

Power System Neutral/Ground Voltages Causes, Safety Concerns and Mitigation

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PSERC Tele-Seminar

Power System Design Principles for Safety

- Any Individual Should be Safe in the Vicinity of an Electrical Installation
- An Individual Touching ANY Grounded Structure Should be Safe Under All Foreseeable Adverse Conditions
- Electrical System Installations Should be Designed so that Meet Above Requirements

Yet, we read in the papers.....→

A12 Wednesday, Oct. 14, 1998 ★★
The Atlanta Journal-Constitution

Boy electrocuted at Miami bus stop

A 12-year-old **Miami** boy reported missing by his parents was found dead after he apparently was electrocuted in a metal bus stop. Police said Jorge Luis Cabrera, who had run away from home, apparently was touching the metal frame of the bus stop's bench at the same time he had stepped on an electrical conduit pipe that led from a power pole to the bus stop's electrical box.

Current making waves in pool

Residents couldn't figure out what was giving them the tingles in the neighborhood pool. Then they looked at the electric substation next door.

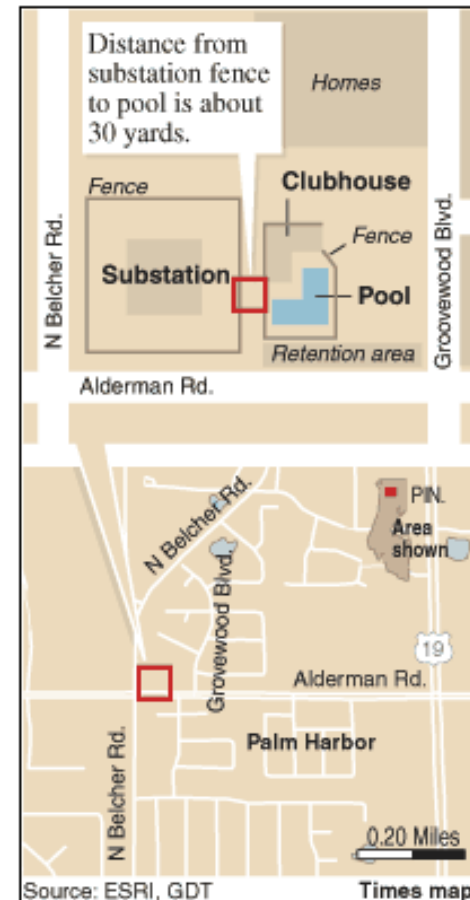
By AARON SHAROCKMAN and RICHARD DANIELSON

Published July 31, 2004



[Times photo: Kathleen Flynn]

The pool at Villas of Beacon Groves is about 30 yards from a Progress Energy substation. It's closed until the problem is fixed.



'Stray voltage' turns up in Stafford pool

Published in the Asbury Park Press 9/25/02

By JOSEPH PICARD
STAFF WRITER

STAFFORD -- The area's stray voltage phenomena has been reported in another power supplier's territory.

Richard Knowles, of 314 Bayberry Court in the Cedar Run section, said his in-ground swimming pool has been emitting between 4 and 7 volts of electricity since it was installed in 1997.

"The power company's been out here a couple times," Knowles said. "They said there was something wrong. They climbed poles, checked this and that. They drove some rods into the ground. But they haven't fixed anything. Now they're acting like it's our problem."

Shocked woman lived a dream

Family recalls her dedication to helping kids

By KERRY BURKE, CARRIE MELAGO and TRACY CONNOR

DAILY NEWS WRITERS

The grieving family of the young woman electrocuted while walking her dogs in the East Village tried to reflect last night on her life, not the freak accident that killed her.

They described Jodie Lane, 30, as living her dream: sharing a home with her boyfriend and their pooches, Reilly and Meeko, and working toward her Ph.D.

Lane, who hailed from Texas but had lived in New York for 10 years, was just one year away from receiving a doctorate in clinical psychology from Columbia University's Teachers College.



By Maki Becker, Daily News, New York -- Feb. 11

Con Edison crews found another 11 manhole and service box covers surging with electricity, bringing to 121 the number of hot spots in the utility's underground system, officials said yesterday.

The figures were announced as Con Ed completed a systemwide check of more than 250,000 locations. The inspection found several causes for the leaking electricity, including corrosion and frayed wires, Con Ed spokesman Joe Petta said.

"There's a fairly wide range of reasons for this," said Petta, adding that all of the hot spots have been repaired.

Another 1,700 Con Ed sites still must be checked, Petta said, but they're all in locations inaccessible to pedestrians, such as in wetlands and on highways.

The inspection was ordered last month after a Manhattan woman walking her dogs was electrocuted when she fell on a Con Ed service box lid.

This week, Con Ed is bracing for another round of bad publicity with dog owners rallying for safer sidewalks this afternoon and public hearings by city and state officials to probe the matter.

Fundamental Facts

Humans are susceptible to even low electric currents

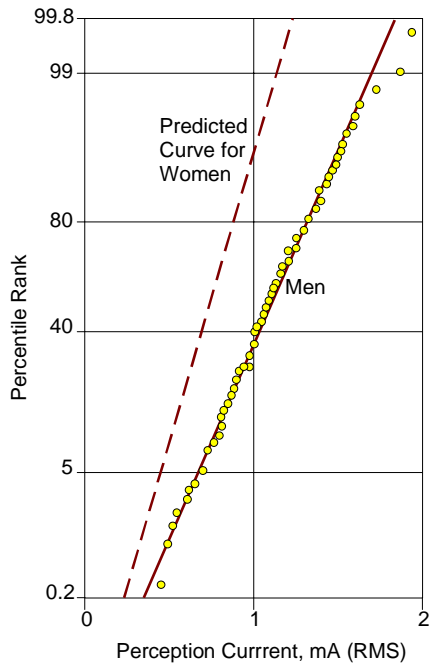
- Perception: 1 mA,
- Let Go 20 mA,
- Ventricular Fibrillation 300 mA for 3 seconds

Several Physical Phenomena will Result in Elevated Voltages of the Neutral of Electrical Installations and Interconnected or not Connected Grounds

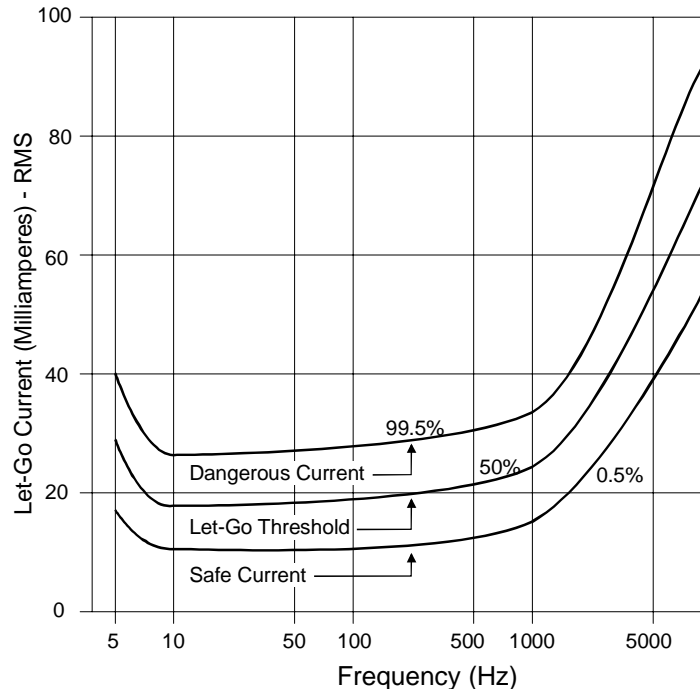
- Ground Faults
- System Imbalance
- High Impedance Ground Faults

