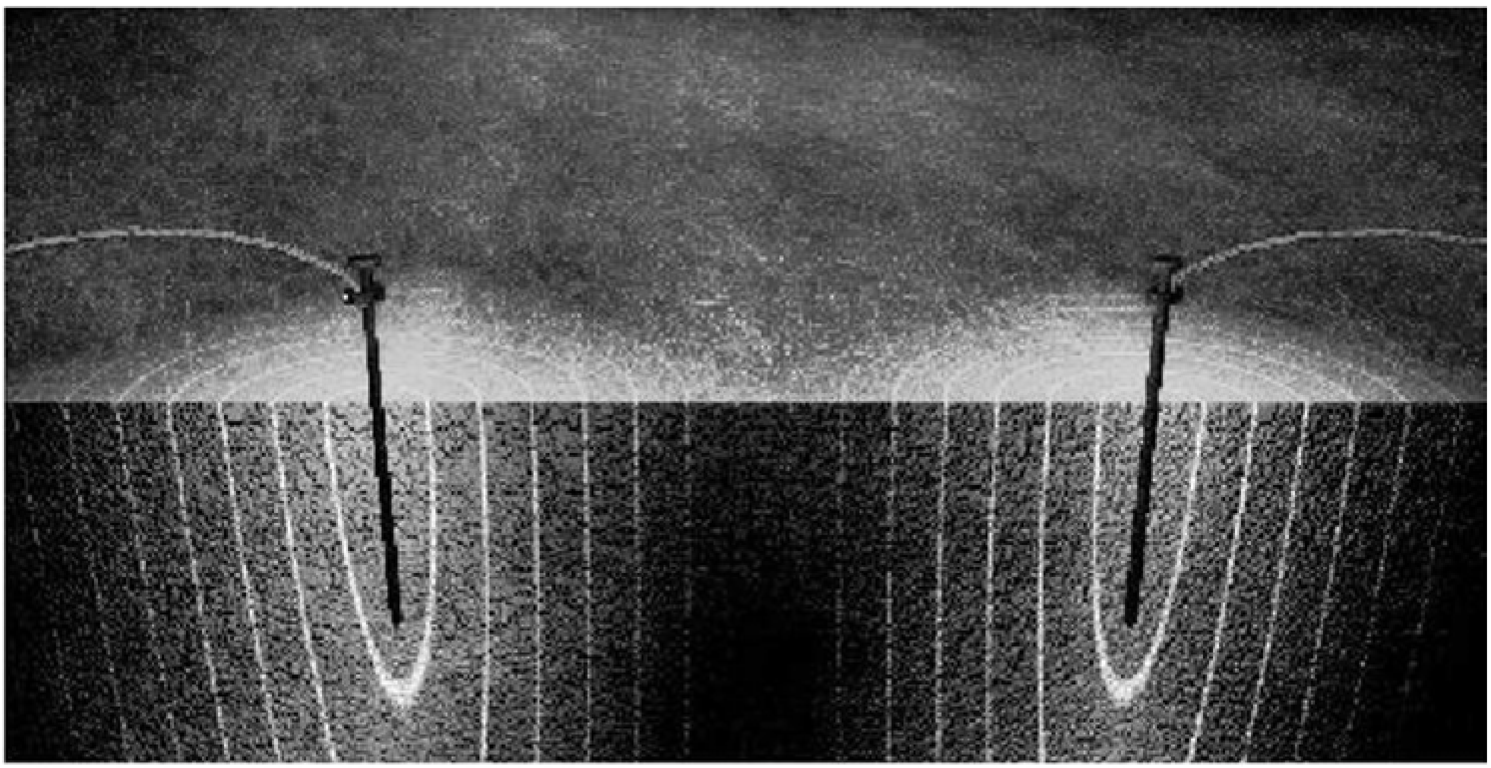
Earth / Ground Basics

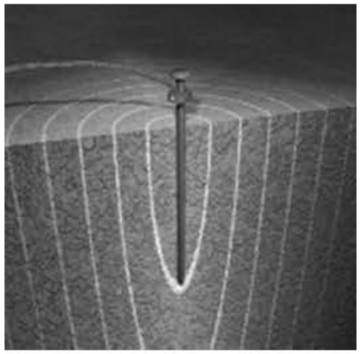
How do you connect to earth?



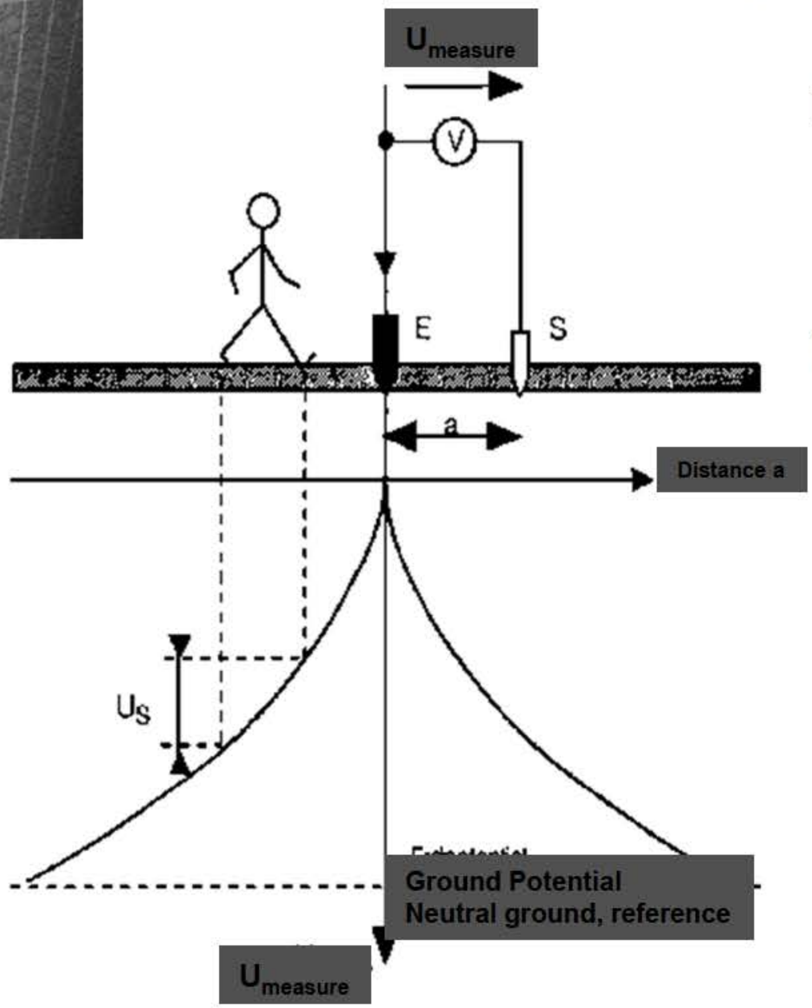
Earth / Ground Basics

Spheres of influence





Attention! Potential gradients!



Potential gradients around the earth electrode can reduce the accuracy of measurements!

The probe must always be placed outside this area! Typical distance: >20m

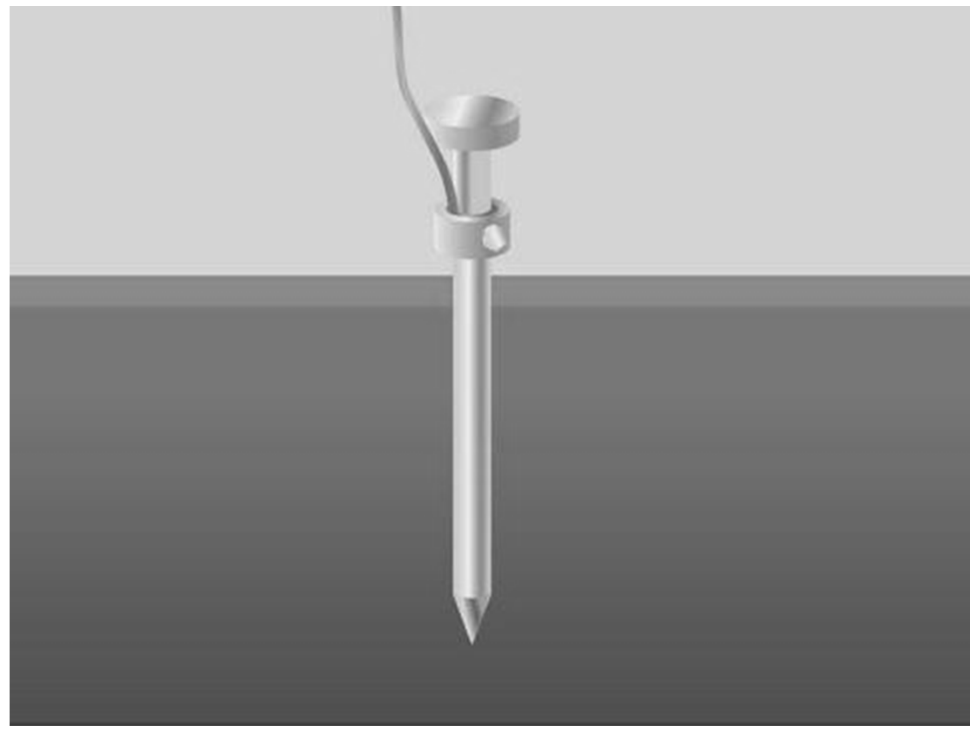
Earth / Ground Basics

Types of Grounding Systems

- Many different types available
- Choice depends on local conditions and required function

- Simplest form is a single stake

- Mostly used for:
  - Lightning protection
  - Stand alone structures
  - Back-up for utility ground



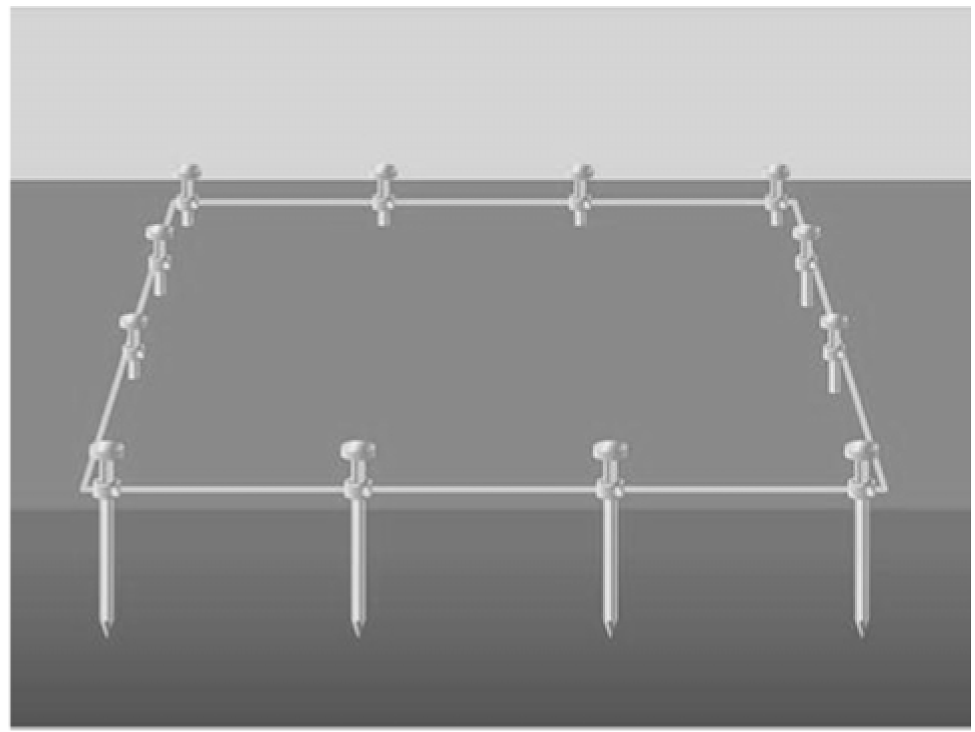
Ground rod

Earth / Ground Basics

Types of Grounding Systems

- ground rod group

- typically for lightning protection on larger structures or protection around potential hotspots such as substations.

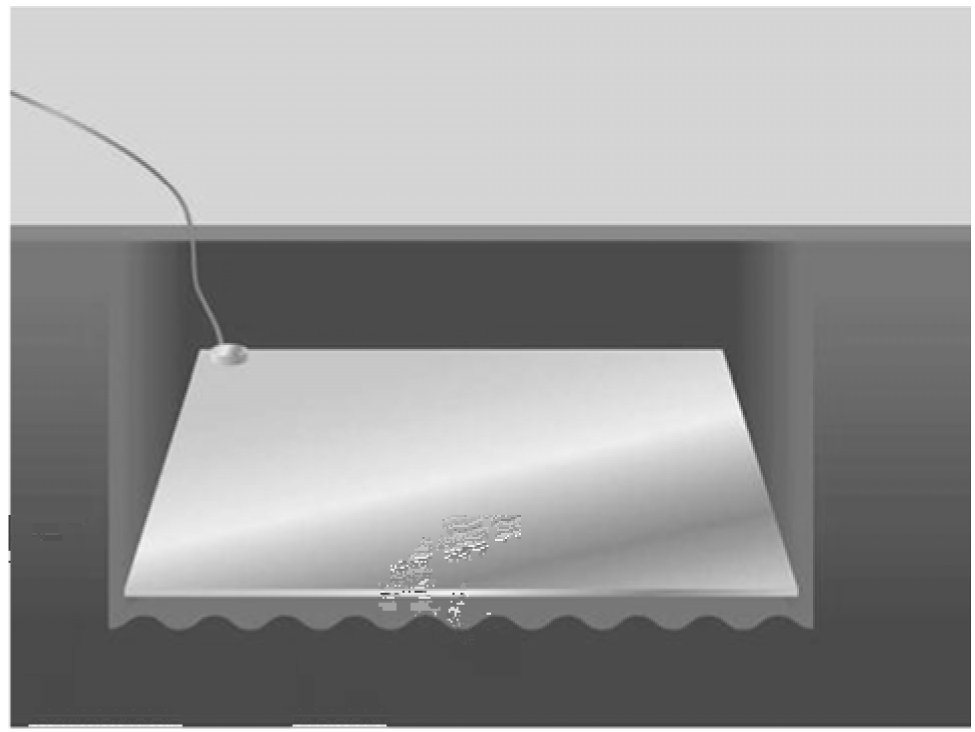


Ground rod group

Earth / Ground Basics

Types of Grounding Systems

- For areas where there is rock (or other poor conducting material) fairly close to the surface ground plates are preferred as they are more effective

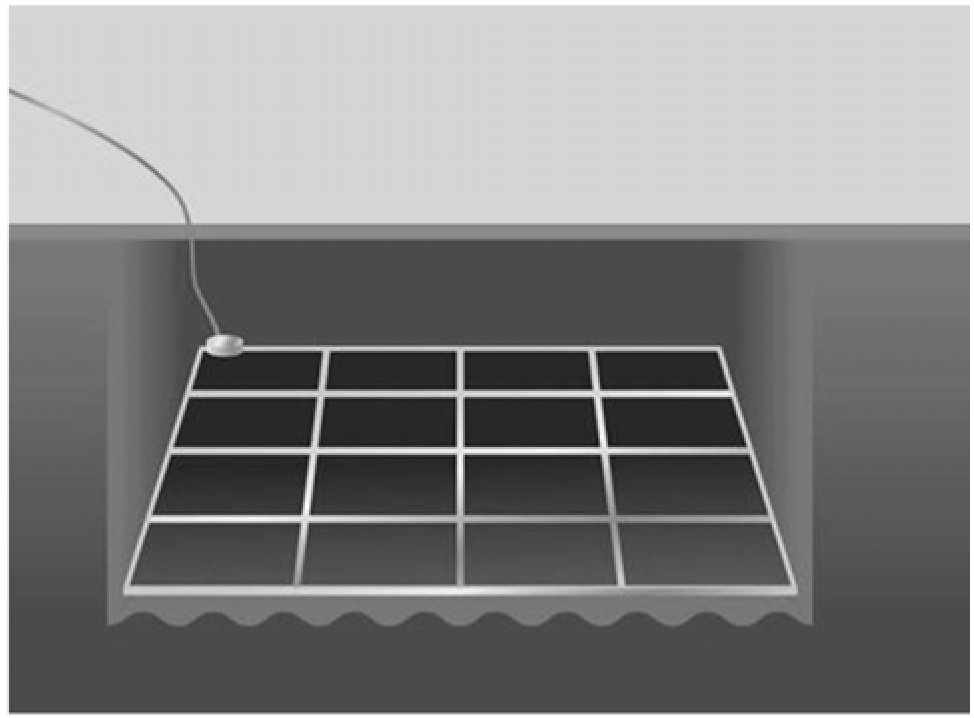


Ground plate

Earth / Ground Basics

Types of Grounding Systems

- A ground mesh consists of network of bars connected together, this system is often used at larger sites such as electrical substations.

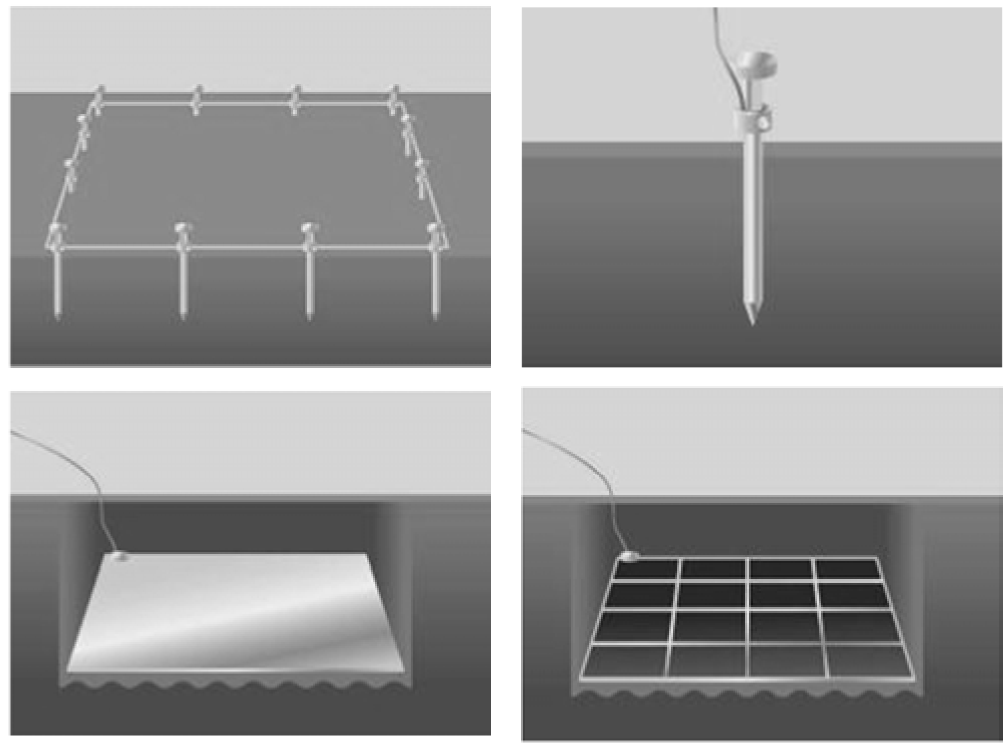


Ground mesh

Earth / Ground Basics

Types of Grounding Systems

For the purposes of this presentation the grounding system will referred to as 'ground electrode'.



Ground Testing Methods

What are the available techniques?

- Resistivity
- Fall of Potential – Three and Four Pole Testing
- Selective Testing
- Stakeless Testing
- Two pole method

Ground Testing Methods

Resistivity Measurement

The purpose of resistivity measurements is to quantify the effectiveness of the earth where a grounding system will be installed.

Differing earth materials will affect the effectiveness of the grounding system.

The capability of different earth materials to conduct current can be quantified by the value ρ_E (resistivity in Ω.m).

Resistivity measurements should be made prior to installing a grounding system, the values measured will have an effect on the design of the grounding system.

Ground Testing Methods (1)

Resistivity values for different earth materials

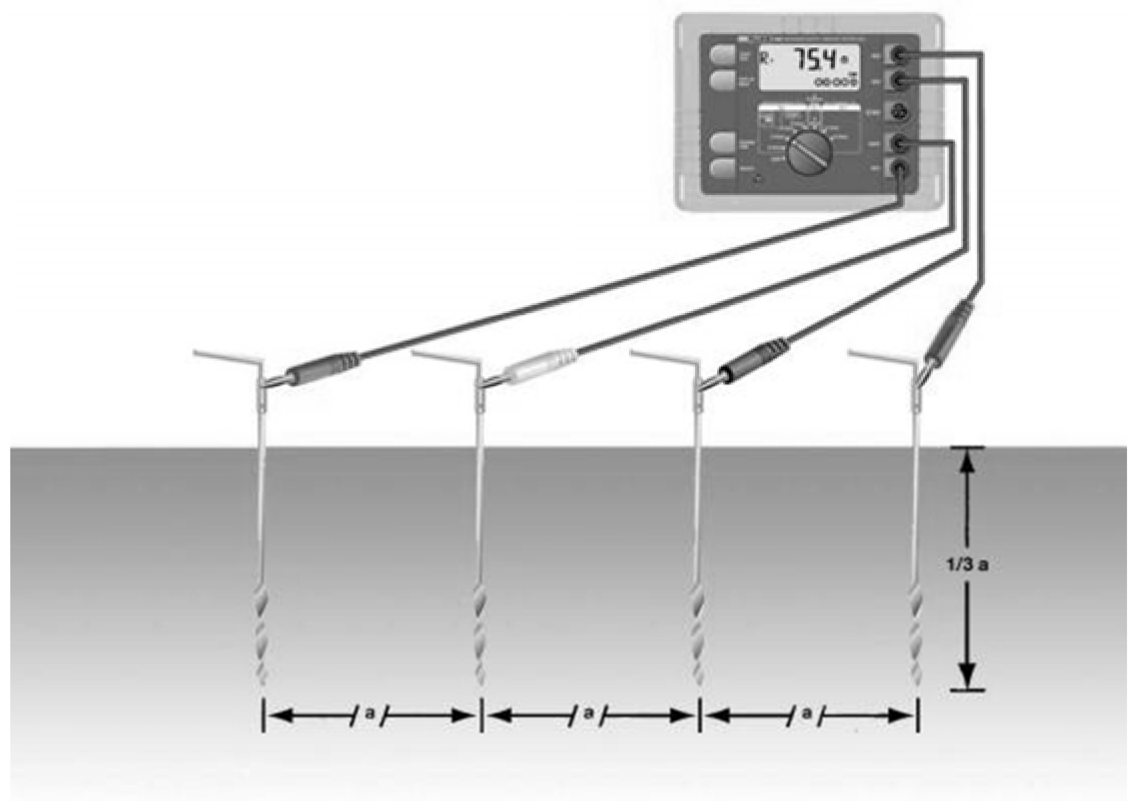
Type of Soil	Soil resistivity R_E	Earthing resistance (Ω)					
		Earthing rod m depth			Earthing strip m		
	Ω m	3	6	10	5	10	20
Moist humus soil, moor soil, swamp	30	10	5	3	12	6	3
Farming soil loamy and clay soils	100	33	17	10	40	20	10
Sandy clay soil	150	50	25	15	60	30	15
Moisty sandy soi	300	66	33	20	80	40	20
Dry sand soil	1000	330	165	100	400	200	100
Concrete 1: 5	400	-	-	-	160	80	40
Moist gravel	500	160	80	48	200	100	50
Dry gravel	1000	330	165	100	400	200	100
Stoney soil	30,000	1000	500	300	1200	600	300
Rock	10^7	-	-	-	-	-	-

Ground Testing Methods

Resistivity Measurement (Wenner method)

Resistivity measurements are performed by using a four wire method.

Used to determine if earthing should be placing earth stakes



Ground Testing Methods

Resistivity Measurement

From the indicated resistance value R_E, the soil resistivity is calculated according to the equation :

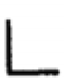
$$\rho_E = 2\,\pi\,.\,a\,.\,R_E$$

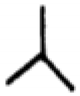
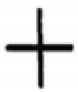
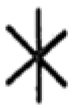
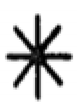
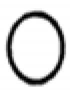
ρ_E ...... mean value of soil resistivity (Ω.m)
R_E ...... measured resistance (Ω)
a ...... probe distance (m)

Equipment Grounding

TABLE II—Formulas for the Calculation of Resistances to Ground

(Approximate formulas including effects of images. Dimensions must be in centimeters to give resistance in ohms.)

	Hemisphere Radius a	$R = \frac{\rho}{2\pi a}$
•	One Ground Rod Length L, radius a	$R = \frac{\rho}{2\pi L}\left(\log_e \frac{4L}{a} - 1\right)$
• •	Two Ground Rods $s > L$; spacing s	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} - 1\right) + \frac{\rho}{4\pi s}\left(1 - \frac{L^2}{3s^2} + \frac{2}{5}\frac{L^4}{s^4} \ldots\right)$
••	Two Ground Rods $s < L$; spacing s	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \log_e \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4} \ldots\right)$
—	Buried Horizontal Wire Length $2L$, depth $s/2$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \log_e \frac{4L}{s} - 2 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4} \ldots\right)$
	Right-Angle Turn of Wire Length of arm L, depth $s/2$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} - 0.2373 + 0.2146\frac{s}{L} + 0.1035\frac{s^2}{L^2} - 0.0424\frac{s^4}{L^4} \ldots\right)$

	Three-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{6\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 1.071 - 0.209\frac{s}{L} + 0.238\frac{s^3}{L^3} - 0.054\frac{s^4}{L^4} \cdots\right)$
	Four-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{8\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 2.912 - 1.071\frac{s}{L} + 0.645\frac{s^2}{L^3} - 0.145\frac{s^4}{L^4} \cdots\right)$
	Six-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{12\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 6.851 - 3.128\frac{s}{L} + 1.758\frac{s^2}{L^3} - 0.490\frac{s^4}{L^4} \cdots\right)$
	Eight-Point Star Length of arm L, depth $s/2$	$R = \frac{\rho}{16\pi L}\left(\log_e \frac{2L}{a} + \log_e \frac{2L}{s} + 10.98 - 5.51\frac{s}{L} + 3.26\frac{s^3}{L^3} - 1.17\frac{s^4}{L^4} \cdots\right)$
	Ring of Wire Diameter of ring D, diameter of wire d, depth $s/2$	$R = \frac{\rho}{2\pi^2 D}\left(\log_e \frac{8D}{d} + \log_e \frac{4D}{s}\right)$
	Buried Horizontal Strip Length $2L$, section a by b, depth $s/2$, $b < a/8$	$R = \frac{\rho}{4\pi L}\left(\log_e \frac{4L}{a} + \frac{a^2 - \pi ab}{2(a+b)^2} + \log_e \frac{4L}{s} - 1 + \frac{s}{2L} - \frac{s^2}{16L^2} + \frac{s^4}{512L^4} \cdots\right)$

	Buried Horizontal Round Plate Radius a, depth $s/2$	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 - \frac{7}{12}\frac{a^2}{s^2} + \frac{33}{40}\frac{a^4}{s^4}\cdots\right)$
	Buried Vertical Round Plate Radius a, depth $s/2$	$R = \frac{\rho}{8a} + \frac{\rho}{4\pi s}\left(1 + \frac{7}{24}\frac{a^2}{s^2} + \frac{99}{320}\frac{a^4}{s^4}\cdots\right)$

Ground Testing Methods

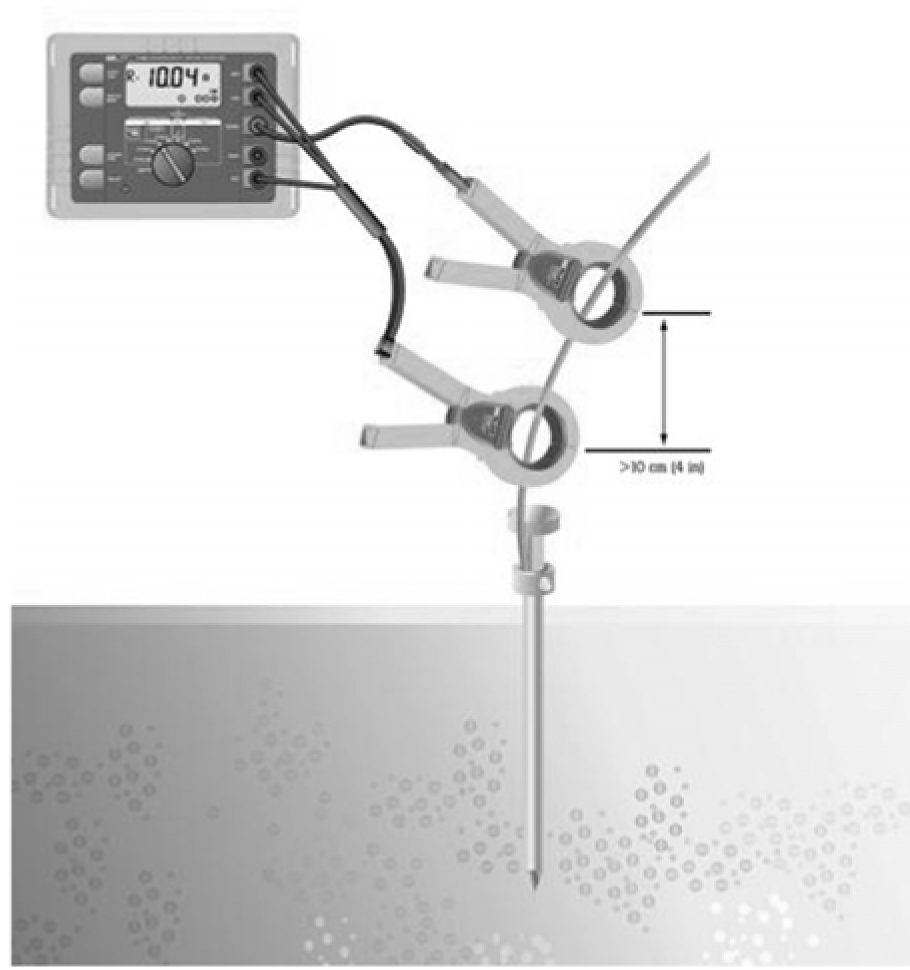
- **The stakeless method** eliminates the need for temporary ground stakes. This is useful in a wide range of situations. Examples include:
  - Inside buildings
  - Airports
  - Urban locations
  - Chemical and industrial plants

- The stakeless method is not available on all ground testers. However, it comes standard on the earth ground testers.

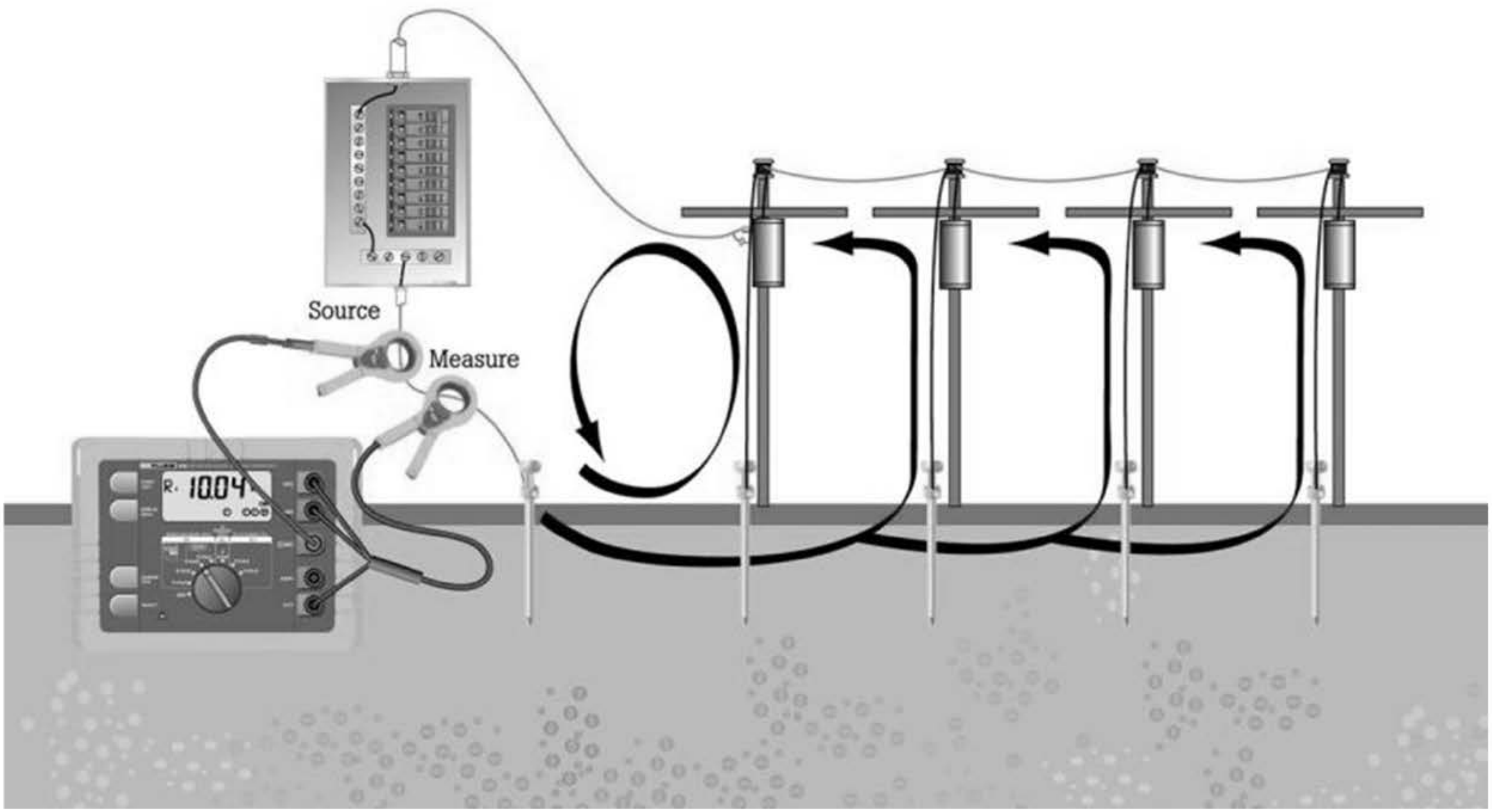
- The temporary ground stakes are replaced by two current clamps. The first clamp generates a voltage on the ground condutor, the second clamp measures the current flowing due to the generated voltage.

