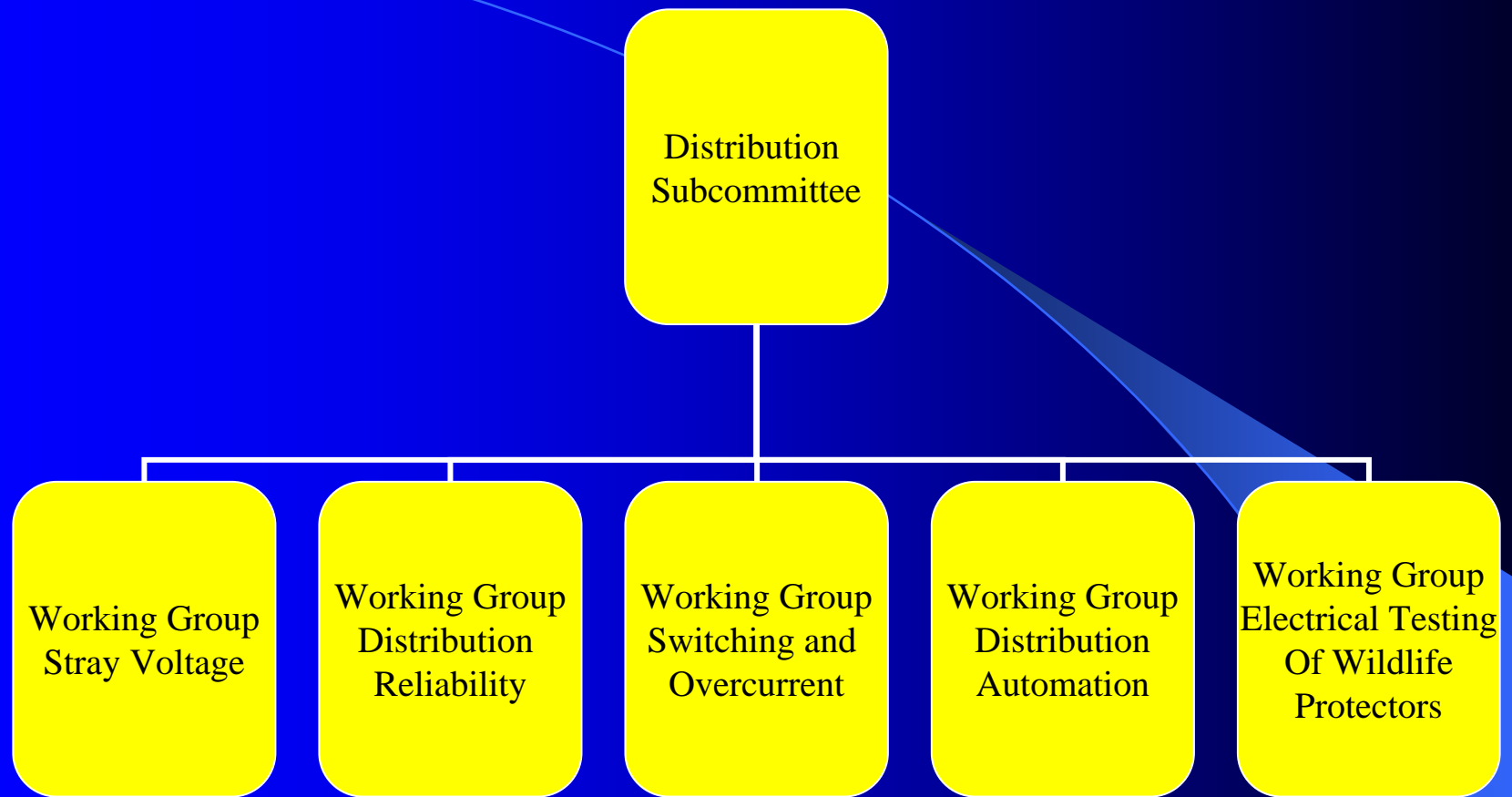


# Welcome!

- The inaugural web based meeting of the Distribution Subcommittee.
- We meet in person twice a year at the PES General Meeting (Montreal this year) in June and at a Winter Technical Meeting (WTM) in January.
- Expect to hold at least 2 web based meetings a year in Spring and Fall.