Safety

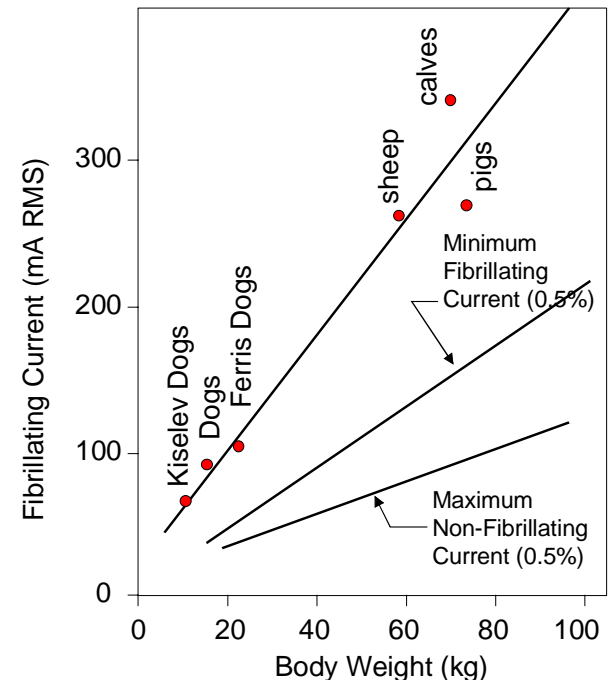
Perception Current



Let-Go Current



Ventricular Fibrillation



Body Impedance Dependence on Voltage - CEI-1984

Total Body Impedance Z_T

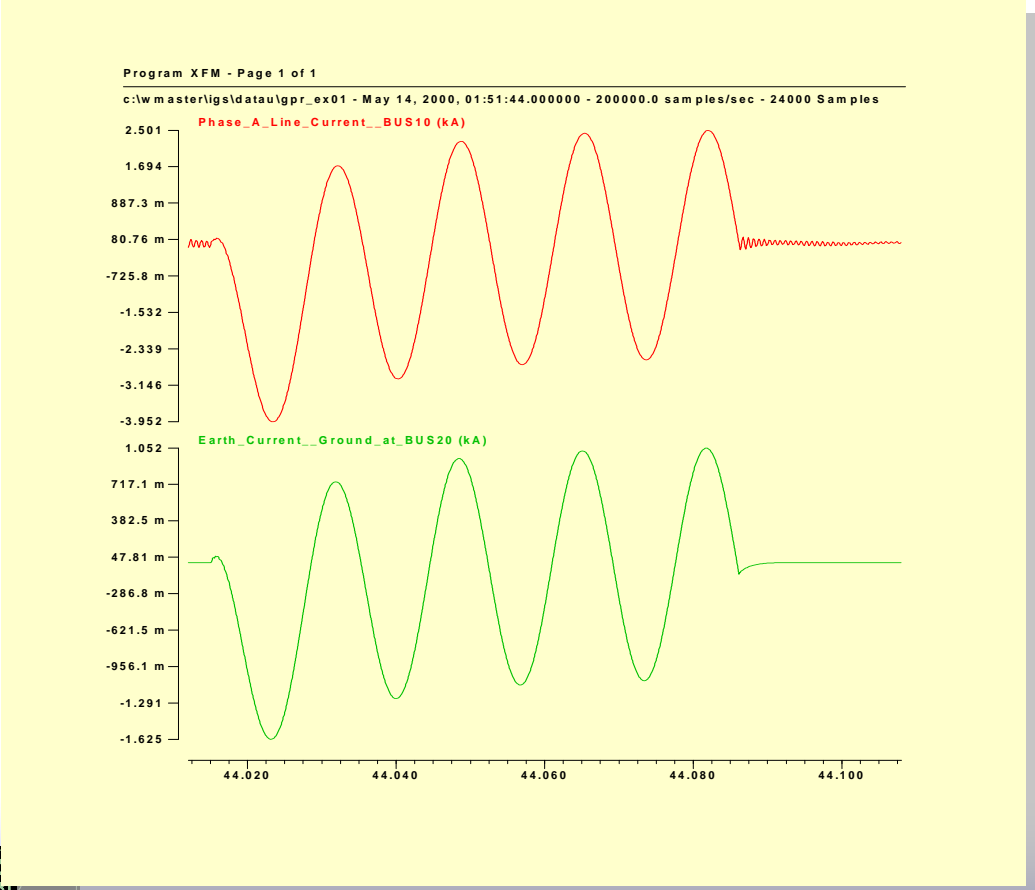
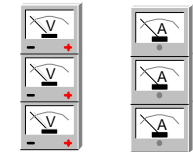
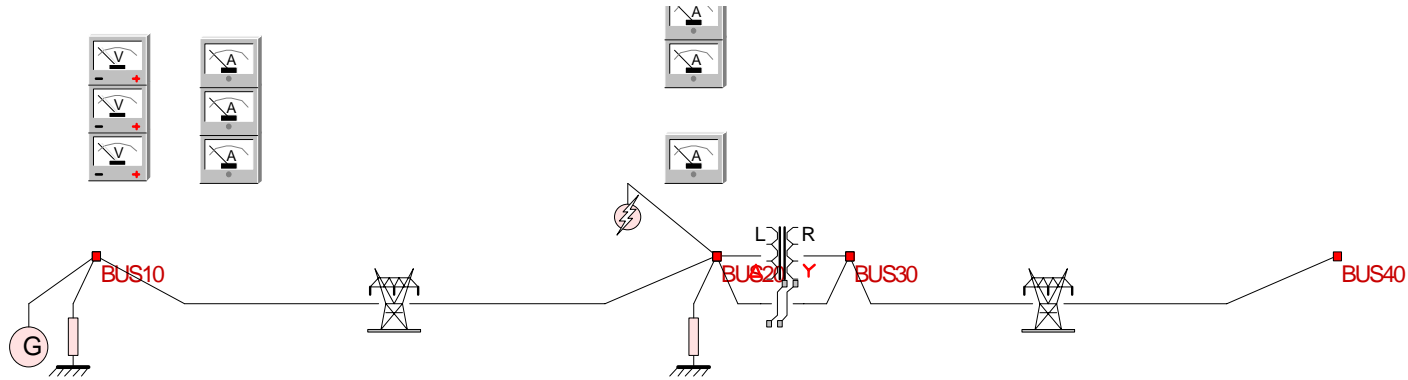
Values for the total body impedance (Ohms) that are not exceeded for a percentage (percentile rank) of

Touch Voltage	5% of the population	50% of the population	95% of the population
25	1750	3250	6100
50	1450	2625	4375
75	1250	2200	3500
100	1200	1875	3200
125	1125	1625	2875
220	1000	1350	2125
700	750	1100	1550
1000	700	1050	1500
Asymptotic Value	650	750	850

Important Facts

- **Humans:** About 2 Volts of Touch Voltage Will Result in “Perception” of Electric Shock. Much Lower for Kids
- **Chicken:** About 0.9 Volts of Voltage Will Make Chickens Stay Away – Importance???
- Claims of Stray Voltage Effects on **Cows** and **Fish** Have Been Very Serious and Fiercely Litigated
- Continuous Voltages of 30 to 60 Volts Have Resulted in Fatalities of Humans and Animals

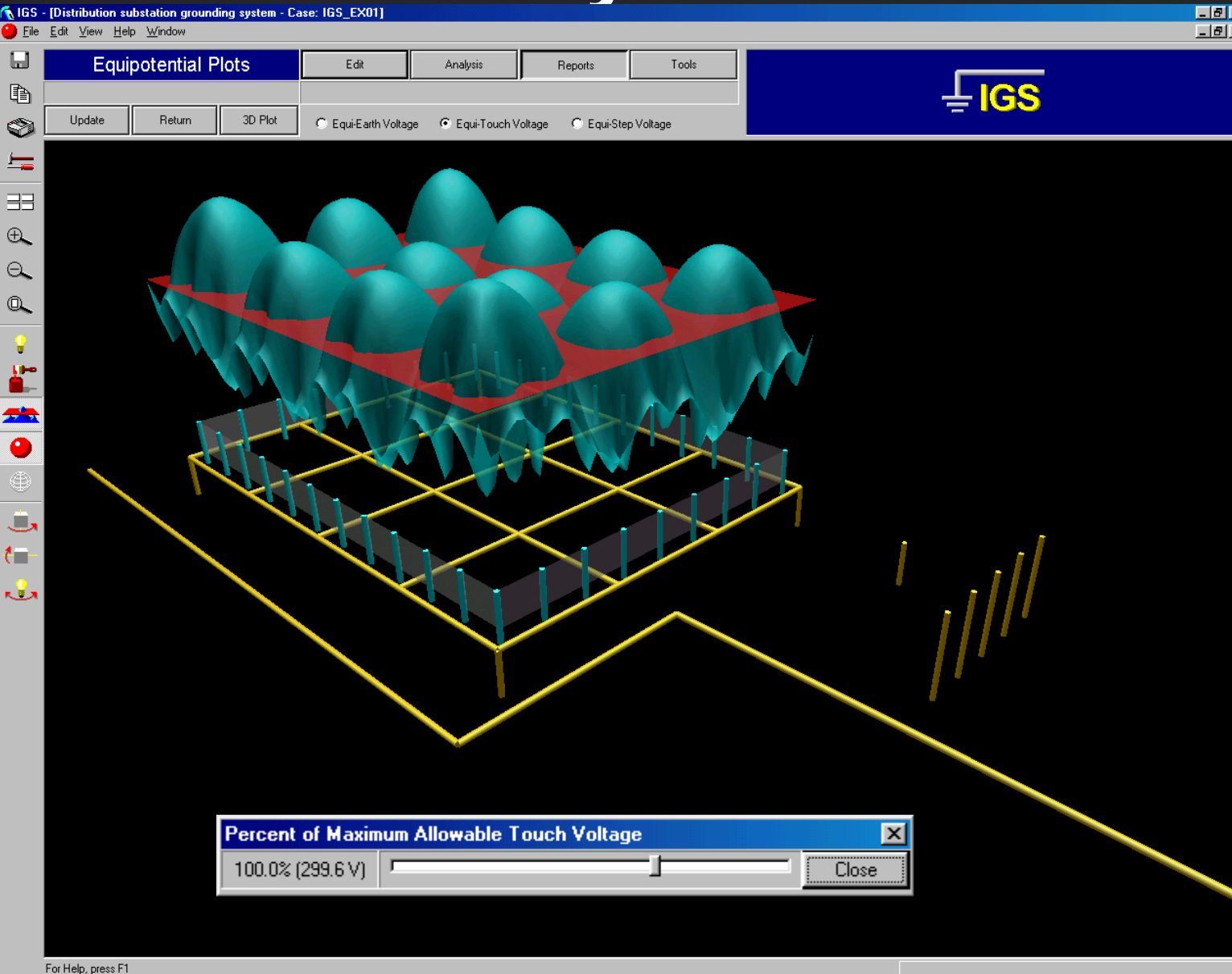
Earth Current / Ground Potential Rise / Safety



Important Issues

- Ground Potential Rise Changes Neutral Voltage
- Customer Voltage is Proportional to Phase to Neutral Voltage
- Grounding and Bonding
- Single Ground/Multi Ground
- Transmission Interconnection

Safety Assessment



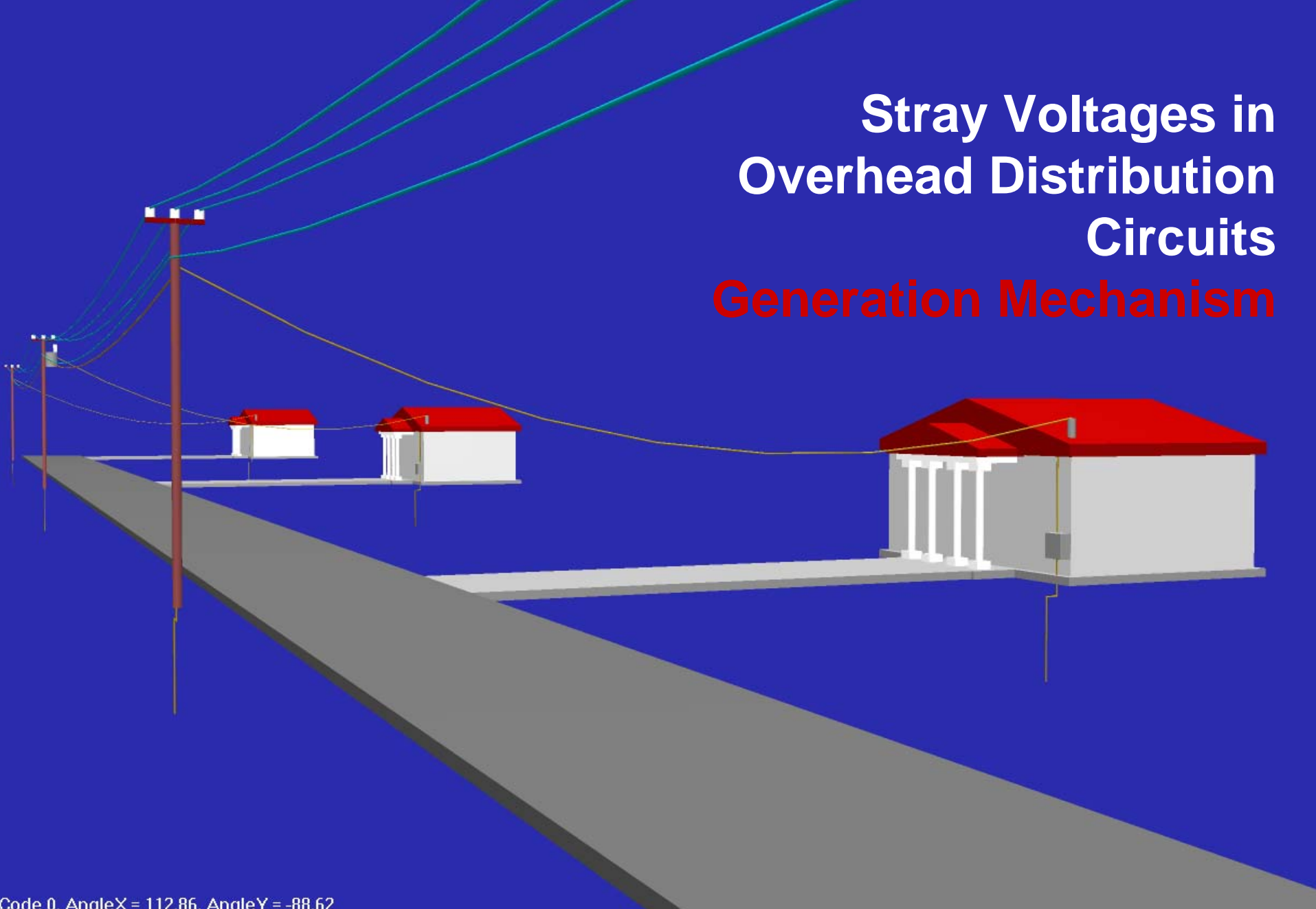
3-D Graph
of
Touch
Voltages
In a
Substation

