Stray & Contact Voltage
Case Studies

IEEE Working Group

January 2008, San Antonio

Craig D. Frommelt PE, CPQ, CEM

AmerenCILCO

Topics

- Goals of this Session
- Brief Review of Terminology
- Brief Review of Stray & Contact Voltage Sources
- Anatomy of a Case Study
- Cases:
  - Outdoor Faucet (Bad Neutral)
  - Basement Shower (Ground Fault)
  - Backyard Pool (Excess Ground Return Current)
  - Municipal Pool (Bad Neutral)

Goals of this Session

- Contribute to discussion on the Typical Sources of Stray & Contact Voltage
- Propose a Straw Man for discussion on format for the Case Studies part of Working Group's product document
- Present selected Case Studies for Discussion and Comment

Terminology

- “Stray Voltage” will refer to voltages that occur as a result of the NORMAL operation of the electric system.
  - NORMAL may not be optimal

Terminology

- “Stray Voltage” will refer to voltages that occur as a result of the NORMAL operation of the electric system.
  - NORMAL may not be optimal
- “Contact Voltage” will refer to voltages that result from ABNORMAL system conditions
  - Open conductors, phase or neutral
  - Shorted or Faulted conductors
  - Wiring errors
  - Insulation failures

Brief Review of Stray & Contact Voltage Sources

- Focus on High Neutral-to-Earth Voltage

Brief Review of Stray & Contact Voltage Sources

- Focus on High Neutral-to-Earth Voltage
- Focus on Ground (Earth) Return Current
  - NOT looking at Induced Voltages (in this discussion)

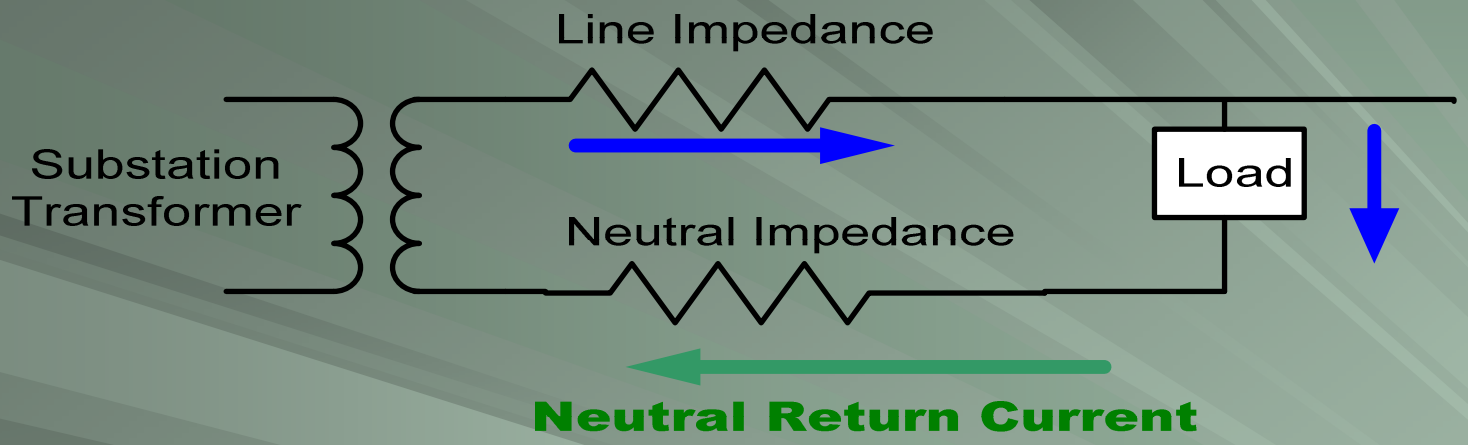
Brief Review of Stray & Contact Voltage Sources

- Focus on High Neutral-to-Earth Voltage
- Focus on Ground Return Current
  - NOT looking at Induced Voltages
- Focus on a Really Simplistic Electric Model
  - NOT showing all of the Transformers, Inductances, and Capacitances
  - NOT showing all of the repeated parallel paths

Brief Review of Stray & Contact Voltage Sources

- Focus on High Neutral-to-Earth Voltage
- Focus on Ground Return Current
  - NOT looking at Induced Voltages
- Focus on a Really Simplistic Electric Model
  - NOT showing all of the Transformers, Inductances, and Capacitances
  - NOT showing all of the repeated parallel paths
- Mention one possible source of Contact Voltage