<http://grouper.ieee.org/groups/td/>

# IEEE

- Become a member at:
- <http://www.ieee.org/web/membership/home/index.html>

# Admin...

- Two segments to the meeting
  - Talk by John Nelson
  - WG on Stray Voltage – Chair Charlie Williams
- Please mute your phone.
- Questions will be answered at the end of John Nelson's Speech.
- During the WG portion of the meeting, questions will be answered as we go.
- Survey will be distributed after the meeting, please take a moment to fill it out and return it to me.

# **The Grounding of Power Systems Above 600 Volts: A Practical Viewpoint**

**John P. Nelson  
Fellow, IEEE  
NEI Electric Power Engineering  
Arvada, CO**

# **ELECTRICITY IS INHERENTLY DANGEROUS**

- **Silent, odorless and tasteless**
- **Shock**
- **Burns**
- **Death**
- **Dangerous voltages**
- **Hazardous currents**

# **ELECTRICITY IS HARMFUL TO SOCIETY**

- **Air pollution**
- **Health problems**
- **Production of dangerous things**
- **Global warming and greenhouse effect**

# REQUIRED WARNING SIGNS

- **“Warning – The Surgeon General has determined that the use of electricity can be harmful to your health”**

**Or,**

- **“Warning: The use of electricity can result in shock, burns and death”**

# Just Say No to Electricity!

- **Outlaw** O/H Electric Lines
- **Outlaw** U/G Electric Lines
- **Outlaw** Power Plants
- **Outlaw** Electric Substations
- **Outlaw** Electric Utilities
- **Crime** to produce, transport, sell or use electricity



**TURN OUT THE LIGHTS!**

**LET'S GO HOME**

# **The Grounding of Power Systems Above 600 Volts: A Practical Viewpoint**

- **Electrical Hazards**
- **Acceptable Risks**
- **System Grounding**
- **Stray voltage examples**
- **Conclusions**

# ELECTRICITY IS OKAY

- The term **Hazardous** is relative
- The term **Dangerous** is relative
- Voltages above 600 V can be hazardous
- Electrical currents can be dangerous
- The **benefits of electricity** outweigh its inherent hazards and dangers

# ACCEPTABLE RISKS

- **Everyday Life Is Filled with Risks**
- **Few Tasks Are Risk Free**
- **Minimize Risk Probabilities**
- **Fatal Car Accident – 1:5000**

# TRAIN-AUTO ACCIDENTS

- 2001 – 491 fatal train-auto accidents – 1:500,000
- \$180K for controlled crossings/\$4 million for Bridges – 1368 Uncontrolled Crossings In CO
- \$250 million for Controlled Railroad Crossings
- \$5.5 Billion Dollars for Bridges
- Colorado accounts for 1% of the fatalities

# ELECTRIC SYSTEMS ABOVE 600 VOLTS

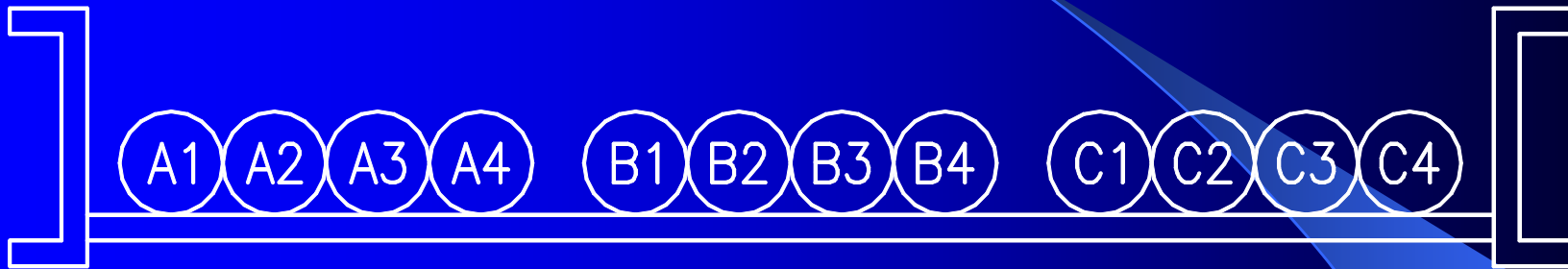
- **AC** versus **DC** systems
- **$V = I \times Z$**  versus  **$V = I \times R$**
- Current flows through the path of least **impedance**
- AC systems have **inductance**