The IEEE Std 80 Addresses Safety in Utility Substation.

In this talk, we will not discuss safety during HV faults.

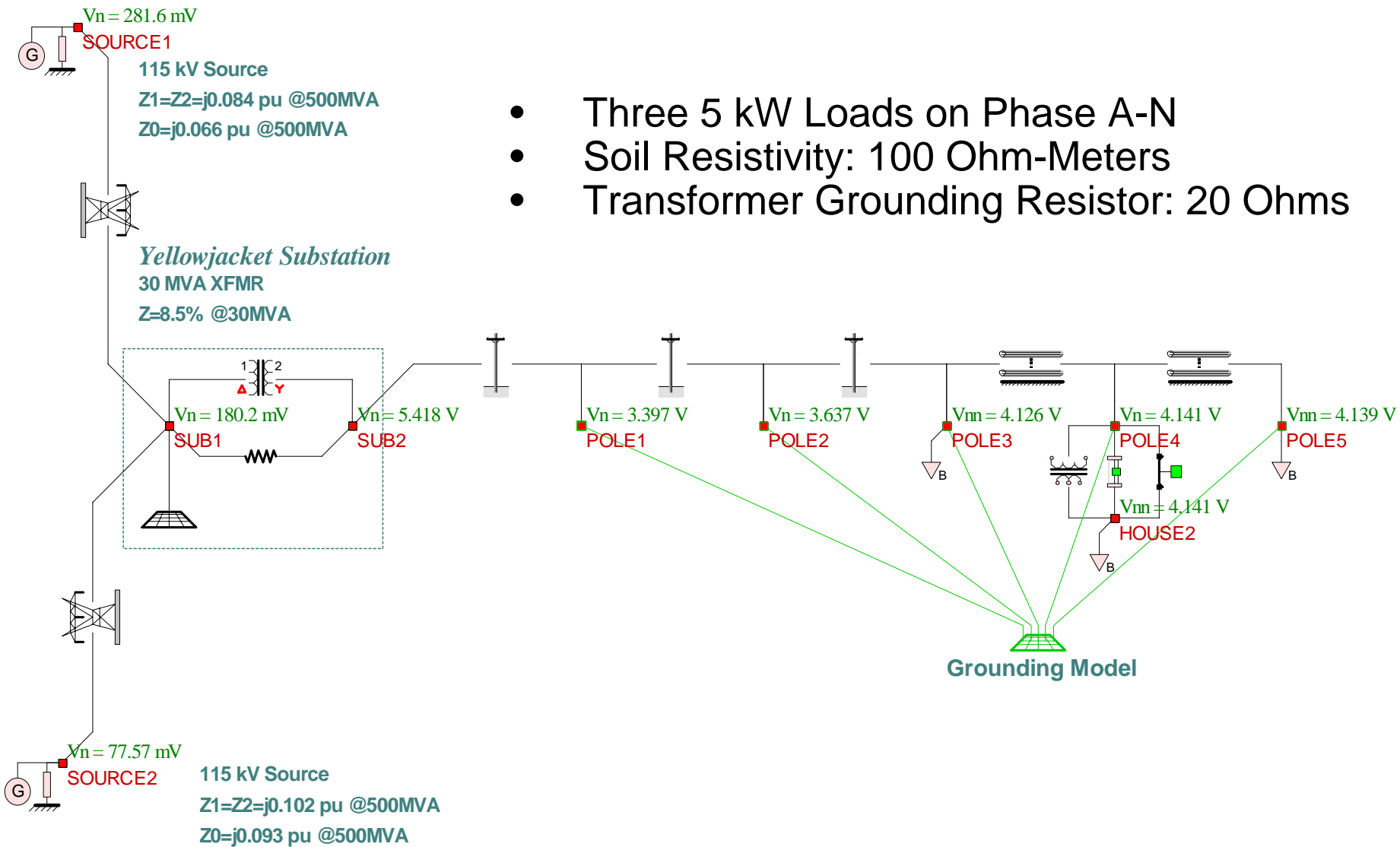
It is important to mention that because the grounding system is continuous, a high voltage elevation of the substation ground will *propagate* through the neutral and reach residences, pools, offices, etc.

Stray Voltages in Overhead Distribution Circuits Generation Mechanism



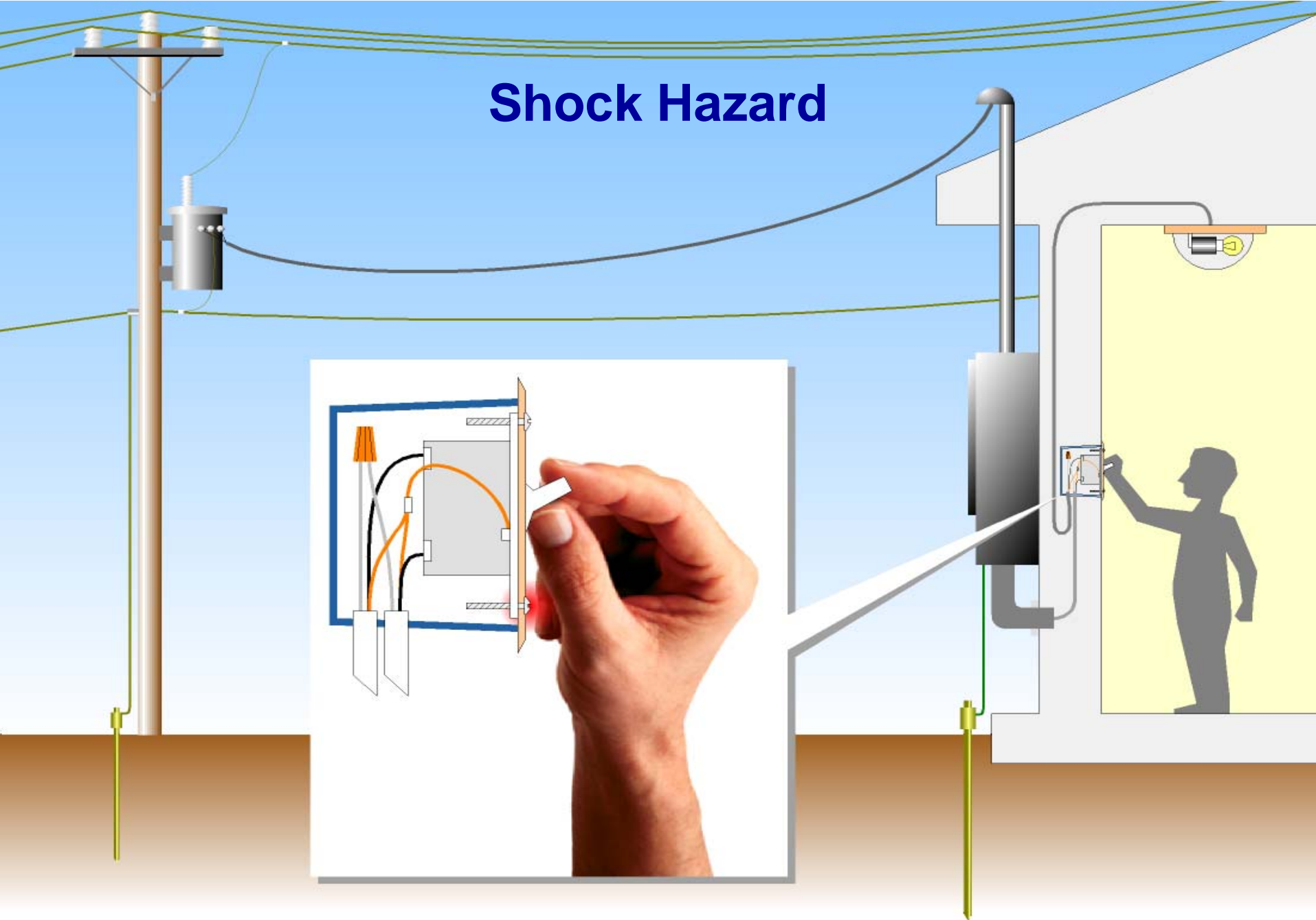
Code 0. AngleX = 112.86. AngleY = -88.62