Ground Testing Methods

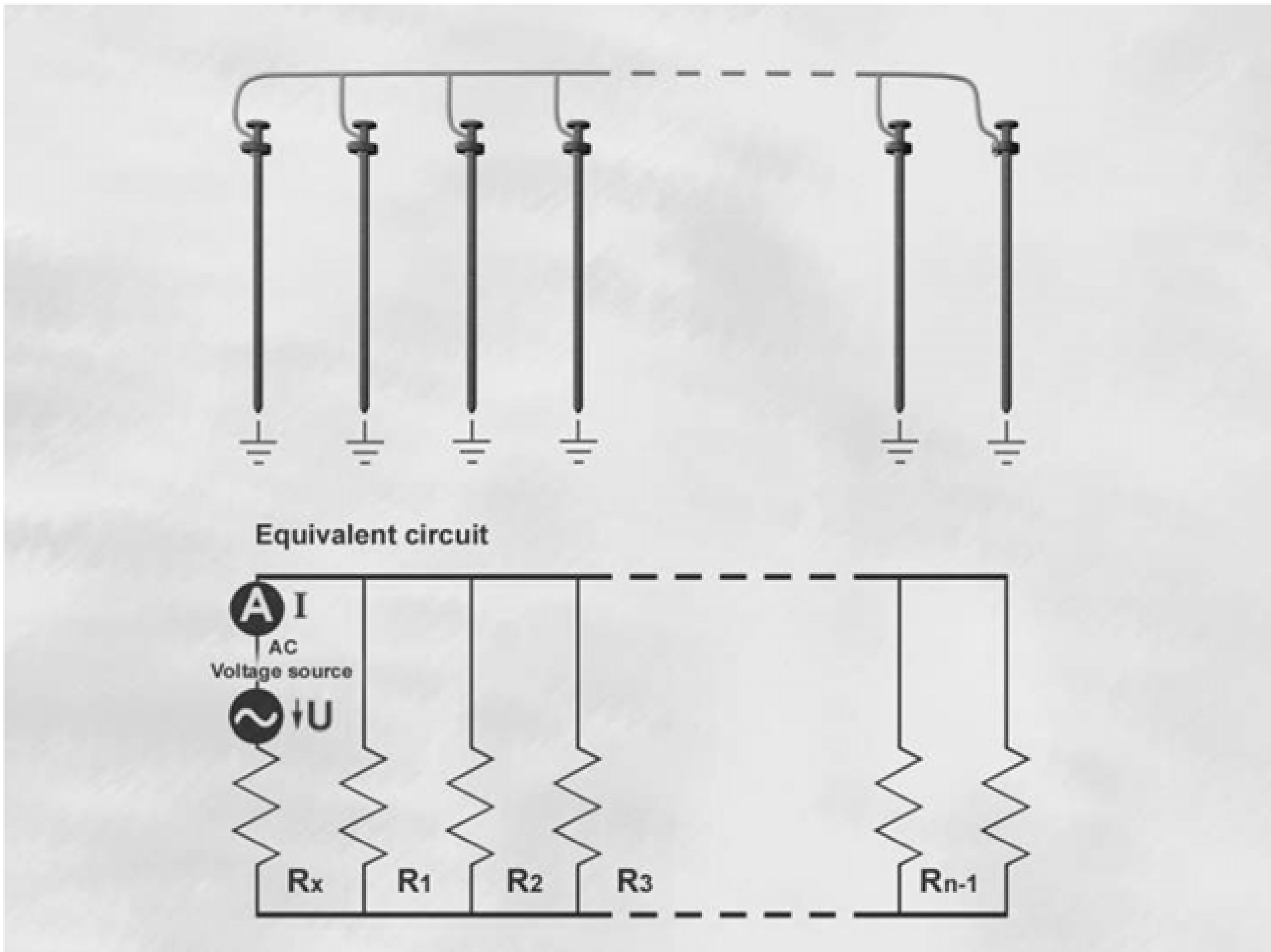
- The ground testers are able to measure earth ground loop resistances for multi grounded systems using only current clamps.
- With this test method, two clamps are placed around the earth ground rod or connecting cable and each connected to the tester. Earth ground stakes aren't used at all.



Ground Testing Methods



Stakeless Measurement Equivalent Circuit



When and why ground test?

Prior to designing an grounding system:
the ground material should be evaluated by resistivity measurement before designing a ground system

Initial test on new ground systems:
the real effectiveness of new ground systems should be measured before connection – fall of potential test

Periodic tests on ground systems:
ground systems should be checked periodically to ensure they are not affected by changes in the ground or corrosion – selective or stakeless test

Grounding Continued:

The Role of Electrical Grounding in Surge and Lightning Protection

Today in Electrical Engineering History

October 24, 1861

The first Transcontinental Telegraph Line across the United States was Completed.

With this improvement in communication came the demise of the Pony Express which was started only 18 months before and the realization of the increased risk to operator life and equipment due to lightning induced surges on overhead lines.

SALT LAKE, OCTOBER 24, 1861, 5:13 P.M.

TO GENERAL H.W. CARPENTIER:

LINE JUST COMPLETED. CAN YOU COME TO OFFICE?

STREET

Why Ground Electrical Power Systems?

- The fundamental purpose of grounding electrical power systems is for safety related to electrical shock hazard.

- Bonding of non-current carrying conductive materials to the mass of Earth fixes their potential to *"Zero Potential"* and so renders them safe for contact by persons even in the event that these materials come into direct contact with ungrounded current carrying conductors.

- As a result of fixing the potential of one of the current conductors of an electrical system the following arise: The potential of all electrical conductors of the system become referenced to the potential of the mass of Earth *(Zero Potential)*. This assists in stabilization of the voltage to ground during normal operation.

- As a secondary consequence of the grounding of one of the current carrying conductors of a system, all other conductors would cause a short-circuit if they come into contact with ground. The value of the ground short-circuit current would be determined by the system voltage, impedance and the ground fault impedance. This would facilitate the operation of over-current protective devices in the event of a ground fault.

In Order to Achieve the Stated Objectives, the Ground System:

- Must be able to withstand the maximum fault current without danger of burn-off or fusing.
- Must produce a sufficiently low voltage between any two points on the ground to prevent all personnel hazard (Touch and Step Potentials).
- Must minimize the "Ground Potential Rise (GPR)" with respect to remote ground (zero potential point) by having low contact resistance to ground (Ground Resistance) fault current.

The Lightning Strikes and Lightning Induced Surges

- Lightning is an atmospheric discharge of electricity. A bolt of lightning can travel at speeds of 60,000 m/s (130,000 mph), and can reach temperatures approaching 30,000 ºC (54,000 ºF)

- Large bolts of lightning can carry up to 120 kA and 350 coulombs. The Voltage being proportional to the length of the bolt.

- It is important to note that although the value of the voltage associated with lightning is proportional to the length of the strike, it is not of critical concern as the main effects are related to the stored charge and the discharge current of the strike.

- Of more concern would be the voltage developed in conductive parts of the system which are exposed to the magnetic fields produced by the flow of high levels of electrical energy.

The Development of a Lightning Strike

- With the development of very large storm clouds the lower part of the cloud consists mainly of water droplets and the upper altitudes are composed of ice crystals.

- These Clouds can range in height from 2 to 16 kM.

- Strong upward currents within the cloud cause the water droplets to be separated resulting in high levels of positive charge at the top and levels of negative charge at the bottom of the cloud.

- The storm cloud thus creates a dipole with the ground.

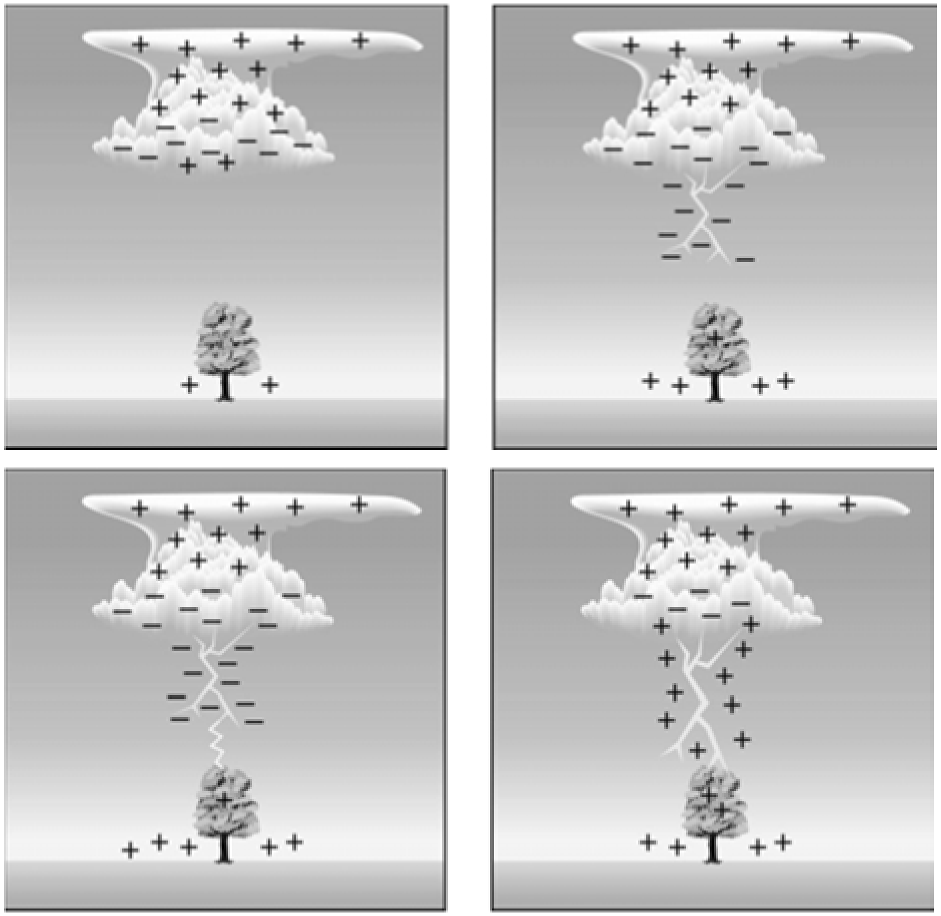
- Initially a discharge originating from the cloud known as a downward leader is formed at the cloud center.

- At the same time the electrical charge in the atmosphere at ground level increases as the downward leader gets closer.

The Development of a Lightning Strike

- Natural ionization begins to occur at points on the ground in the vicinity and eventually turns into an upward discharge, the upward leader.
- The upward leader develops toward the cloud.
- When one of these upward leaders comes into contact with the downward leader a conductive path is created and a powerful current flows.
- It is important to note that the lightning strike may be made up of a number of successive return strokes.

Lightning Formation



www.geog.ucsb.edu

Types of Lightning

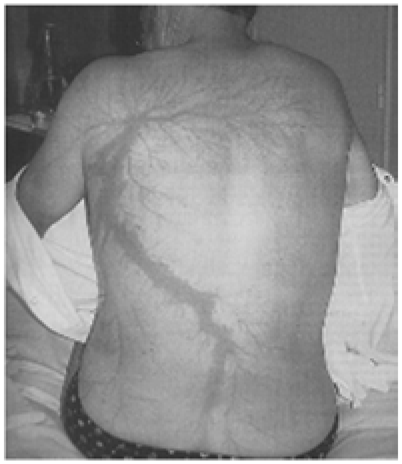
Negative Downward Lightning Cachoeira Paulista (Brazil)

Positive upward lightning Nadachi Nadachi (Japan)

www.indelec.com/

Effects of Lightning

- There are two (2) main effects of lightning strikes.
- Direct strikes can cause damage to buildings equipment and property, injury or death to people and animals.
- Because of the high levels of electrical current discharged during strikes in addition to the above electrical surges can result which can cause damage to electrical equipment.



NFPA 780 Standard for the Installation of Lightning Protection Systems

- The NFPA 780 Standard deals with the protection of structures by the placement of air terminals and downward conductors to the grounding system to provide a path for the electrical energy to the mass of earth.

- The fundamental concept for determining the zone of protection offered by the system is based on the rolling sphere method (3.10.2). Basically this is based on the rolling of a sphere of radius 46m (150ft) over the structure. The space not intruded by the sphere is the zone of protection. (fig 3.10.3.1).

- It is important to note that this standard was initially developed from the document, "Specifications for Protection of Buildings Against Lightning" first adopted by the NFPA in 1904. The standard has been revised more than 25 times over the years until in 1992 it was designated the number NFPA 780.

NFPA 780 Standard for the Installation of Lightning Protection Systems

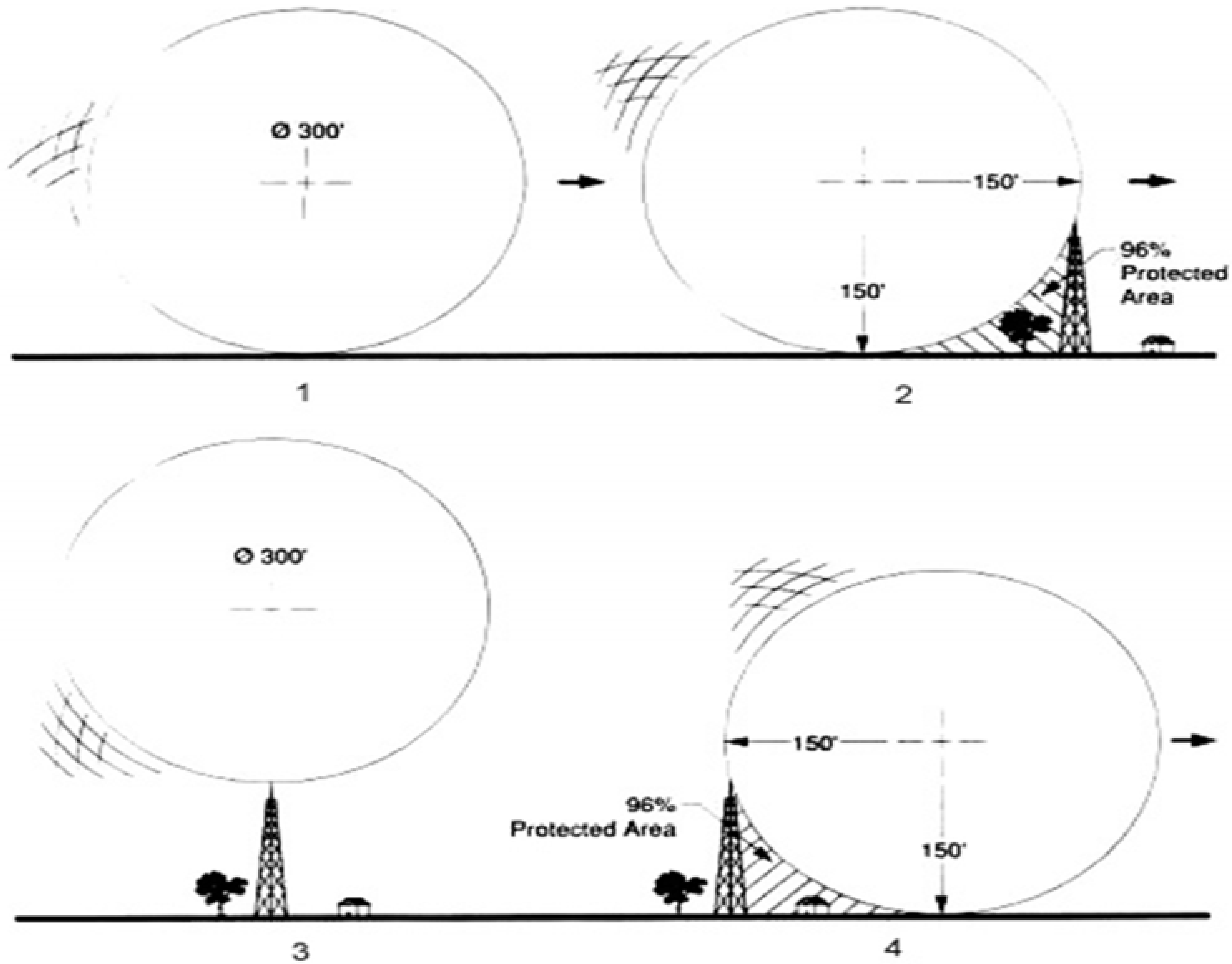
- The underlying principle of protection of structures is the provision of an easy and alternative path for the dissipation of the electrical energy or the strike.

- This is contingent on having a low impedance path to ground. Although the air terminals and downward conductors of the system are designed to meet this requirement, a common weak link in the system is the ground system.

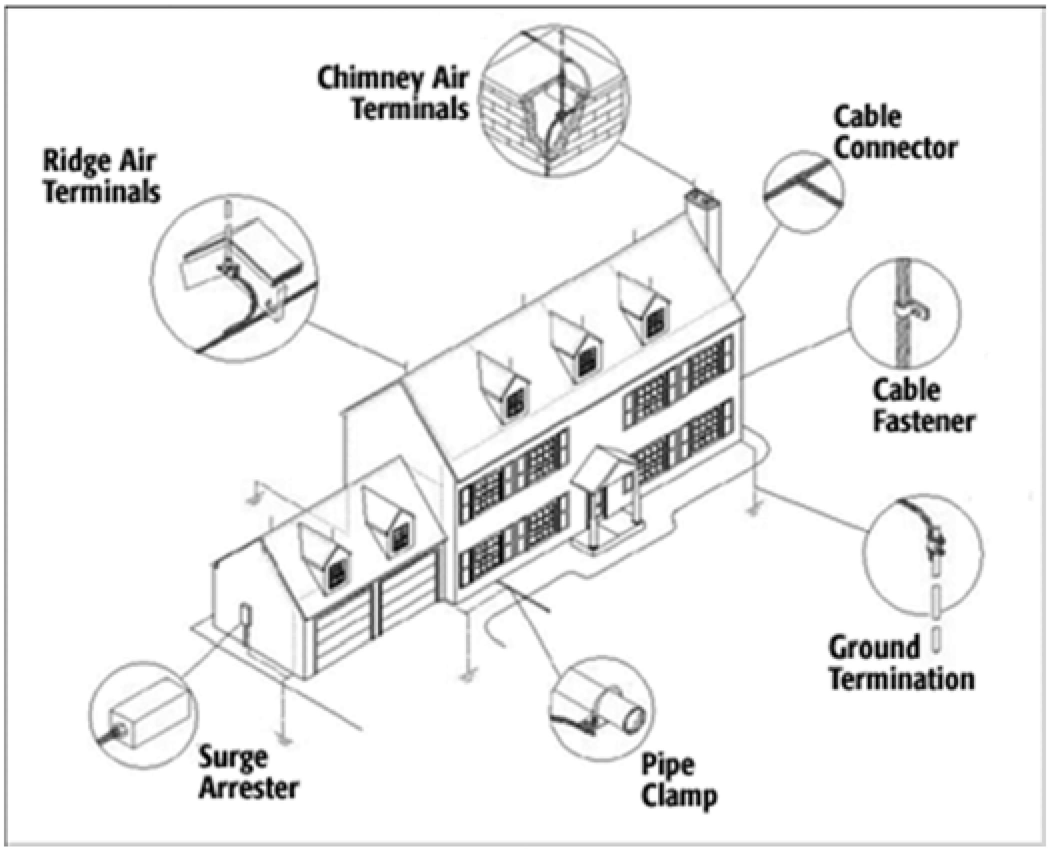
- The NEC Code requires single point grounding which means that all systems must be tied to a common ground connection point to the mass of Earth.

- This has implications for the rise in the ground voltage when the protection system is required to dissipate a large amount of energy as in the case of a lightning strike. In the case of multiple point grounding, differential voltages can develop between the grounds of independent systems within the same structure.

Rolling Sphere Method

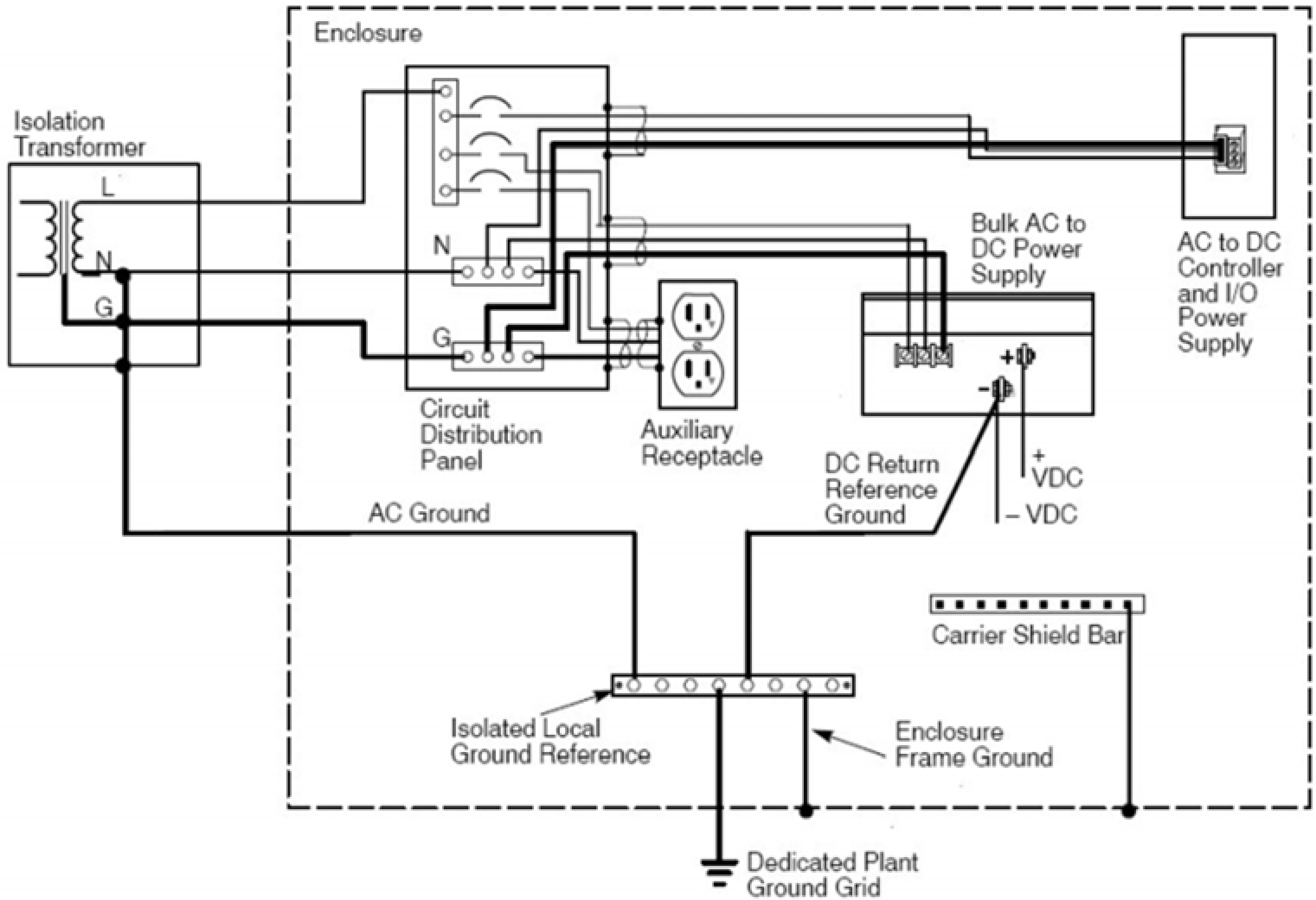


Typical Lightning Protection System



www.bondedlightning.com

Single Point Grounding



NFPA 780 Standard for the Installation of Lightning Protection Systems

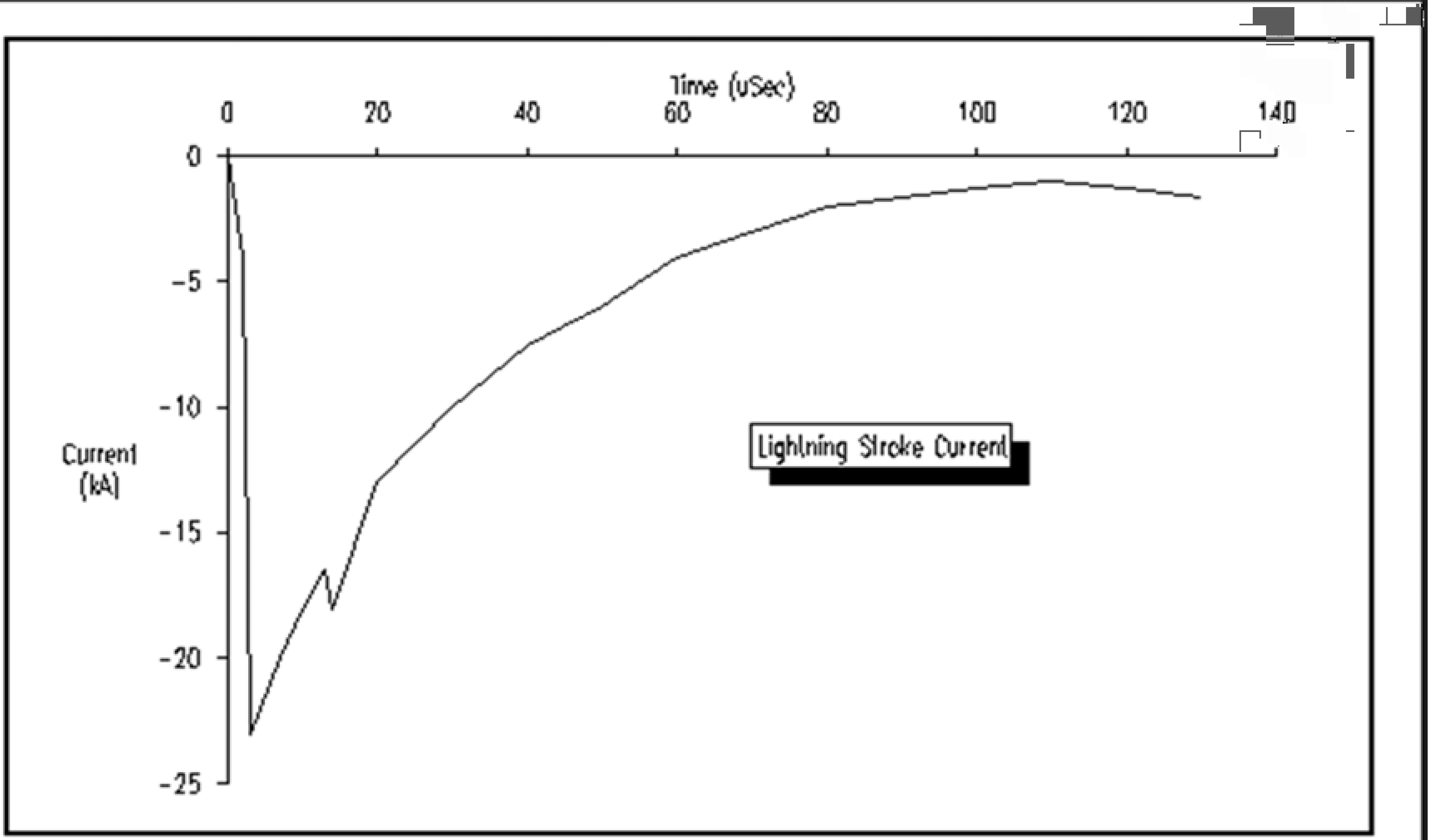
- Although the Standard is comprehensive and is based on over 100 years of practical experience, studies and statistical data its scope does not cover the issue of the effects of secondary impulsive transients on electrical systems and equipment.

- These secondary surges are caused by the induction of impulsive transients into conducting systems by the magnetic fields associated with the primary strike. They travel along conductors and usually take the form high amplitude, short duration voltages which have the potential to deliver large amounts of energy. The effect of these impulsive transients is to damage sensitive electronic equipment.

Impulsive Transients

- IEEE Std 1159, IEEE Recommended Practice for Monitoring Electric Power Quality, defines a Impulsive Transient as:
- “A sudden non-power frequency change in the steady state condition of a voltage or current that is unidirectional in polarity (primarily either positive or negative).
- These transients are associated with lightning strikes.
- Again the fundamental principle for the dissipation of these transients is the shunting to ground. There also it is seen that ultimately it is the impedance to the general mass of Earth that will be the limiting factor in the level to which the ground voltage will raise during a surge.

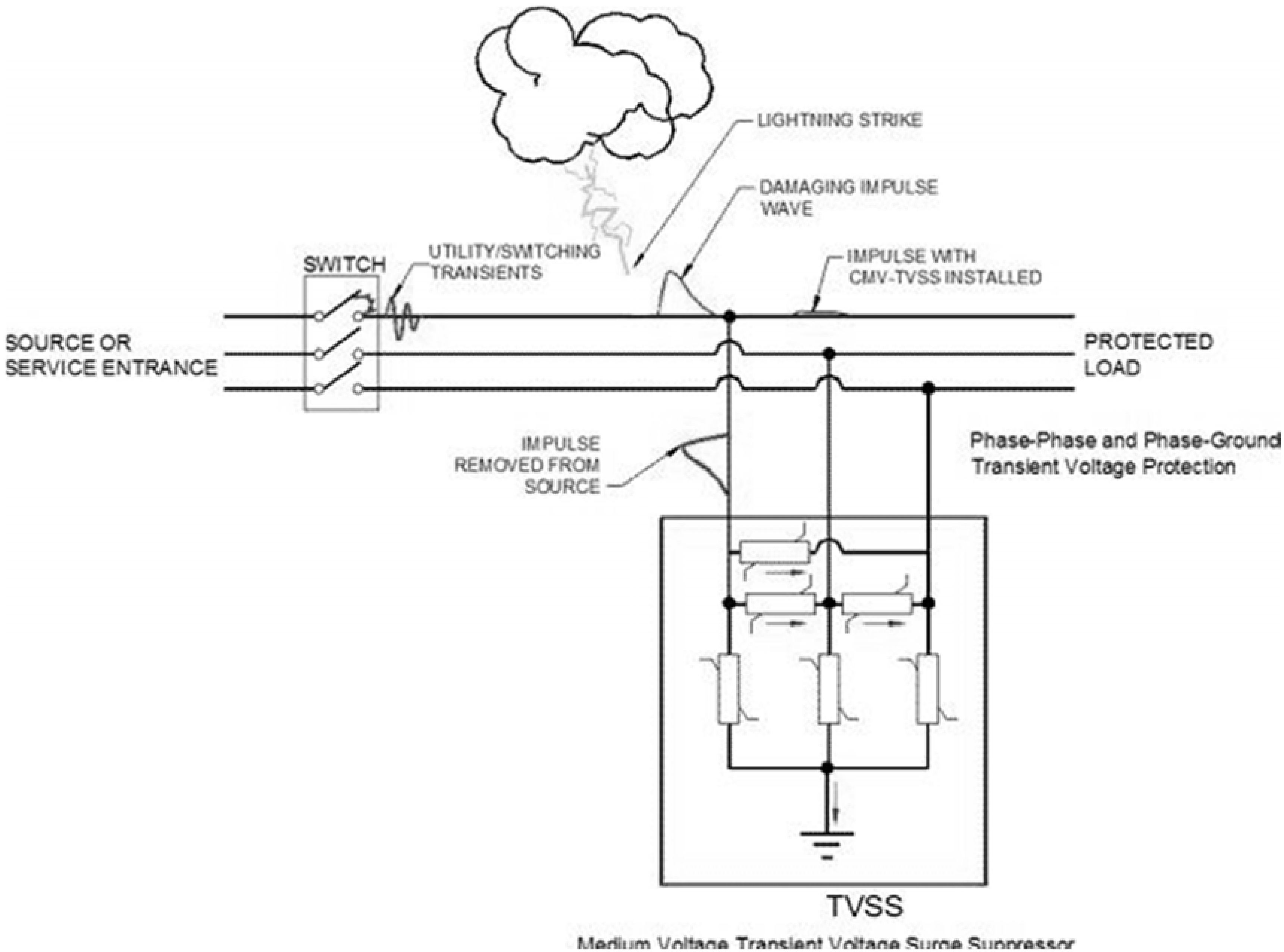
Typical Lightning Stroke Impulsive Transients



Lightning Stroke Current Impulsive Transient

www.mtm.at/pqnet/PQDEF.htm

Typical Impulsive Transient Suppression



What Happens with a direct lightning strike on equipment

- The protection systems for both lightning protection of structures and for the protection of electrical systems against secondary induced impulsive transients is contingent on the dissipation of the electrical energy to the general mass of Earth.

- The fact that for single point grounded systems the point of connection to the general mass of Earth is the electrical grounding system emphasizes the need for care to be taken when designing the grounding system.

Introduction to Lightning Protection

- **Purpose of Lightning Protection**
  - **The practical safe guarding of persons and property from hazard arising from exposure to lightning.**

Introduction to Lightning Protection

- Who invented lightning Protection?
  - Benjamin Franklin invented lightning rods in 1752

Introduction to Lightning Protection

- Lightning Facts
  - Globally some 2000 on going thunderstorms cause about 100 lightning strikes to earth each second.
  - Insurance Company information shows on home owner's damage claim for every 57 lightning strikes.
  - Annually in the USA lightning causes more than 26,000 fires with damage to property in excess of 5 billion dollars.
  - Lightning usually travels at 1/3 the speed of light.

Introduction to Lightning Protection

- Lightning Definitions
  - Air Terminal – A strike termination device that is a receptor for attachment of flashes to the lightning protection system and is listed for the purpose.
  - Class I Materials – Lightning conductors, air terminals, ground terminals and associated fittings required by this standard for protection of structures not exceeding 75ft. in height.
  - Class II Materials - Class I Materials – Lightning conductors, air terminals, ground terminals and associated fittings required by this standard for protection of structures exceeding 75ft. in height.

Introduction to Lightning Protection

- Lightning Definitions
  - Bonding Conductor – A conductor used for potential equalization between grounded metal bodies and a lightning protection system.
  - Ground Terminal – The portion of a lightning protection system such as a ground rod, ground plate or ground conductor that is installed for the purpose of providing electrical contact to earth.
  - Side Flash – An electrical spark caused by difference in potential that occurs between conductive metal bodies and a component of a lightning protection system or ground.

Introduction to Lightning Protection

- Lightning Definitions
  - Surge Arrester – A protective device used for limiting surge voltages by discharging or by passing surge current that can also prevent continued flow of follow current while remaining capable of discharging or by passing surge current.
  - Zone of Protection – The space adjacent to a lightning protection system, that is substantially immune to direct lightning flashes.