Basic Electric Model

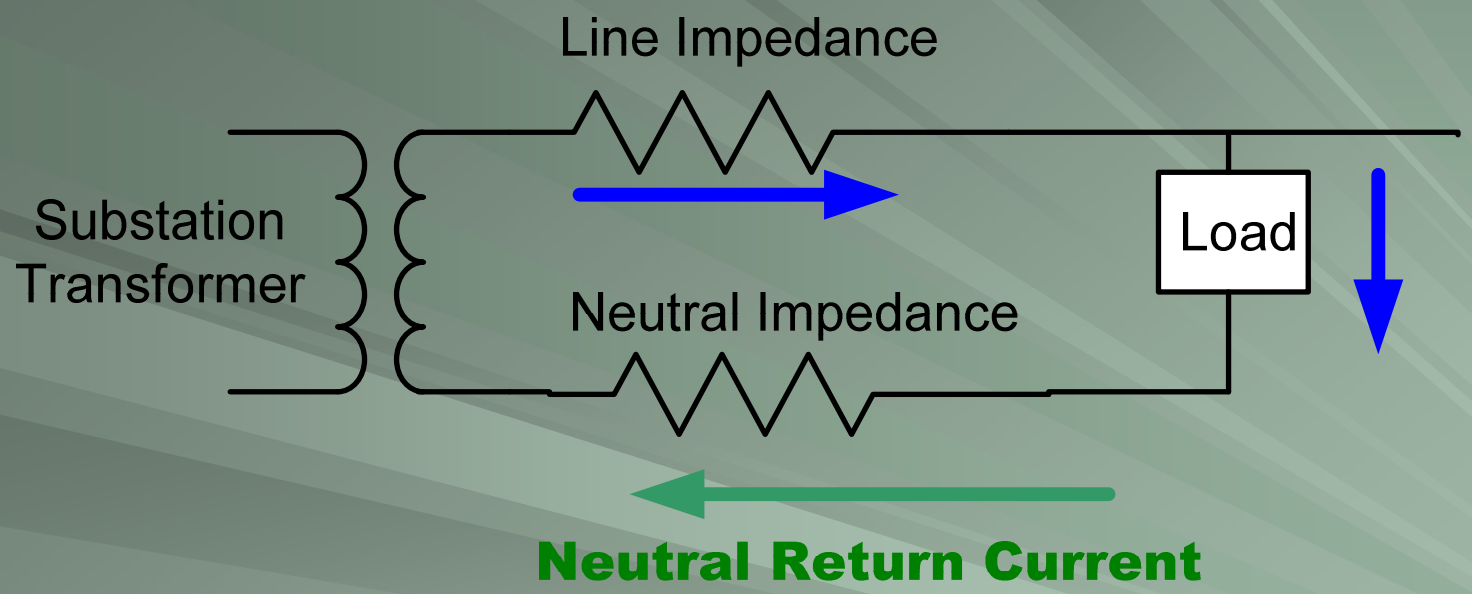


-We must think of EE-201 “Fundamentals” (This is NOT Rocket Science so “KISS”)

-Remember Kirchhoff's Law about the behavior of Currents:
All of the Line Current must return to the source (substation transformer), to complete the ‘circuit’. And
Currents will flow in ALL possible paths, inversely proportional to Impedances.

-Remember Ohm’s Law :
Currents flowing through Impedances ALWAYS create Voltage Drops (Potential Differences)

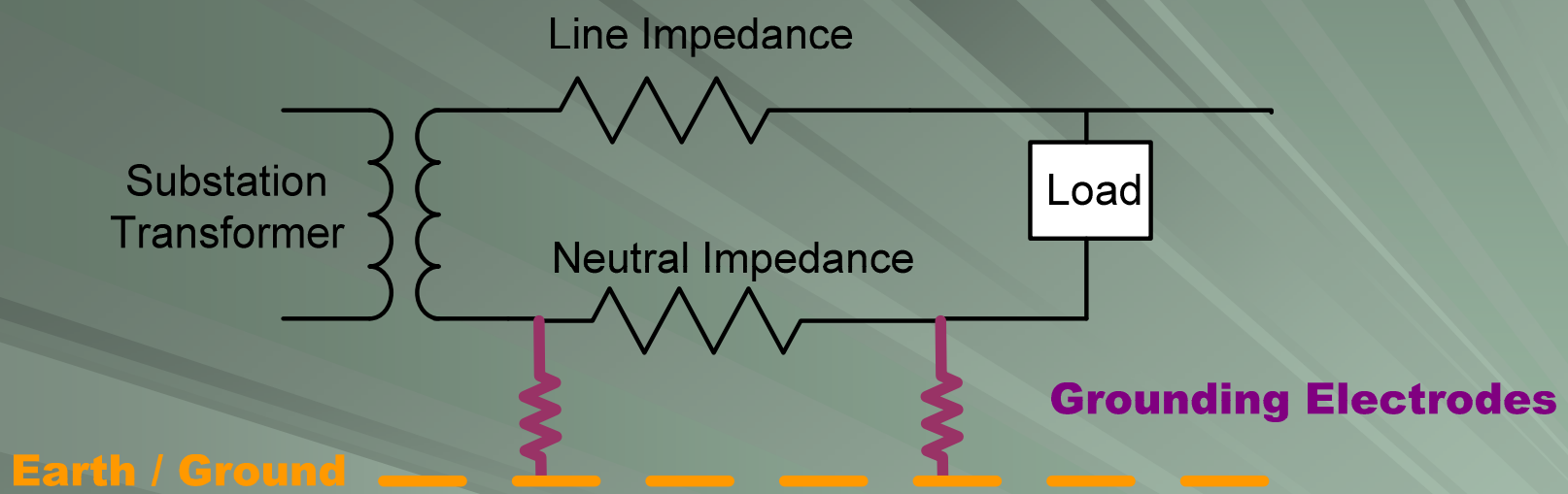
Basic Electric Model



-Load Impedance is typically much higher than the Line + Neutral Impedances.