Neutral Voltages Under Normal Operation

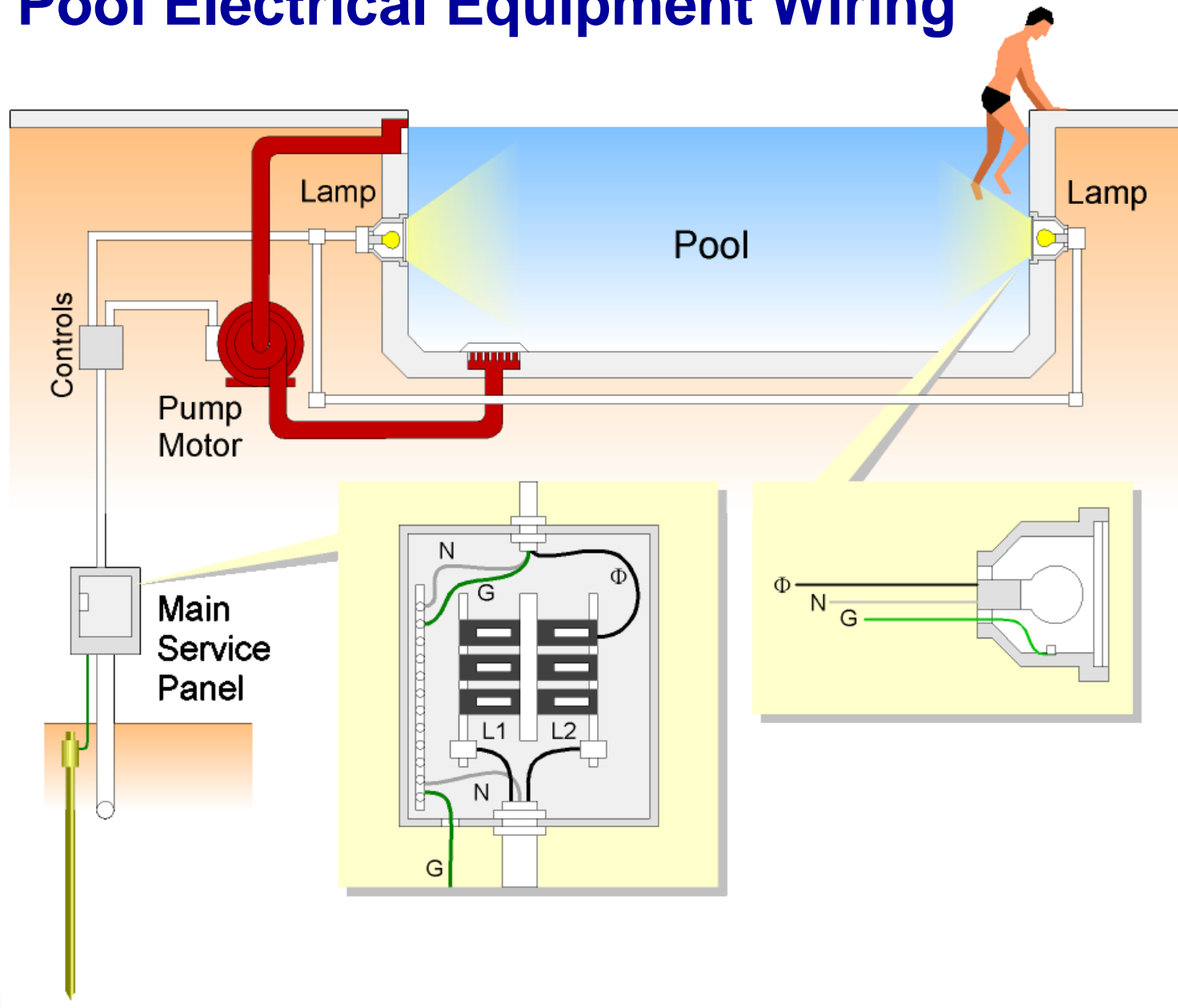


- Three 5 kW Loads on Phase A-N
- Soil Resistivity: 100 Ohm-Meters
- Transformer Grounding Resistor: 20 Ohms

Shock Hazard

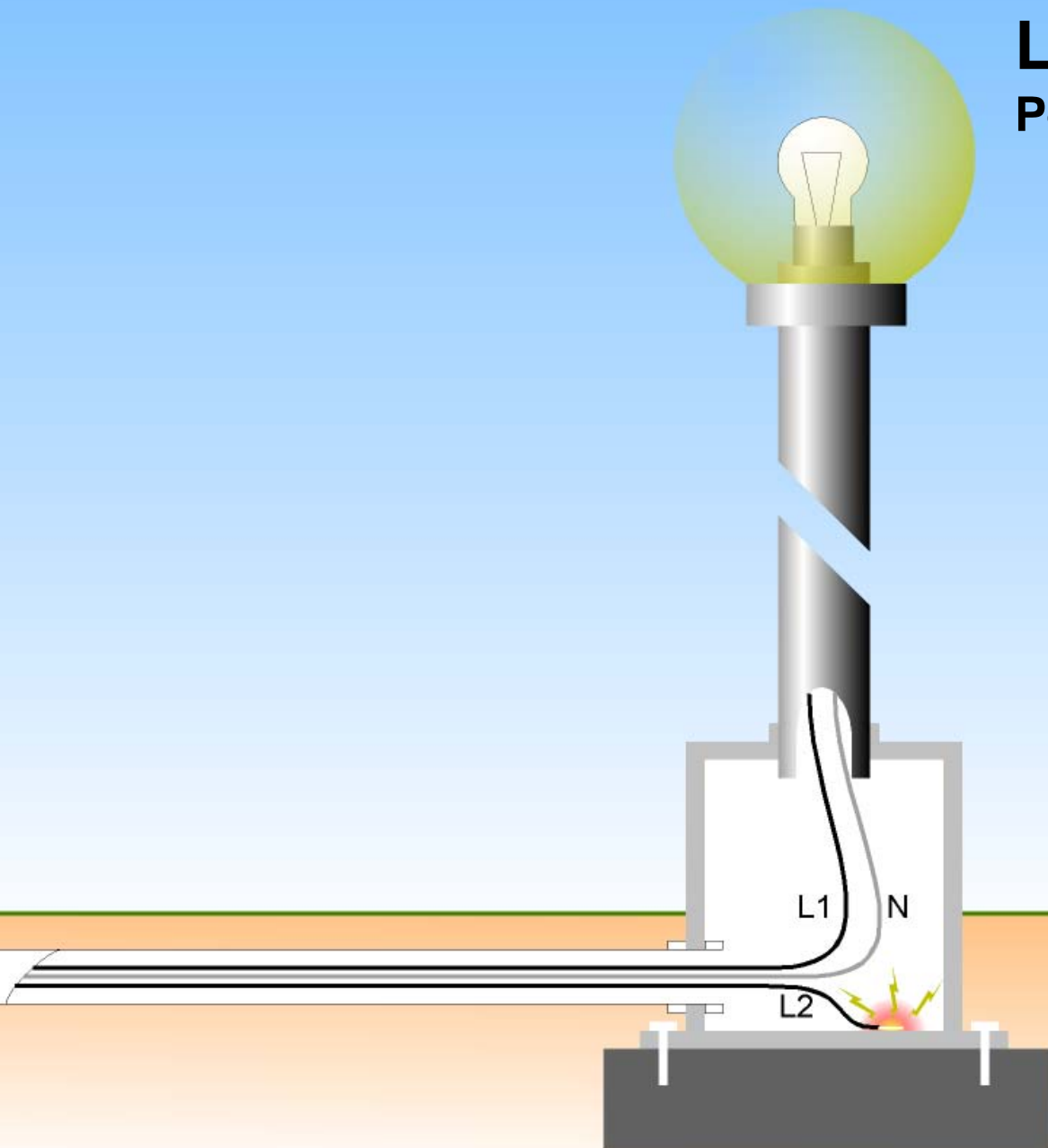


Pool Electrical Equipment Wiring



Line Touching Case

Permanent Ground Fault



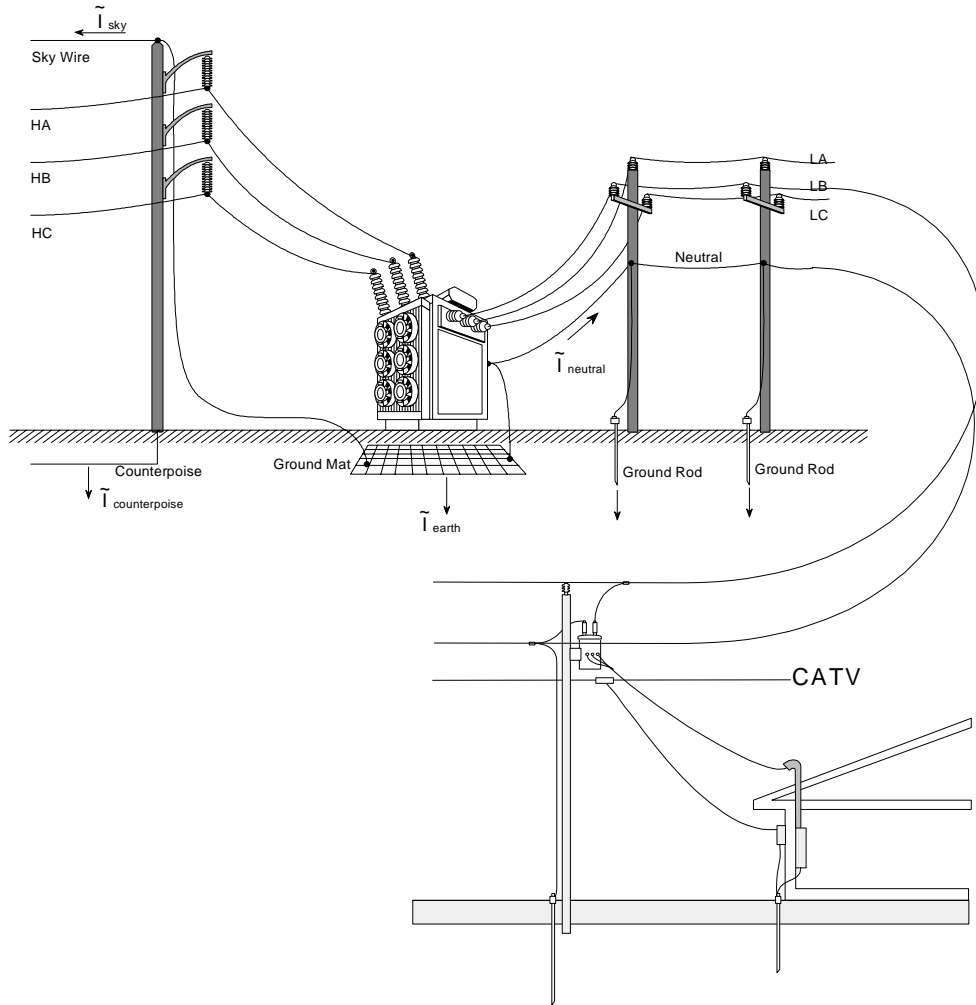
Can These Phenomena Be Simulated?

Grounding, Safety and Neutral Voltage Analysis Requires:

**Physically-Based
Detailed-Models**

Why Physically Based Models?