Introduction to Lightning Protection

- Considerations before designing a lightning protection system

  1. Roof types and pitch

     a) Gable

     b) Hip

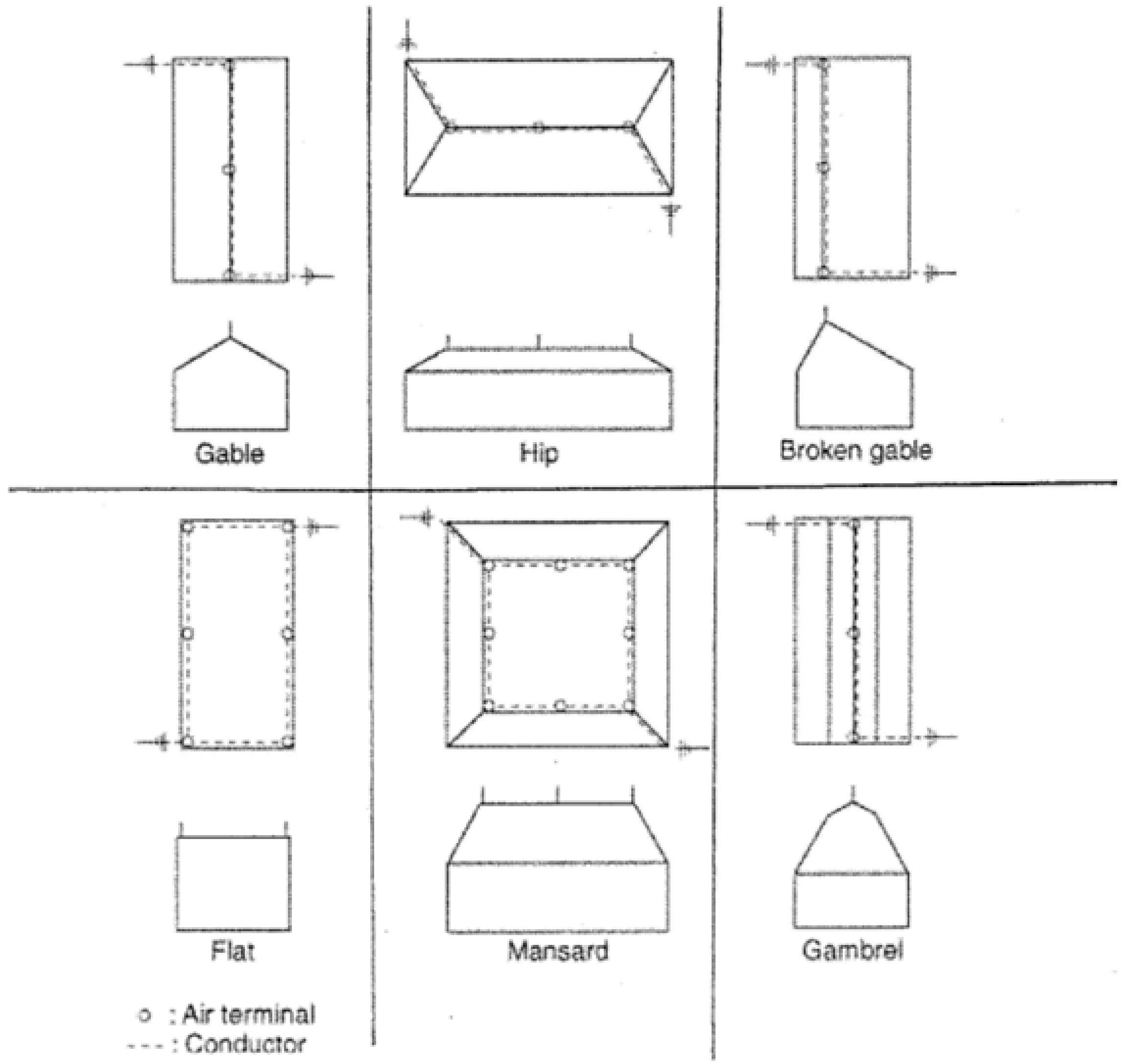
     c) Broken Gable

     d) Flat

     e) Mansard

     f) Gambrel

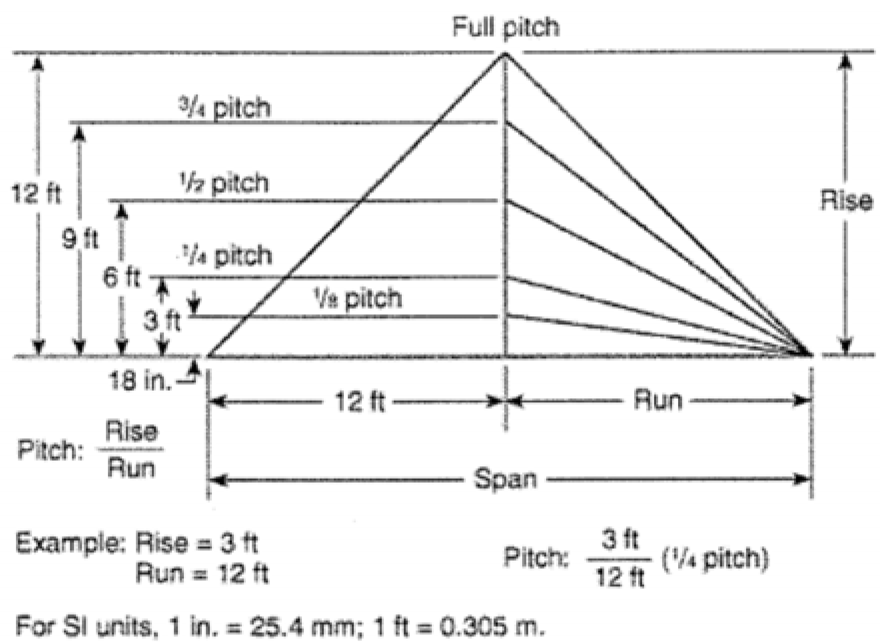
Introduction to Lightning Protection



Introduction to Lightning Protection

2. Pitch

   The roof span, rise and run is taken into account.



Introduction to Lightning Protection

3. Materials used shall be resistant to corrosion
   a) Copper
   b) Copper Alloys
   c) Aluminum
      i. Notes:
         » Copper lightning protection materials shall not be installed on aluminum roofing, siding or other aluminum surfaces.
         » Aluminum lightning protection materials shall not be installed on copper surfaces.

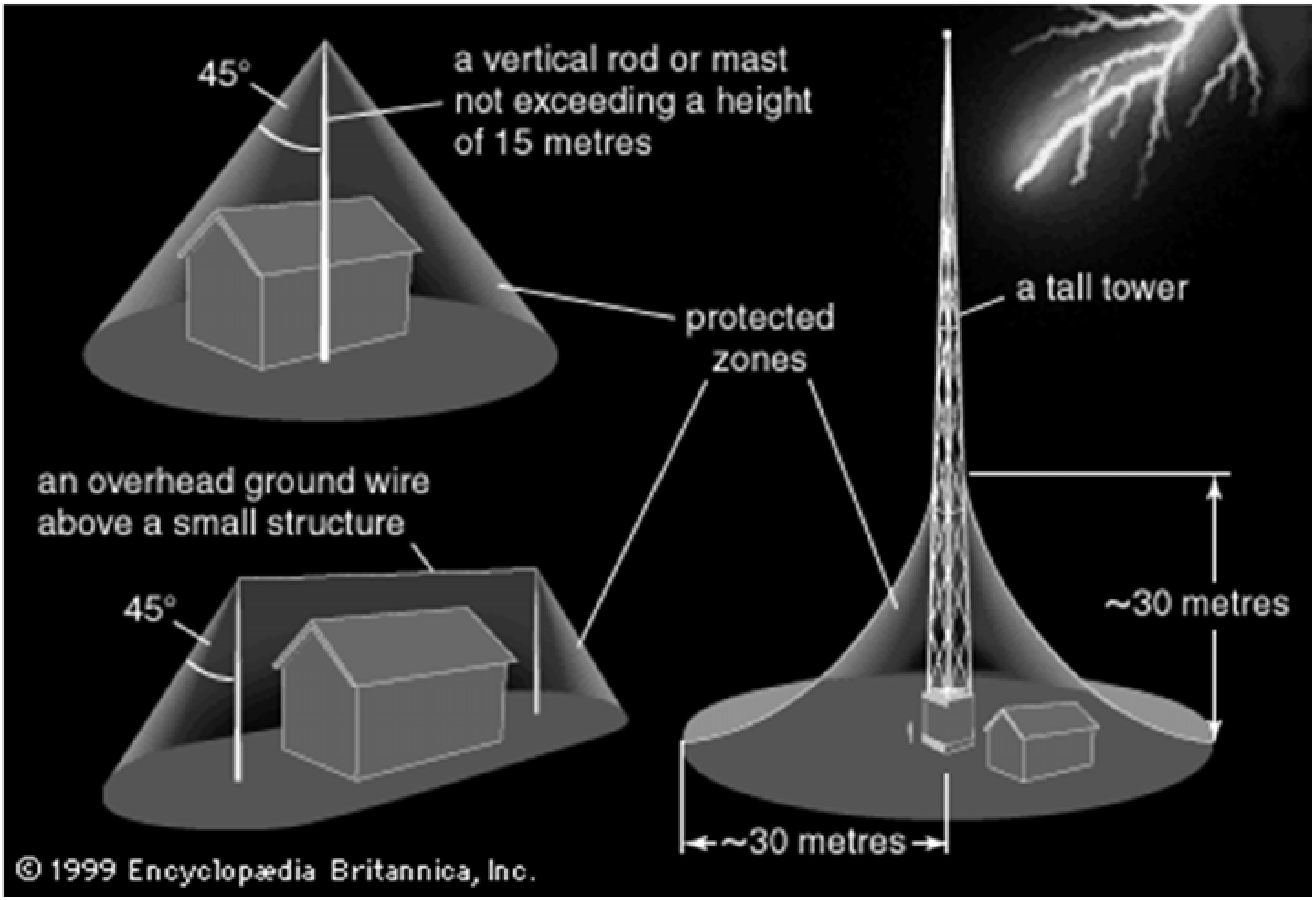
Introduction to Lightning Protection

i. Notes continued:

   » Aluminum materials shall not be used where they come in to direct contact with earth. A bimetallic connector shall be installed not less than 10” above earth level.

   » Aluminum conductors shall not be attached to a surface coated with alkaline base paint, embedded in concrete or masonry, or installed in a location subject to excessive moisture.

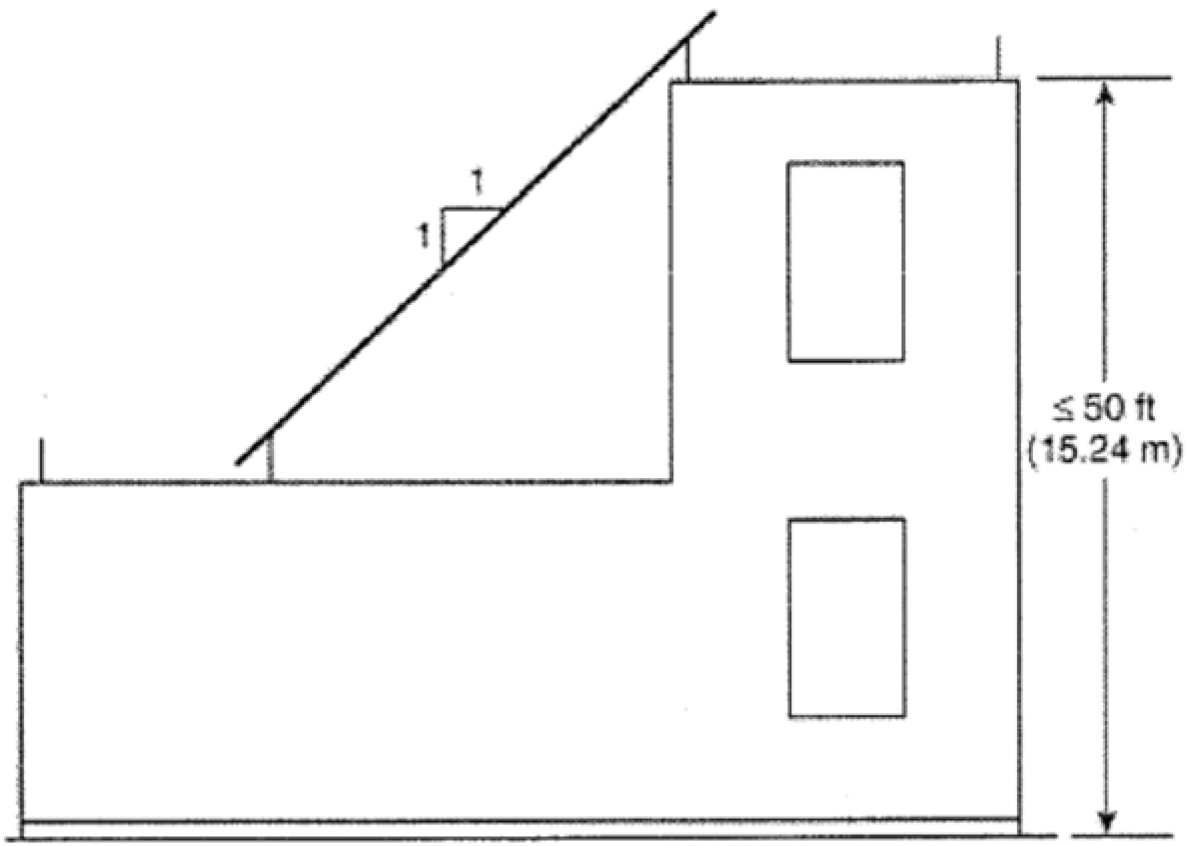
Introduction to Lightning Protection



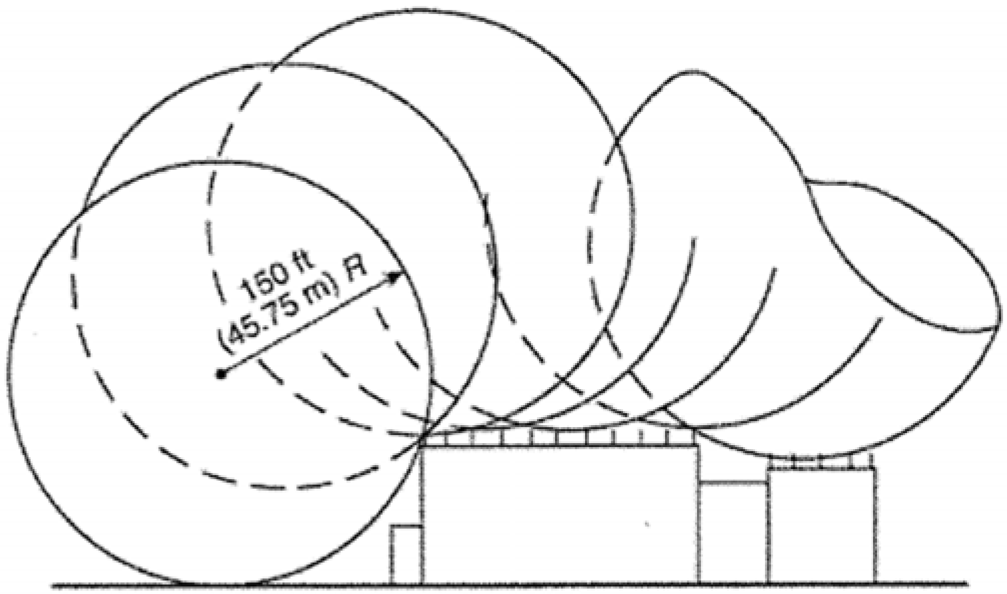
Introduction to Lightning Protection

4. Air Terminal height
   - The tip of an air terminal shall not be less then 10 inches above the object or area it is to protect.
5. Zone of protection
   - To determine the zone of protection, the geometry of the structure shall be considered.

Introduction to Lightning Protection



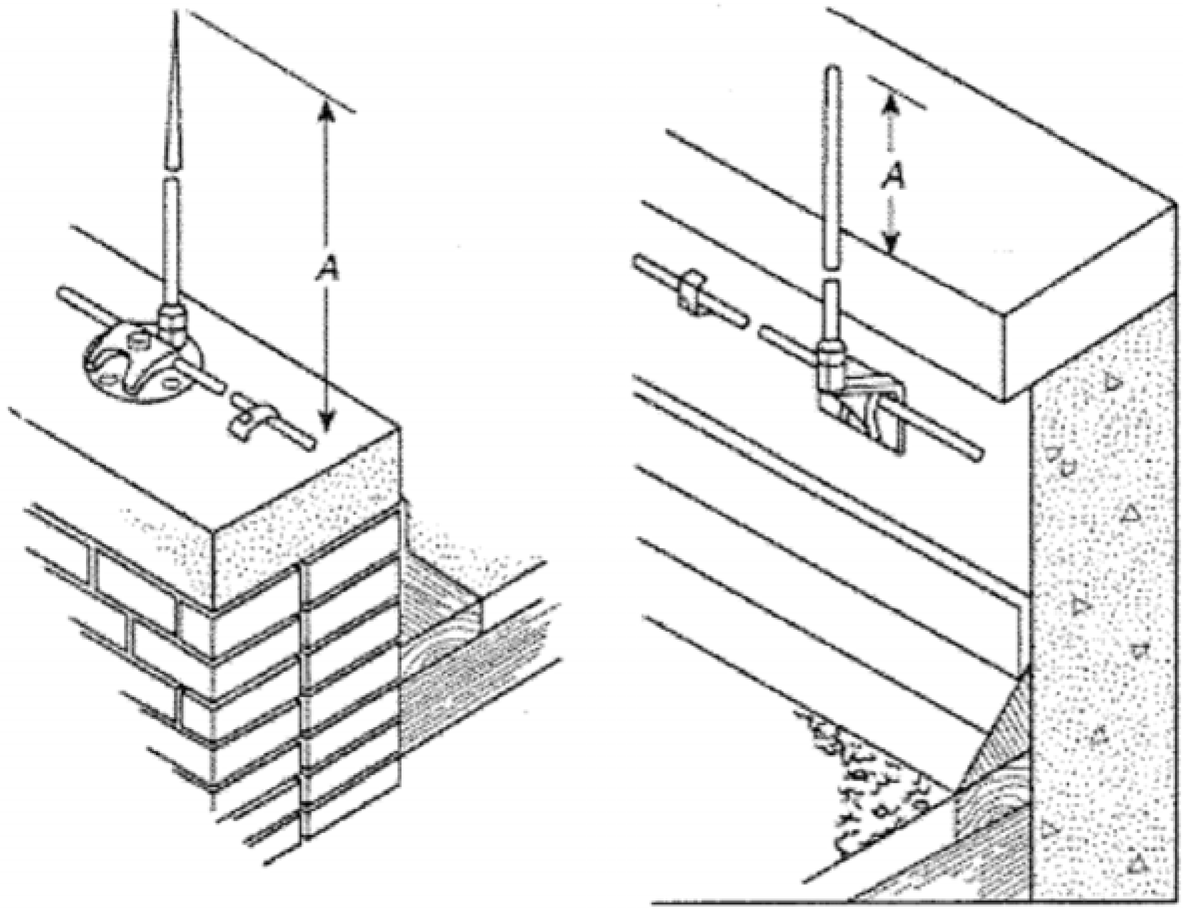
Introduction to Lightning Protection



Introduction to Lightning Protection

6. Location of devices
   - There are set distances that an air terminal can be installed apart from each other on a roof peak or at the edge of the roof that is pitched or flat.
     a) Within 2’ of the edge of the roof
     b) 20-25 ft. maximum spacing along the ridge.

Introduction to Lightning Protection



Introduction to Lightning Protection

7. Area on roofs that require special attention
   a) Dormers
   b) Exhaust
   c) Flues
   d) Chimneys
   e) Stacks
   f) Handrails
   g) Anything that is higher than the roof tip

Introduction to Lightning Protection

8. Cross-run conductors
   - Cross-run conductors (main conductors) shall be required to interconnect the strike termination devices on flat or greatly sloping roofs that exceed 50ft. In width
9. Down Conductors
   - Down conductors shall be widely separated as practical. Their location shall depend on the following considerations:
     a) Placement of strike termination devices
     b) Most direct course of conductors
     c) Earth conditions
     d) Security against displacement
     e) Location of large metallic bodies
     f) Location of underground metallic piping systems

Introduction to Lightning Protection

10. Number of down conductors
    a) At least two down conductors shall be provide on any kind of structure.
    b) Structures exceeding 250ft. In perimeter shall have a down conductor for every 100ft. of perimeter.
11. Protecting down conductors
    - The down conductor shall be protected for a minimum distance of 6ft. Above ground level. Usually in a PVC raceway.
12. Ground terminals
    - Each down conductor shall terminate at a ground terminal dedicated to the lightning protection system.

Introduction to Lightning Protection

13. Ground Electrodes (Ground rods)
    a) Shall be installed below the frost line where possible.
14. Concrete encased electrode (Ufer ground)
    - These shall only be used in new construction. The electrode shall be located near the bottom of the concrete foundation or footing encased by not less than 2” of concrete. The encased electrode shall consist of the following:
        a) Not less that 20ft. of bare copper
        b) An electrode consisting of at least 20ft. of one or more steel reinforcing bars that have been bundled together by welding or secure wire tying.

Introduction to Lightning Protection

15. Ground plates are an option when soil is shallow and rods can't be driven deep enough.
    - Ground plates are a minimum 2ft. Square, buried no less than 18" deep and are at least .032in thick.
16. Lightning protection for miscellaneous structures
    - Metal towers and tanks constructed so as to receive a stroke of lightning without damage shall require only bonding to ground terminals.
17. Concrete tanks and silos
    - Lightning protection systems for concrete tanks containing flammable vapors, flammable gases, and liquids that can produce flammable vapors and concrete silos containing materials susceptible to dust explosions shall be provided with either external conductors or with conductors embedded in the concrete.

Introduction to Lightning Protection

18. Protection for heavy duty stacks

    a) Smoke or vent stack shall be classified as heavy duty if cross sectional area of flue is greater that 500 in squared and a height greater than 75ft.

    b) Air terminals shall be placed at 8' spacing max.

    c) All equipment on upper 25ft. Of stack to be lead covered copper, stainless steel or approved corrosion resistant material.

    d) If the stack has platform and ladders each of these will be bonded to the lightning protection system on the way down the stack.

Introduction to Lightning Protection

19. Surge Suppression

a) Surge suppression should also be considered for your main electrical devices in the plant.

In all instances use high quality, high speed, self-diagnosing protective components. Transient limiting devices may use a combination of arc gap diverters-metal oxide varistor-silicon avlanche diode technologies. Hybrid devices using a combination of these technologies are preferred.

Know your clamping voltage requirements. Confirm that your vendors products have been tested to rigid ANSI/IEEE/ISO 9000 testing standards.

Introduction to Lightning Protection

20. Standards for Lightning protection

- Standard NFPA 780
- 2008 NEC Article 250
- Article 280 Surge Arrester over 1 Kv
- Article 285 Surge Protective Devices 1 Kv or less

Introduction to Lightning Protection
Any Questions?

Grounding Continued:

The Differences Between and Purposes for Bonding, Grounding, and Earthing in North American Power Distribution Systems

Applicable Codes and Standards Pertaining to the Testing of Bonding and Grounding Systems

- NEC Article 250 **(Contrary to popular belief, there are no testing or maintenance requirements in Article 250.)**
- NFPA 99, Chapter 4 – Electrical System Requirements (Paragraph 4.3.3 – "Performance Criteria and Testing")
- NFPA 99, Chapter 8 – Electrical Equipment (Paragraph 8.4.1.3 – "Testing Requirements")
- IEEE Standard 81 (IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and earth Surface Potentials of a Ground System)
- IEEE Standard 142, Chapter 4 (IEEE Recommended Practices for Grounding of Industrial and Commercial Power Systems)
- IEEE Standard 601, Clause 6.8.6.e – Field inspection procedure (This clause recommends testing, but does not mandate testing or provided for specific testing methods.)
- **If a grounding system is not routinely inspected or tested, how do you know if it is adequate or effective for the needs of your facilities?**

Differences Between Bonding and Grounding

- **The terms “bonding” and “grounding” are often employed interchangeably as general terms in the electrical industry to imply or mean that a specific piece of electrical equipment, structure, or enclosure is somehow referenced to earth.**
- **In fact, “bonding” and “grounding” have completely different meaning and employ different electrical installation methodologies.**

Bonding

"Bonding" is a method by which all electrically conductive materials and metallic surfaces of equipment and structures, not normally intended to be energized, are effectively interconnected together via a low impedance conductive means and path in order to avoid any appreciable potential difference between any separate points.

The bonded interconnections of any specific electrically conductive materials, metallic surfaces of enclosures, electrical equipment, pipes, tubes, or structures via a low impedance path **are completely independent and unrelated to any intended contact or connection to the Earth.**

For example, airplanes do not have any connection to the planet Earth when they are airborne. It is extremely important for the safety and welfare of passengers, crew, and aircraft the all metallic parts and structures of an airplane are effectively bonded together to avoid difference of potential between structures and parts when traveling at high rates of speed or when the frame of the aircraft is struck by lightning.

.

Bonding

- The common mean to effectively bond different metallic surfaces of enclosures, electrical equipment, pipes, tubes or structures together is with a copper conductor, rated lugs, and the appropriate bolts, fasteners, or screws.

- Other effectively bonding means between different metallic parts and pieces might employ brackets, clamps, exothermic bonds, or welds to make an effectively connections.

- In addition to preventing potential differences that may result in hazards, effectively bonded equipment can also be employed to adequately and safely conduct phase-to-ground fault current, induced currents, surge currents, lightning currents, or transient currents during such abnormal conditions. .

Grounding

- “Grounding” is a term used rather exclusively in North American to indicate a direct or indirect connection to the planet Earth or to some conducting body that serves in place of the Earth.
- The connection(s) to Earth can be intentional or unintentional by an assortment of metallic means intended to be employed as a designated grounding electrode.
- A designated grounding electrode is the device that is intended to establish the direct electrical connection to the earth.
- A common designated grounding electrode is often a copper clad or copper flashed steel rod.
- The designated grounding electrode might be a water pipe, steel columns of a building or structure, concrete encased steel reinforcement rods, buried copper bus, copper tubing, galvanized steel rods, or semi conductive neoprene rubber blankets. Gas pipes and aluminum rods can not be employed as grounding electrode
- The grounding electrode conductor is the designed conductor that is employed to connect the grounding electrode(s) to other equipment grounding conductors, grounded conductor, and structure.

Earthing

- “Earthing” is a term developed by the United Kingdom and part of the British Electrical Code and is employed in Europe or other countries that employs International Electric Commission (IEC) standards.

- The term “earthing” in European or IEC countries is synonymous with the term “grounding” in North America. .

The Five Principal Purposes of Bonding & Grounding Systems

The principle purposes for an "effectively bonded grounding system via a low impedance path to earth" are intended to provide for the following.

1. Provide for an applicable reference to earth to stabilize the system voltage of a power distribution system during normal operations.
2. Create a very low impedance path for ground fault current to flow in a **relatively** controlled path.
3. Create a very low impedance path for ground fault current to flow in order for overcurrent protective devices and any ground fault protection systems to operate effectively as designed and intended.
4. Limit differences of potential, potential rise, or step gradients between equipment and personnel, personnel and earth, equipment and earth, or equipment to equipment.
5. Limit voltage rise or potential differences imposed on a power distribution system from lightning, a surge event, any phase-to-ground fault conditions, or the inadvertent commingling of or the unintentional contact with different voltage system.

Selected Clauses from IEEE 142

- Clause 2.1.4 Overcurrent Protection Operation

  "The equipment ground system is an essential part of the overcurrent protection system. The overcurrent protection system requires a low-impedance ground return path in order to operate promptly and properly. **The earth ground system is rarely of low enough impedance and is not intended to provide an adequate return path.** The impedance of the grounding conductor must be low enough that sufficient ground-fault current will flow to operate the overcurrent protective device and clear the fault rapidly."

- Clause 2.8.8 – Earth Resistivity

  "Earth is inherently a rather poor conductor whose resistivity is around one billion times that of copper."

Selected Clauses from IEEE 142

- Clause 4.1.3 - Resistivity of Soils:

  “**It is *strongly* recommended that the resistivity of the earth at the desired location of the connection be investigated**. The resistivity of soils varies with the depth from the surface, the type and concentration of soluble chemicals in the soil, the moisture content, and the soil temperature. The presence of surface water does not necessarily indicate low resistivity.”

- Clause 4.1.6 - Soil Treatments:

  “ To be effective, a regular maintenance scheme must be established to ensure low resistance grounding is achieved.)

Selected Clauses from IEEE 142

- Clause 4.4.5 - Electrical Grounding and Corrosion:

  "The effect of the grounding installation on corrosion must be considered. **Systems, equipment, and lighting sometimes unknowingly contribute to galvanic corrosion of underground conductors, structures, and piping.** Galvanic corrosion is caused by electrically connected dissimilar metals which form a galvanic cell. Under these conditions the following factors determine the rate of corrosion."

Selected Clauses from IEEE 142

ARRANGEMENT OF METALS IN GALVANIC SERIES

CORRODED END
Anodic or less noble
Magnesium
Zinc
Aluminum
Cadmium
Steel
Lead
Tin
Nickel
Brass
Bronzes
Copper
Nickel-Copper Alloys
Stainless Steels (passive)
Silver
Gold
Platinum
PROTECTED END
Cathodic or most noble

Any one of these metals and alloys will theoretically corrode while offering protection to any other which is lower in the series, so long as both are electrically connected.

In actual practice, however, zinc is by far the most effective in this respect.

Figure 1. Summary of the "electromotive series of metals" address on corrosion.

Clause 4.4.5 - Electrical Grounding and Corrosion:

The rate of oxidation and corrosion is determined by;

– The potential difference between the two metals.
– The ratio of the exposed areas of the two metals.
– The resistance of the electrolyte.
– The resistance of the external circuit.
– Stray currents between electrodes, conductors, structures, pipes, and earth.
– **Current of one ampere flowing for one year will corrode away 20lbs of steel, 22 lbs of copper, 24 lbs of aluminum, 75 lbs of lead, or 26 lbs of zinc. With greater current flow, more metal will corrode away.**

NFPA 70 [The National Electrical Code (NEC)]

"Article 250 in the NEC covers grounding.

- The NEC is NOT a design document .
- The NEC is NOT a maintenance document.
- The NEC is NOT a performance document .
- The NEC is NOT a testing document.
- The NEC is ONLY a **minimum** construction and installation '**requirement**' document.
- "Minimum requirements" are insufficient for the construction and installation of grounding systems associated with Critical, Emergency, and Life Safety Power Distribution Systems in Healthcare Facilities.

Definitions in the 2005/2008/2011 Edition of the NEC

- What is “Effectively Grounded”?

  The 2005/2008/2011 National Electrical Code defines effectively grounded as: “Intentionally connected to earth through a ground connection or connections of sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltage that may result in undue hazards to connected equipment of persons."

- What is “Grounded”?

  The 2005 NEC defines “Grounded” as: “Connected to earth or to some conducting body that serves in place of the earth."

  The 2008 NEC defines “Grounded” as: “Connected to earth.”

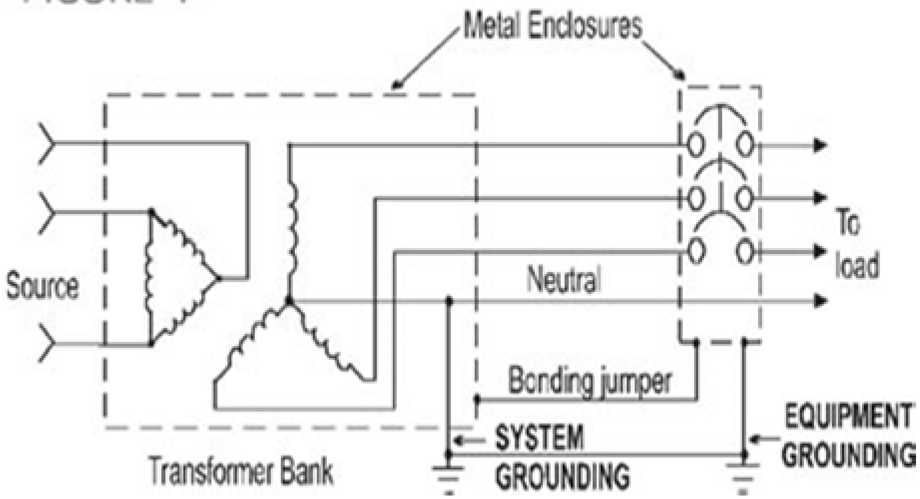
  The 2011 NEC defines “Grounded” as: “Connected (connecting) to ground or to a conductive body that extends the ground connection.”

- What is “Solidly Grounded”?

  “Connected to ground (earth) without inserting any resistor or impedance device."

Definitions in the 2005/2008/2011 Edition of the NEC

FIGURE 1



- What is “Solidly Grounded”?

  “Connected to ground without inserting any resistor or impedance device."

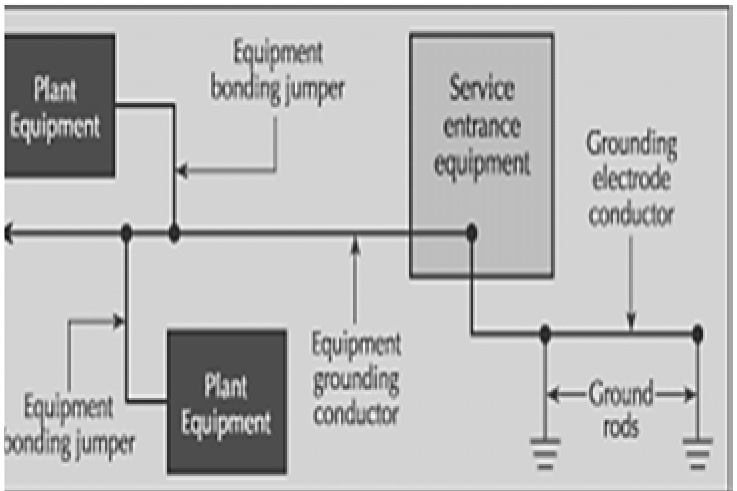
- What is “Grounded Conductor”?

  “A system or circuit conductor that is intentionally grounded."

  A “grounded conductor” carries current during “normal” operations of the power distribution system.

  (The “grounded conductor” is commonly referred to as the neutral conductor.)

Definitions in the 2005/2008/2011 Edition of the NEC



- What is "Grounding Conductor"?