$$Z = R + jX$$

$$\text{Therefore: } I = V / (R + jX)$$

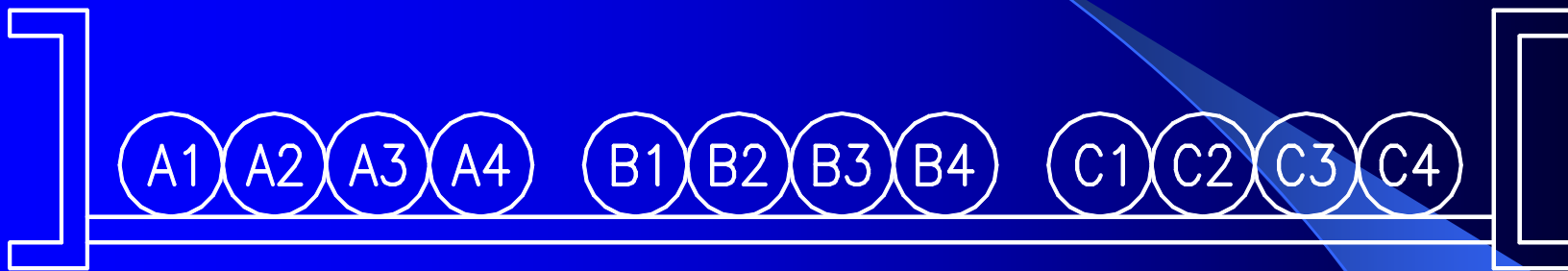
- Ohms Law for AC systems is more complex than for DC systems
- For current to flow, there must be a voltage
- “Path of Least Resistance” is meaningless in AC systems
- Reduction of “stray” **Voltage does** reduce “stray” **Current**

# HOW MUCH CURRENT FLOWS IN EACH CABLE?



- **Cables laid flat across a cable tray**
- **Four cables per phase – A1-A4, B1-B4, C1-C4**
- **750 MCM Insulated Copper Cables**
- **Length approximately 200 feet per conductor**
- **2000 Amps of circuit load**