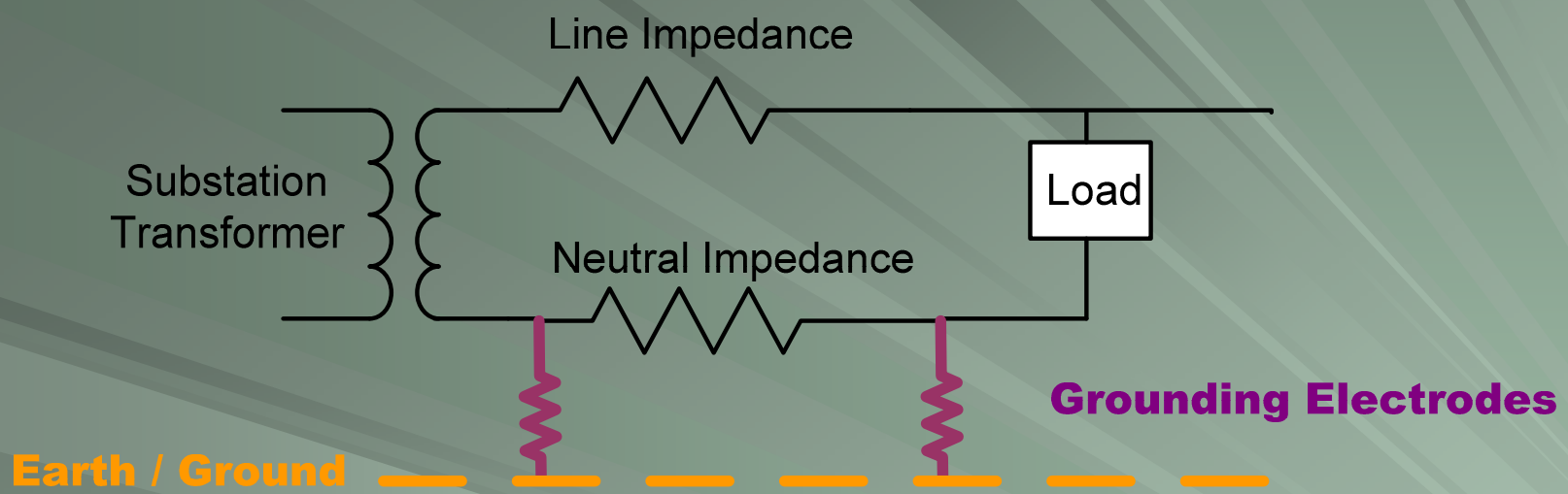
-**Neutral Impedance is NOT ZERO.**

Basic Electric Model



The model must also include the "Multiple Grounded Neutral".

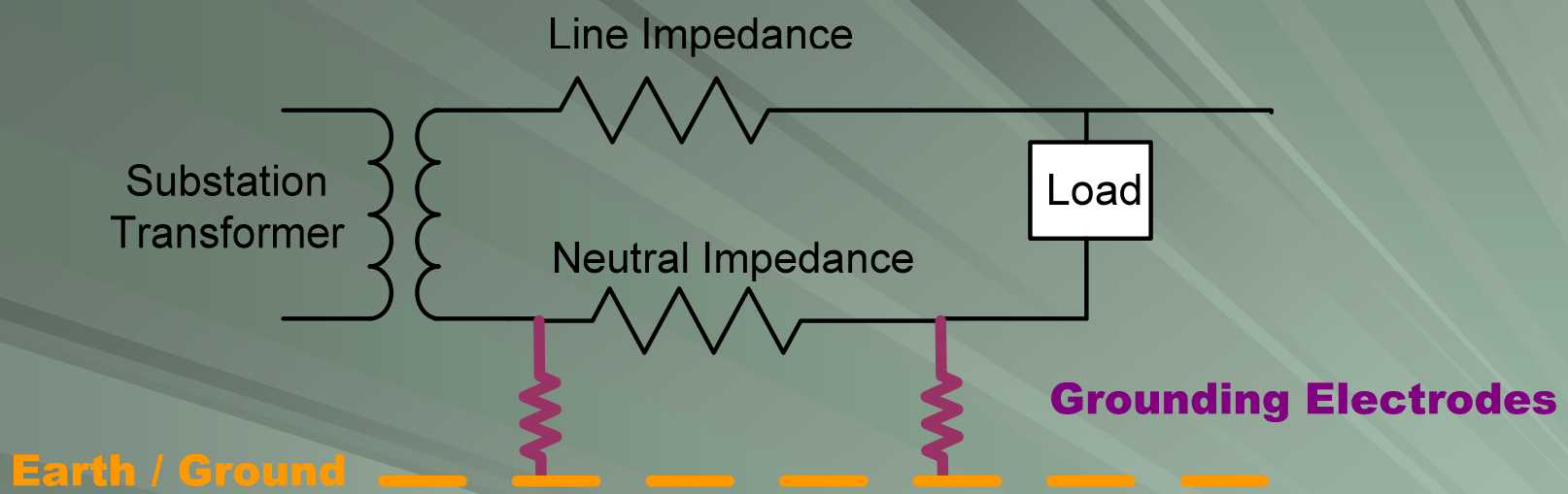
Basic Electric Model



The model must also include the "Multiple Grounded Neutral".

Grounding Electrodes (Ground Rods) may have impedances to "Remote Earth" in the range of 10-50 ohms and can be much higher in dry soil, sand, or rock.