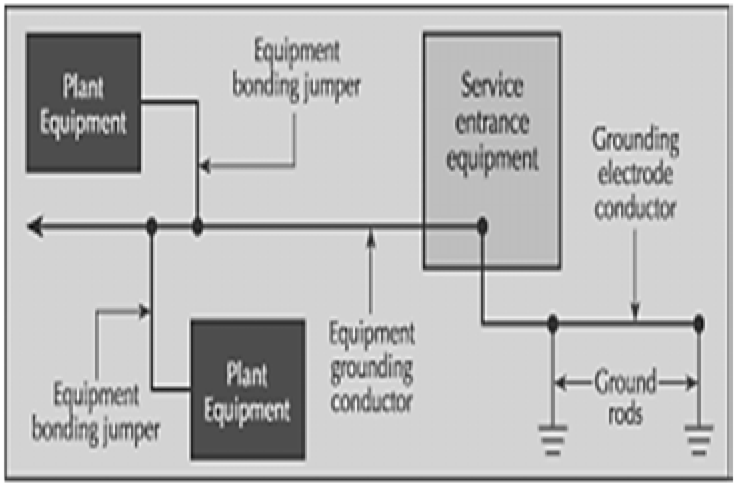
  "A conductor used to connect equipment or the grounded circuit of a wiring system to a grounding electrode or electrodes."
  A "grounding conductor" is intended to only carry current during an "abnormal" operation of the power distribution system or a faulted condition.

- What is the "Equipment Grounding Conductor"?

  "The conductor used to connect the non-current carrying metal parts of equipment, raceways, and other enclosures to the system grounded conductor, the grounding electrode conductor, or both at the service equipment or at the source of a separately derived system."

.

Definitions in the 2005/2008/2011 Edition of the NEC



- What is "Grounding Electrode"?

  "A device that establishes an electrical connection to the earth."

- What is a "Grounding Electrode Conductor"?

  "The conductor used to connect the grounding electrode(s) to the equipment grounding conductor, to the grounded conductor, or to both, at the service, at the building or structure where supplied by a feeder(s) or branch circuit(s), or at the source of a separately derived system."

Definitions in the 2005/2008/2011 Edition of the NEC

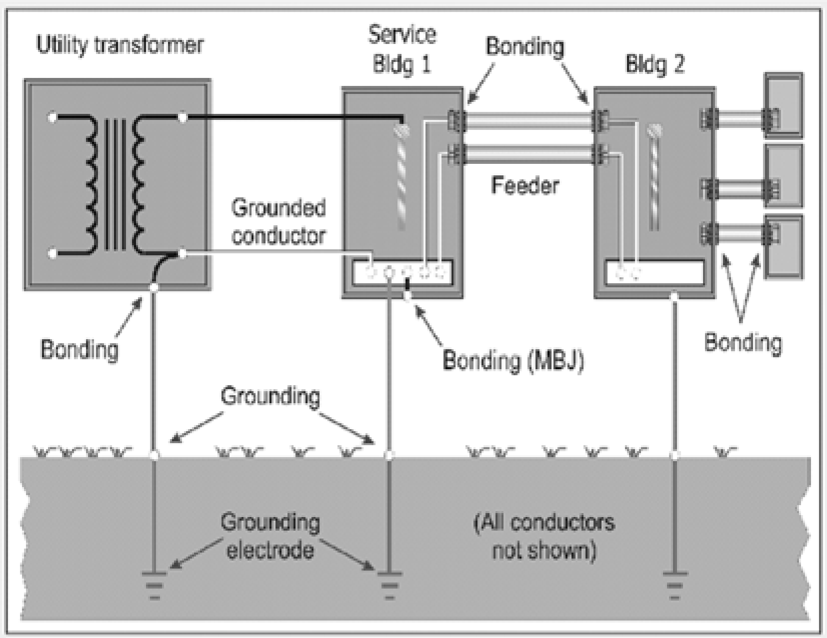


Figure 1. Grounding and bonding functions

- What is "Main Bonding Jumper (MBJ)"?

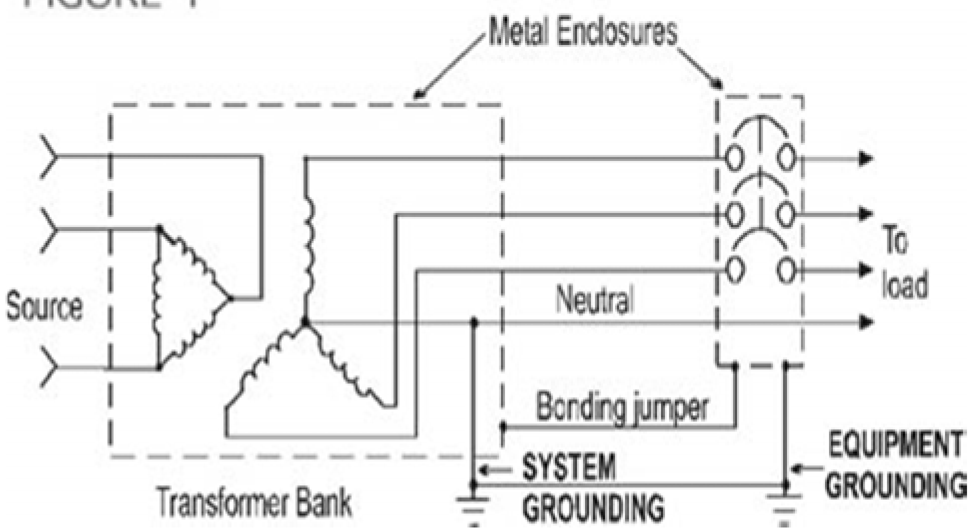
  "The connection between the grounded circuit conductor and the equipment grounding conductor at the service."

  The primary function or purpose of the MBJ is to provide a low impedance return path for the return of phase-to-ground fault current from the ground bus in the service equipment to the power supply source (transformer, generator, or output terminals of an UPS).

  The MBJ must be adequately sized to effectively carry all phase-to-ground fault current likely to be imposed on it.

Definitions in the 2005/2008/2011 Edition of the NEC

FIGURE 1



- What is "Bonding Jumper"?

  "A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected."

  The primary function or purpose of a bonding jumper is to provide a low impedance electrically conductive connection between separate enclosures, conduits, raceways, structures, or equipment frames.

  Must be properly sized to effectively carry any and all current likely to be imposed on it.

Definitions in the 2005/2008/2011 Edition of the NEC

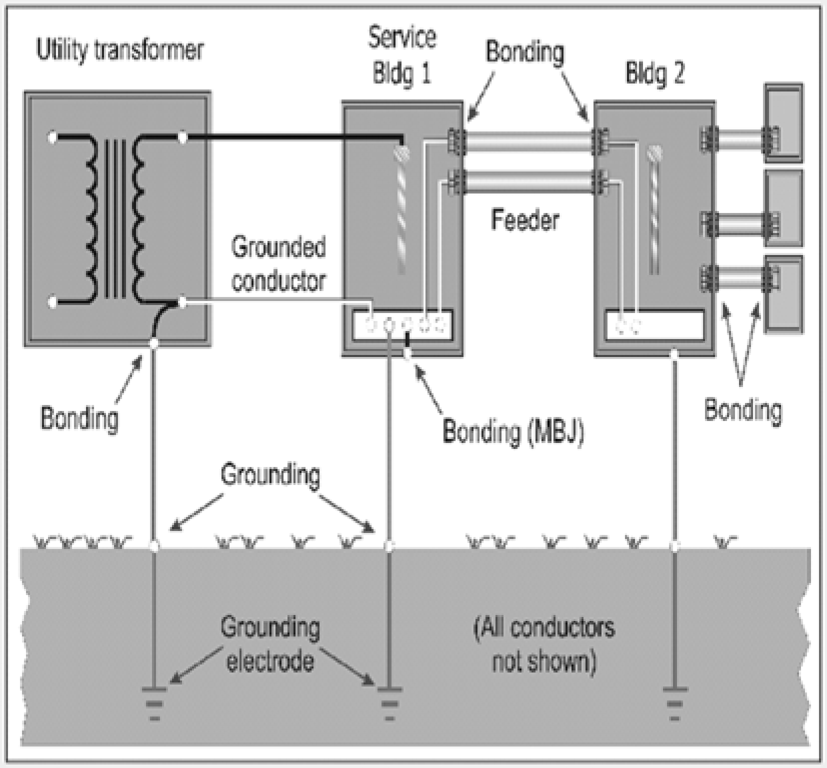


Figure 1. Grounding and bonding functions

- What is "System Bonding Jumper"?

  "The connection between the grounded circuit conductor and the equipment grounding conductor at a separately derived system." (New definition introduced into the 2005 NEC.)

  "The connection between the grounded circuit conductor and the supply-side bonding jumper, or the equipment grounding conductor, or both, at a separately derived system." (As revised in the 2011 NEC.)

  The primary function or purpose of the system bonding jumper is to provide for an applicable reference to earth for the system voltage at the origins of the specific and separately derived system. The system bonding jumper is a connection between the Xo terminal of a transformer, generator, or UPS output terminals and earth. This jumper is not normally sized to carry ground fault current.

  (i.e. 600Y/347V, 480Y/277V, or 208Y/120V, 3 Phase, 4 Wire, Solidly Grounded, "WYE" Systems)

Common Issues Found with Bonding and Grounding Systems

- **All utilities are not effectively bonded together.**
- **All structures are not effectively bonded together**
- **EMT conduits with set screw couplings employed as the ground fault return path.**
- **No grounding bushings employed**
- **Improper or loose connections. Undersized grounding conductors**
- **Oxidization and reduction of mechanical grounding connections**
- **Lightning abatement system directing lightning currents into the building via connections to building steel**
- **No access to external ground grid system**
- **Deterioration of external ground grid system over time**
- **No records of initial ground grid testing.**
- **No records of regular inspections and maintenance of grounding systems**.
- **Excessive impedance in the ground fault return path**
- **No drawings or records available for the facility's grounding system**

Advantages and Disadvantages of Different Types of Neutral Grounding Systems

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.

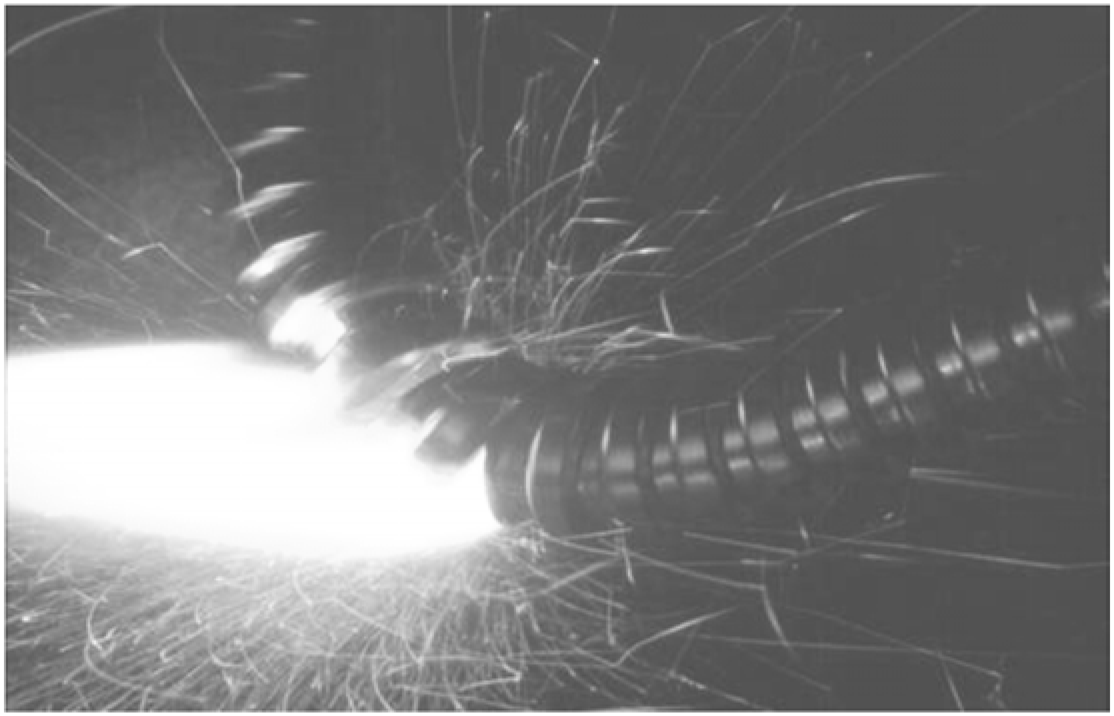
DISCUSSION OF GROUNDING

1. Ungrounded system
2. Solidly grounded system
3. Reactive grounded system
4. Low resistance grounded system
5. High resistance grounded system

Are You at Risk?

•**Do you use electricity?**

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

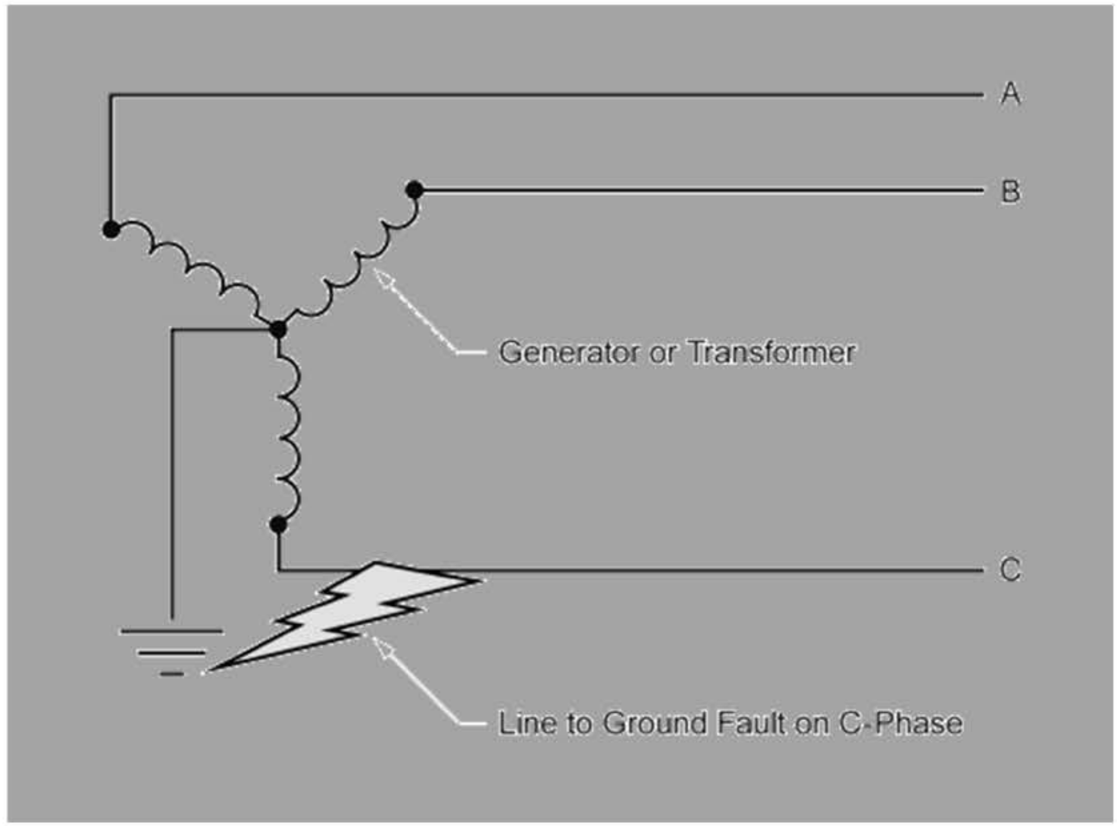


What is a Ground Fault?

Contact between ground and an energized conductor

Unleashes large amount of electrical energy

Dangerous to equipment and people



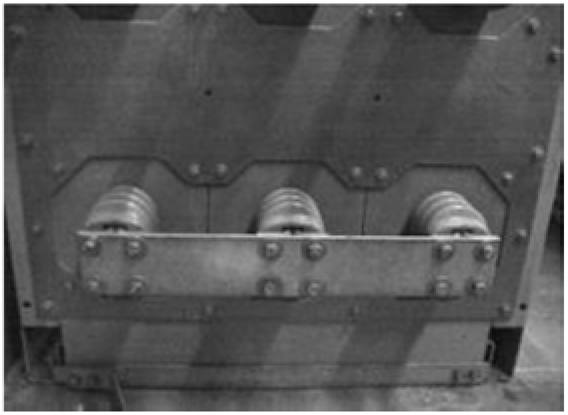
POWER SYSTEM GROUNDING
SYSTEM FAILURES – SHORT CIRCUITS (FAULTS)
INDUSTRIAL POWER SYSTEMS

FAILURE MODE	PERCENTAGE OF FAILURES
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.

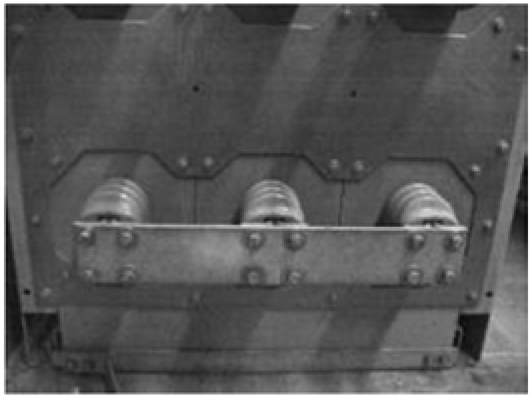
•Stresses are well contained so fault creates less destruction.

•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

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

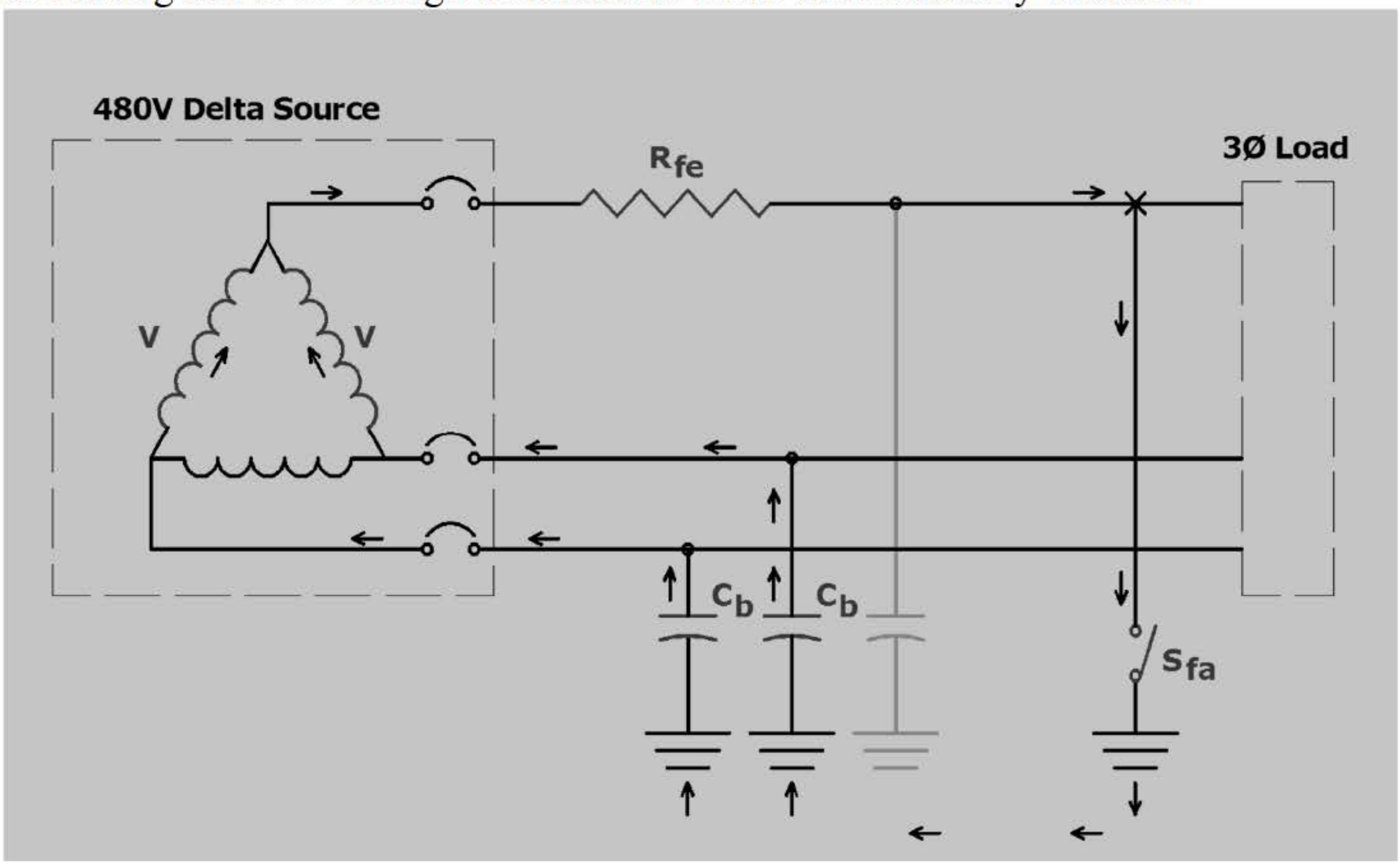
An arcing fault is an intermittent failure between phases or phase to ground. It is a discontinuous current that alternately strikes, is extinguished and restrikes again. For solidly grounded systems, the arc currents are: in percent of bolted three phase faulted

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

Arcing Ground Faults
Intermittent or Re-strike

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

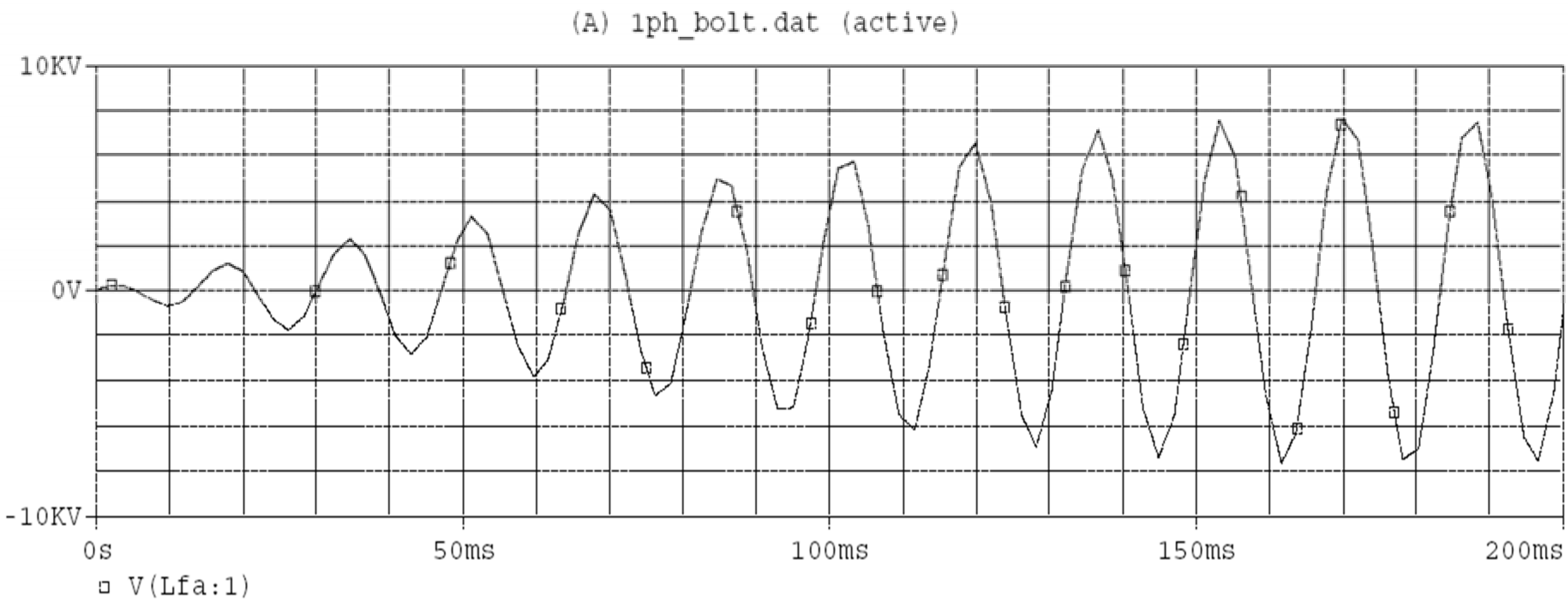
- i.e. re-striking due to ac voltage waveform or loose wire caused by vibration



Arcing Ground Faults

Intermittent or Re-strike

•Plot of transient over-voltage for an arcing ground fault



Industry Recommendations

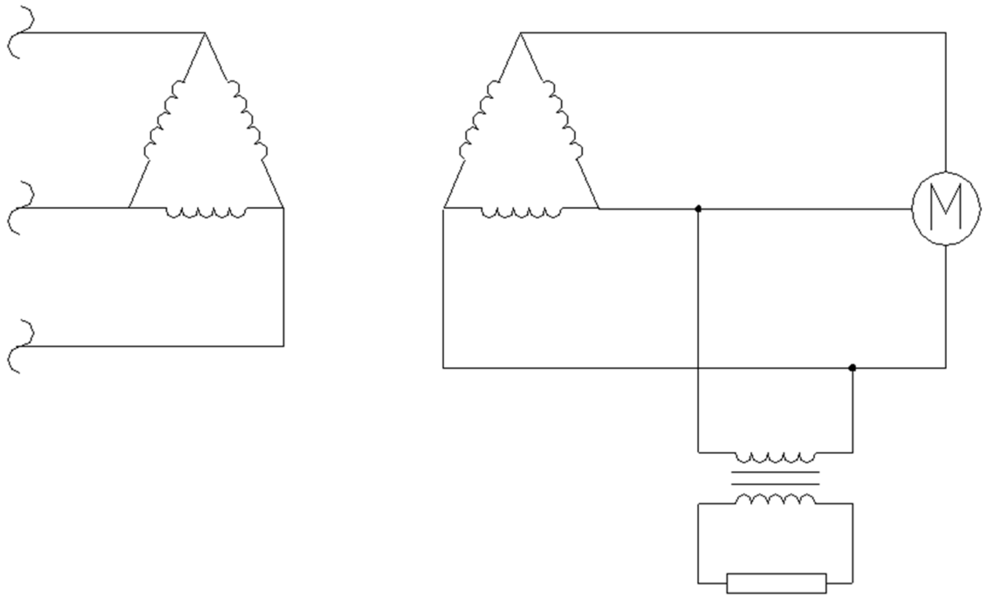
- **IEEE Std 242-2001 (Buff Book)**
- Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems

- 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 <u>six to eight times</u> 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 UNGROUNDEDED POWER SYSTEM