Consider Actual Wiring and Grounding

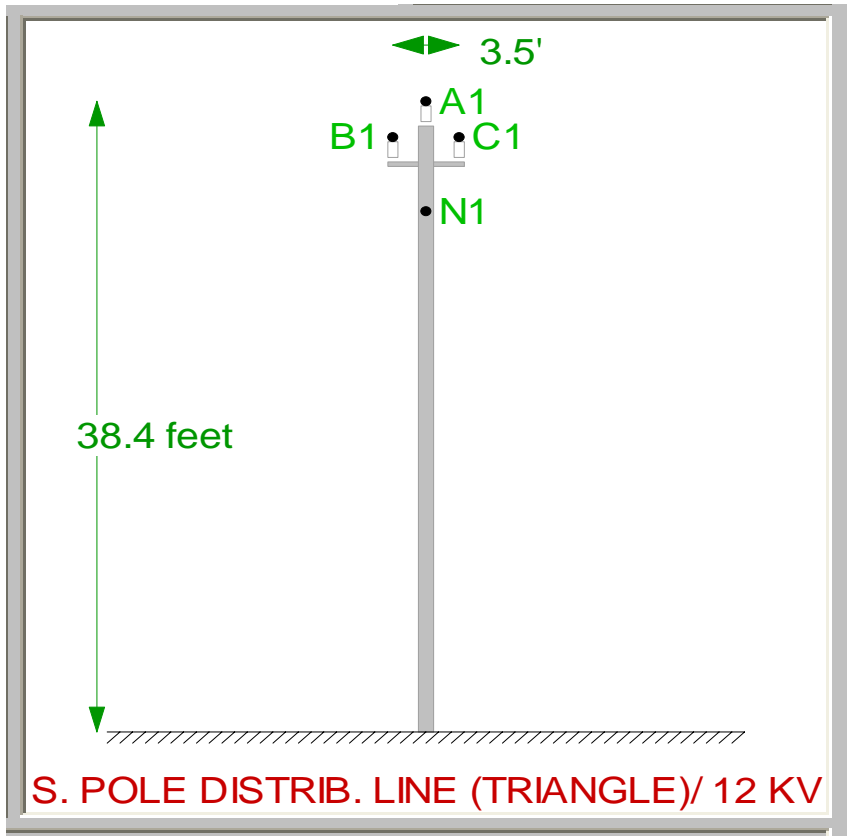


- **Circuits are Asymmetric**
Phase Voltages Vary
- **Circuits Are Unbalanced**
Phase Voltages Vary
- **Finite Ground Impedances**
NonZero Neutral Voltages
- **Customer Phase to Neutral Voltage**

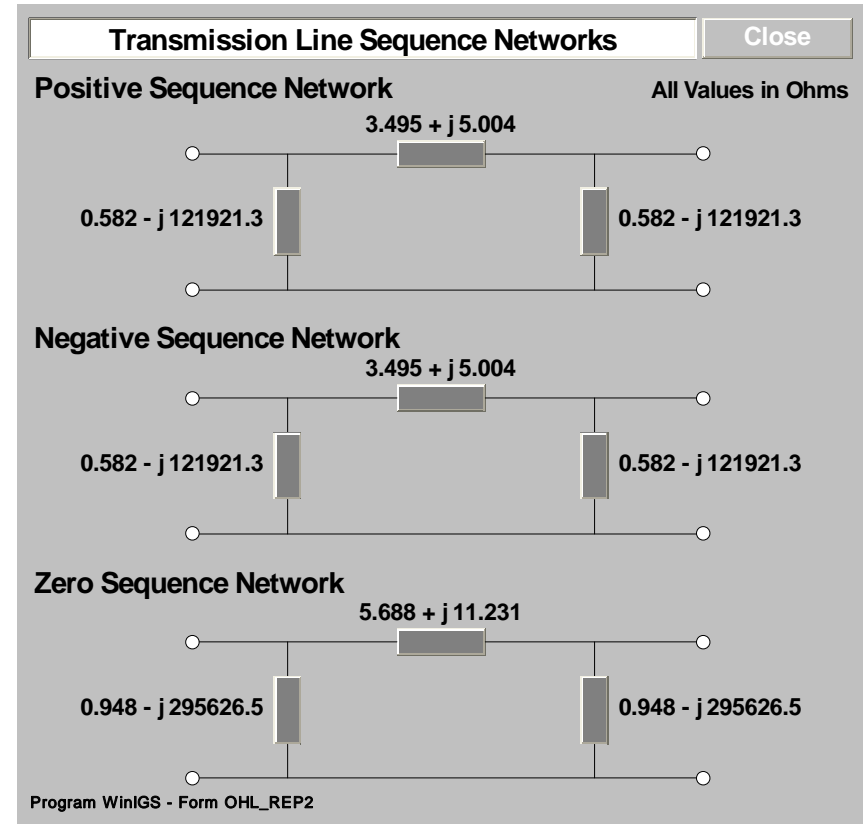
Physically Based Models

Example: Three Phase Power Line

- Physically Based Model
- Neutral is Represented
- Asymmetry is Represented

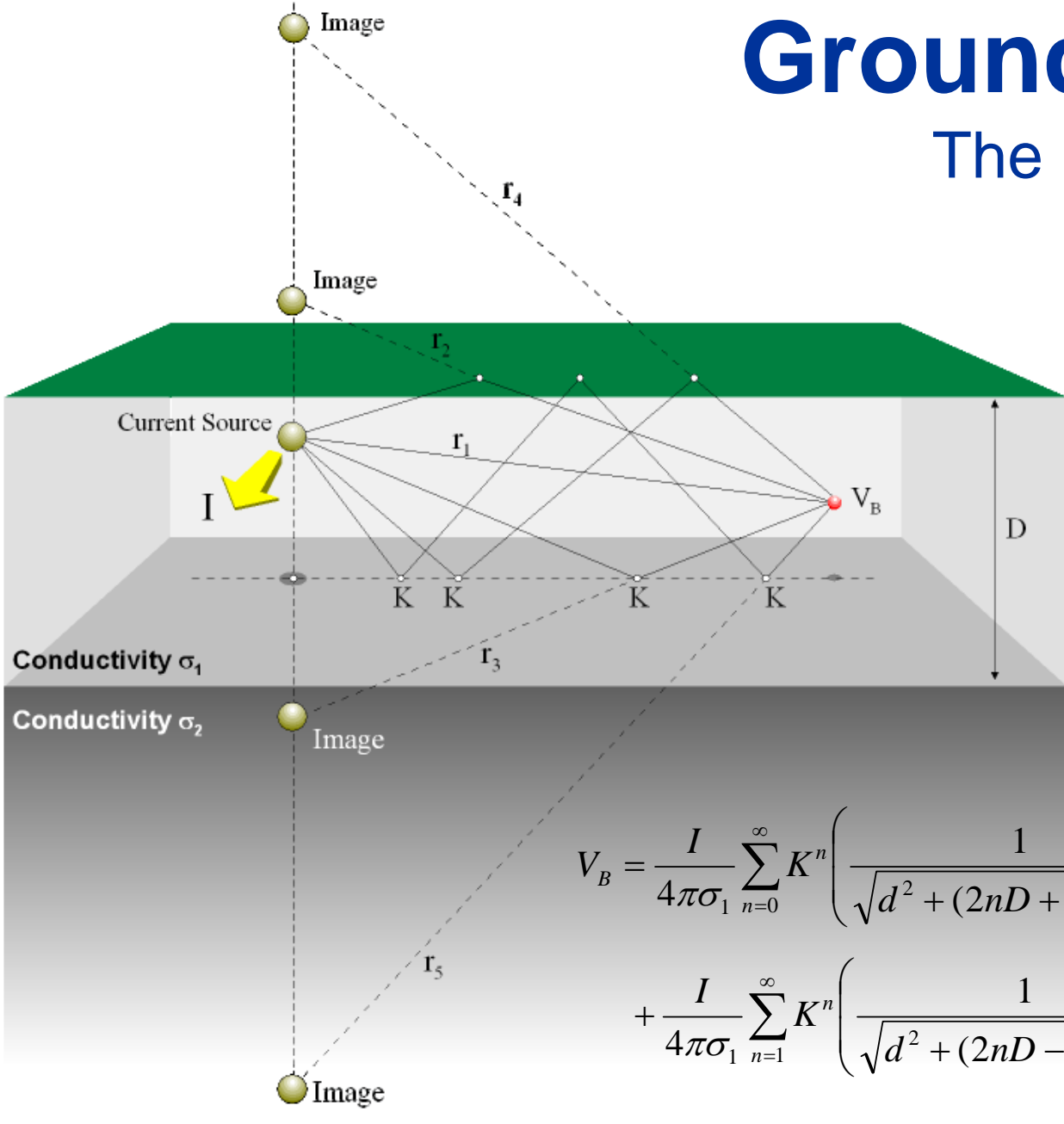


- Sequence Parameter Model
- Neutral is “Lost”
- Asymmetry is Lost



Ground Modeling

The Method of Images (Two Layer Soil)