Basic Electric Model

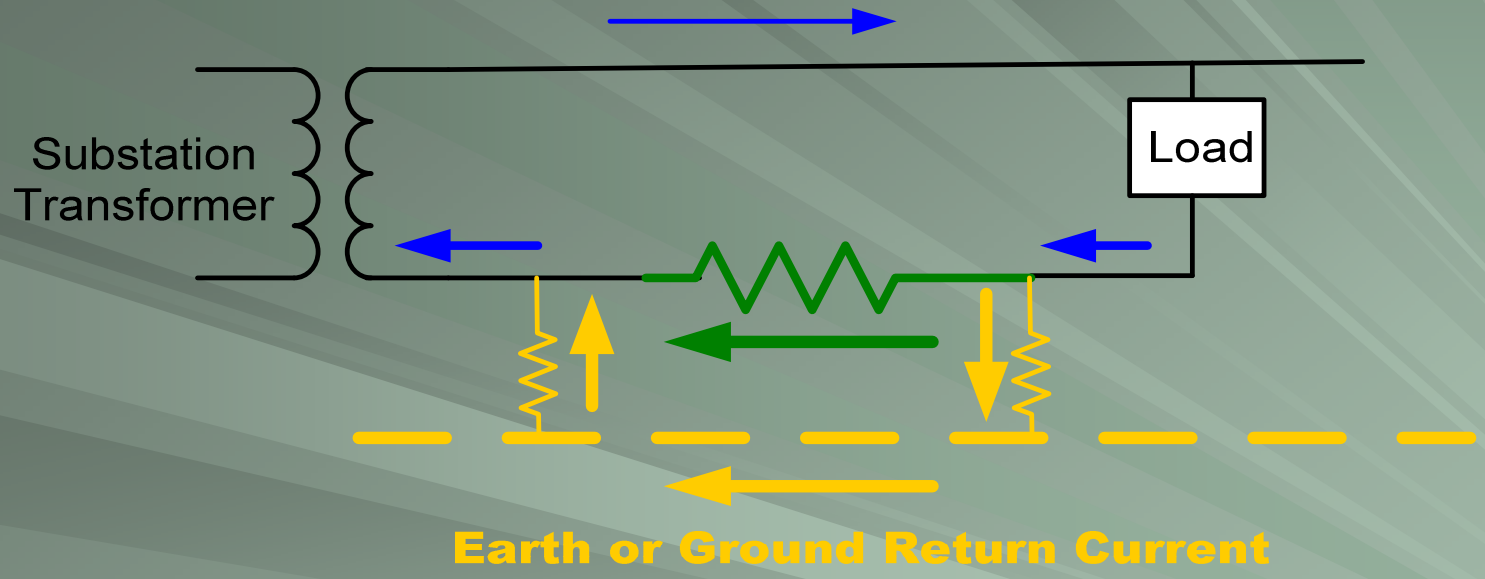


The model must also include the "Multiple Grounded Neutral".

Grounding Electrodes (Ground Rods) may have impedances to "Remote Earth" in the range of 10-50 ohms and can be much higher in dry soil, sand, or rock.

Simpler to think of all of the impedance being at the ground rod interfaces to earth, with impedance of earth itself as near zero.

Electric Model
Return Current "Divider"

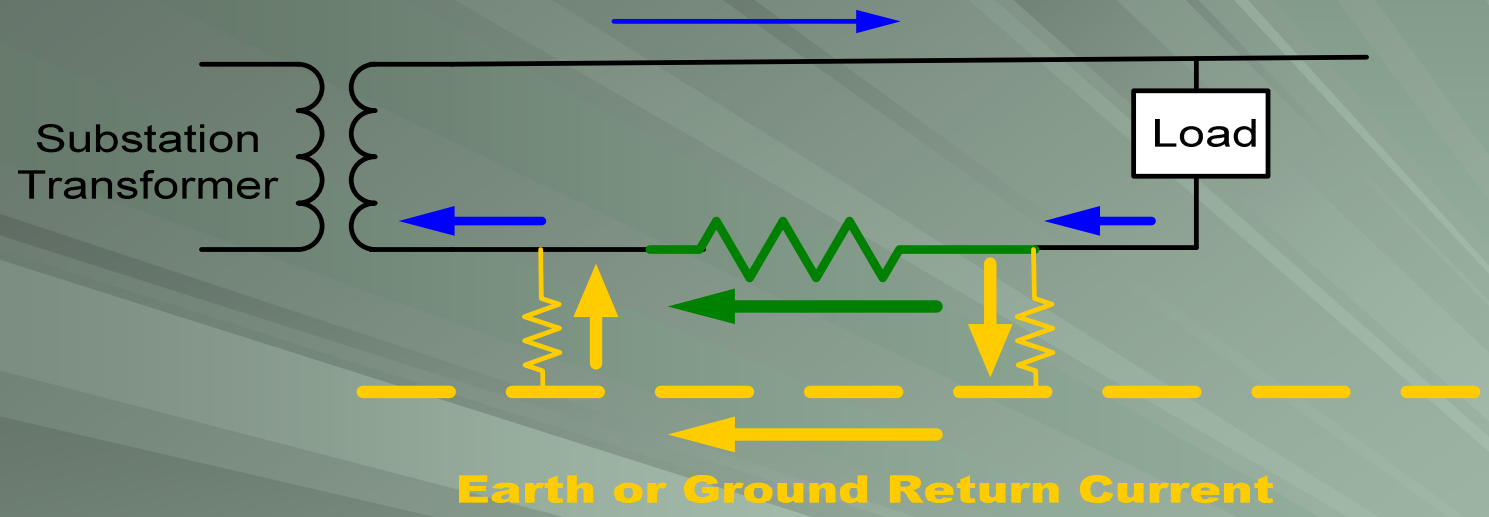


Return current divides between **Neutral** and **Earth** return paths.

Current follows ALL possible paths back to Substation.

Current divides in ratios inversely proportional to impedances.