DELTA - DELTA CONNECTION

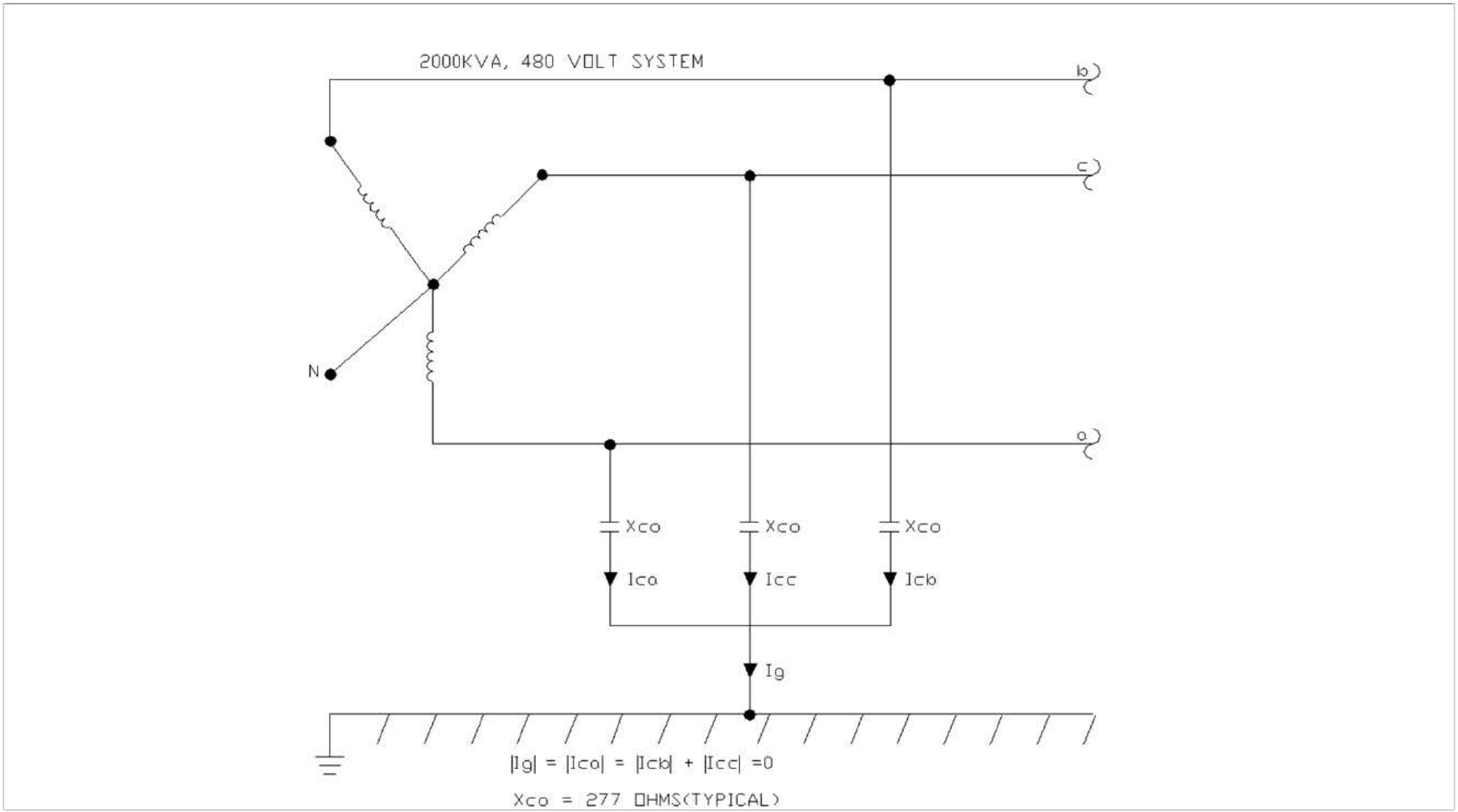


SINGLE PHASE LOAD

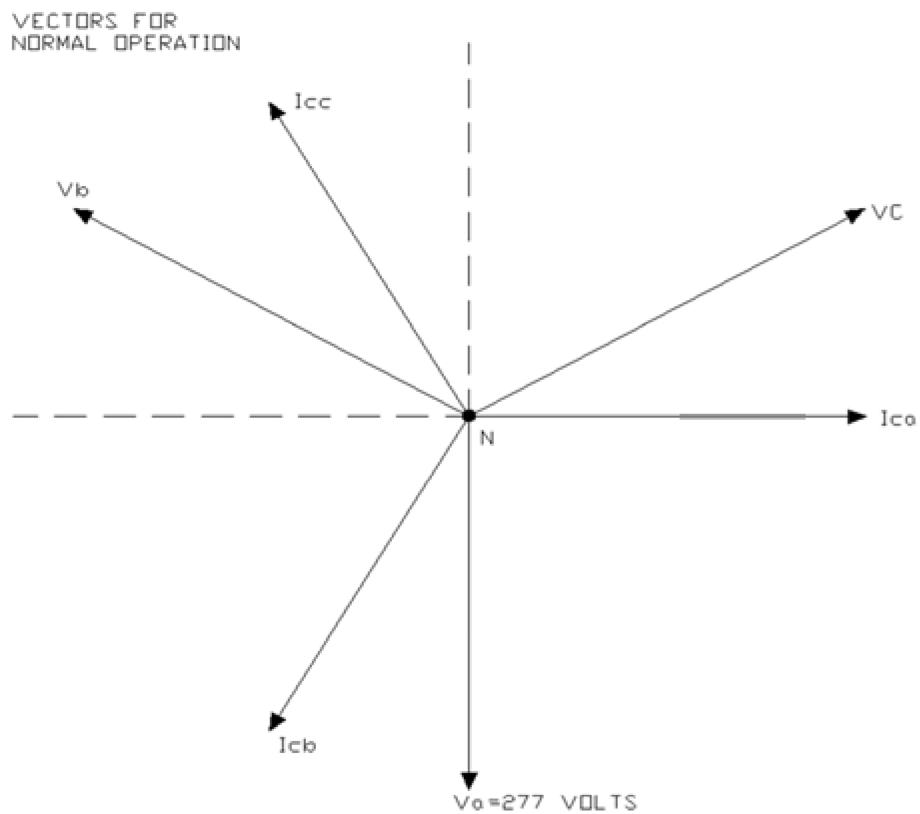
SUITABLE FOR

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

UNGROUNDED SYSTEM NORMAL CONDITIONS

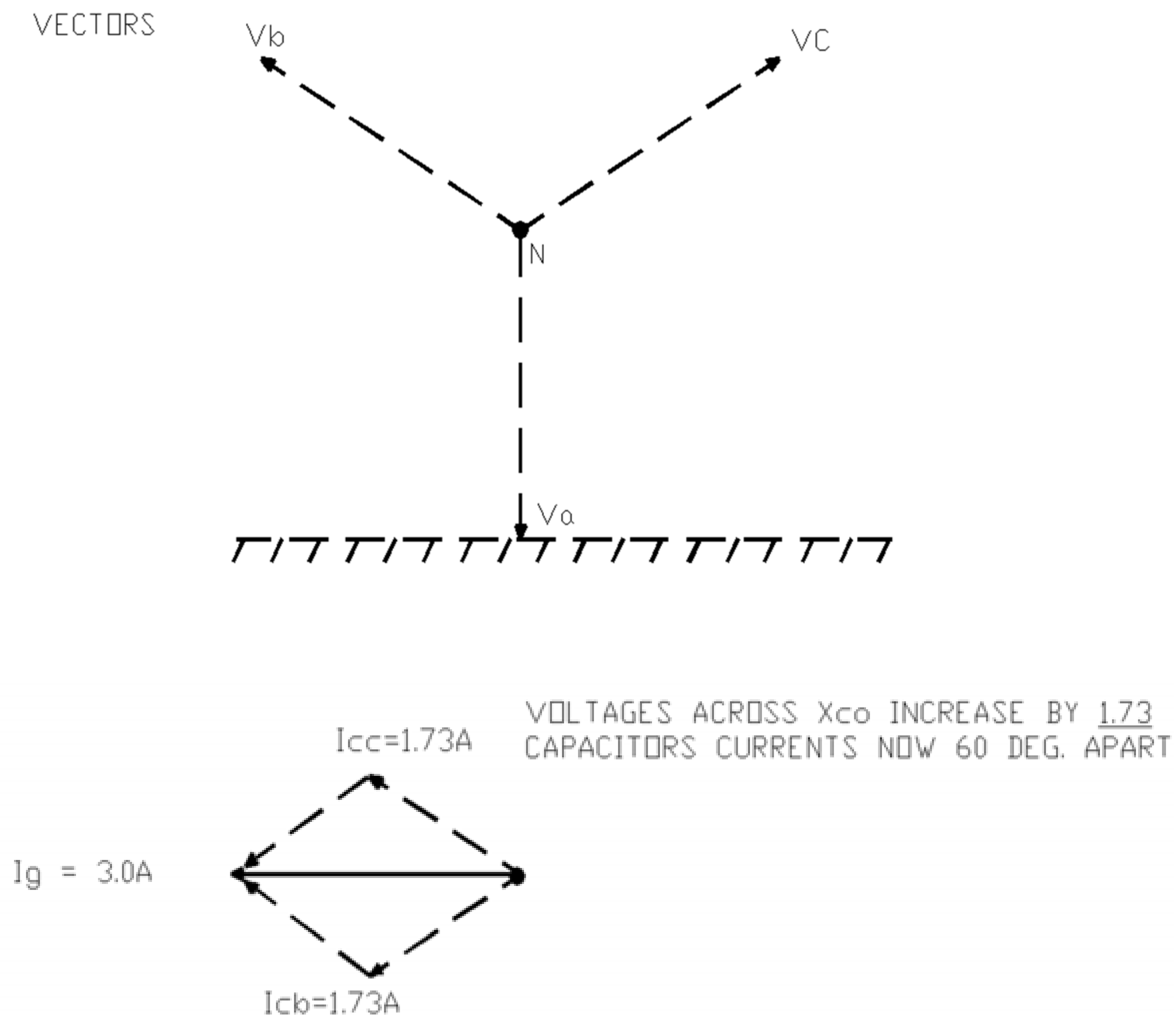


UNGROUNDED SYSTEM NORMAL CONDITIONS

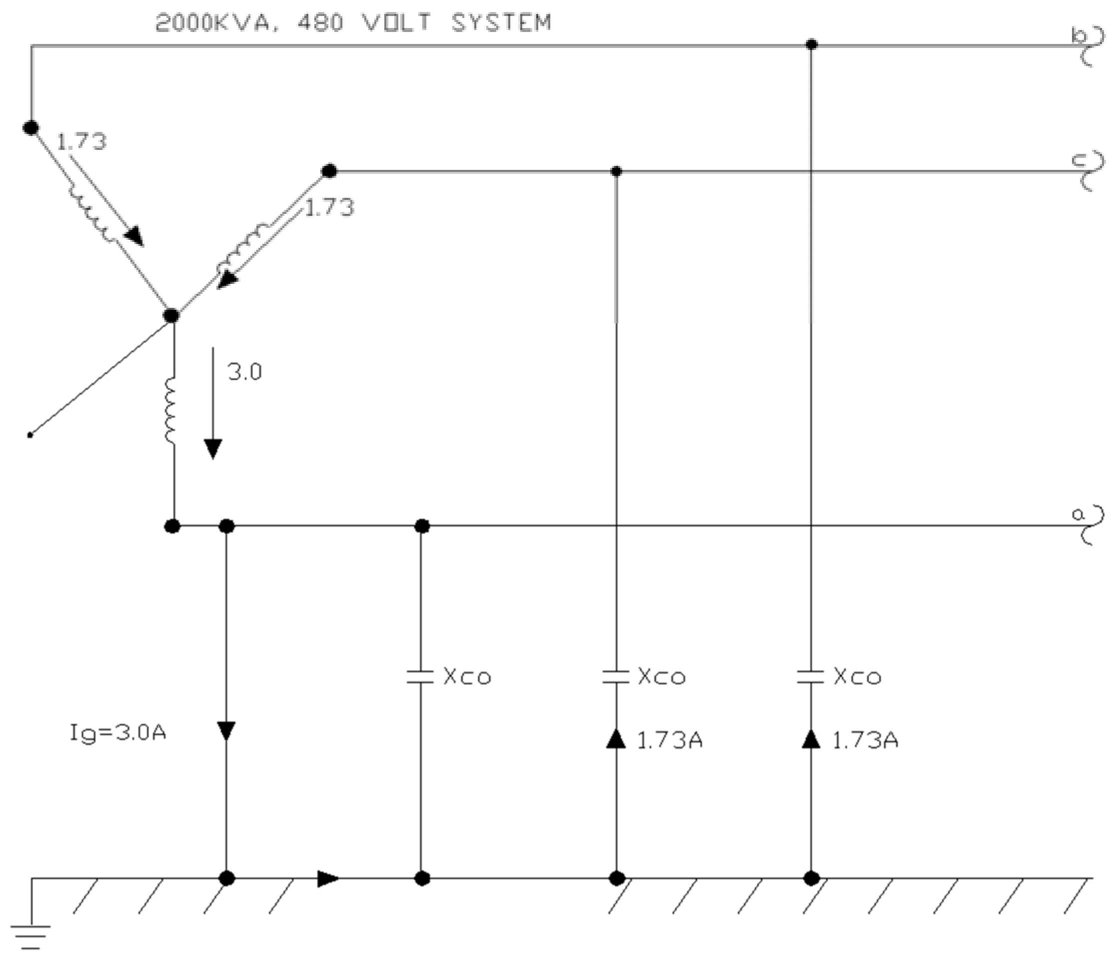


- BALANCED CONDITIONS
- CURRENTS DISPLACED 120 DEGREES
- CAPACITOR NEUTRAL AT SAME POTENTIAL AS TRANSFORMER NEUTRAL
- CAPACITOR CURRENT LEADS CAPACITOR VOLTAGE BY 90 DEGREES

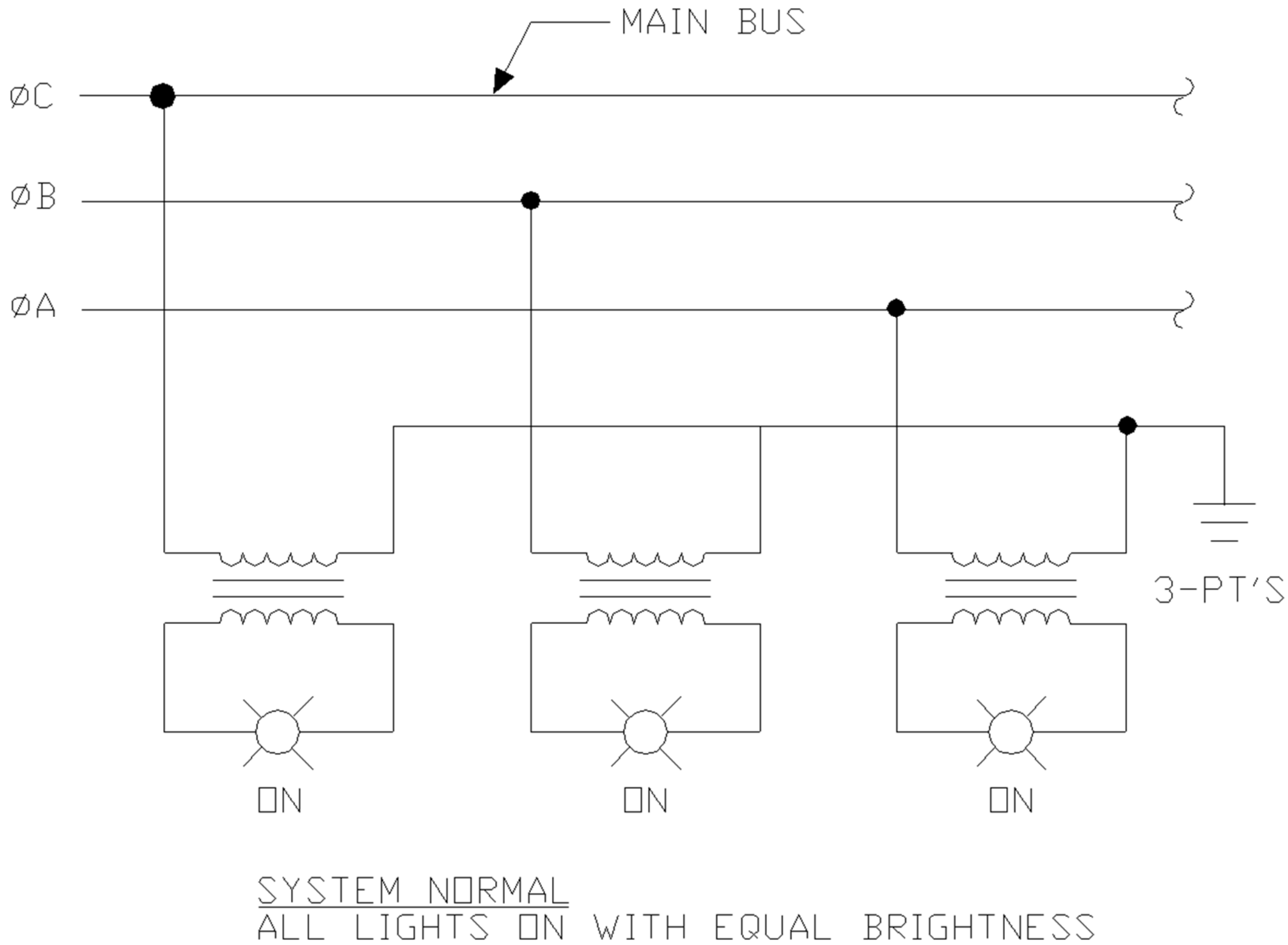
UNGROUNDED SYSTEM
GROUND FAULT ON PHASE A



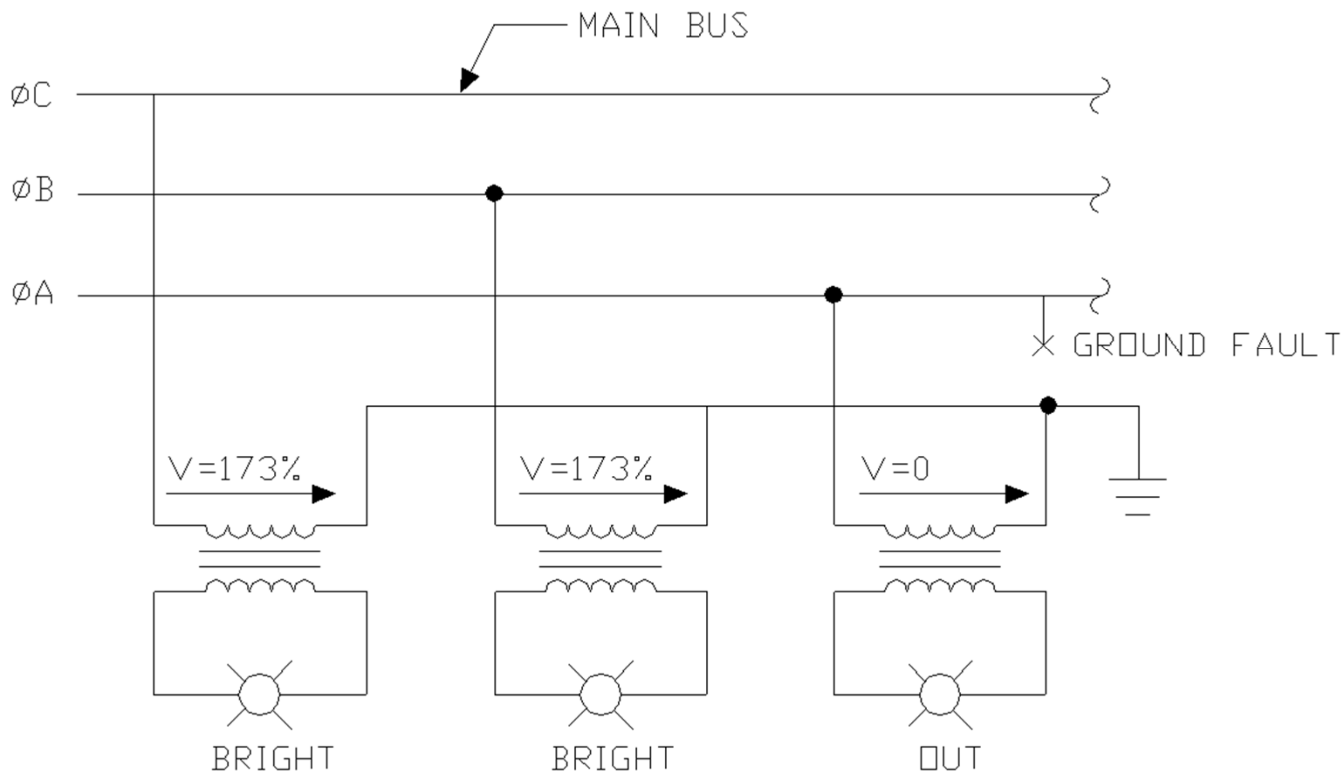
UNGROUNDED SYSTEM
GROUND FAULT ON PHASE A



THE UNGROUNDED POWER SYSTEM
GROUND DETECTION CIRCUIT



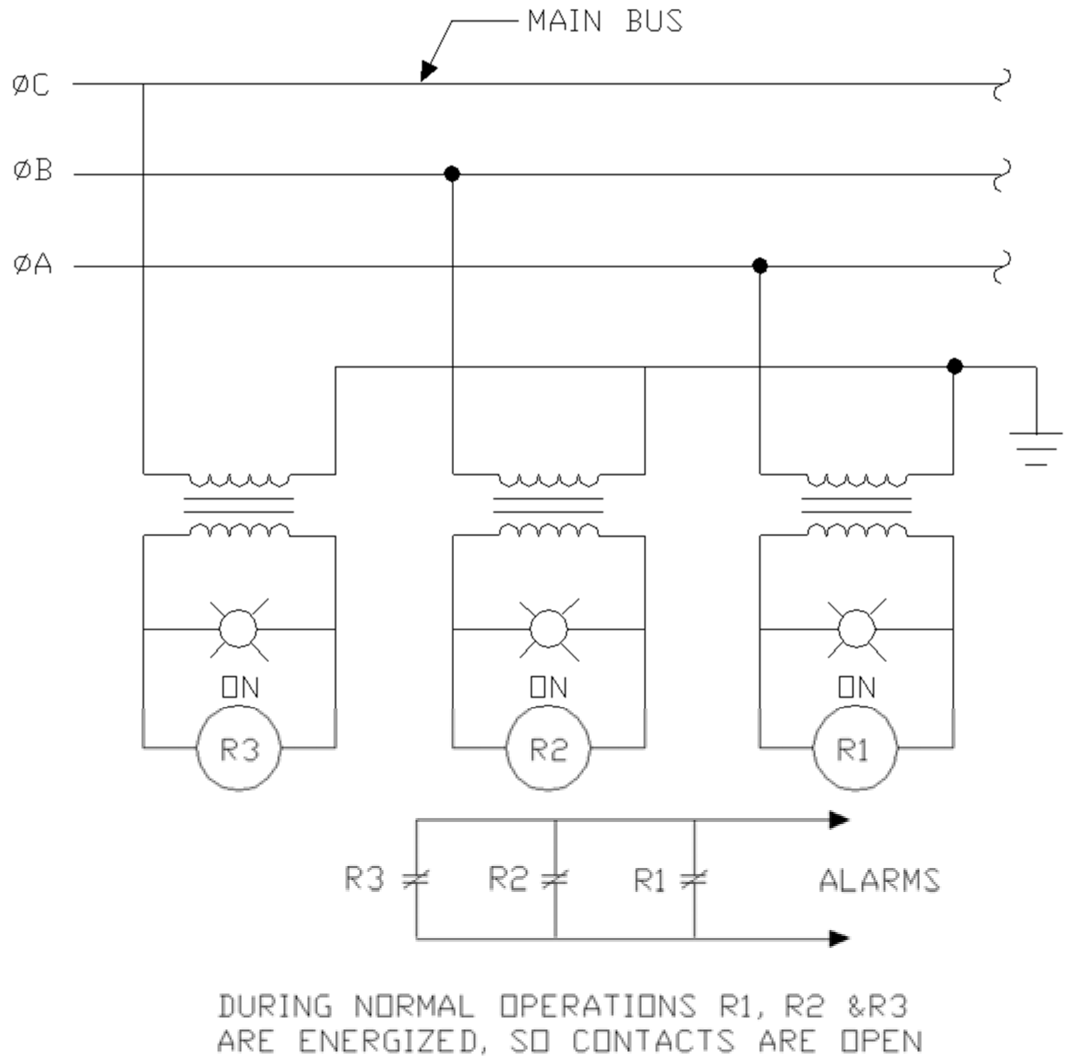
THE UNGROUNDED POWER SYSTEM GROUND DETECTION CIRCUIT



GROUND FAULT ON PHASE A

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

THE UNGROUNDED POWER SYSTEM
GROUND DETECTION CIRCUIT WITH ALARM



THE UNGROUNDED POWER SYSTEM ADVANTAGES

1. Low value of current flow for line to ground fault-amps 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 phase to ground fault.

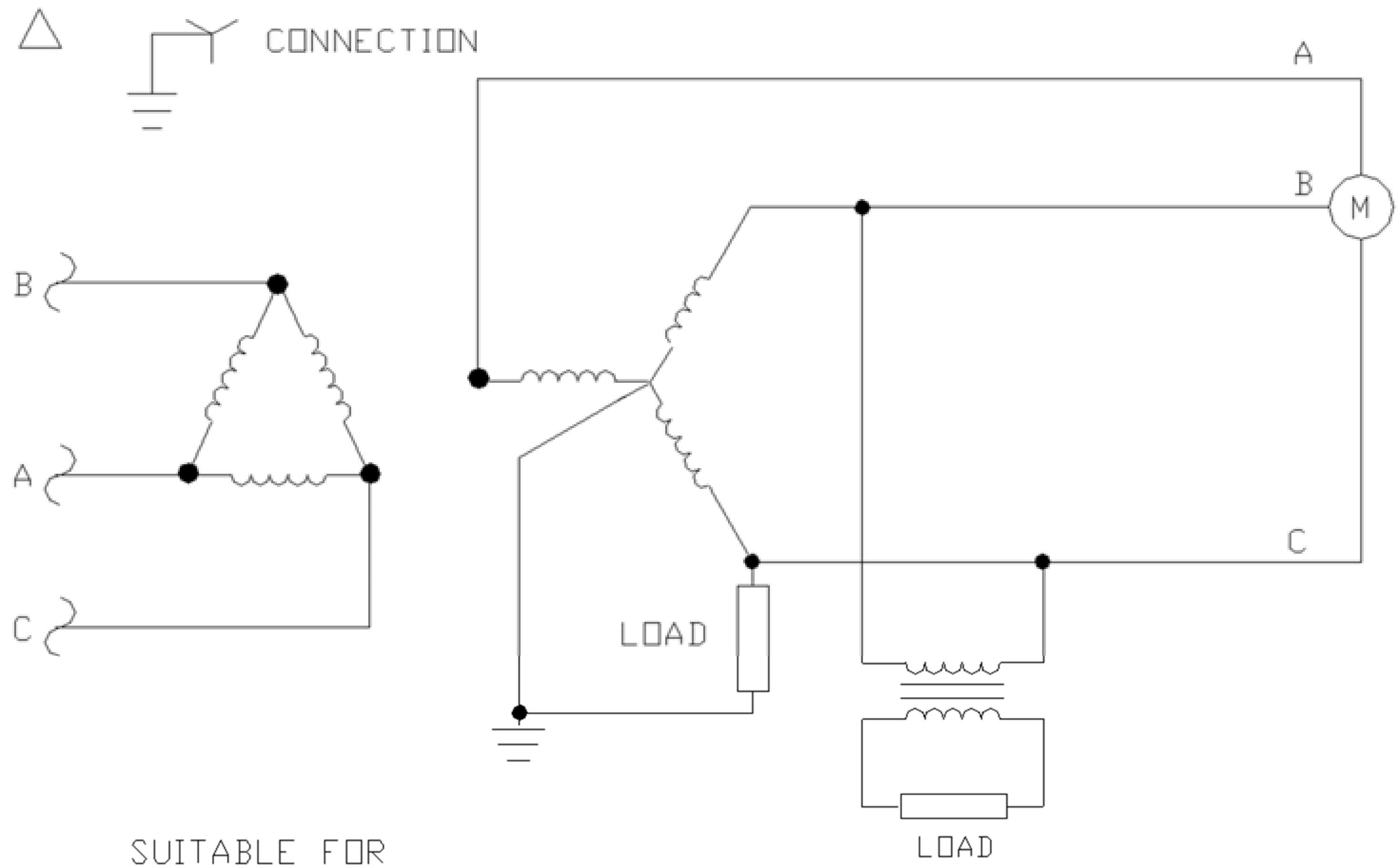
2. The ungrounded system does not control transient overvoltages. If you have a 4160V delta system you need to install 5kV 133% or 8kV 100% rated cable.

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

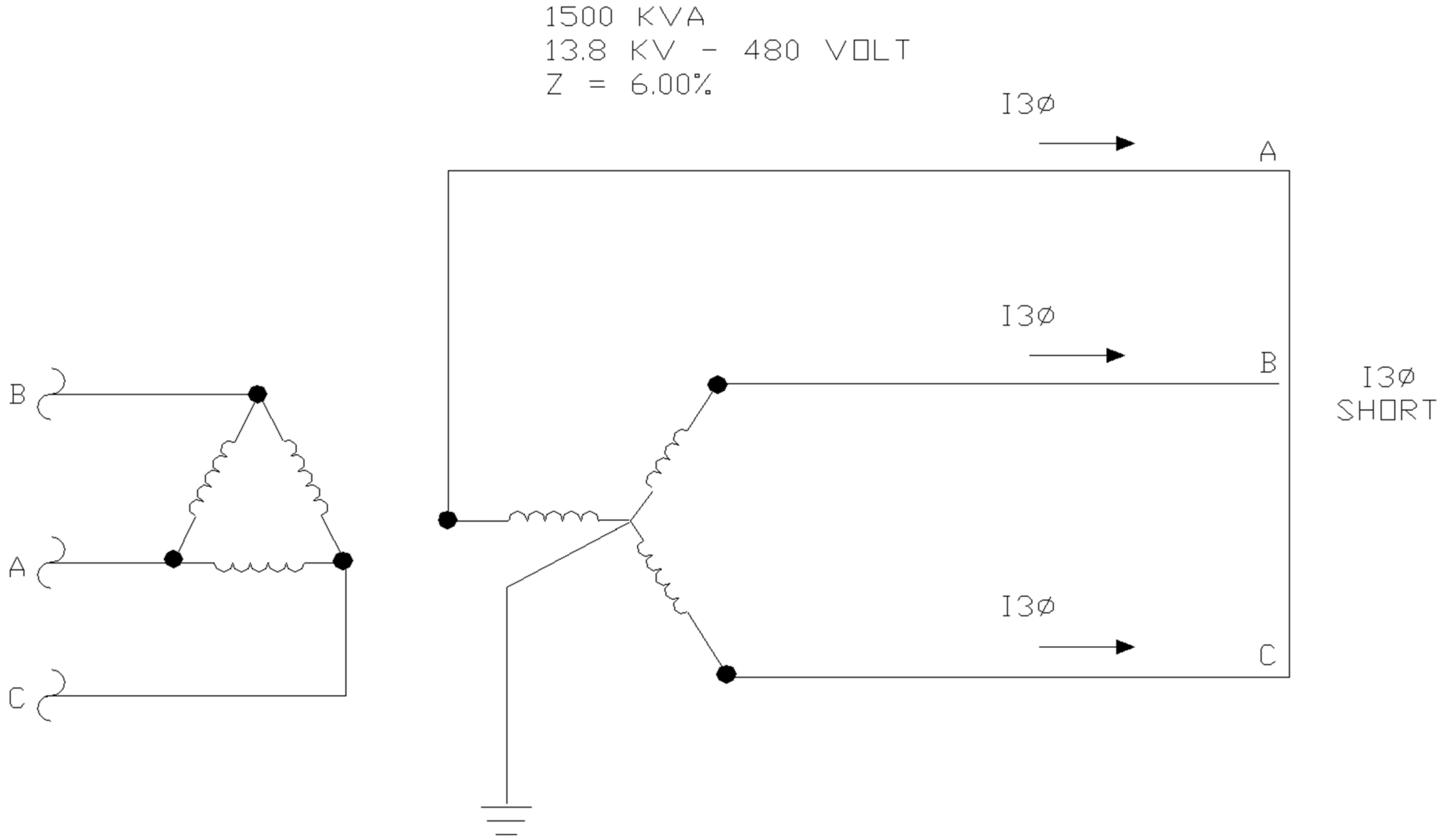
THE SOLIDLY GROUNDED POWER SYSTEM



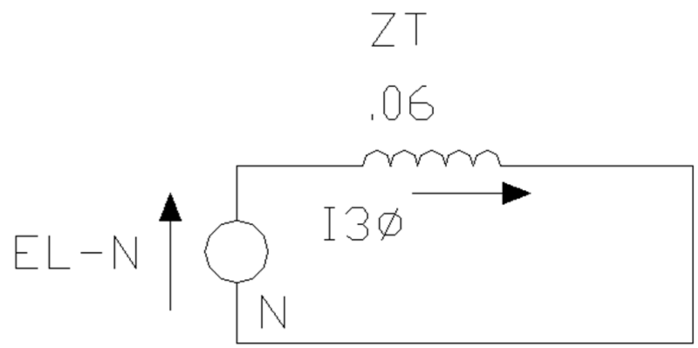
SUITABLE FOR

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

SOLIDLY GROUNDED SYSTEM
THREE PHASE SHORT CIRCUIT



SOLIDLY GROUNDED SYSTEM
THREE PHASE SHORT CIRCUIT

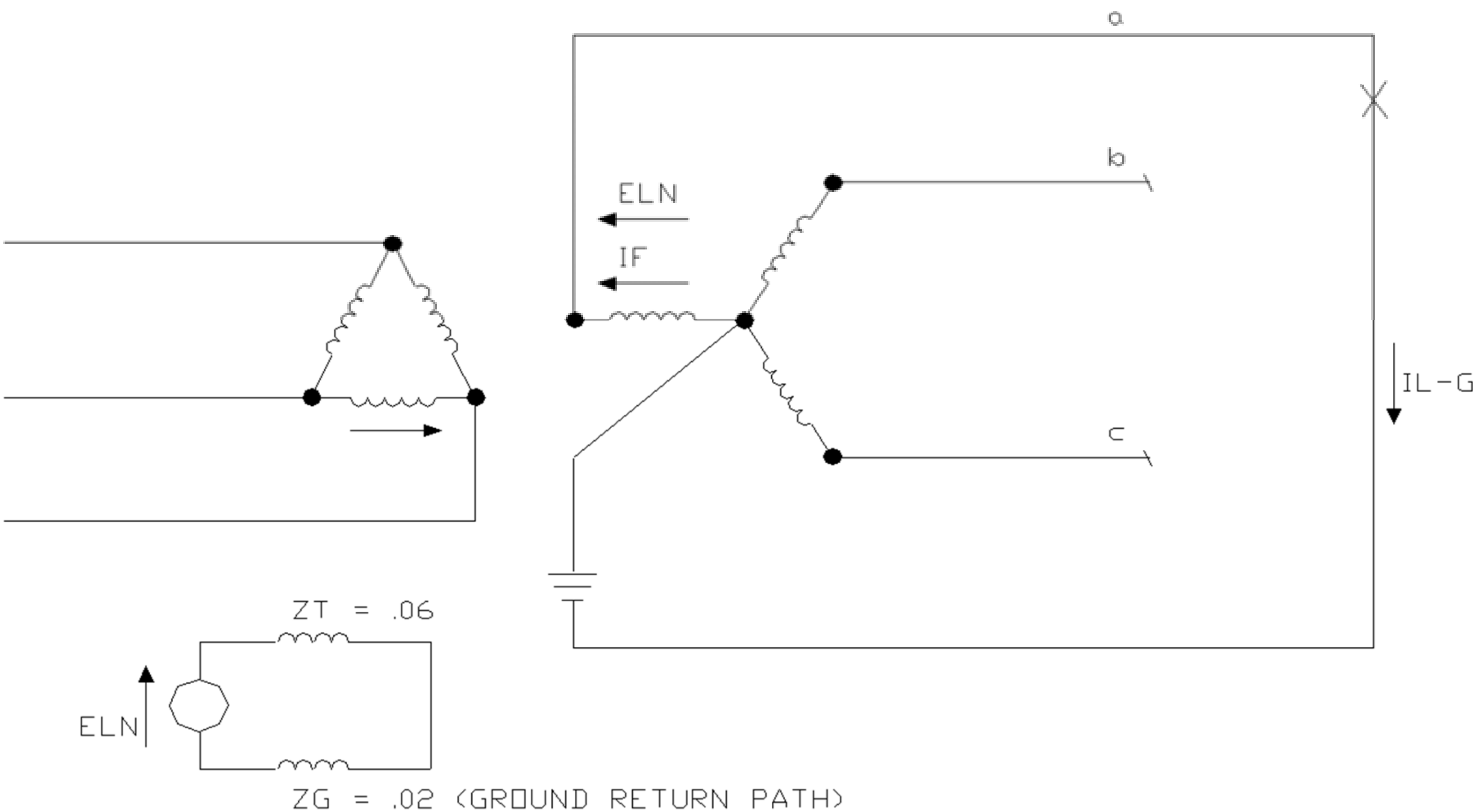


$$IFL = \frac{1500\ KVA}{3\ X\ .48KV} = 1804\ AMPS = 1\ PER\ UNIT$$

$$I\text{-}3PH = \frac{E\ L\text{-}N}{ZT} \quad \frac{1.0\ PER\ UNIT}{.06\ PER\ UNIT} = 16.67\ P.U.$$

I3Ø = 16.67 X 1804
I3Ø = 30,065 AMPS

SOLIDLY GROUNDED SYSTEM
LINE – GROUND SHORT CIRCUIT

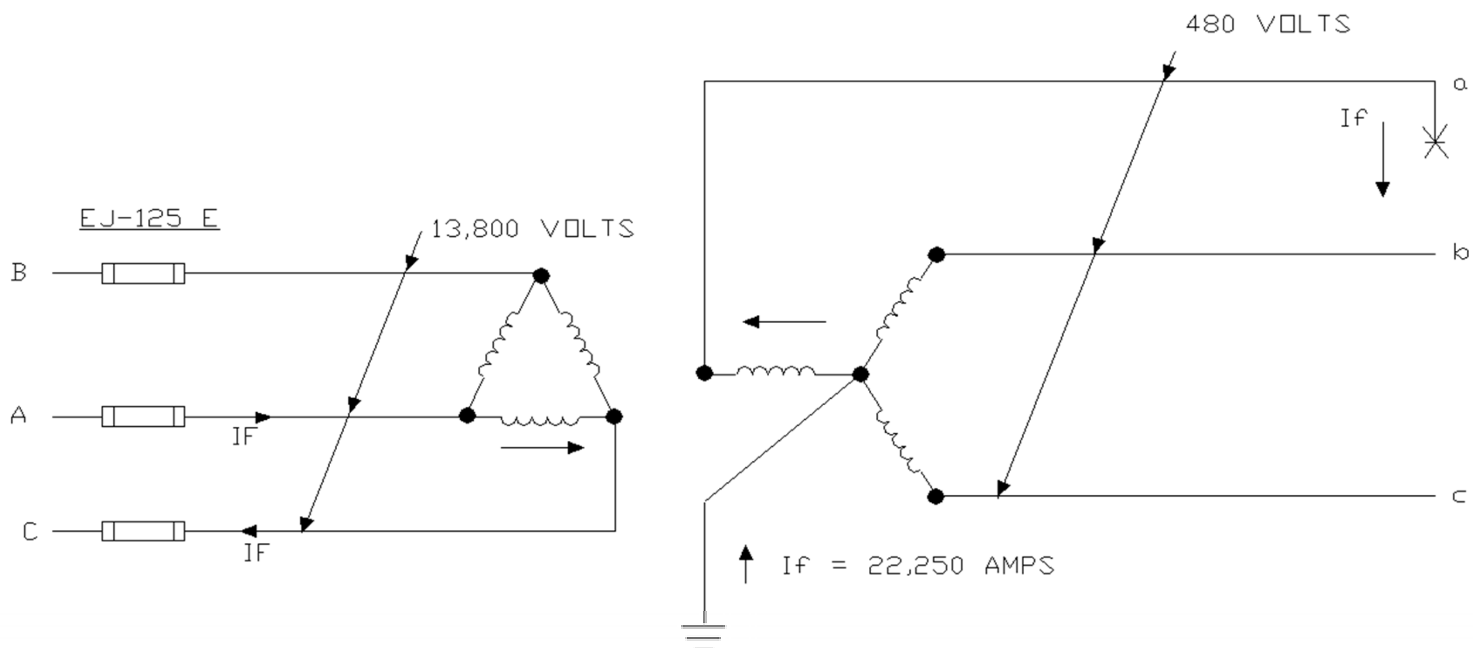


$$I = \frac{E\ L\text{-}N}{ZT + ZG} = \frac{1.0}{.06 + .02} = 12.5 \text{ PER UNIT}$$