# PATH OF LEAST IMPEDANCE



$$A1 = 100 \text{ A}$$

$$A2 = 300 \text{ A}$$

$$A3 = 600 \text{ A}$$

$$A4 = 1000 \text{ A}$$

$$B1 = 550 \text{ A}$$

$$B2 = 450 \text{ A}$$

$$B3 = 450 \text{ A}$$

$$B4 = 550 \text{ A}$$

$$C1 = 1000 \text{ A}$$

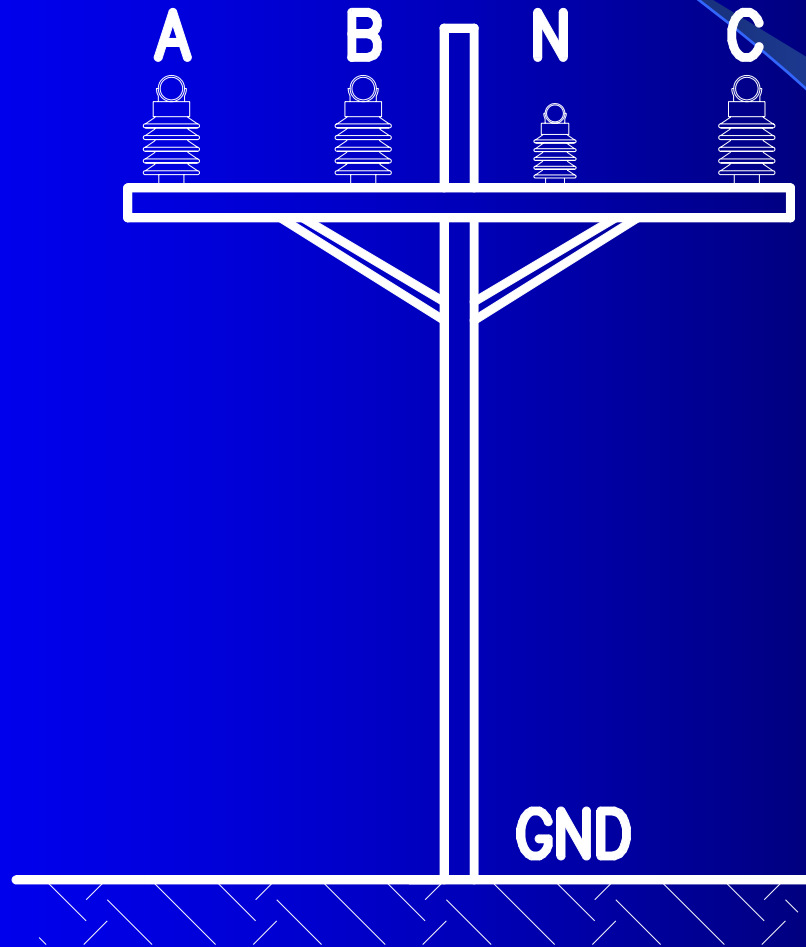
$$C2 = 600 \text{ A}$$

$$C3 = 300 \text{ A}$$

$$C4 = 100 \text{ A}$$

**THEREFORE:  $I = V/R$  DOES NOT HOLD FOR AC SYSTEMS!**

# PATH OF LEAST IMPEDANCE



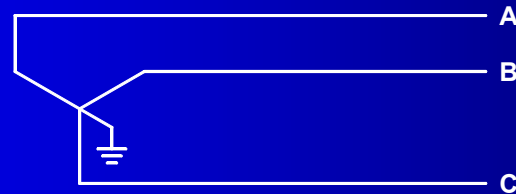
# **System Grounding**

- **Establishment of Intentional Ground**
- **Avoidance of Transients from Arcing Ground Faults**
- **Necessary to Sense Unintentional Grounds**
- **Knowledge Important for Ground Fault Protection**

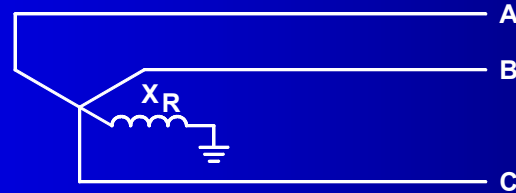
# Three-wire ungrounded-wye connected transformer



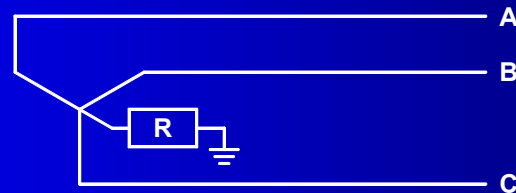
# Three-wire single point grounded system