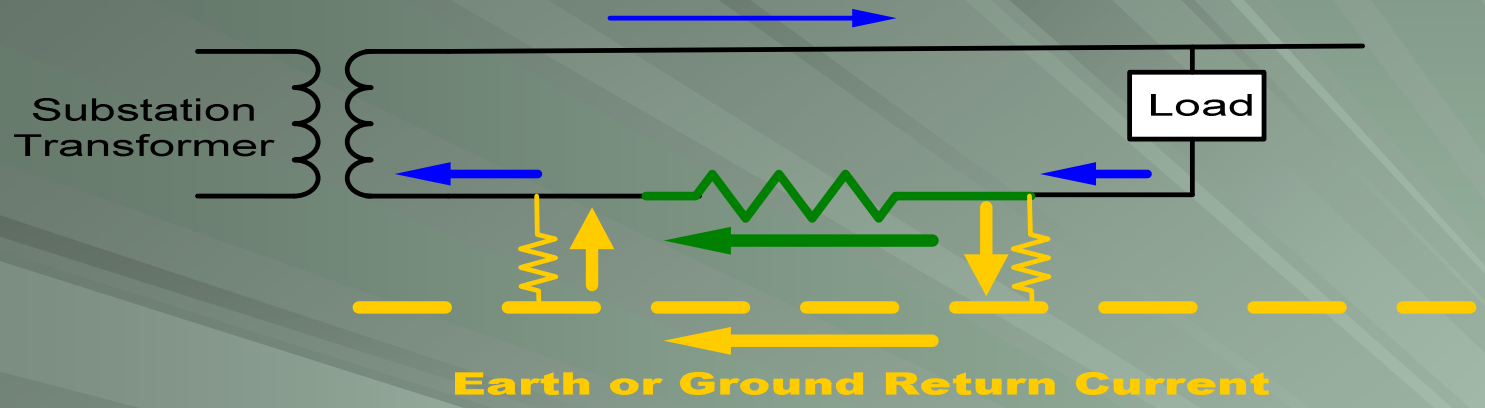
Electric Model
Return Current "Divider"



Return current divides between **Neutral** and **Earth** return paths.

Ideally, the earth impedance is 50 times or more higher than the neutral impedance, so there is relatively little earth (ground) return current.

Electric Model
Return Current "Divider"

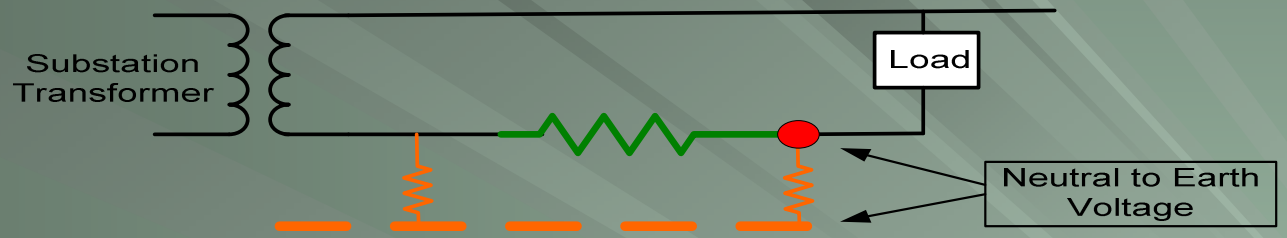


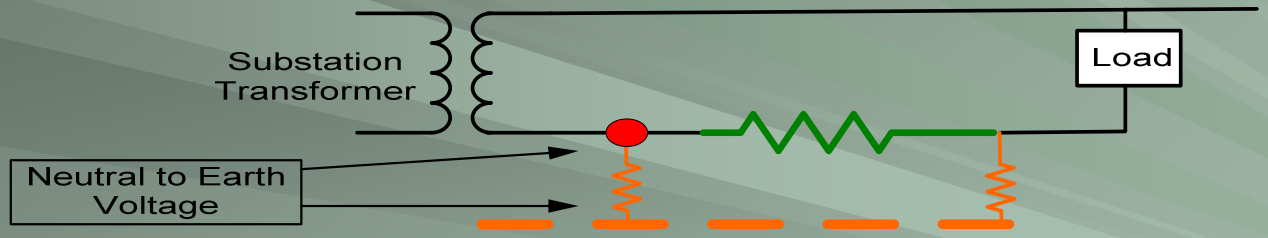
Return current generally flows "In To" the Earth near the remote ends of the feeder. So expect higher Stray Voltages near 1-ph ends of a long feeder.

Earth current then generally flows "Out Of" the Earth and back to the Neutral near the substation. So there is another likelihood of Stray Voltages very near the substation, even if 3-phase.

Generally, little to no Stray Voltage in the center of the circuit, at maybe 1-3 miles from the substation.