ILG = 12.5 X 1804 = 22,550

SOLIDLY GROUNDED SYSTEM

LINE – GROUND SHORT CIRCUIT



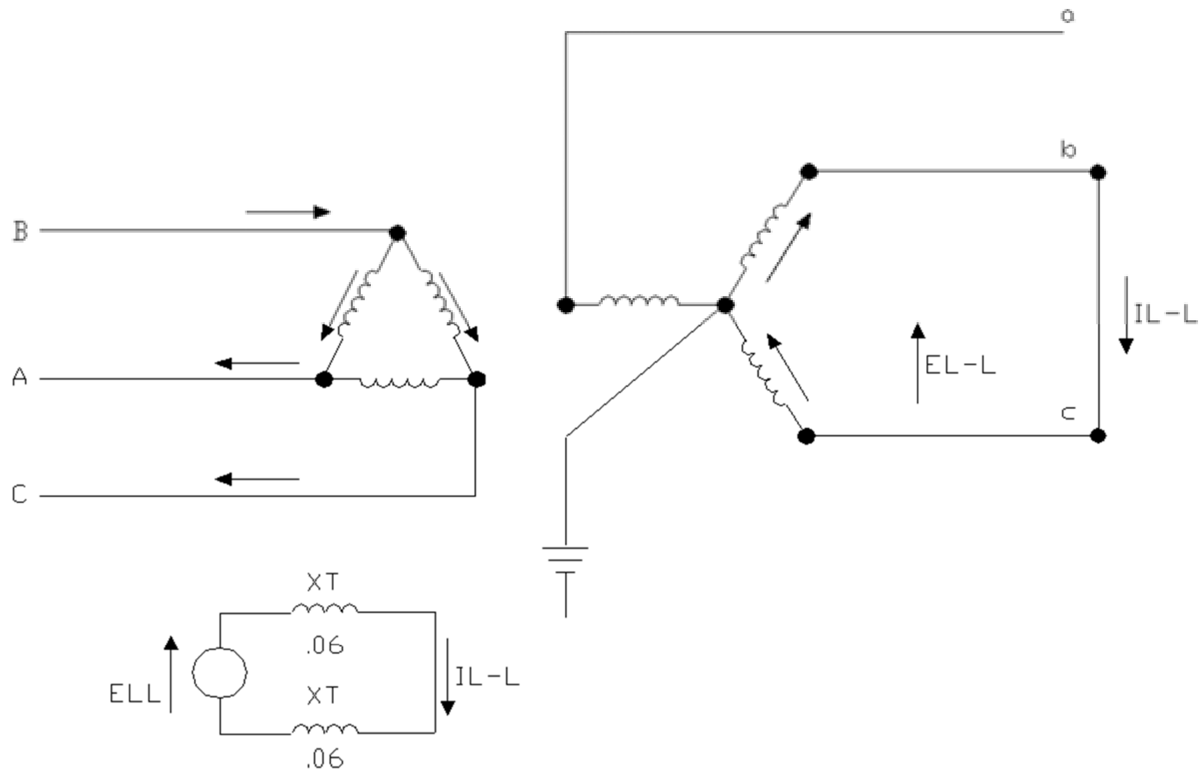
$$I\ PRIMARY = I\ SEC \times \frac{Vs/\sqrt{3}}{Vp}$$

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

I PRIMARY = 447 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



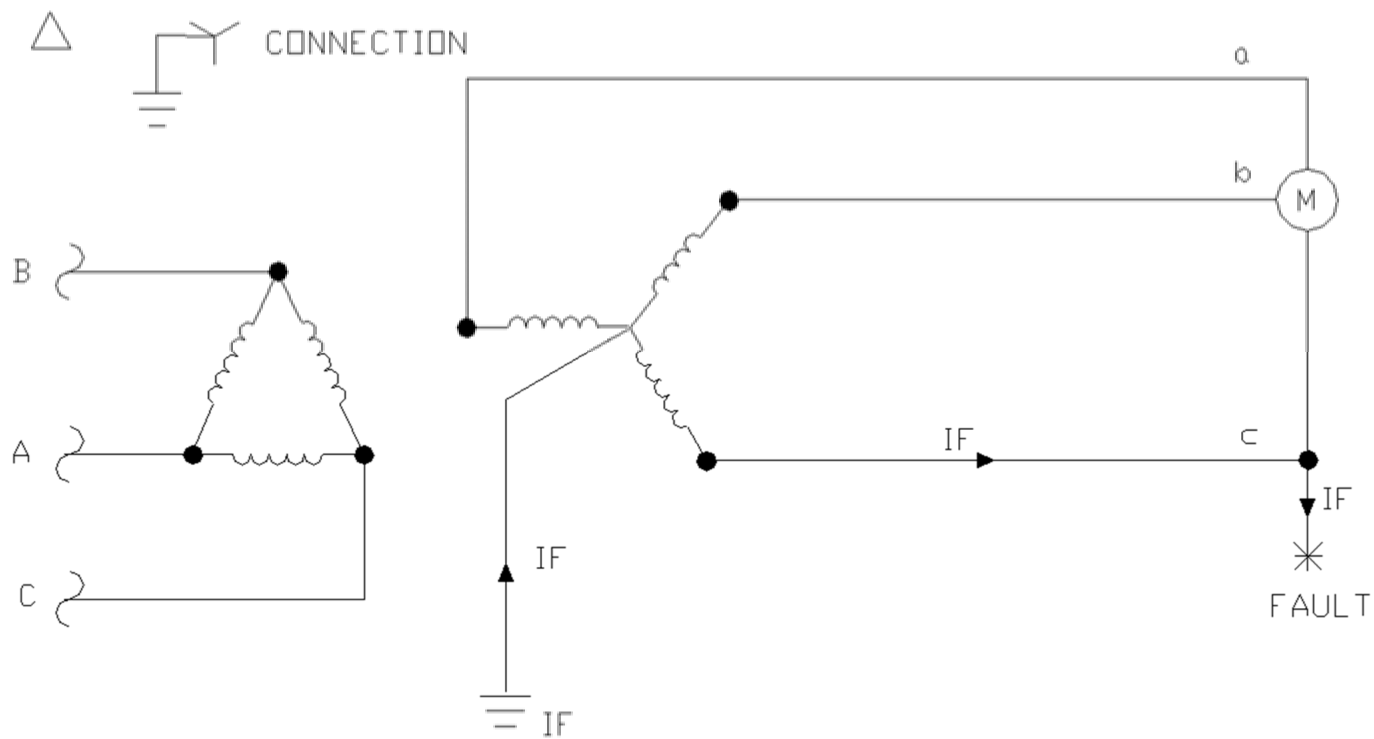
$$I_{L-L} = \frac{E_{L-L}}{2X_T} = \frac{E_{L-N} \times \sqrt{3}}{2 \times T} = \frac{\sqrt{3}}{2}\,\frac{E_{L-N}}{X_T}$$

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

$= .877\ I\ 3\phi$

$I_{L-L} = 26{,}367$ 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	20,000 AMPS	10,000 AMPS
1500KVA	30,000 AMPS	15,000 AMPS
2000KVA	40,000 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 between the neutral and ground.

2. Not difficult to locate the fault.

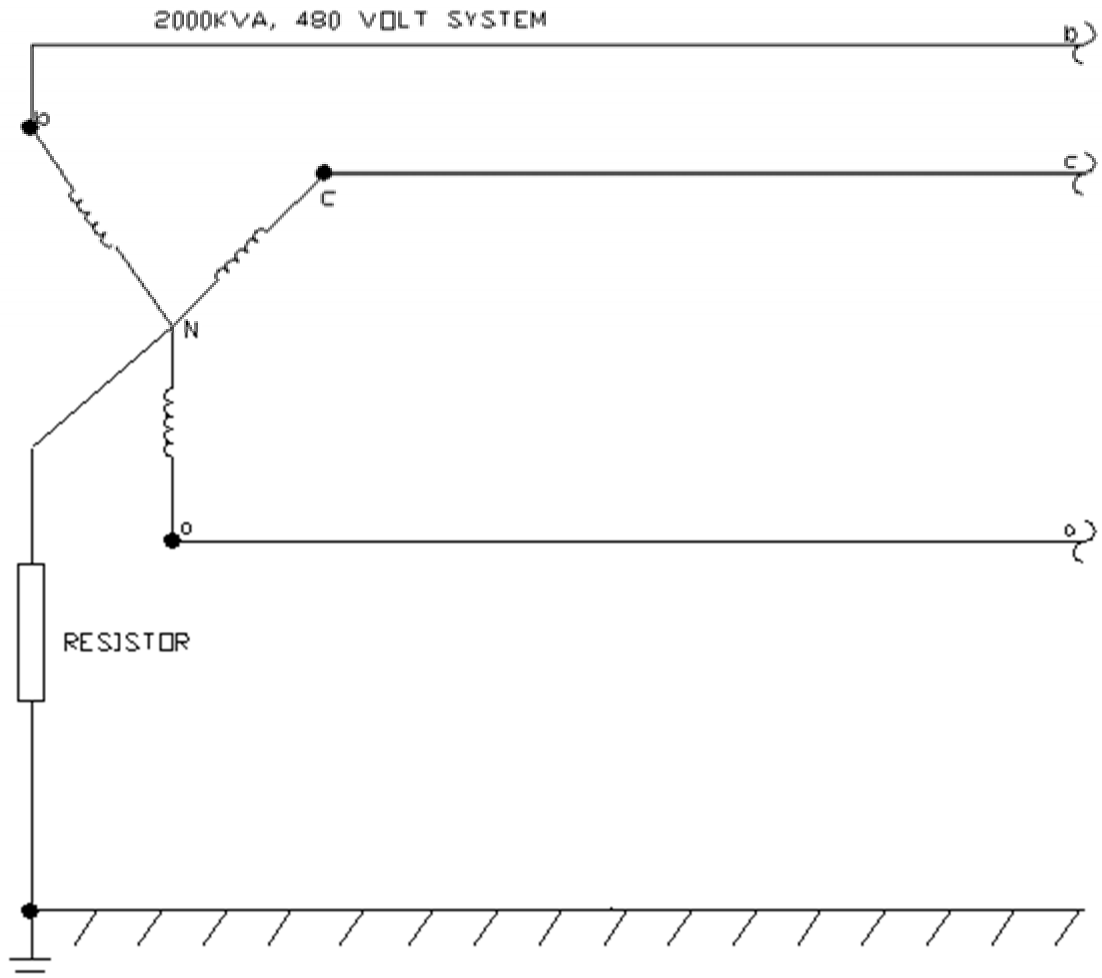
3. Can be used to supply line-neutral loads

THE SOLIDLY GROUNDED POWER SYSTEM

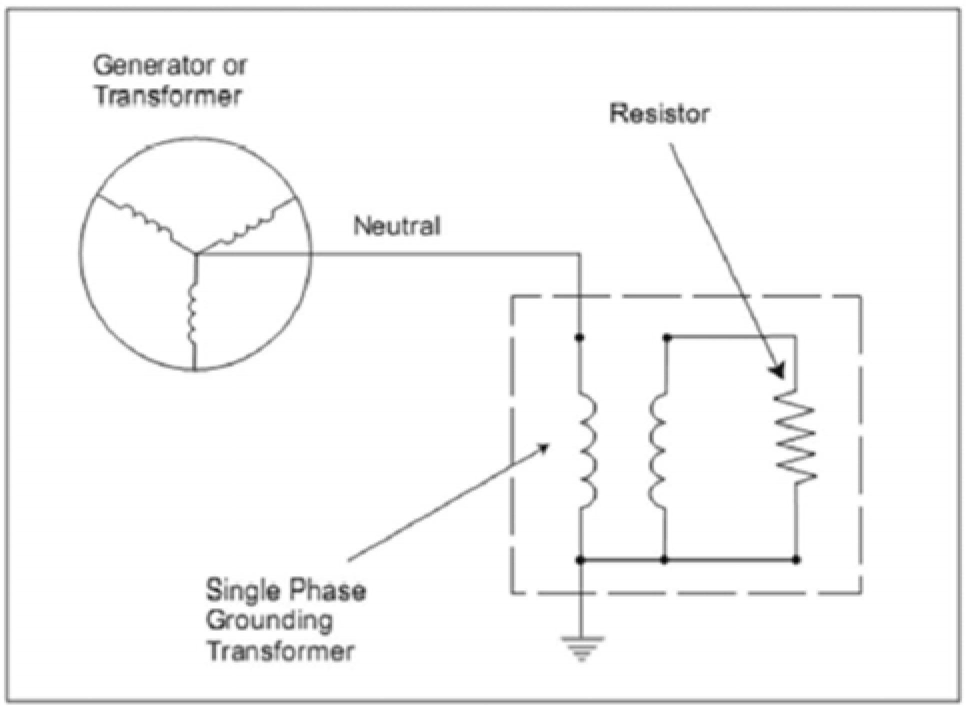
DISADVANTAGES

1. Severe flash hazard
2. Main breaker may be 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



NEUTRAL GROUNDING RESISTOR with Transformer



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

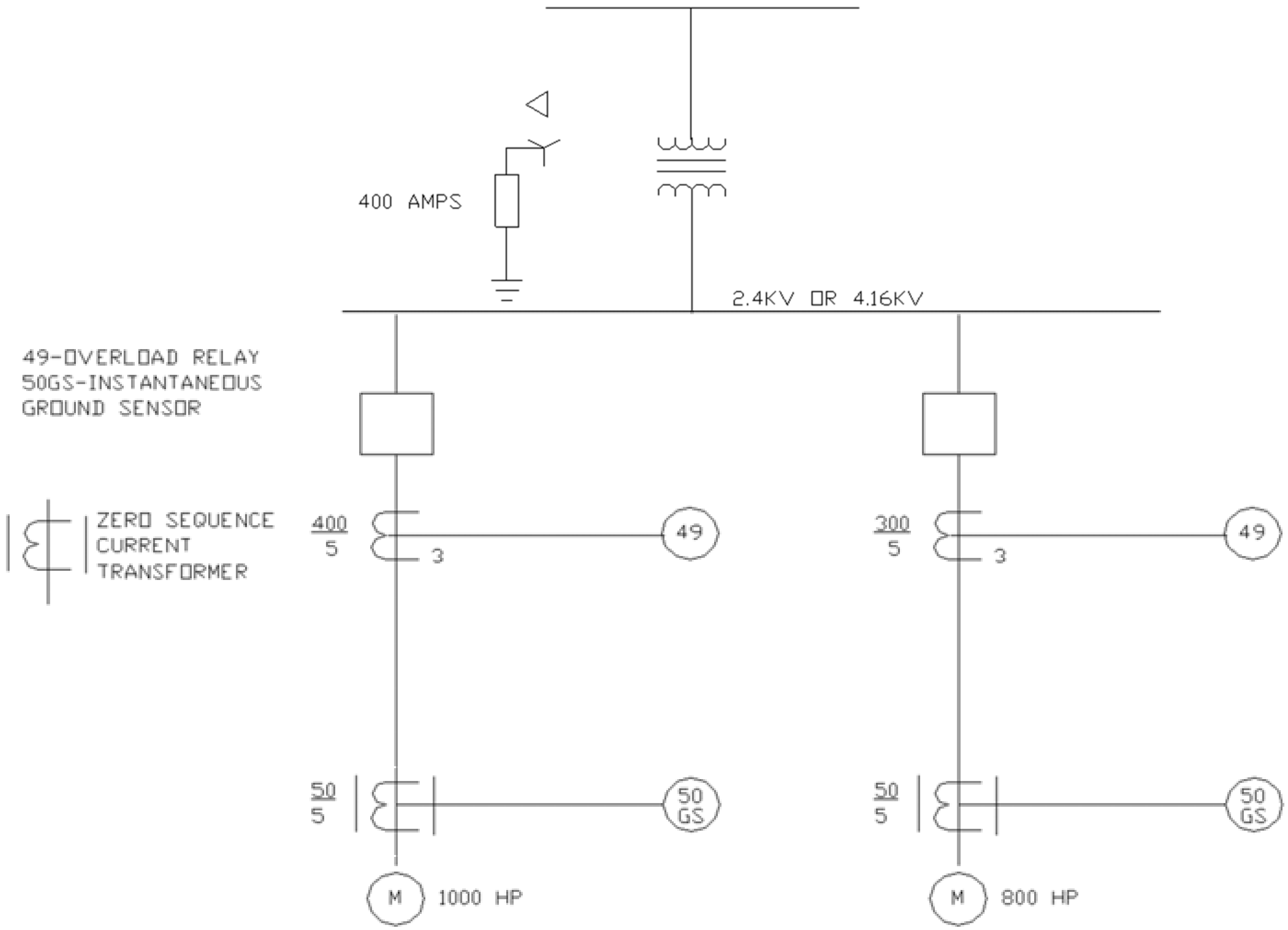
LOW RESISTANCE GROUNDING OF POWER SYSTEMS

- This design is generally for the following systems:

- At 2.4 kv through 25 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 ZERO SEQUENCE RELAYING

PARTIAL SINGLE LINE

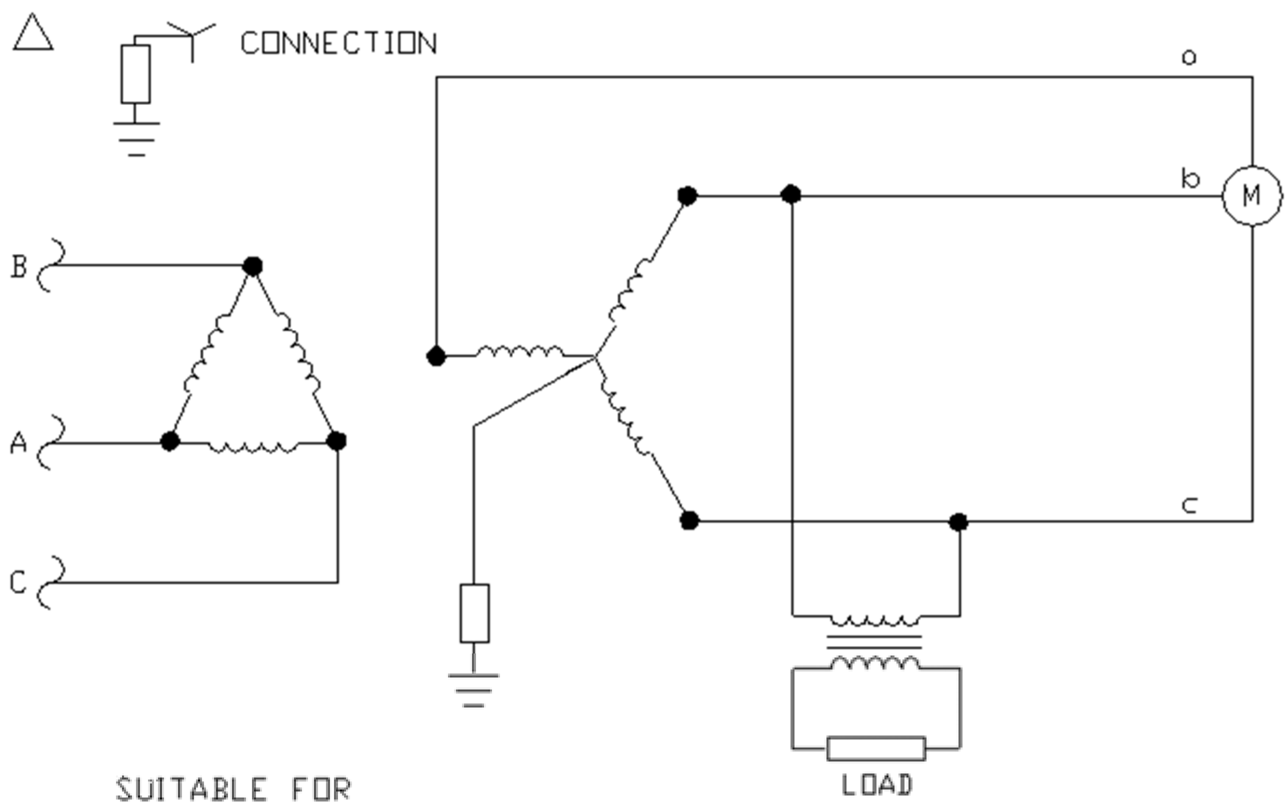


LOW RESISTANCE GROUNDED POWER SYSTEMS

- 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.
- 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

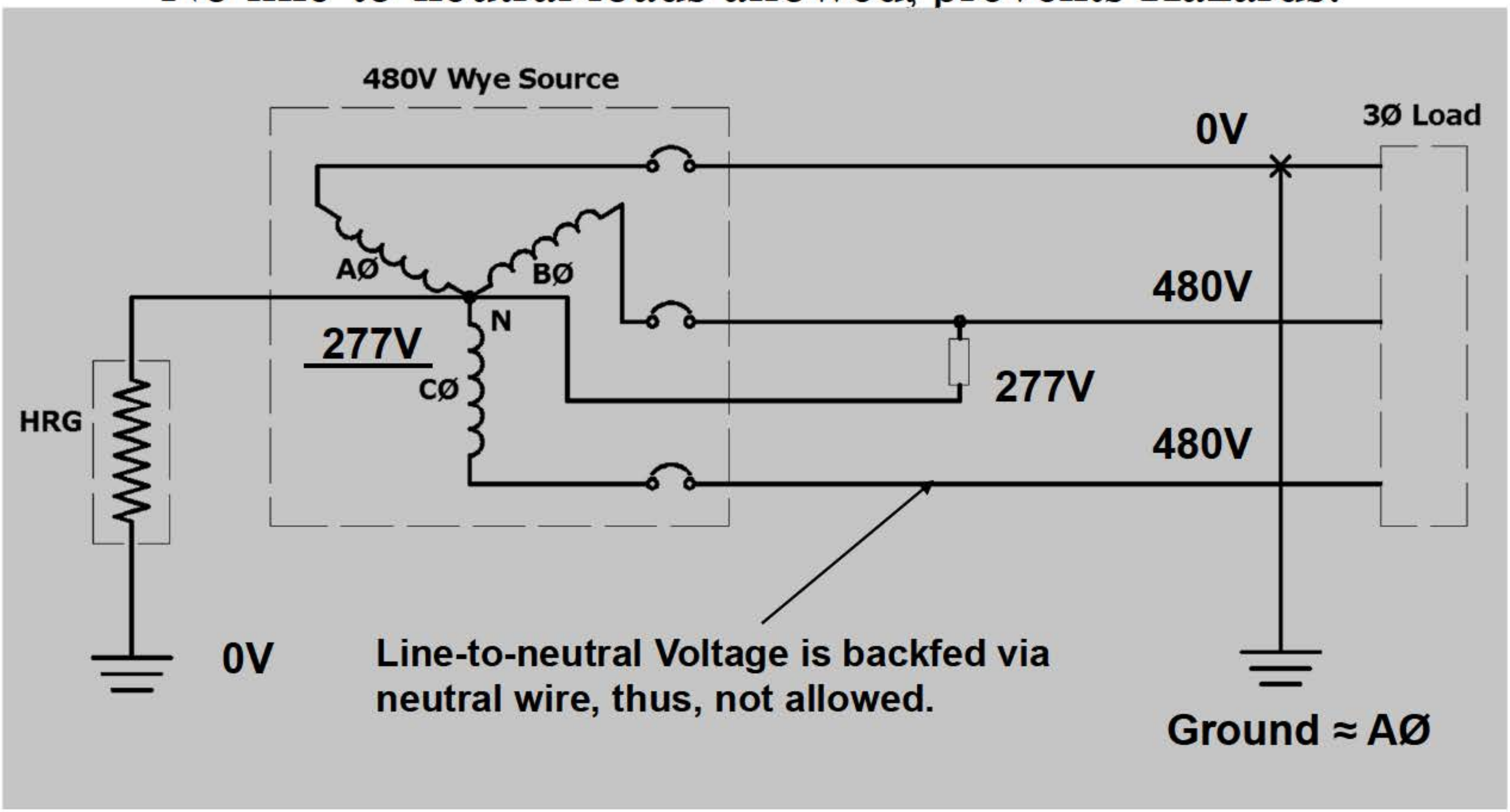
- TWO WIRE, SINGLE PHASE LOADS
- THREE WIRE, THREE PHASE LOADS

NOT SUITABLE FOR

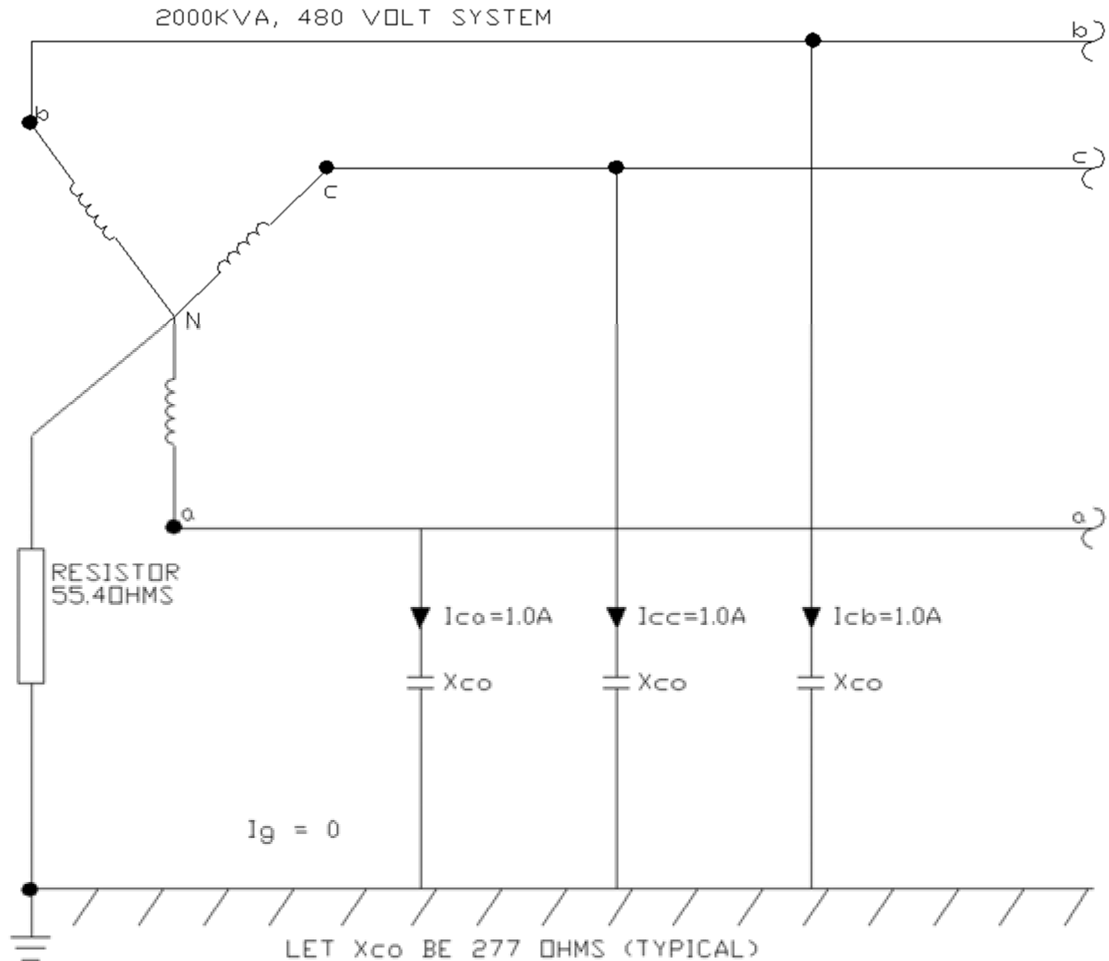
- TWO WIRE, LINE TO NEUTRAL LOADS

No Single Phase Loads

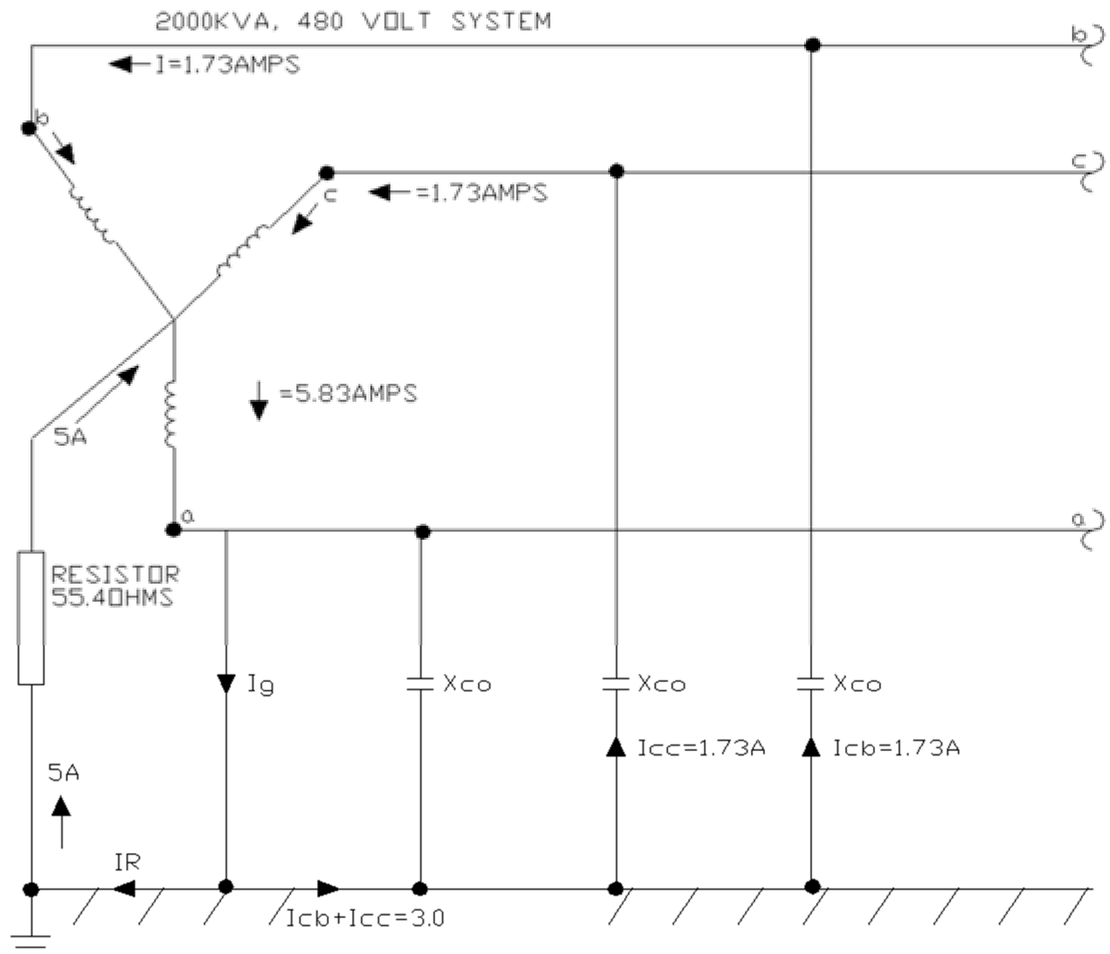
- No line-to-neutral loads allowed, prevents Hazards.