a) Solidly Grounded

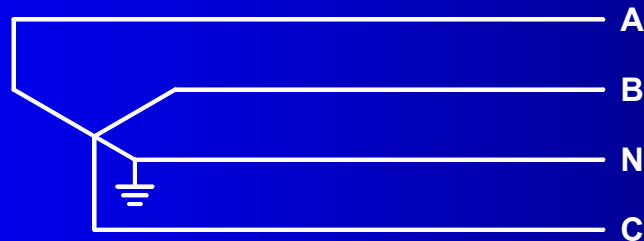


b) Reactance Grounded

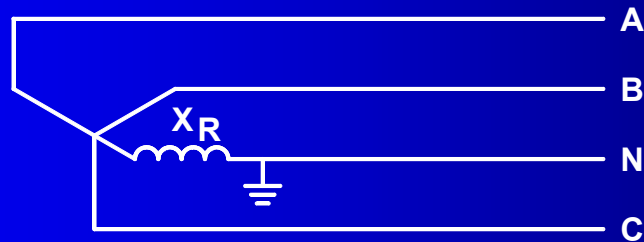


c) Resistance Grounded

# Four-wire single point grounded-neutral system

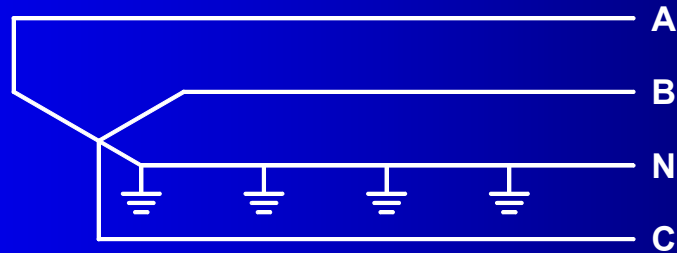


a) Solidly Grounded

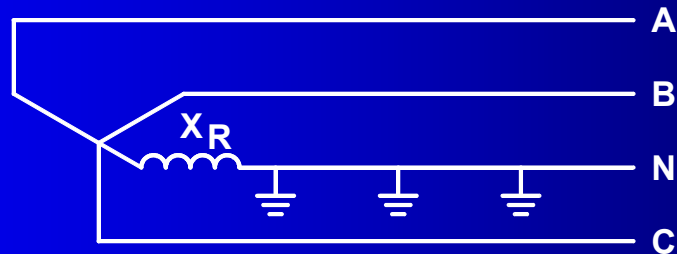


b) Reactance Grounded

# Four-wire multi-grounded neutral system



a) Solidly Grounded

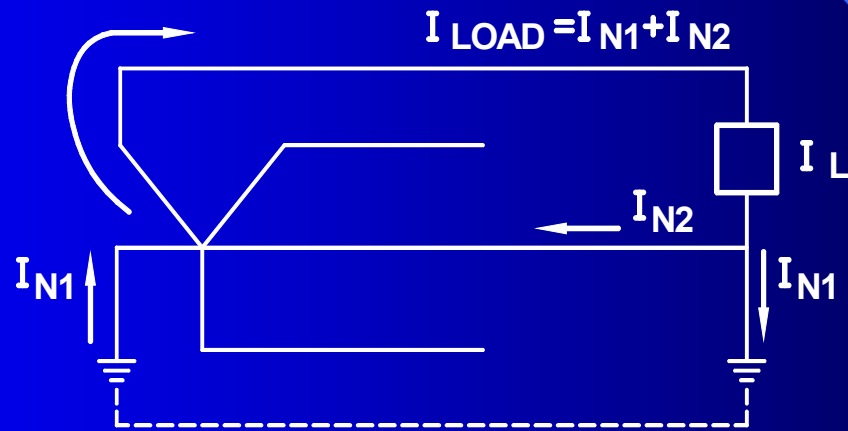


b) Reactance Grounded

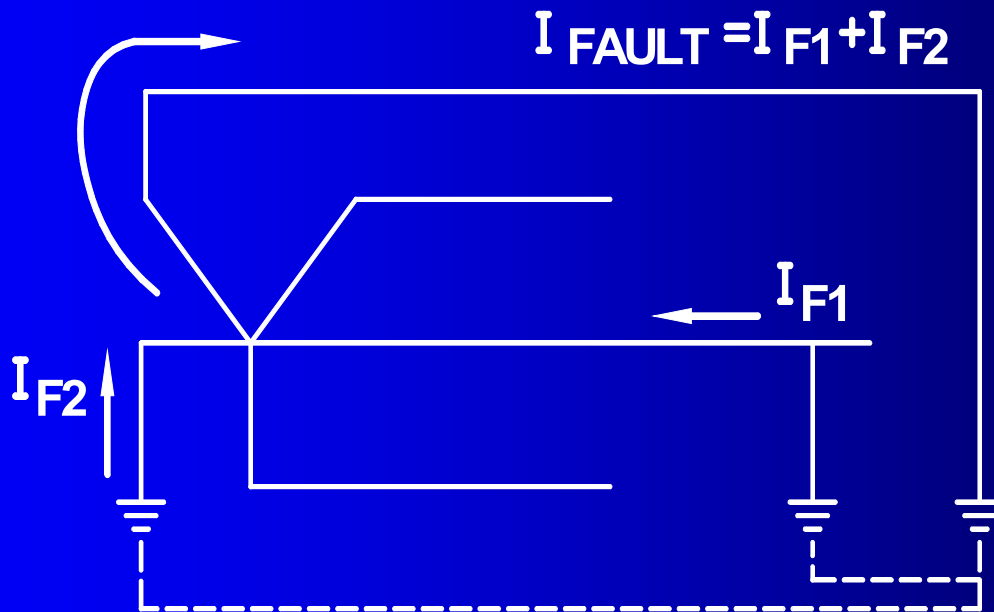
# **REASONS FOR MULTI-GROUNDED NEUTRAL**