Basic Electric Model

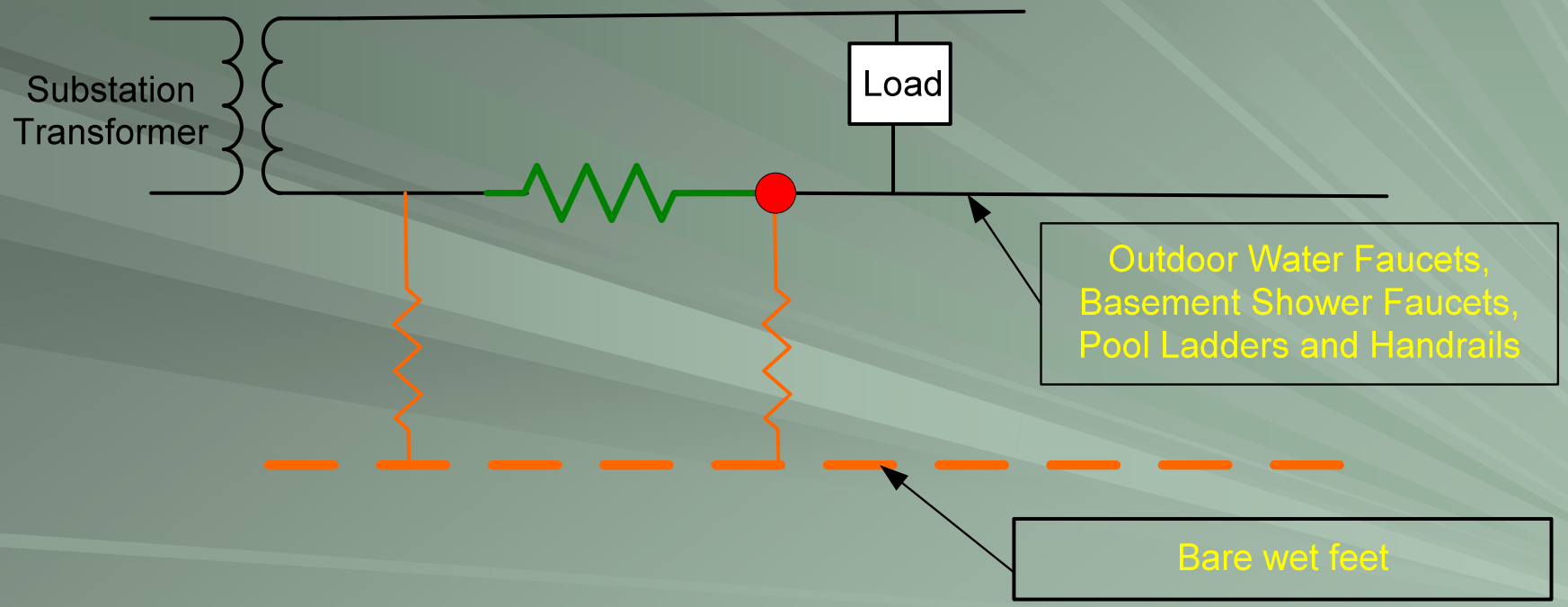




Ohm's Law:
Current flowing through these neutral to earth Impedances
(grounding electrode impedances) **<u>always</u> causes a Voltage drop.**

Normally it is very small (maybe 0.010 – 0.500 volts) **but never ZERO.**

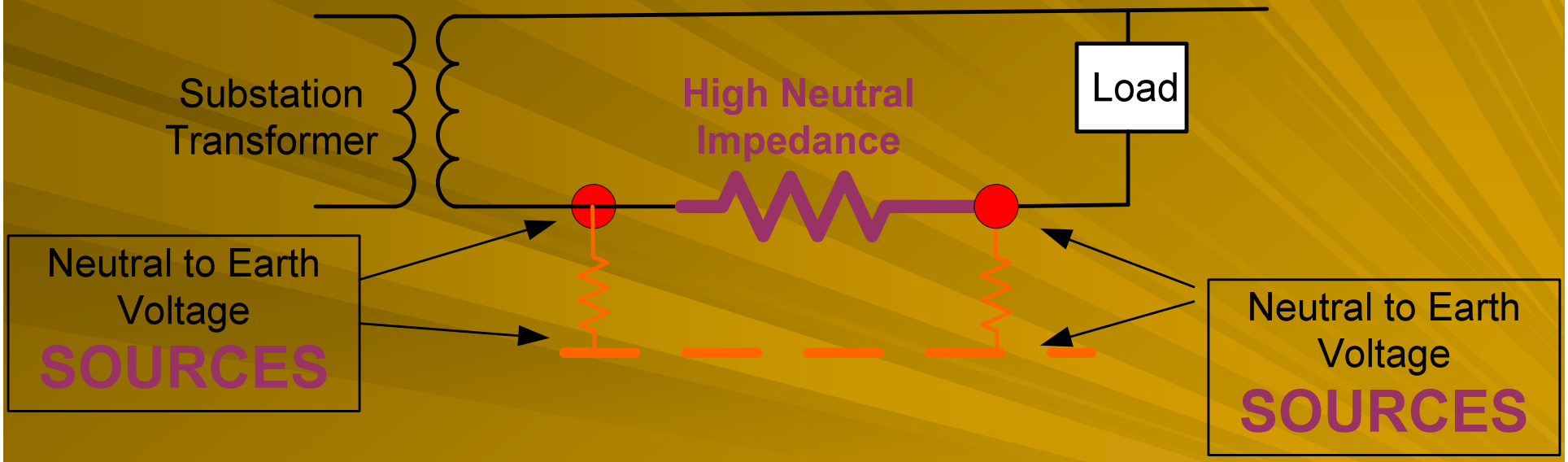
Basic Electric Model
Most Likely "Human" Touch Potential



Most "Human" stray voltage complaints arise in areas where people can touch "grounded' metal parts and "earth", with bare wet hands & feet .

In this context, "Grounded" usually means "Bonded to the Neutral and the Top of the Ground Rods".