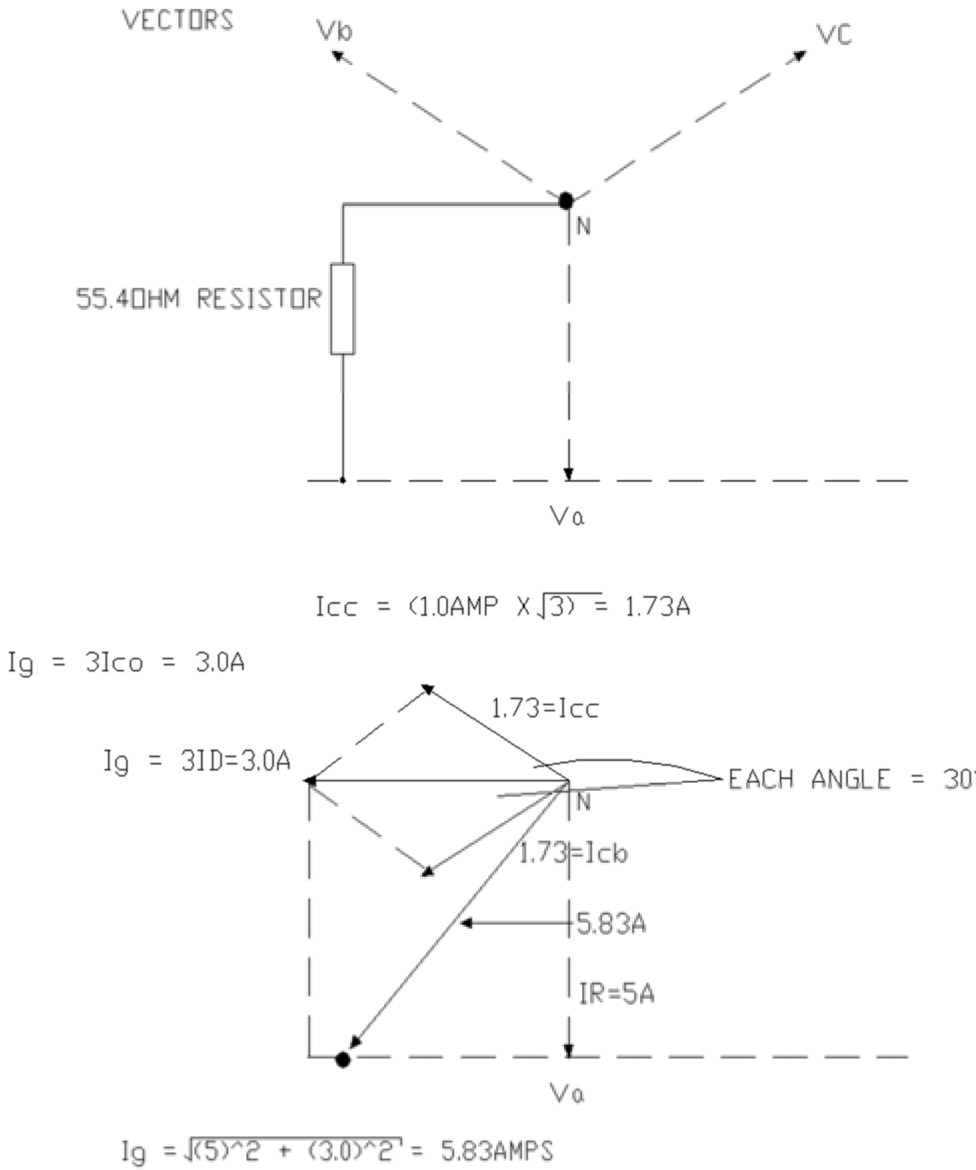
HIGH RESISTANCE GROUNDING EXAMPLE



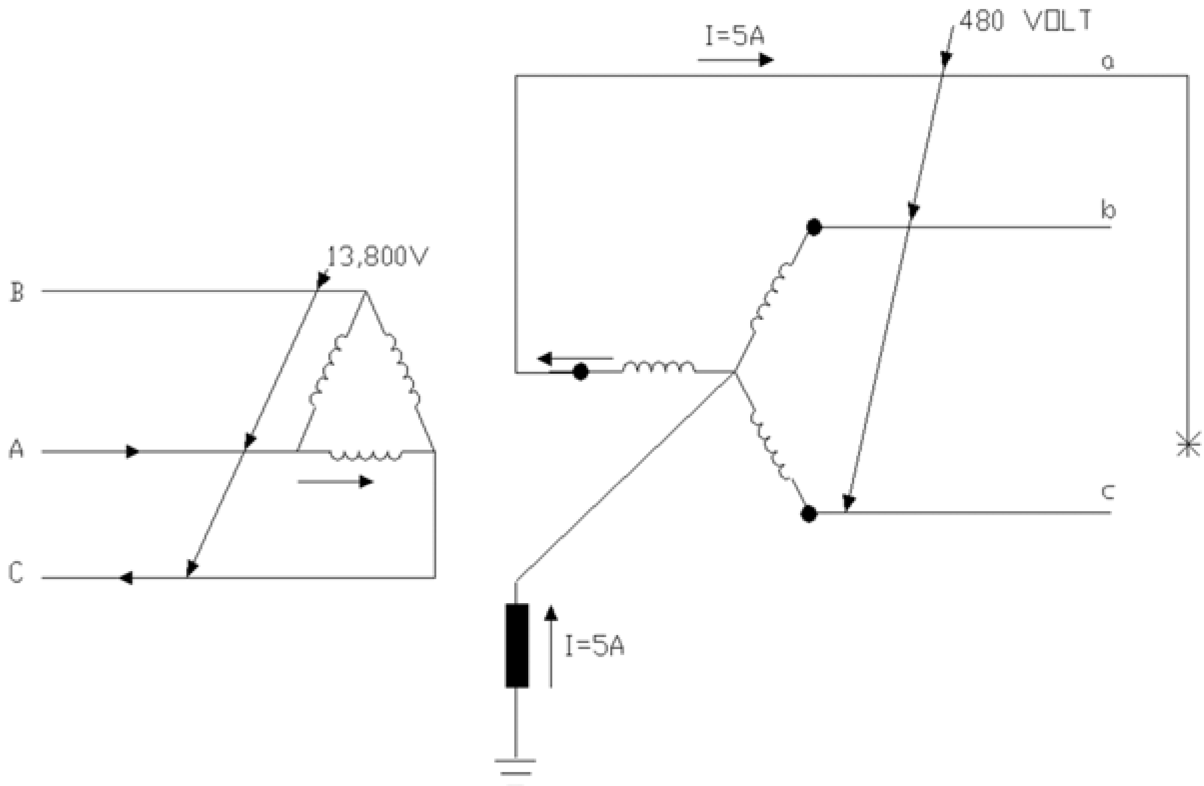
HIGH RESISTANCE GROUNDING – GROUND FAULT ON PHASE A



HIGH RESISTANCE GROUNDING – GROUND FAULT ON PHASE A



HIGH RESISTANCE GROUNDED SYSTEM
LINE-GROUND SHORT CIRCUIT

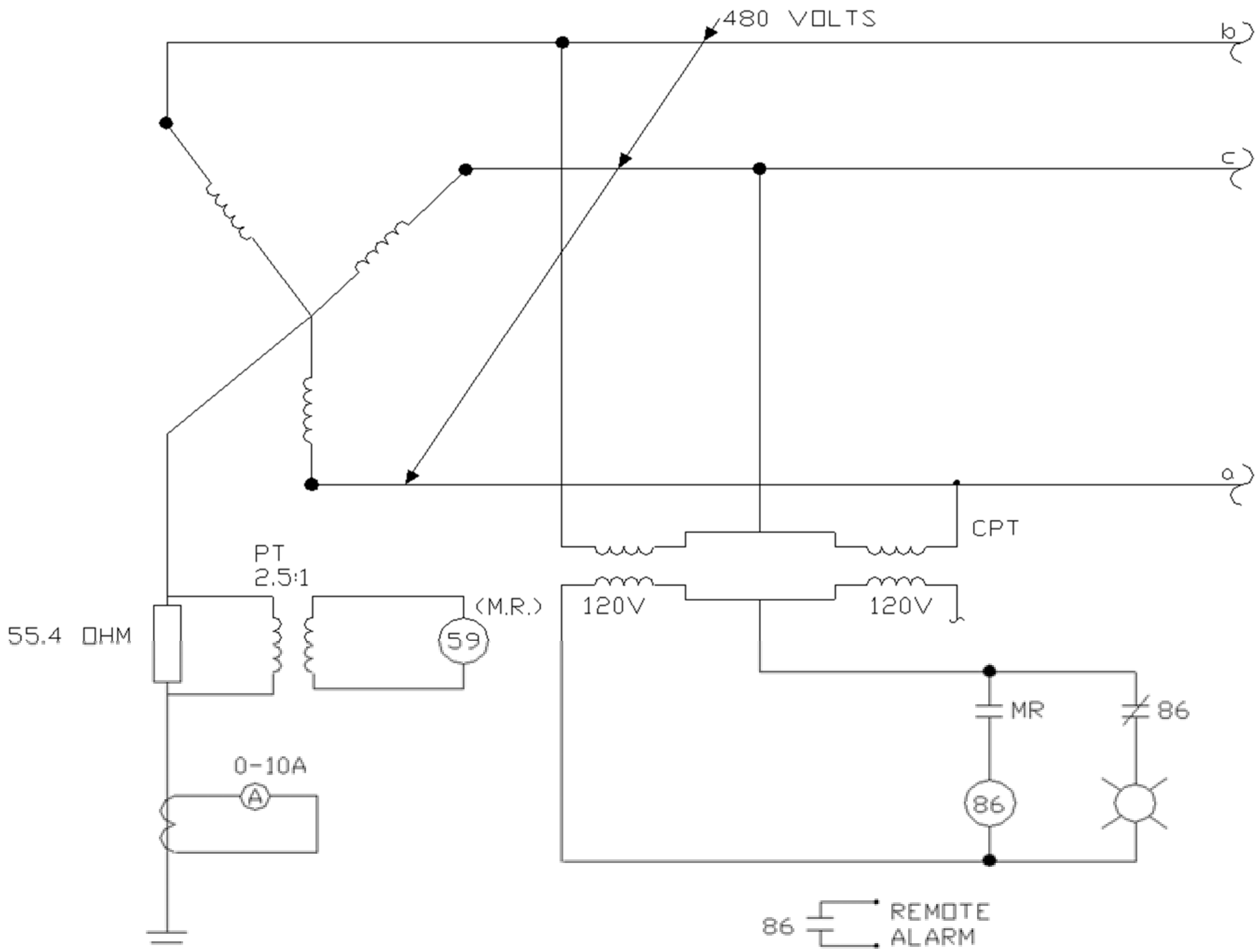


TRANSFORMER TURNS RATIO = $\frac{13{,}800 \text{ VOLTS}}{(480/\sqrt{3}) \text{ VOLTS}} = 49.79$

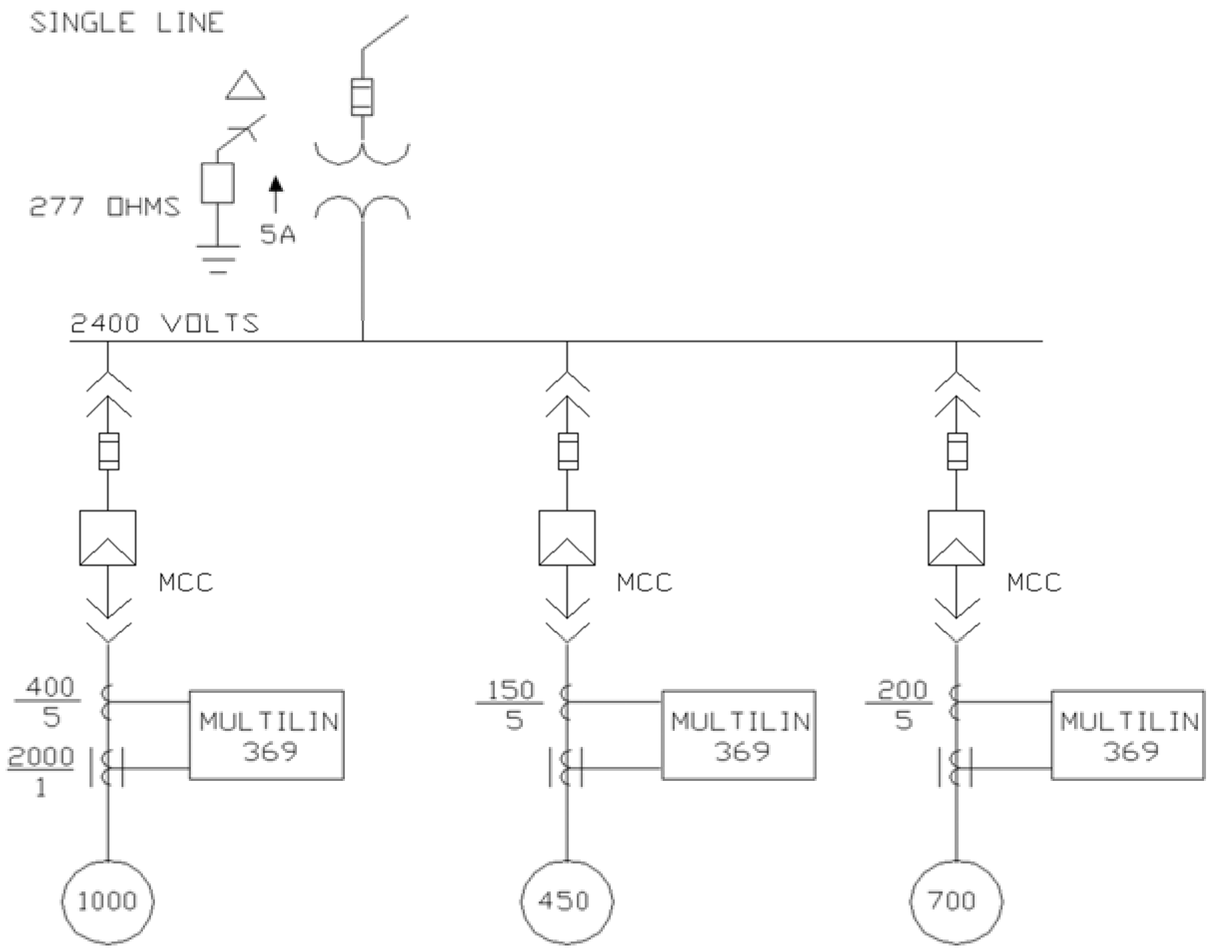
$IP = \frac{5A}{49.79} = .1$ AMP

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

HIGH RESISTANCE GROUNDING



HIGH RESISTANCE GROUNDING OF A 2400 / 1385 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.

SYSTEM VOLTAGE	RESISTOR AMPS	RESISTOR OHMS	RESISTOR WATTS (CONTINUOUS)
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 HIGH RESISTANCE 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

PROCEDURE FOR LOCATING GROUND FAULT

1. Alarm indicates ground fault.

2. Technician confirms ground faults by visiting substation.

3. Voltage on meter relay

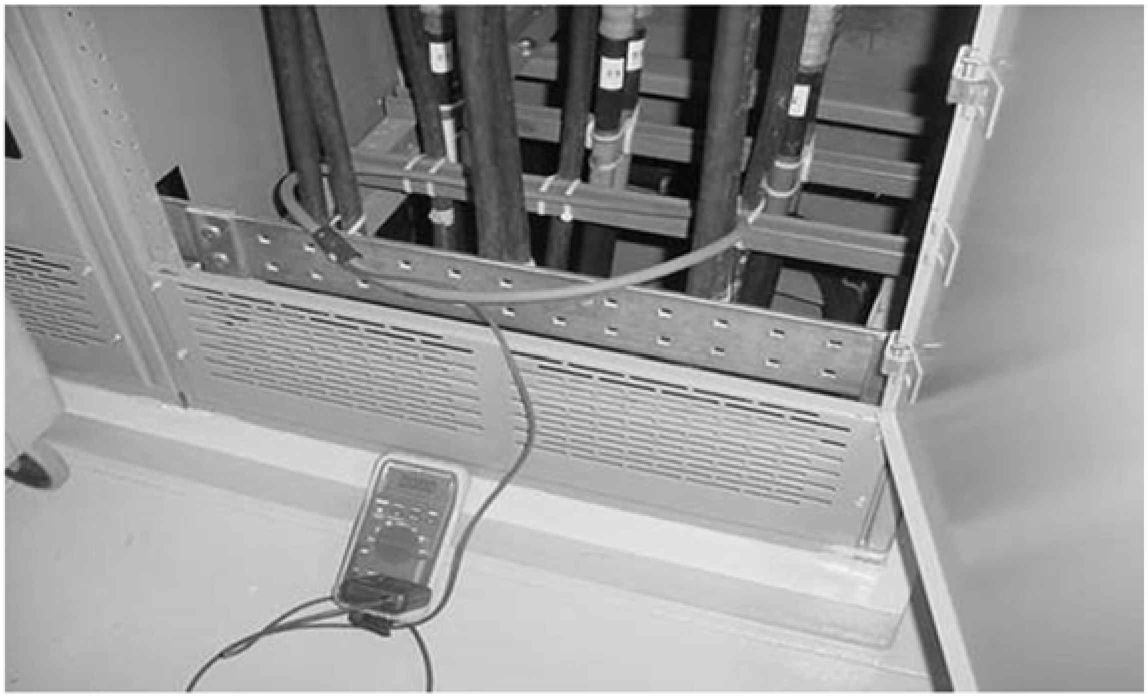
4. Current through ground resistor.

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

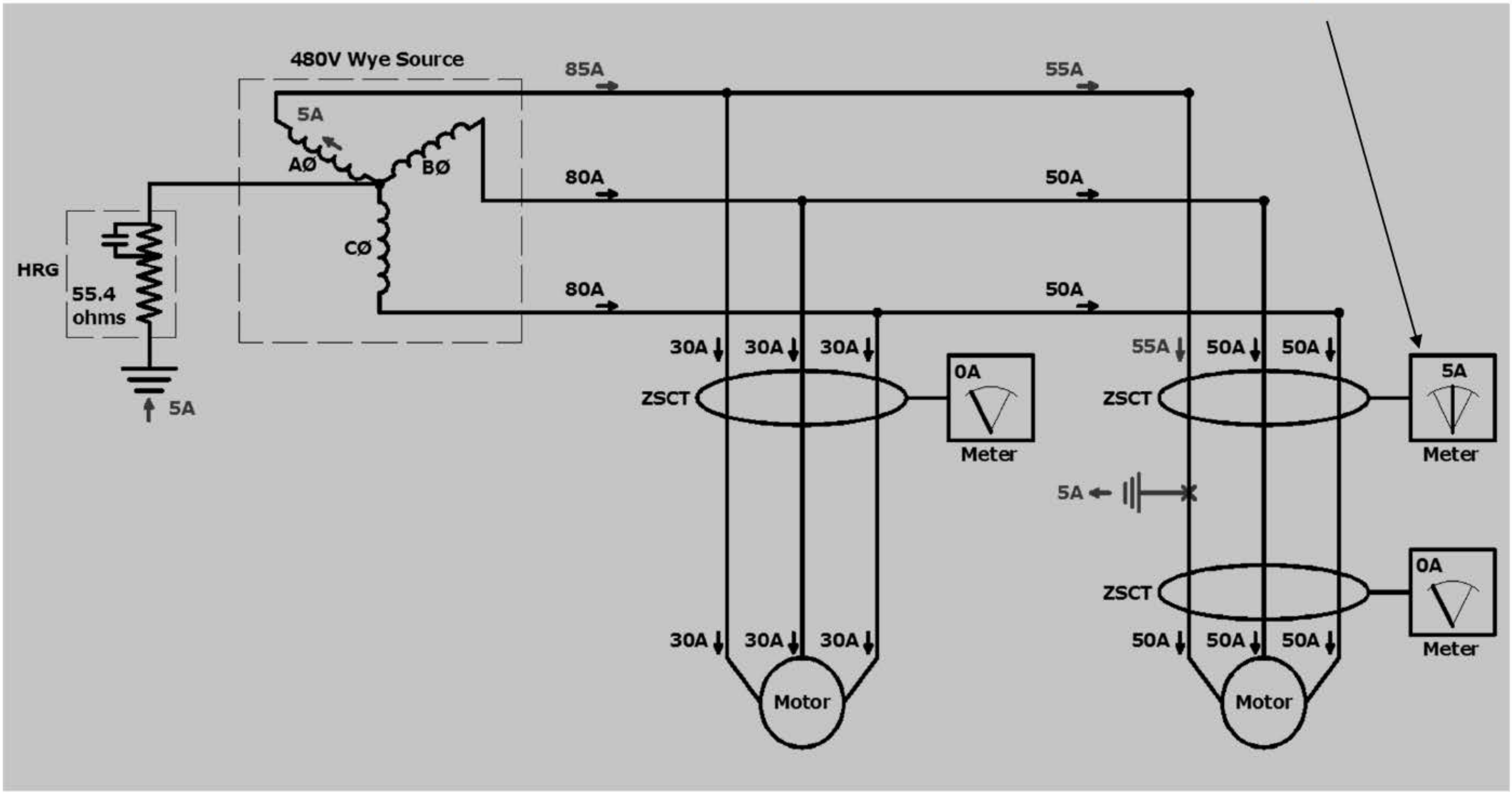


NOTE: *Tracking a ground fault can only be done on an energized system. Due to the inherent risk of electrocution this should only be performed by trained and competent personnel wearing proper PPE clothing.*

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?***

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.***

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^{o}C
One Minute (Short Time)	760^{o}C
Ten Minutes (Short Time)	610^{o}C
Extended Time	610^{o}C
Continuous	385^{o}C

Increased Fault Time Requires Larger Resistor

Duration Must Be Coordinated With Protective Relay Scheme

THE HIGH RESISTANCE GROUNDING OF POWER SYSTEM

The high resistance grounded power 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

Should High Resistance Grounding be used to help prevent Arc Flash Hazards to Personnel?

Absolutely!! Since 98% of faults start off as a phase to ground faults, this will lower the current that is supplied to the fault.

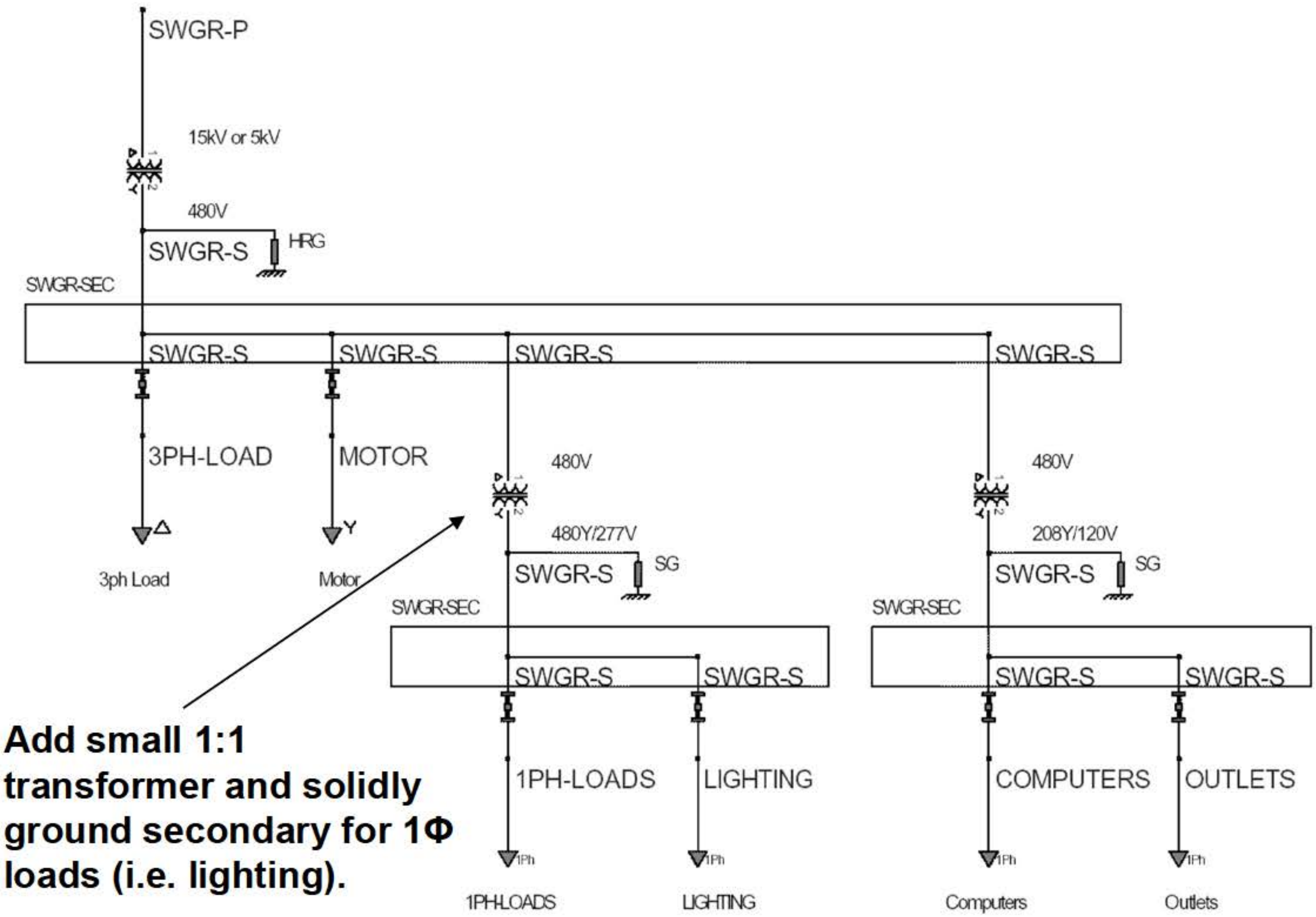
Can I lower the Amps Interrupting Capacity (AIC) rating of my switchgear, if I have a neutral grounding resistor?

No. You could still have a phase to phase fault that could produce the high current fault levels.

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

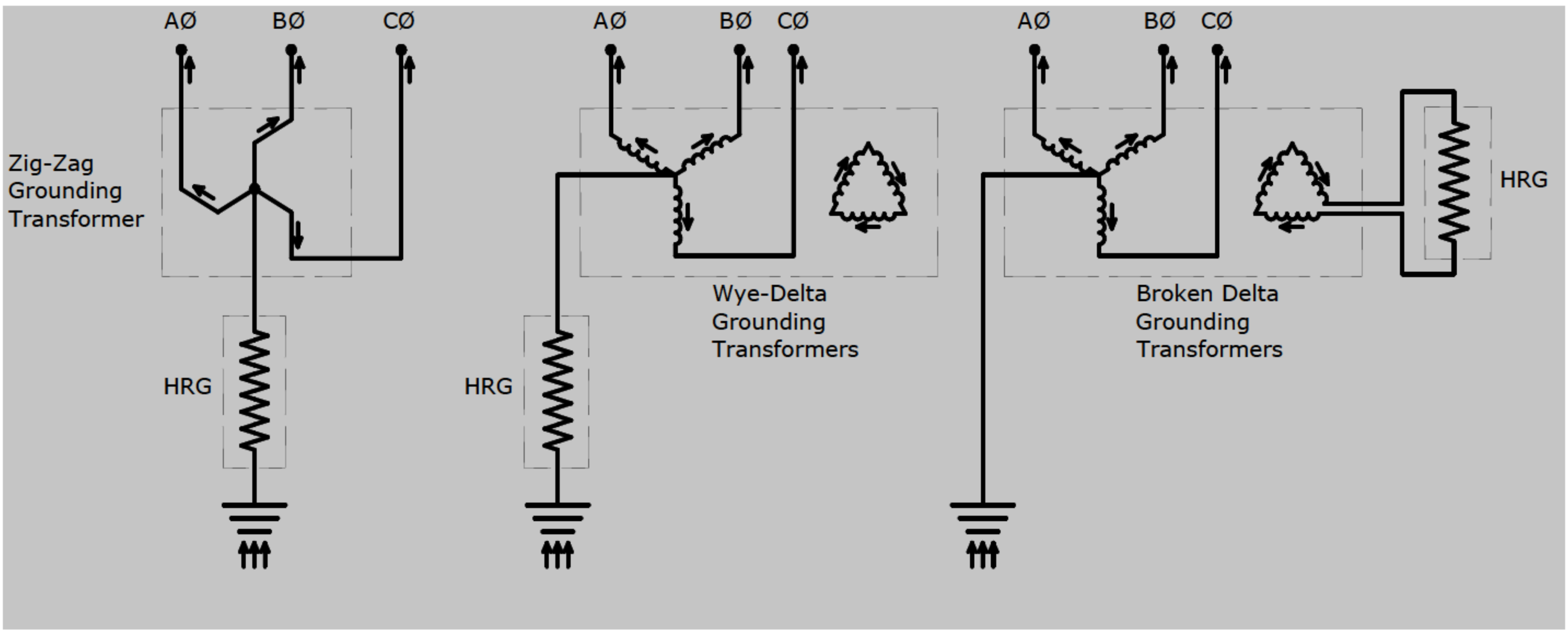
Resolve NEC requirement



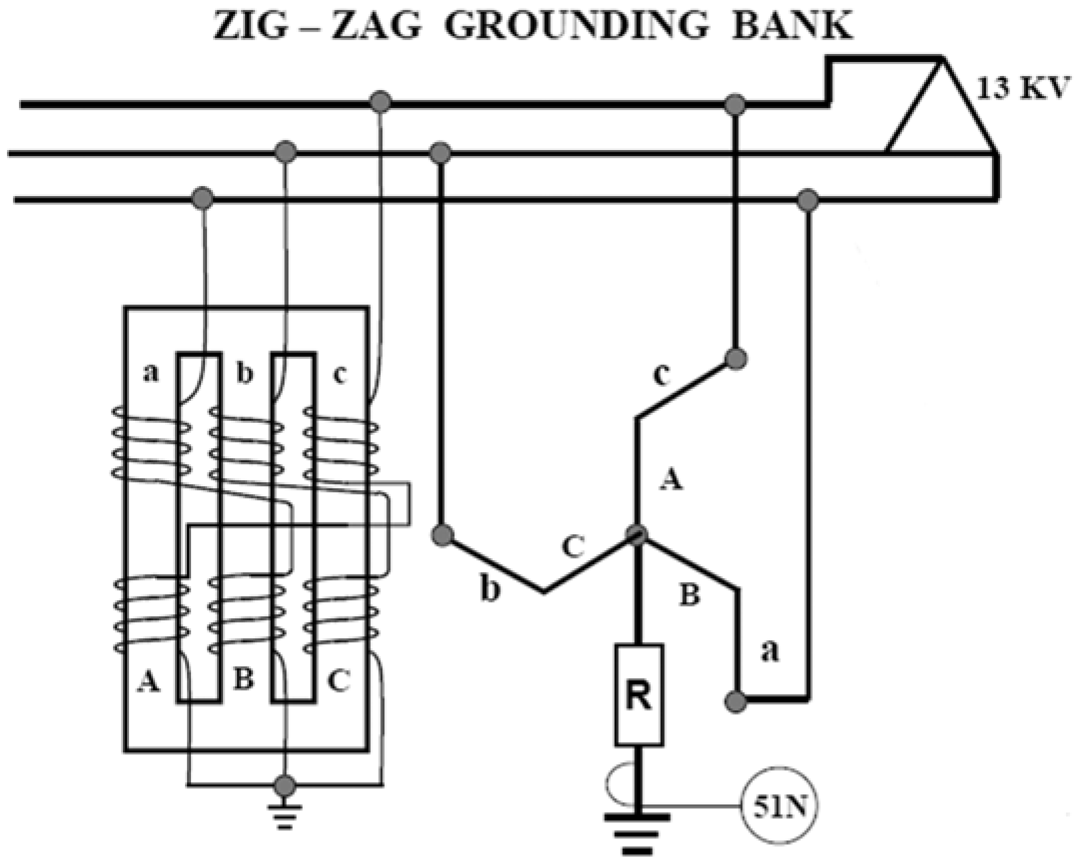
Add small 1:1 transformer and solidly ground secondary for 1Φ loads (i.e. lighting).

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.



Zig-Zag Wiring



Minimum Specifications

- 120 Volt Control Circuit
- 385ºC 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

GENERATOR APPLICATONS OF NEUTRAL GROUNDING RESISTORS

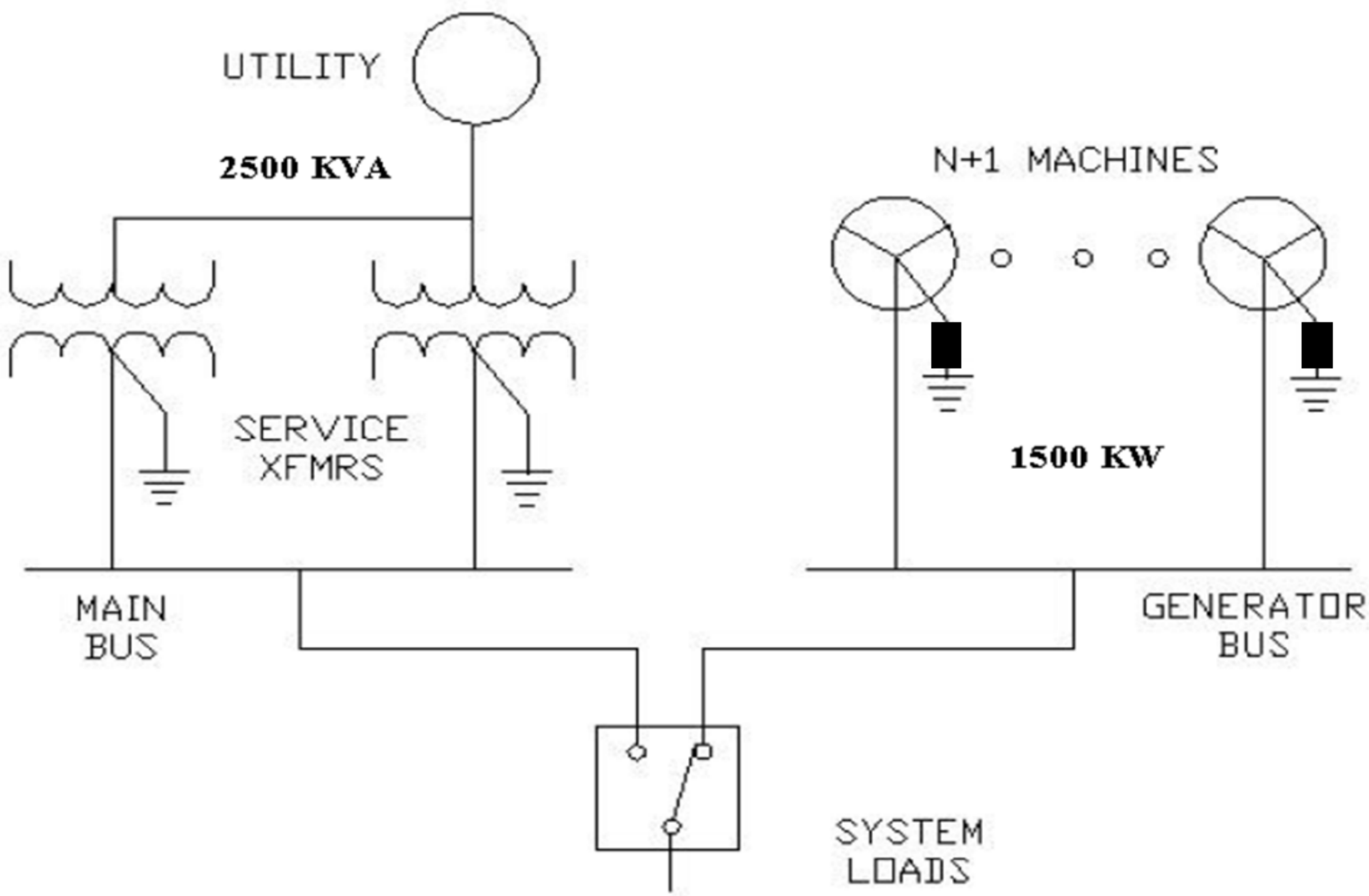


Figure 1 – One line Diagram

GENERATOR APPLICATONS 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…***

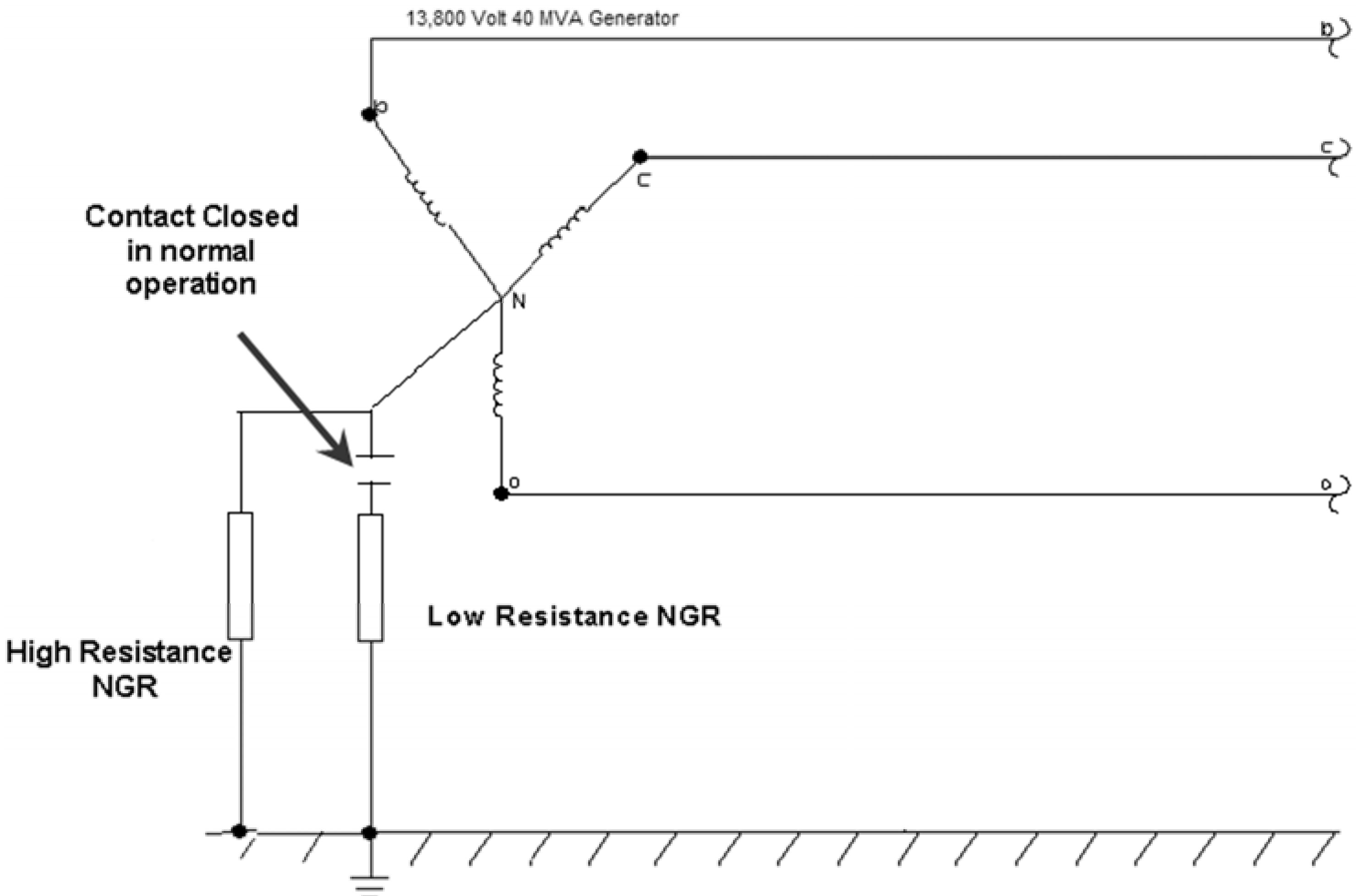
  A generator can develop a significant third-harmonic voltage when loaded. A solidly grounded neutral and lack of external impedance to third harmonic current will allow flow of this third-harmonic current, whose value may approach rated current. If the winding is designed with a **two-thirds pitch**,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