- **Minimizes Neutral Shift**
- **Minimizes Hazardous Voltages to Ground**
- **Provides Low Impedance Path for Ground Faults**
- **Safety for Utility Workers & General Public**
- **Improves Customer Grounds**
- **Better Grounding for Lightning Protection**

# Neutral current flowing in neutral and ground



# Ground Fault Current Flowing in the Ground and Neutral





# **INTERESTING TECHNICAL FACTS**

# Earth Resistance ( $R_e$ ) & Earth Reactance ( $X_e$ )

- $R_e = 0.00477f$
- $X_e = 0.006985f \text{ Log}_{10} [4.665600 \times 10^6 (\rho/f)]$

# TABLE 1

## Re and Xe @ f = 60 Hz

$\rho$ Ohm-meters	Re $\Omega$ /mi	Xe $\Omega$ /mile
1	0.286	2.050
5	0.286	2.343
10	0.286	2.469
50	0.286	2.762
100	0.286	2.888
500	0.286	3.181
1000	0.286	3.307
5000	0.286	3.600
10000	.0286	3.726

# Table 3

## Rod and Resistances with Varying Soil Resistivity

$$R = (\rho/2\pi L)(\ln 4L/a - 1) \text{ Ohms}$$

Soil Resistivity ( $\Omega$ -m)	Rod Resistance ( $\Omega$ )
10	3.35
100	33.5
1,000	335
10,000	3,350
100,000	33,500