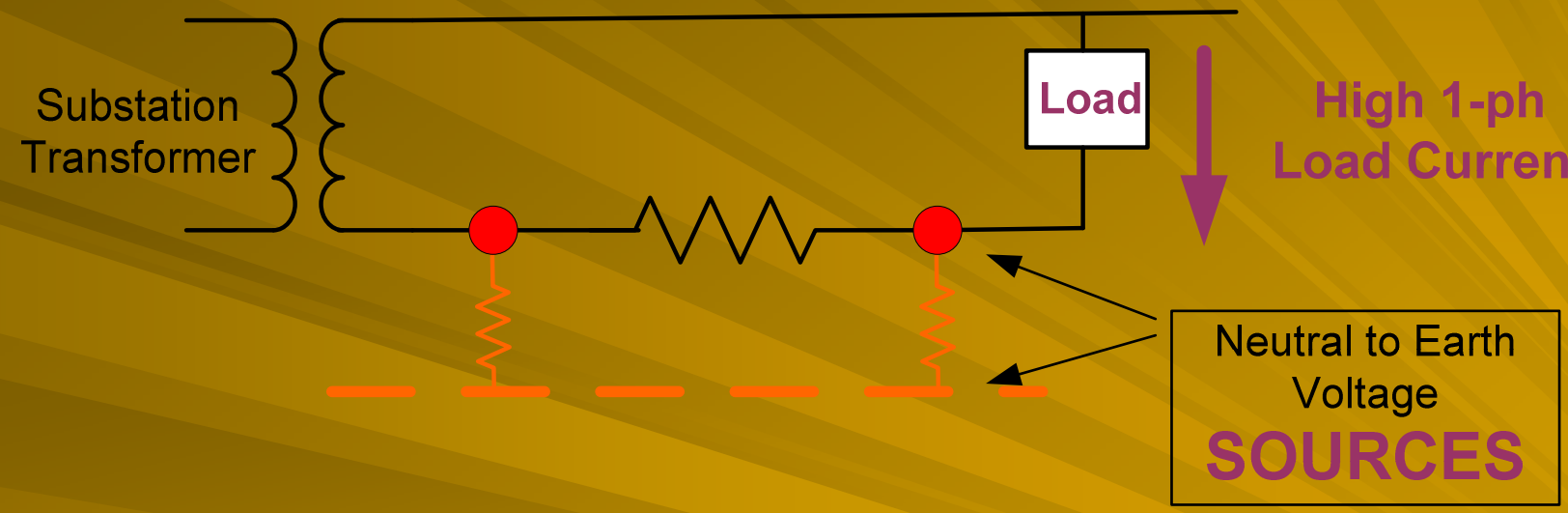
Basic Electric Model
"Stray" Voltage Source - A



Most frequent source of the problem is a higher than normal Neutral impedance.
- **Maybe high impedance connections.**
- **Maybe corroded URD concentric neutrals, or broken strands in OH wires**
- **May simply be long 1-ph taps with small neutral conductors.**

Results in higher than normal grounding electrode currents and voltage drops.

Basic Electric Model
"Stray" Voltage Source - B

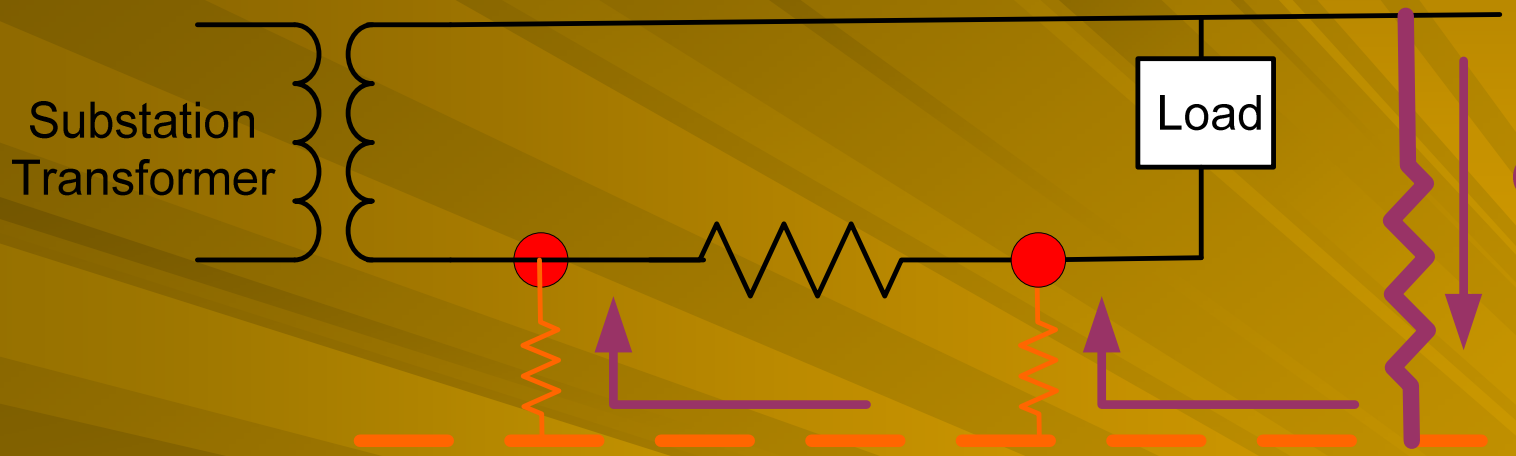


Another frequent cause, or contributing factor, is higher than normal 1-ph load currents. (Relative to conductor sizes)

High Load Currents means that the Load Impedance is getting smaller, relative to conductor impedances.

Thus, there is relatively more Voltage Drop elsewhere in the circuit, such as across the Neutral and across the Ground Rods.

Basic Electric Model
A "Contact" Voltage Source



One likely source of "Contact Voltage" on a neutral is a nearby Ground Fault.