Reflection Coefficient

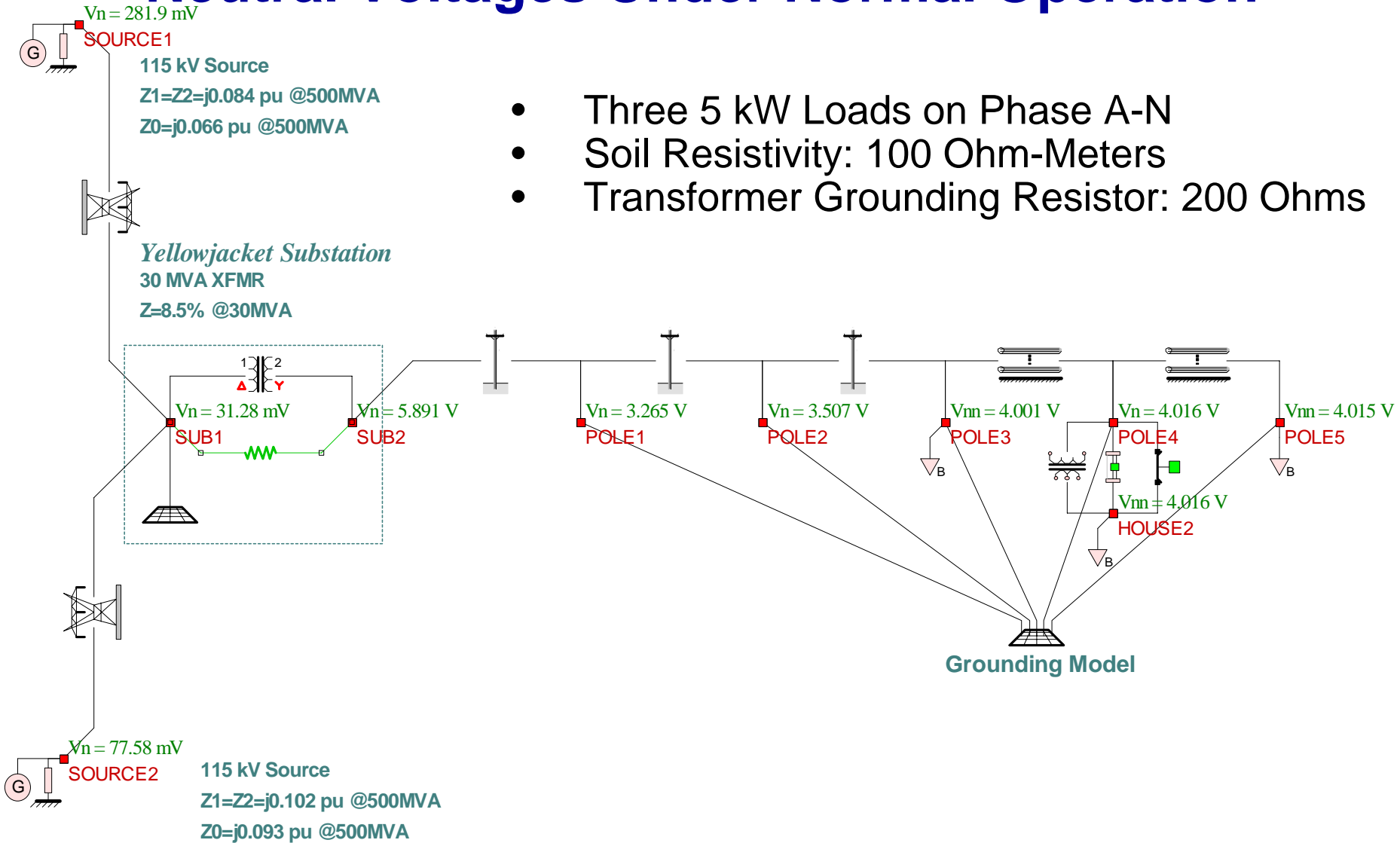
$$K = \frac{\sigma_1 - \sigma_2}{\sigma_1 + \sigma_2}$$

$$V_B = \frac{I}{4\pi\sigma_1} \sum_{n=0}^{\infty} K^n \left(\frac{1}{\sqrt{d^2 + (2nD + z + z_c)^2}} + \frac{1}{\sqrt{d^2 + (2nD + z - z_c)^2}} \right) + \frac{I}{4\pi\sigma_1} \sum_{n=1}^{\infty} K^n \left(\frac{1}{\sqrt{d^2 + (2nD - z + z_c)^2}} + \frac{1}{\sqrt{d^2 + (2nD - z - z_c)^2}} \right)$$

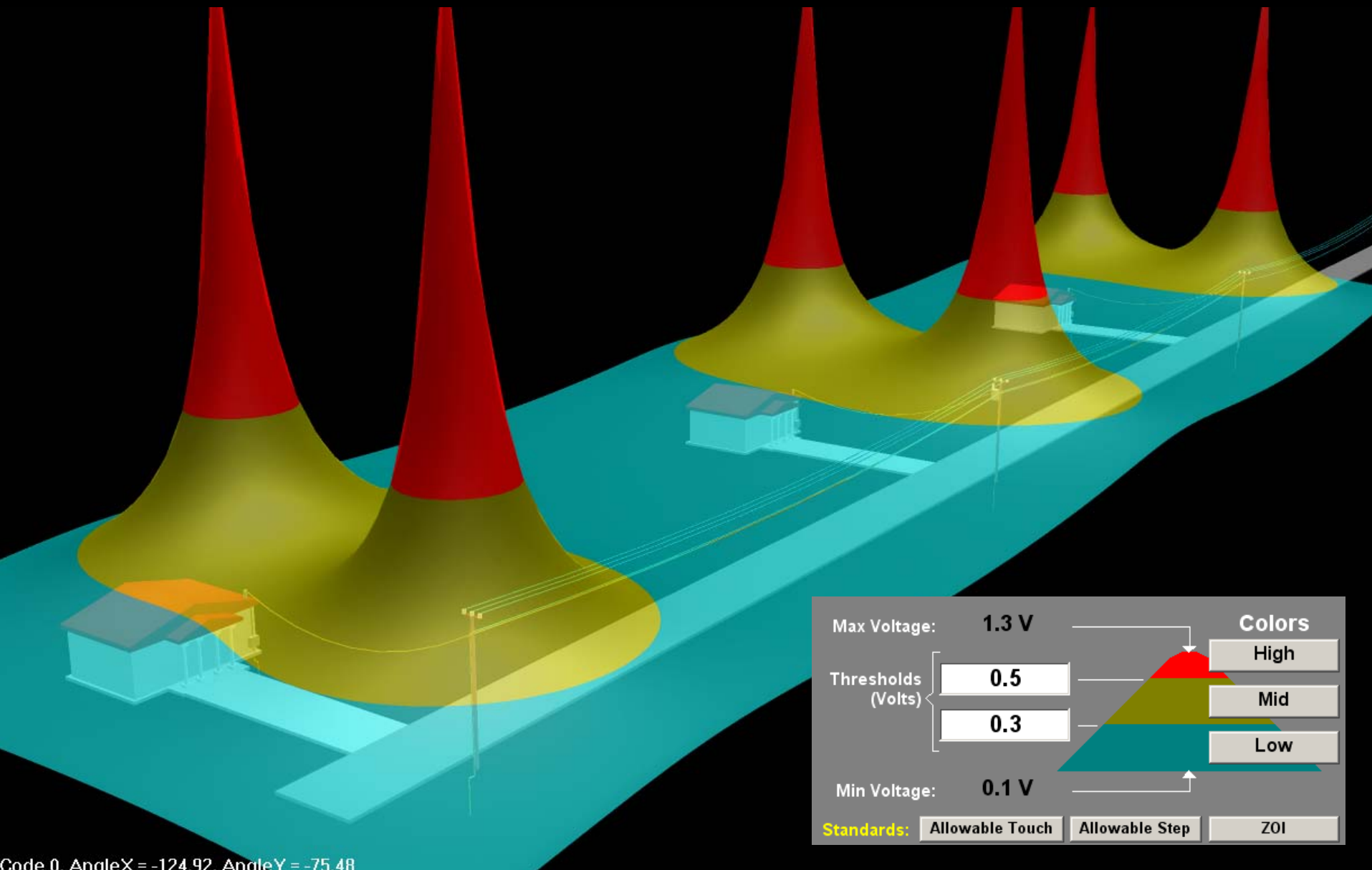
Computer Generated Example 1

Neutral Voltages Under Normal Operation

- Three 5 kW Loads on Phase A-N
- Soil Resistivity: 100 Ohm-Meters
- Transformer Grounding Resistor: 200 Ohms



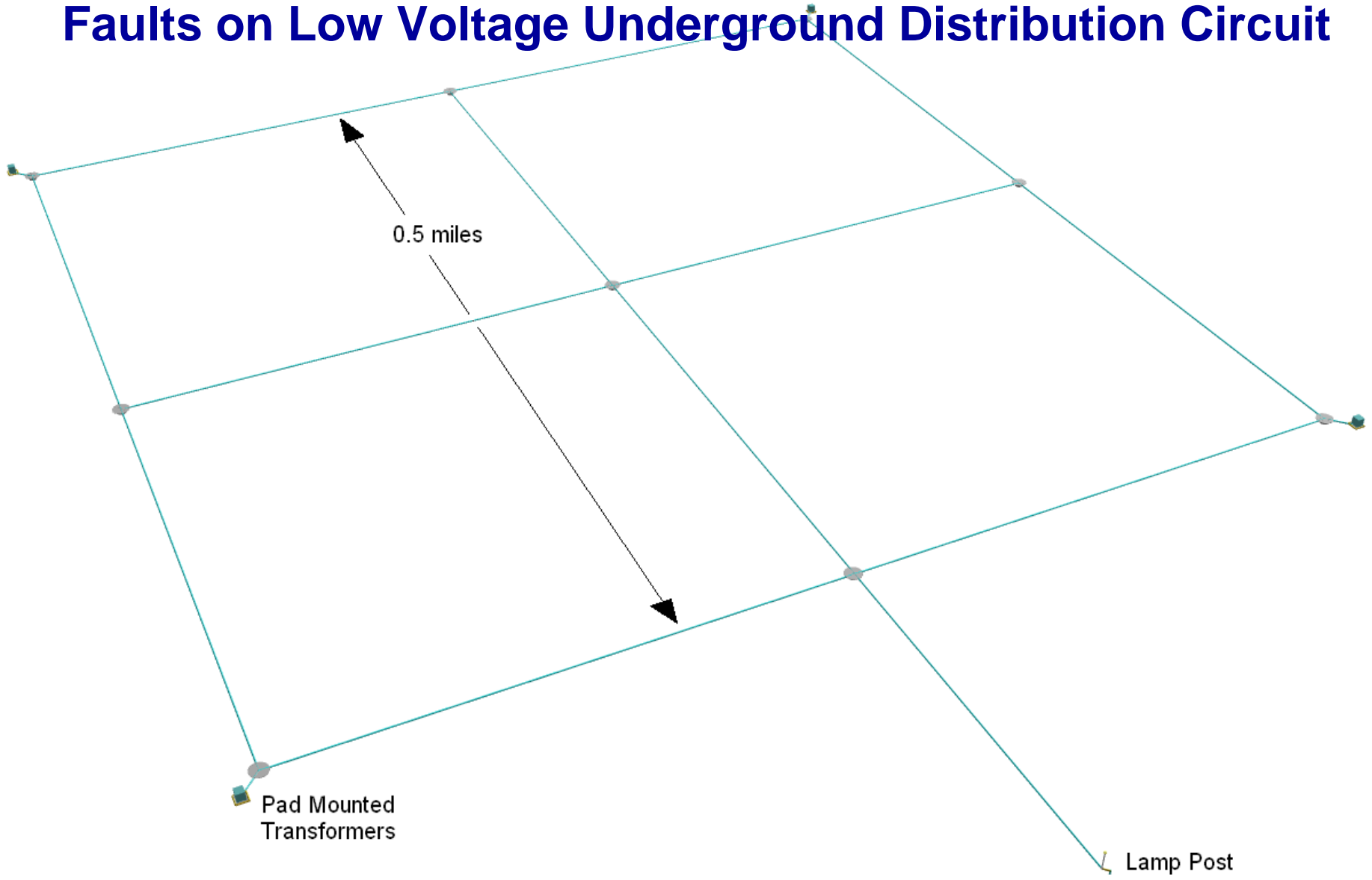
Earth Surface Voltages Under Normal Operation