GENERATOR APPLICATONS OF NEUTRAL GROUNDING RESISTORS

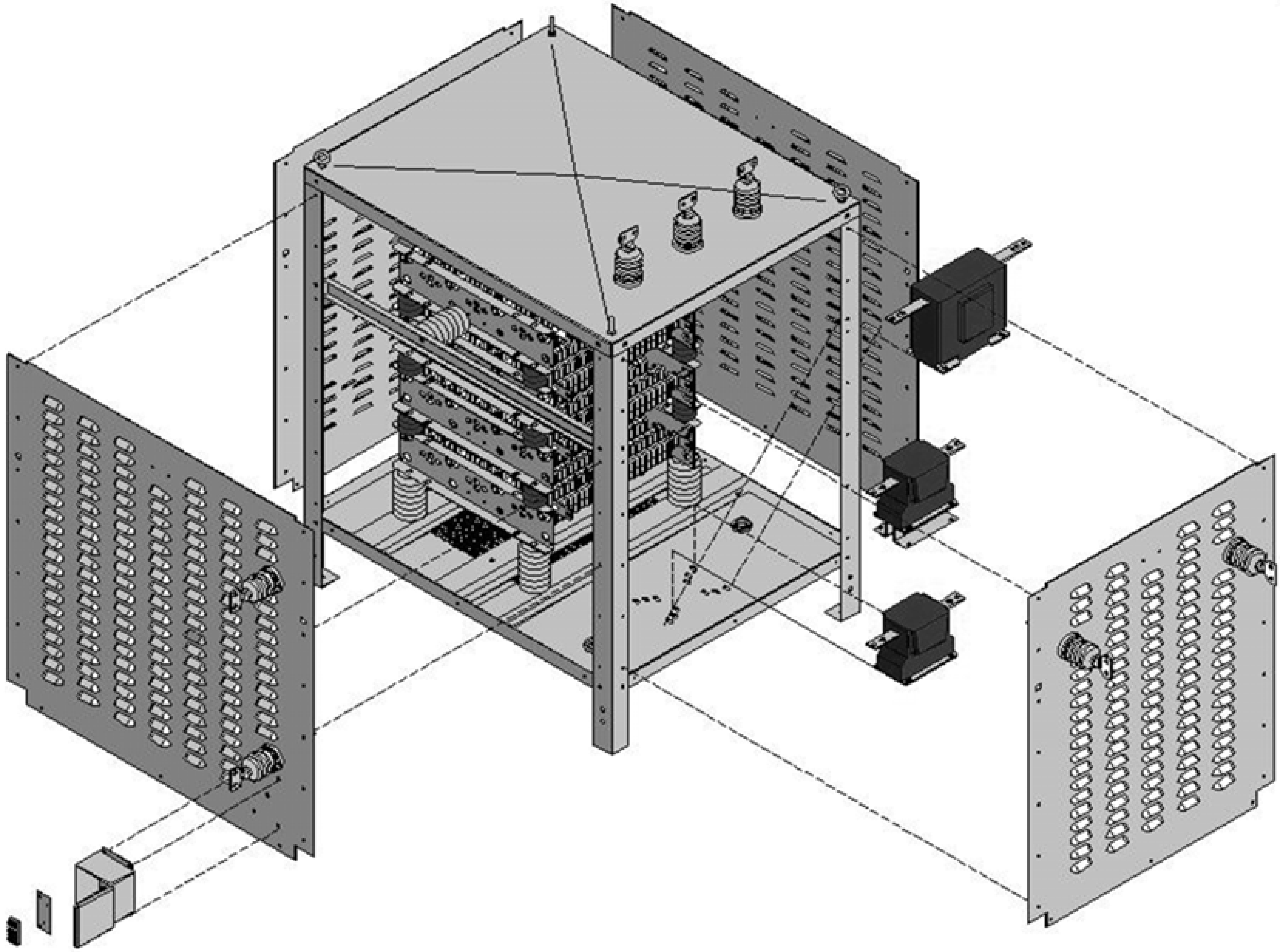
- A large generator ($\geq$ 20 MVA, 13,800 volt) may take 5 to 20 seconds to stop. A IEEE working group wrote a series of four papers. They proposed a hybrid system having a low resistance grounding system and when the fault occurred switch to a high resistance grounded system.

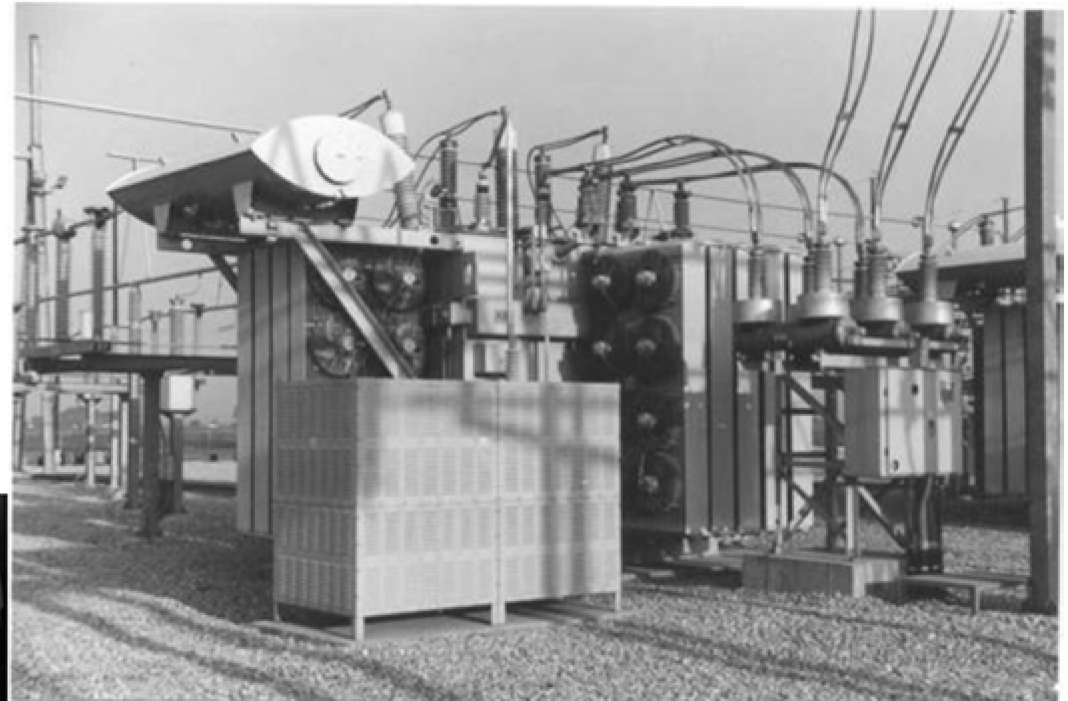
HYBRID SYSTEM

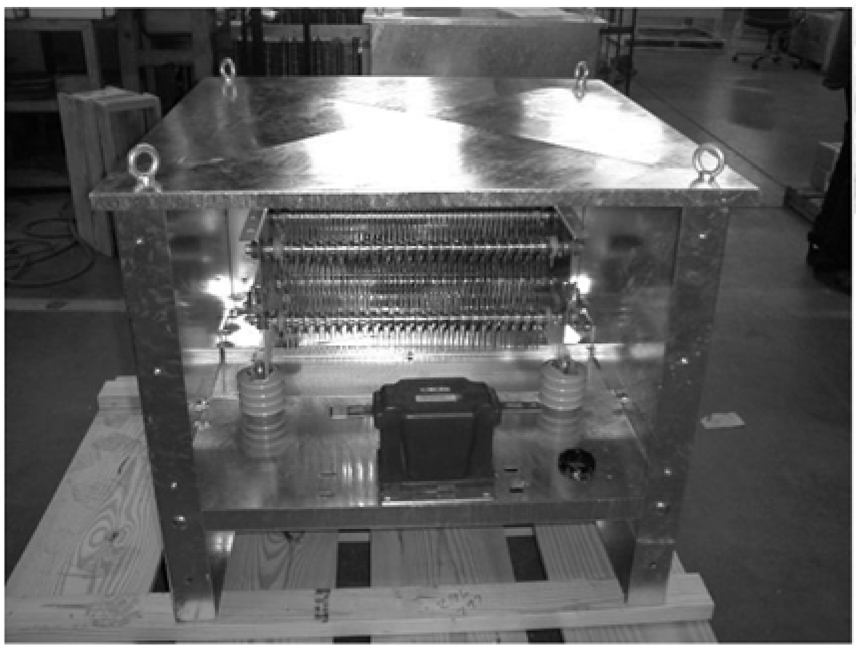


Common options

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








Post Glover
"The Resistor Specialists"
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Post Glover
"The Resistor Specialists"
SYSTEM INFO
F1
F2
ESC/ BACK
HELP
VIEW ALARM 1
ACK ALARM 2
CLEAR ALARM 3
PULSE 4
MENU 5
EDIT 6
TEST 7
CHRGNG CURRENT 8
LAMP TEST 9
SYSTEM RESET 0
PULSERPLUS.NET


Post Glover
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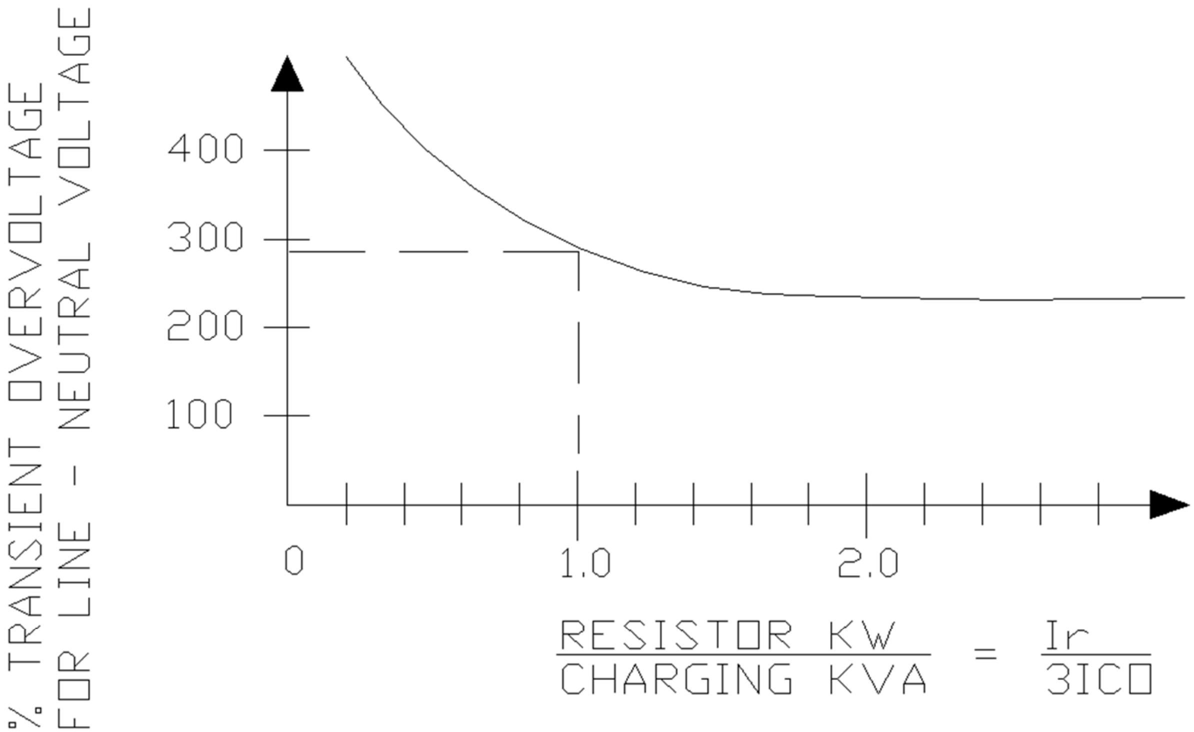
HIGH RESISTANCE GROUNDING SYSTEM
DANGER

Ground Fault Detection	Under voltage and under current detection and alarm
Resistor Monitoring	NEW – Sensing resistor for neutral path monitoring standard
Pulsing System	Adjustable from 10 to 50 pulses per minute allowing custom setup within your system
Password Security	NEW – Prevent unauthorized parameter and setting changes
Harmonics Filtering	Avoids nuisance tripping by measuring only fundamental frequency
Communications	NEW – Remote operation and monitoring via Ethernet and RS 232/485 (Modbus)
Data Logging	NEW – Comprehensive data logging of all alarms and events for fault isolation and trending
Tapped Resistors	NEW – Quickly and easily change resistance taps via terminal strip

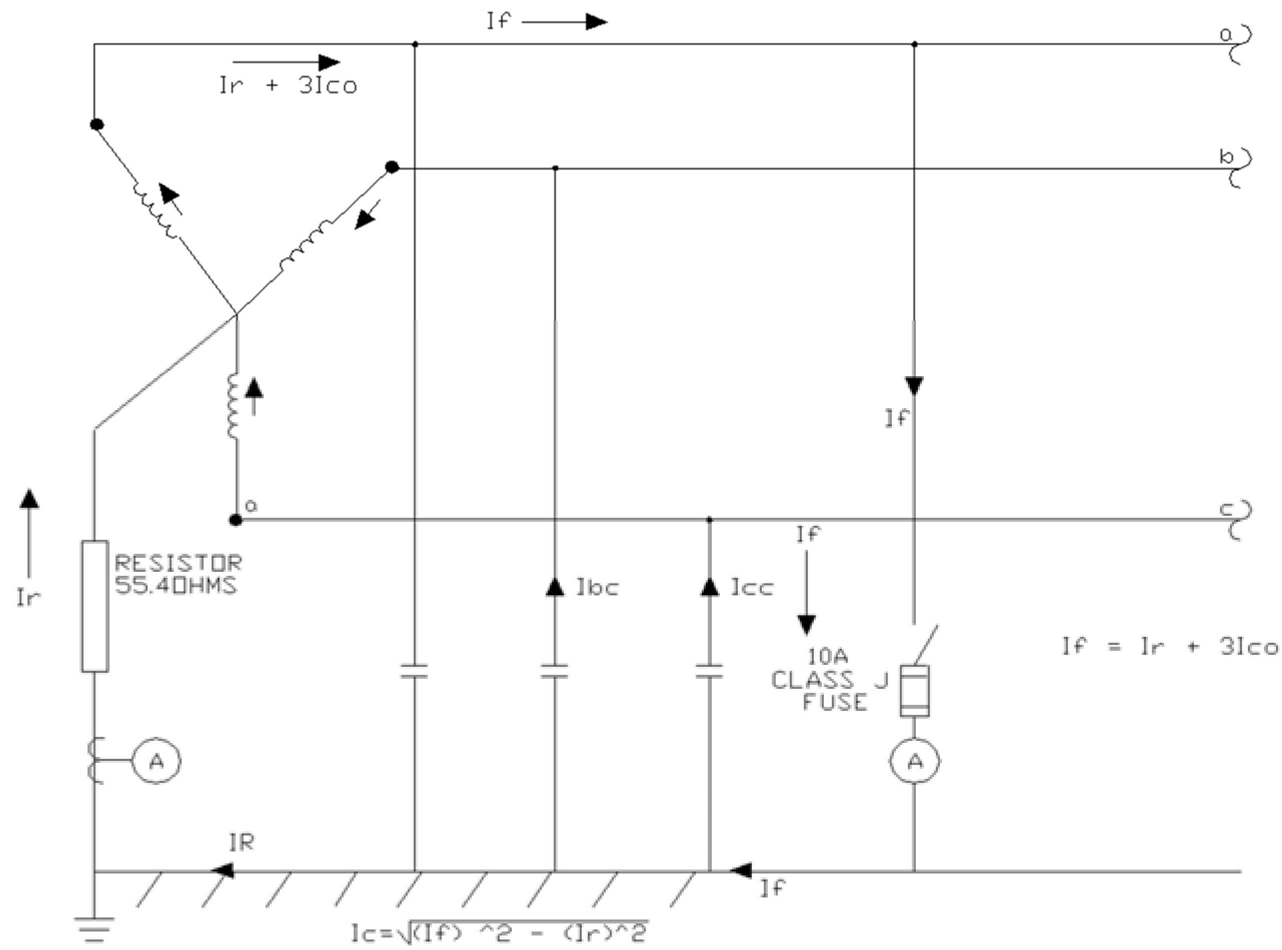
THE HIGH RESISTANCE GROUNDED POWER SYSTEM

CONTROL OF TRANSIENT OVERVOLTAGE



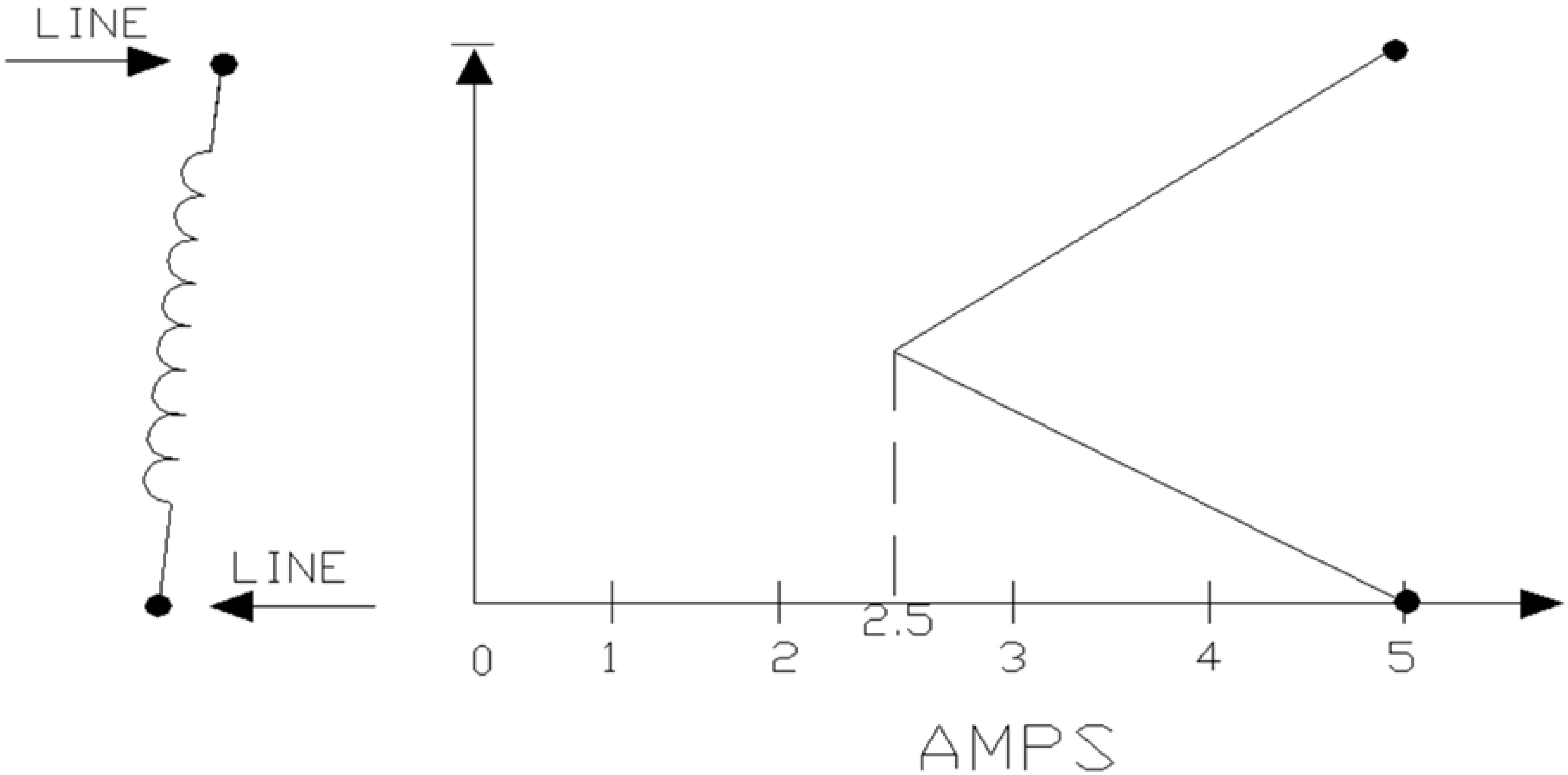
REF. WESTINGHOUSE TRANSMISSION & DISTRIBUTION
REFERENCE BOOK p. 521

How Modern High Resistance Grounding Systems Calculate the Capacitive Charging Current



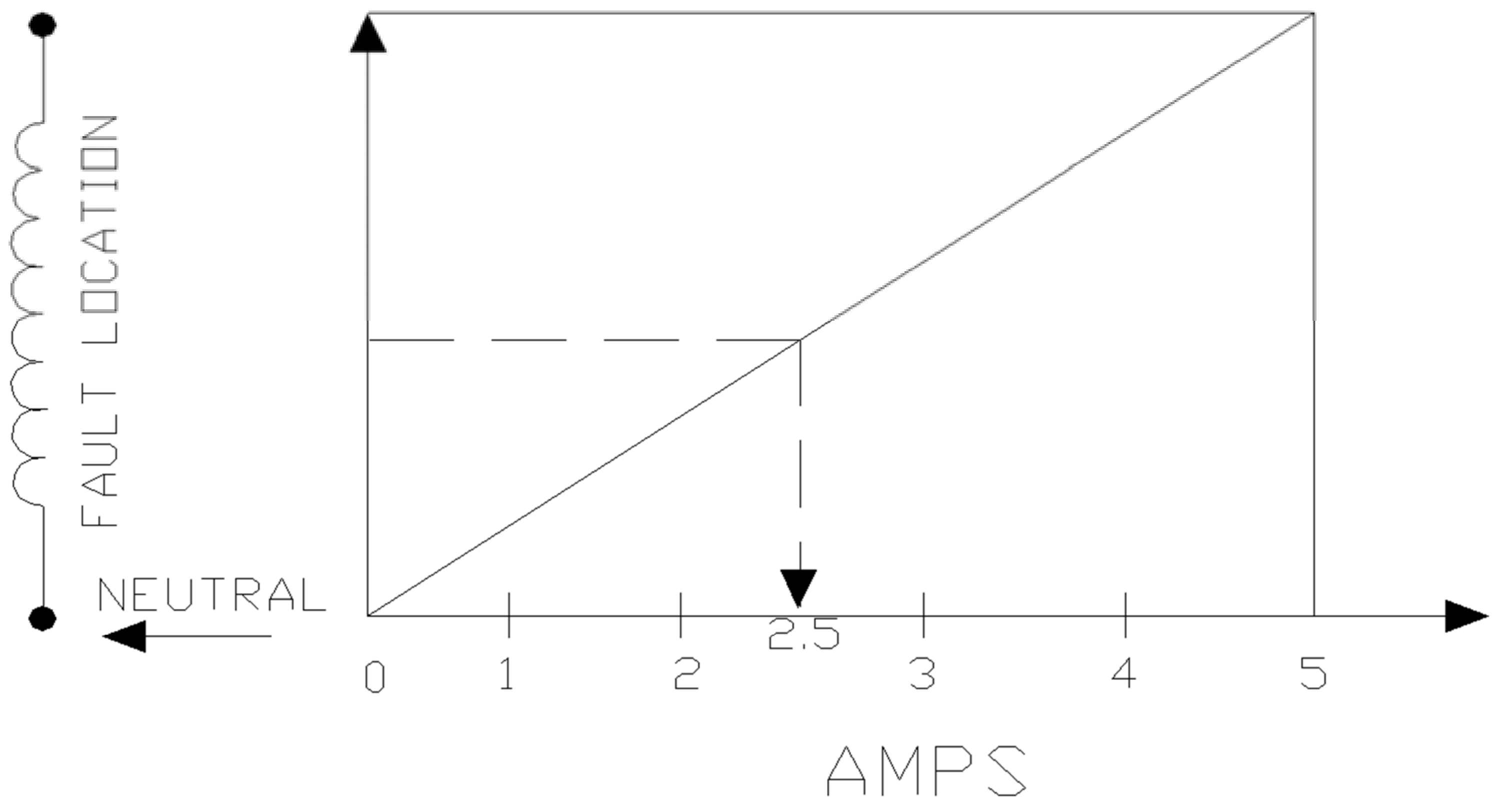
THE HIGH RESISTANCE GROUNDED POWER SYSTEM

LINE – GROUND FAULTS – DELTA CONNECTED MOTORS



THE HIGH RESISTANCE GROUNDED POWER SYSTEM

LINE-GROUND FAULTS WYE CONNECTED MOTORS



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

COMPARISON OF THE FOUR METHODS

HIGH RESISTANCE GROUNDING OF A 2400 VOLT MOTOR SYSTEM

COMPARISON OF SOME CHARACTERISTICS

CHARACTERISTIC	UNGROUNDED	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	← NEW WINDING INSULATION →			
			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

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

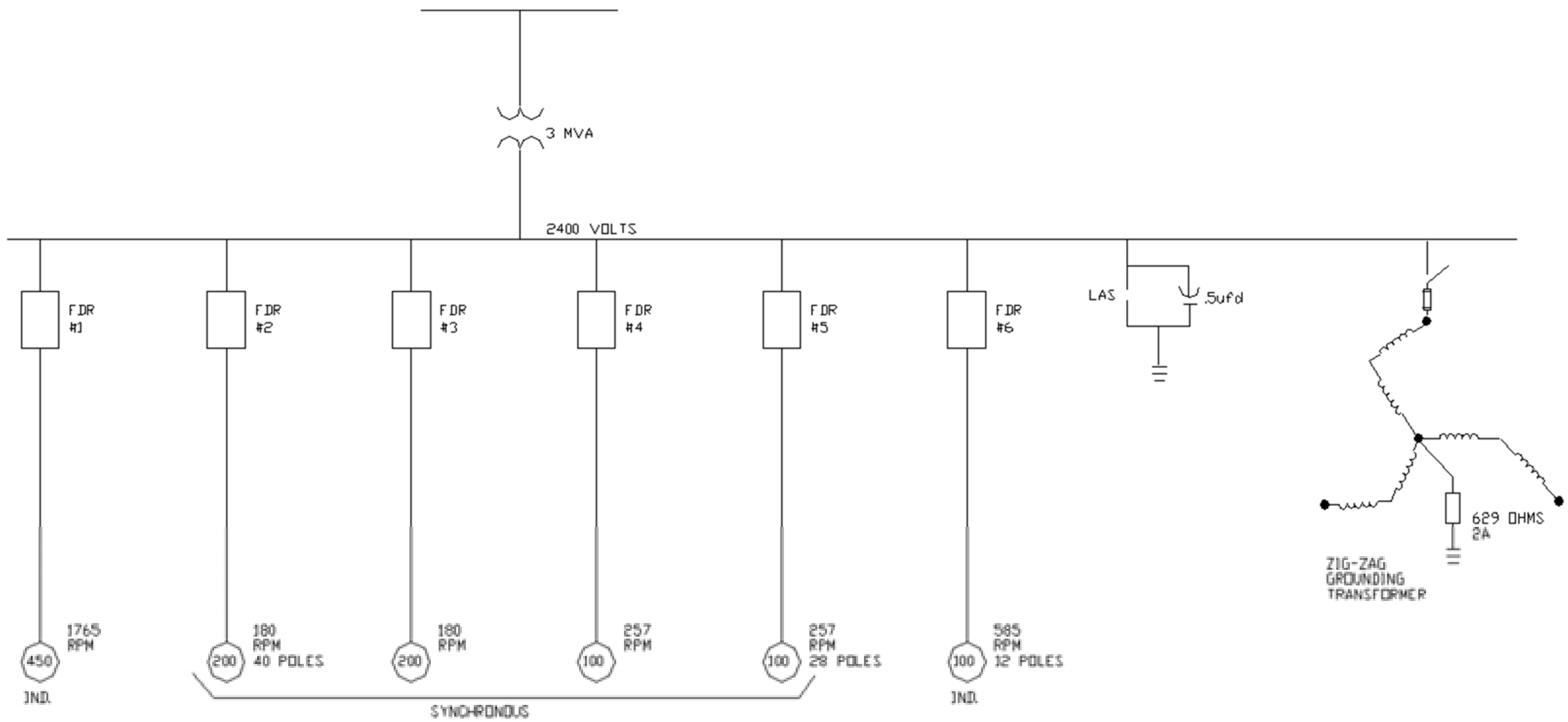
$$\text{Increase in damage} = \left(\frac{20{,}000\ \text{A}}{5\ \text{A}} \right)^2 = 16{,}000{,}000$$

CHARGING CURRENT CALULATIONS

Some manufactures are now bringing in the 3 phase voltages and determining the capacitive charging current on the actual system.

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	CHARGING CURRENT
1000	.02 - .06 AMPS
1500	.03 - .09 AMPS
2000	.04 – .12 AMPS
2500	.05 – .15 AMPS

HIGH RESISTANCE GROUNDING 2.4KV SYSTEM

CALCULATION OF CHARGING CURRENTS

- 1. SURGE CAPACITORS

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

2. MOTORS

$$3\ ICO = \left[0.005X\left(\frac{HP}{RPM}\right)\right]$$ REF. ALVIN KNABLE

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

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

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

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

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

$$XC = \frac{10\text{^}6}{377X10\text{^}{-2}} = 2.65 X 10\text{^}5 \text{ TO } 2.65 X 10\text{^}6 \text{ OHMS}$$

$$3ICO = \frac{2400/3\text{^}(1/2)}{2.65X10\text{^}5} = .0156 \text{ TO } .00156 \text{ AMPS.}$$ DISREGARD THIS VALUE

HIGH RESISTANCE GROUNDING 2.4KV SYSTEM

CALCULATION OF SYSTEM CHARGING CURRENT

- CABLE CAPACITANCE

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

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

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

$$C=\frac{0.00735*3}{LOG\ (.56.34)}$$

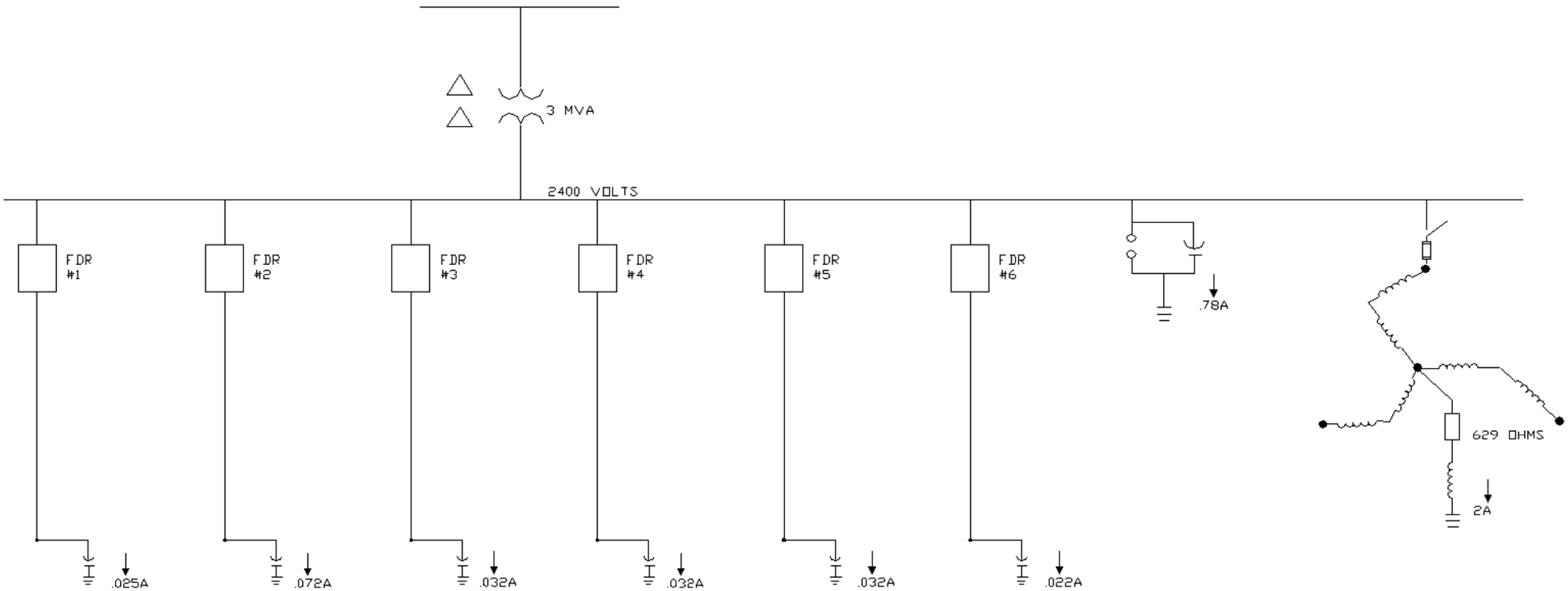
$$C= .1017\ X\ \frac{75\ f}{1000\ ft} = 7.63X10\text{^}-3\ ufd$$

$$Xc=\frac{10\text{^}6}{377\ X\ 7.63x10\text{^}-3} =3.47x10\text{^}5\ OHMS.$$

$$3Ico=\frac{2400/\ 3\text{^}(1/2)}{3.47X10\text{^}5\ OHMS} = .0119AMPS = .012AMPS\ PER\ FEEDER$$

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
- CHOSE GROUNDING RESISTOR OF 5 AMPS
- NOTE: SURGE CAPACITORS ACCOUNT FOR 75% OF THE TOTAL