# Zero Sequence Impedance

**Zoa = Self Impedance of Phase Conductors**

**Zog = Self Impedance of Ground Wire**

**Zog(n) = Self Impedance of (n) Ground Wires**

**Zoag = Mutual Impedance of Phase and Gnd Conductors**

**$Z_0 = Z_{oa} - (Z_{oag})^2 / Z_{og} \Omega$**

# Zero Sequence Impedance

$$Z_{oa} = R_c + R_e + j(X_e + X_c - 2X_d) \Omega$$

$$Z_{og} = 3R_a + R_e + j[X_e + 3X_a] \Omega$$

$$Z_{og}(n) = 3R_a/n + R_e + j[X_e + 3X_a/n - (3(n-1)/n)X_d] \Omega$$

$$Z_{oag} = R_e + j(X_e - 3X_d) \Omega$$

$$Z_o = Z_{oa} - (Z_{oag})^2/Z_{og} \Omega$$

# Effectively Grounded System

$$X_0/X_1 \leq 3$$

# Table 3

## $X_0/X_1$ ratios with and w/o gnd wire

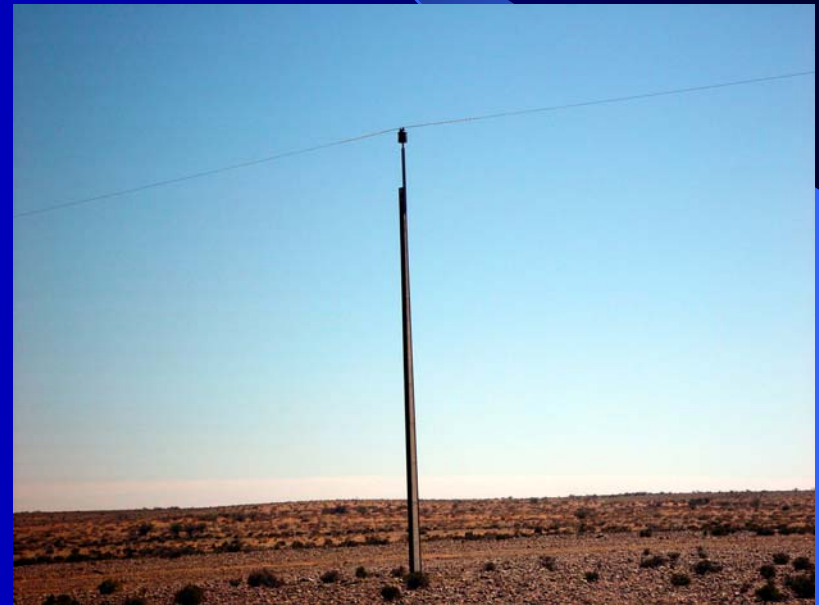
Resistivity $\rho$	$X_0/X_1$ w/gnd wire	$X_0/X_1$ w/o gnd wire
50	2.80	4.43
100	2.85	4.62
500	2.95	5.07
1000	2.99	5.27
5000	3.07	5.72
10000	3.11	5.91

# **Three-Phase, Five Wire System**

- **Simpler ground fault protection**
- **Reduction of stray voltages – Steady State**
- **Dangerous voltage on fifth wire**
- **Increased costs**
- **Additional structural load on Poles**
- **Not practical due to neutral shift**
- **Not practical for U/G Circuits**

# Single Conductor Circuits

- **Single Conductor 19 kV Circuit in South Australia with Earth Return**



# **Stray Voltage Example #1**

**Mount Evans – 50 Elk Killed from Stray Voltage**

- 14,000 Ft Peak**
- No Power Lines**
- Cause – Lightning**
- Solution - None**

# **Stray Voltage Example #2**

## **Woman In Shower**

- Received Shock When Taking Shower**
- O/H Power Line in Area**
- Septic System and Water Well**
- Stray Voltage**
- Cause – Improper Grounding**
- Solution – Bonded septic and well**

# **Stray Voltage Example #3**

## **Computer Failures**

- Computer and Modem Failures**
- Occurred Only During System Faults**
- Telephone, Electric and Well Separately Grounded**
- Cause – Improper Grounding**
- Solution – Proper Bonding**

# **Stray Voltage Example #4**

## **Saltwater Swimming Pool**

- Tingling Sensation in Pool**
- Problem 1 – Improper Grounding/Bonding of Pool**
- Problem 2 – Corroded Bare Concentric Neutral**
- Pool Bonding Still a Problem**
- Replacement Cable Used Jacketed Concentric Neutral**

# **Stray Voltage Example #5**

## **Baseball Diamond**

- Players received tingling sensation**
- No O/H lines**
- Cause – Corroded Concentric on U/G**
- Solution – Replace power cable with jacketed concentric**

# Summary of 4 Wire, Multi-Grounded System

- **Ideally, the earth is “true ground”. Practically, that is not true!**
- **System Grounding is Optimized with the Multi-Grounded System!**
- **Problems and limitations exist on all systems!**
- **Fourth wire provides better ground and additional safety during faults involving ground!**
- **Five wire system will not properly work and is more dangerous!**

# Summary of Multi-Grounded System

- **The Zero Sequence Impedance is lower!**
- **Lower rated surge arresters can and are normally used which enhance equipment protection!**
- **The System is safer for utility personnel and the general public!**
- **The Multi-Grounded System meets all NEC and NESC code requirements!**

# **CONSIDERATIONS FOR MR. ZIPSE'S Presentation**

- **AC versus DC Systems - AC Current is going to follow the power line**
- **Stray Voltages Exist**
- **Proper Grounding with Bonding is the Solution**
- **A Voltage must exist for current to be harmful**
- **Safety is major factor for 4 wire M-G System**
- **ZIPSE'S LAW IS ONLY AN OPINION!**

# **MULTI-GROUNDED NEUTRALS AND STRAY CURRENTS**

- **Least hazardous system in the electric industry**
- **Minimizes a shift in the neutral**
- **Proper grounding helps mitigate the hazards and dangers during ground faults**
- **Stray current and voltage are inherent**

**ANY  
QUESTIONS ?  
And/OR  
COMMENTS!**