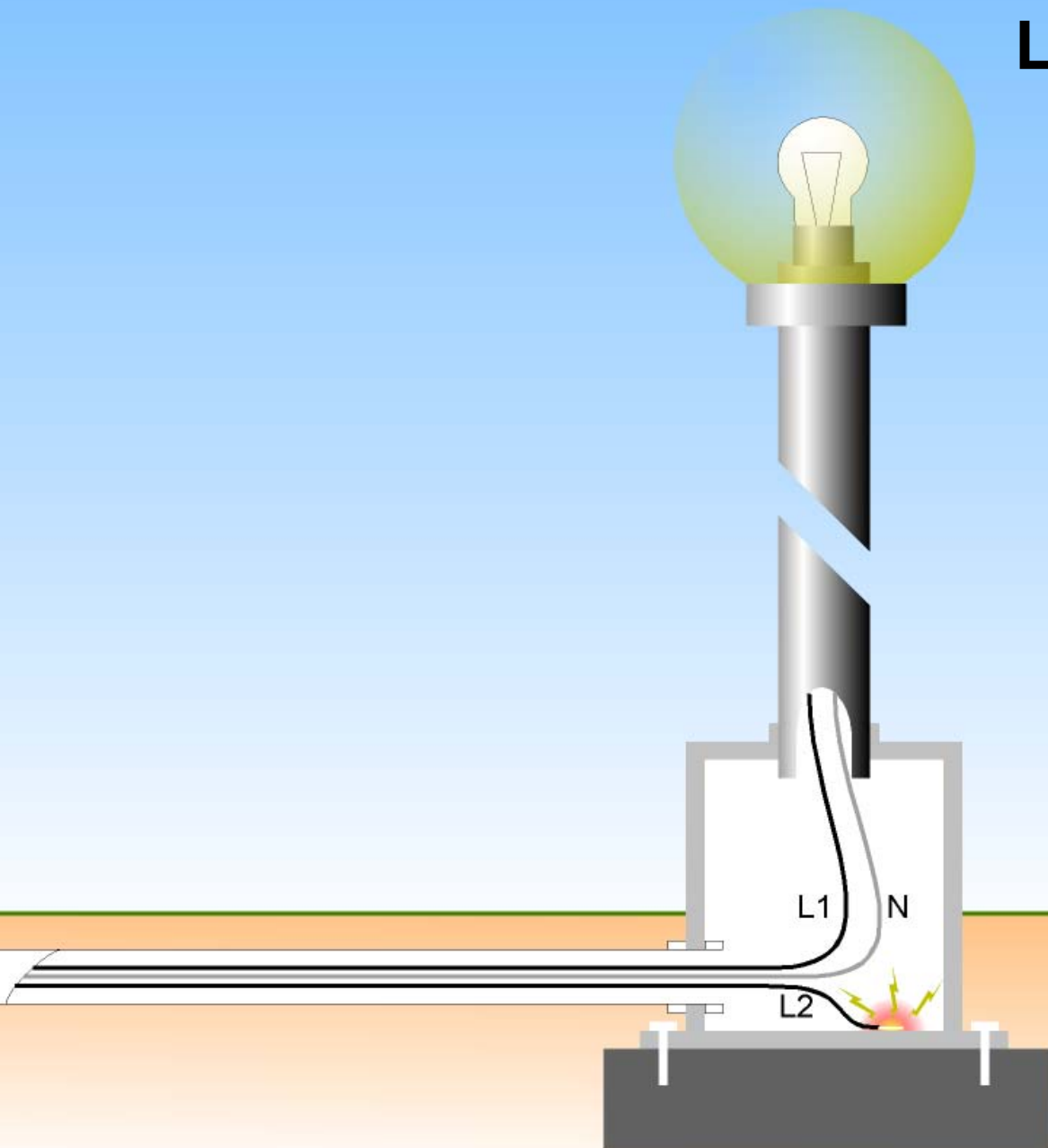
Max Voltage:	1.3 V		
Thresholds (Volts)	0.5		High
	0.3		Mid
Min Voltage:	0.1 V	Low	
Standards:	Allowable Touch	Allowable Step	ZOI

Computer Generated Example 2

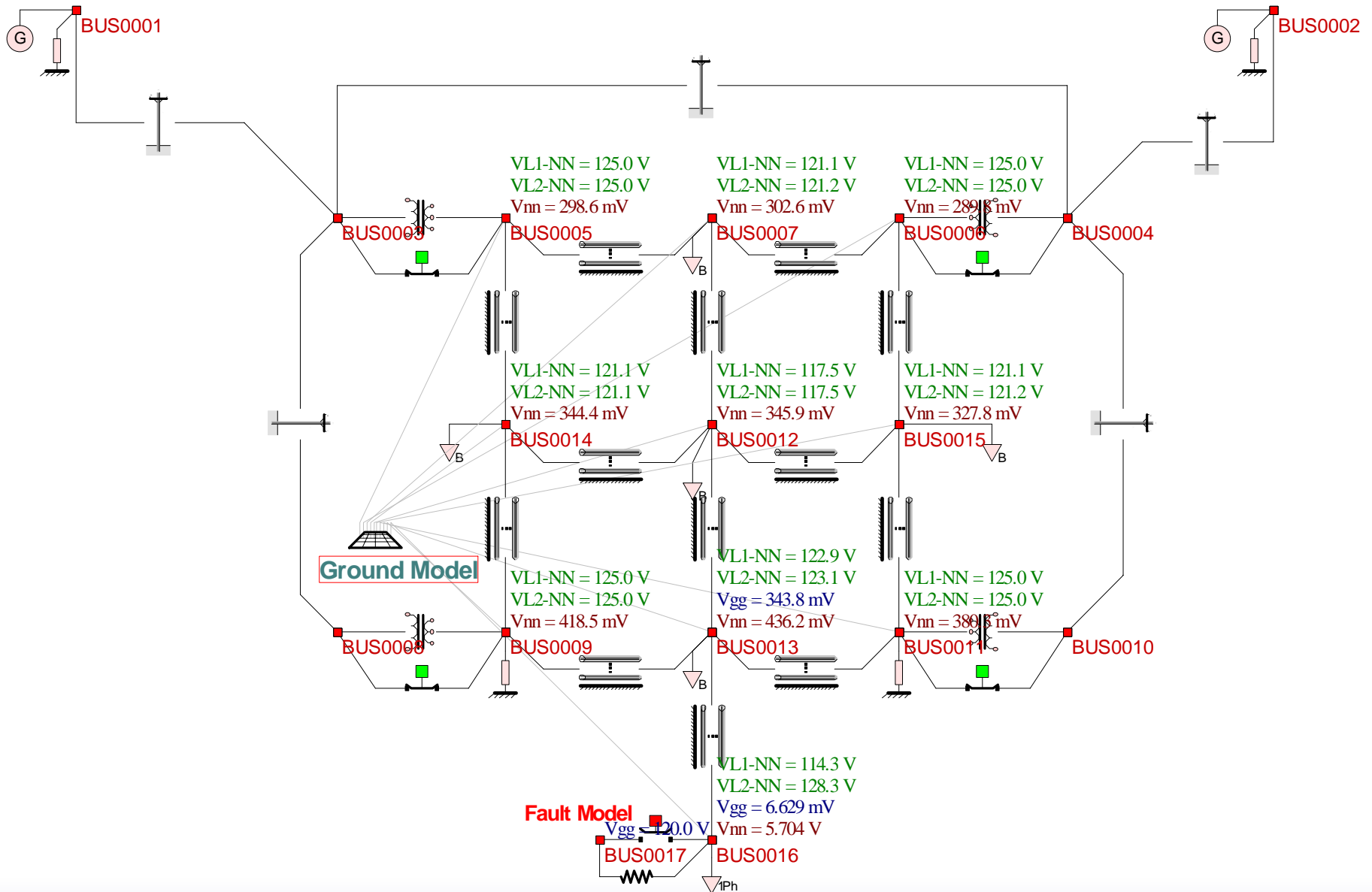
Faults on Low Voltage Underground Distribution Circuit



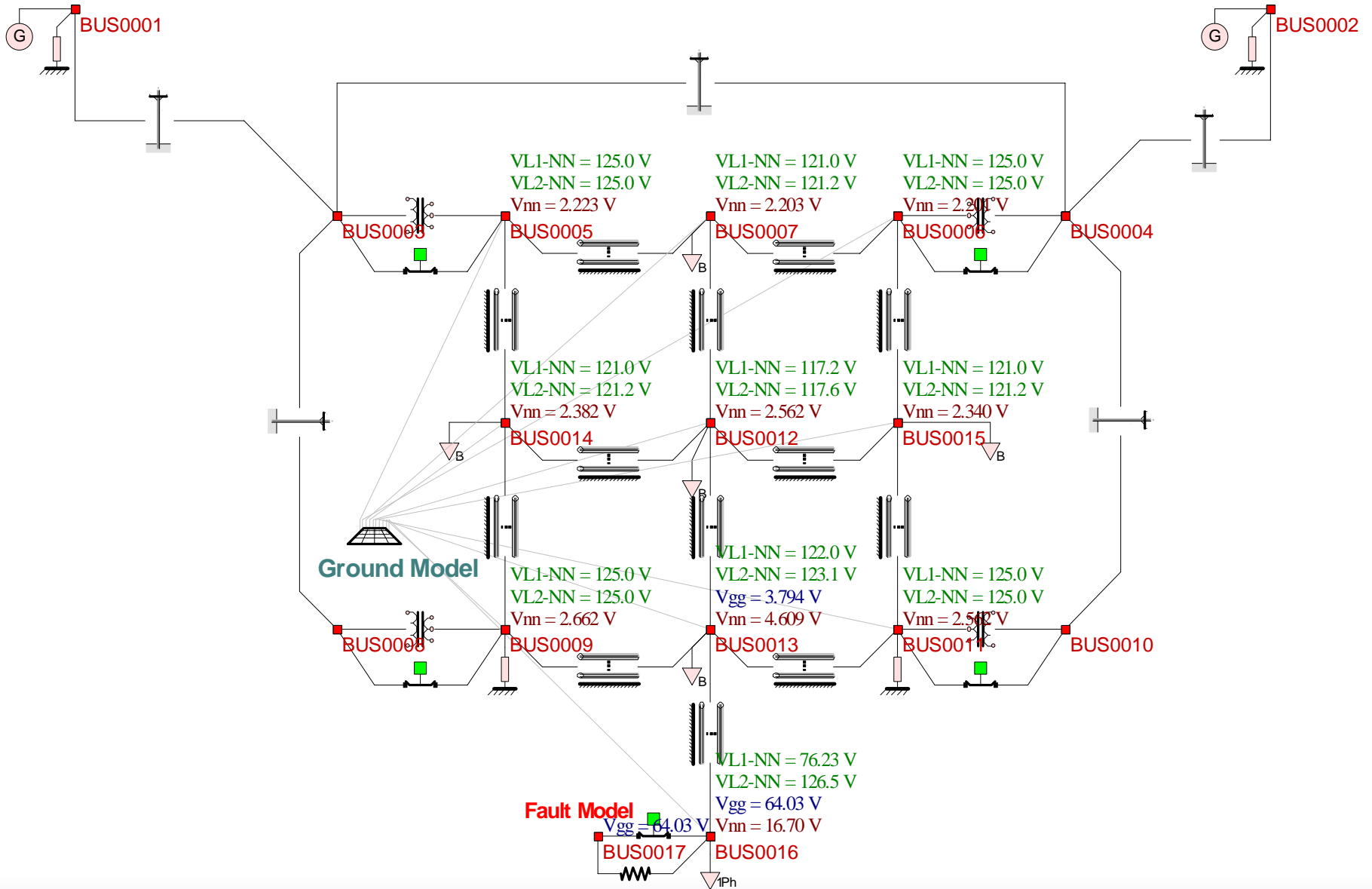
Line Touching Case



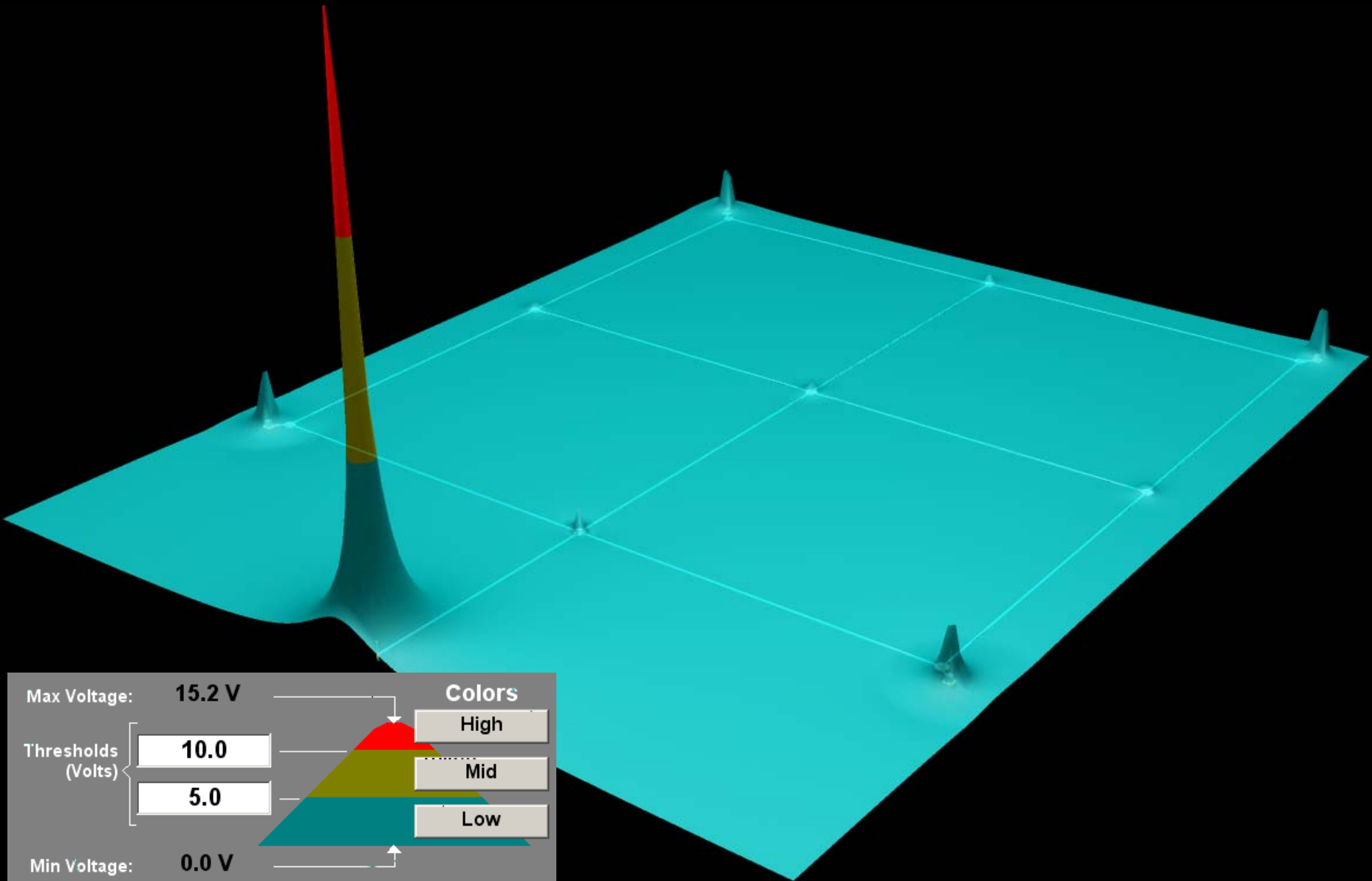
Neutral Voltages Under Normal Operation



Neutral Voltages During Permanent Fault



Earth Surface Voltages During Fault



Detection of Stray Voltages

- Many approaches are being pursued

Mitigation of Stray Voltages

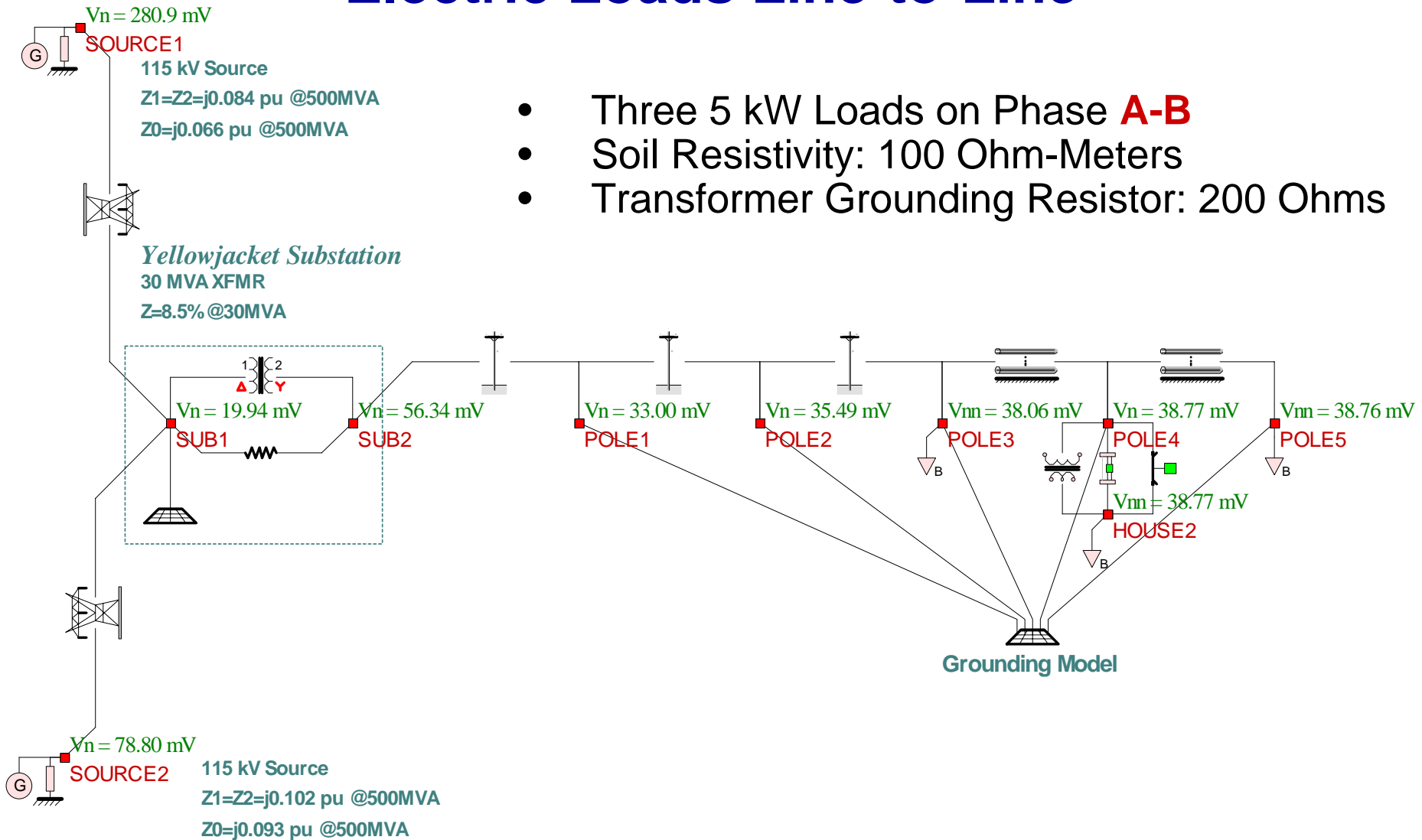
- Minimize system imbalance
- Improve Grounds/neutrals

Avoidance of Neutral/Ground Voltages from Permanent Faults

- Improve grounds
- Provide ground fault protection
- Need to re-design some old systems
- Avoid same design mistakes in new systems

Example of Neutral Voltages Mitigation Electric Loads Line-to-Line

- Three 5 kW Loads on Phase **A-B**
- Soil Resistivity: 100 Ohm-Meters
- Transformer Grounding Resistor: 200 Ohms



For more in-depth information

Integrated Grounding System Design and Testing	March 22-25, 2005
Grounding, Harmonics, & Electromagnetic Influence Design Practices	May 16-18, 2005
Power Distribution System Grounding and Transients	September 21-23, 2004

Conclusions

- Elevated voltages in neutrals and grounds is reality. Proper design practices can mitigate these voltages.
- Physically based modeling provides the basis to study simultaneously grounding, neutral voltages and safety.
- **Disadvantage:** More Complex Models.
- **Observation:** Electric power installations can be designed to be safe at low cost. Retrofitting is relatively expensive. However, there is a substantial percentage of the industry that does not pay attention to this issue at the design phase.

Τελος