Can be primary or secondary voltage.

Maybe a grounded secondary conductor.

Maybe a wire insulation failure, such as on a submersible water pump.

This ground Current 'returns to the neutral' through the grounding electrodes, resulting in higher than normal electrode Voltage drops.

Anatomy of a Case Study
(A Straw Man)

- Details of Customer Complaint
- Previous Actions & Findings by Service Technician
- Engineering Diagnostic Actions & Findings
- Problem Cause (Classification)
- Remedial Actions Taken
- Results
- Any Next Steps

We will Discuss 4 Case Studies:

- Outdoor Faucet
- Basement Shower
- Backyard Pool
- Municipal Pool

Cases:

- #1 Outdoor Faucet
- #2 Basement Shower
- #3 Backyard Pool
- #4 Municipal Pool

Case #1 - Outdoor Faucet

- Customer Complaint:
  - Kids getting “Tingled” while filling water balloons at outdoor faucet
  - Customer measured voltages as high as 10 VAC

Case #1 - Outdoor Faucet

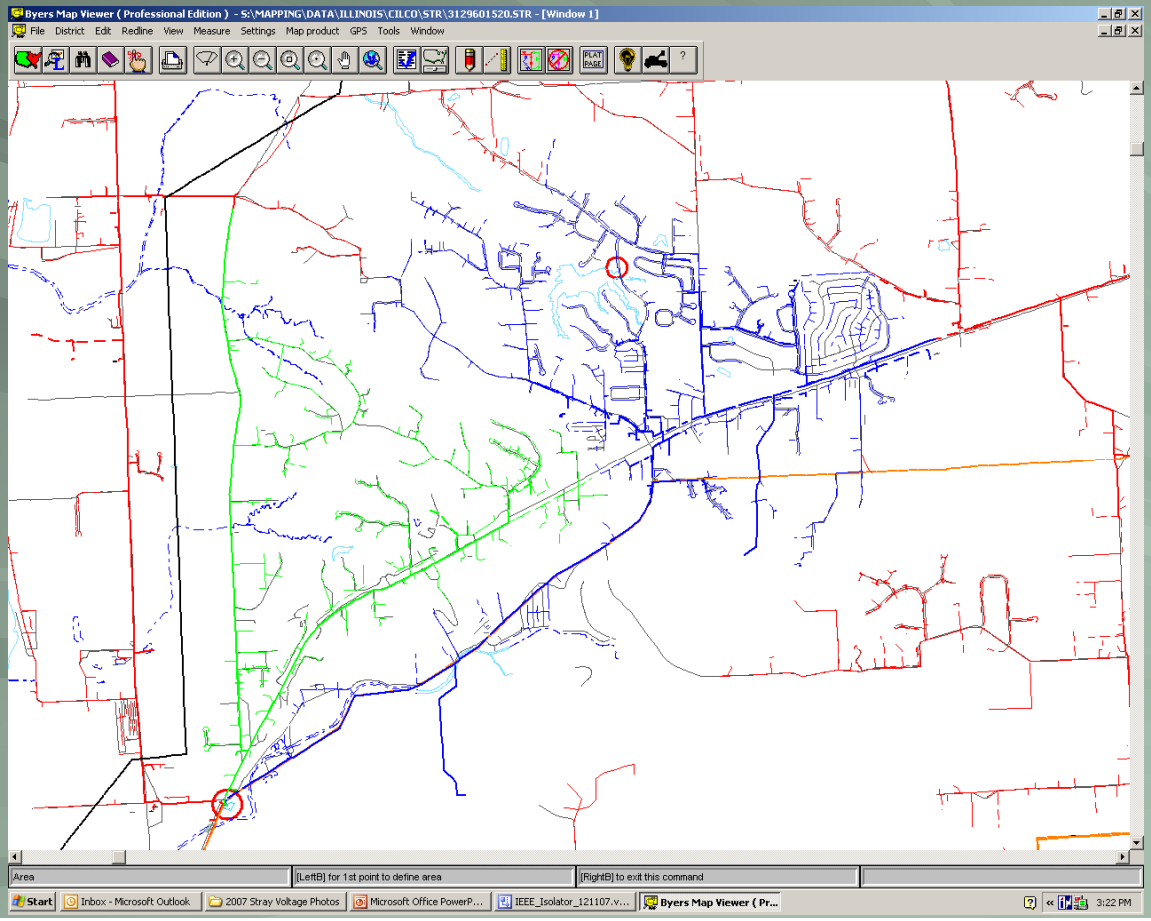
- Previous Actions & Findings by Service Technician:
  - Confirmed 5 VAC measurement at faucet
    - Weather was cooling, so all Loads were going down
    - Not unusual for these voltage measurements to vary over time
  - Checked all grounds and bonds – OK
  - Called Engineering

Case #1 - Outdoor Faucet

- Engineering Diagnostic Actions & Findings:
  - Confirmed “Stray Voltage” measurements.
  - Voltage measured several times, and seen to be load dependent (Increased during the ‘Heat’ of the day)
  - Confirmed all Grounds and Bonds to be “OK”

Case #1 - Outdoor Faucet

- Engineering Diagnostic Actions & Findings:
  - Location is near end of 1-ph Tap, 4 miles from Substation.



Case #1 - Outdoor Faucet

- Engineering Diagnostic Actions & Findings:
  - Location is near end of 1-ph Tap, distant from Substation.
  - Significant 1-ph loads downstream of this customer.

Case #1 - Outdoor Faucet

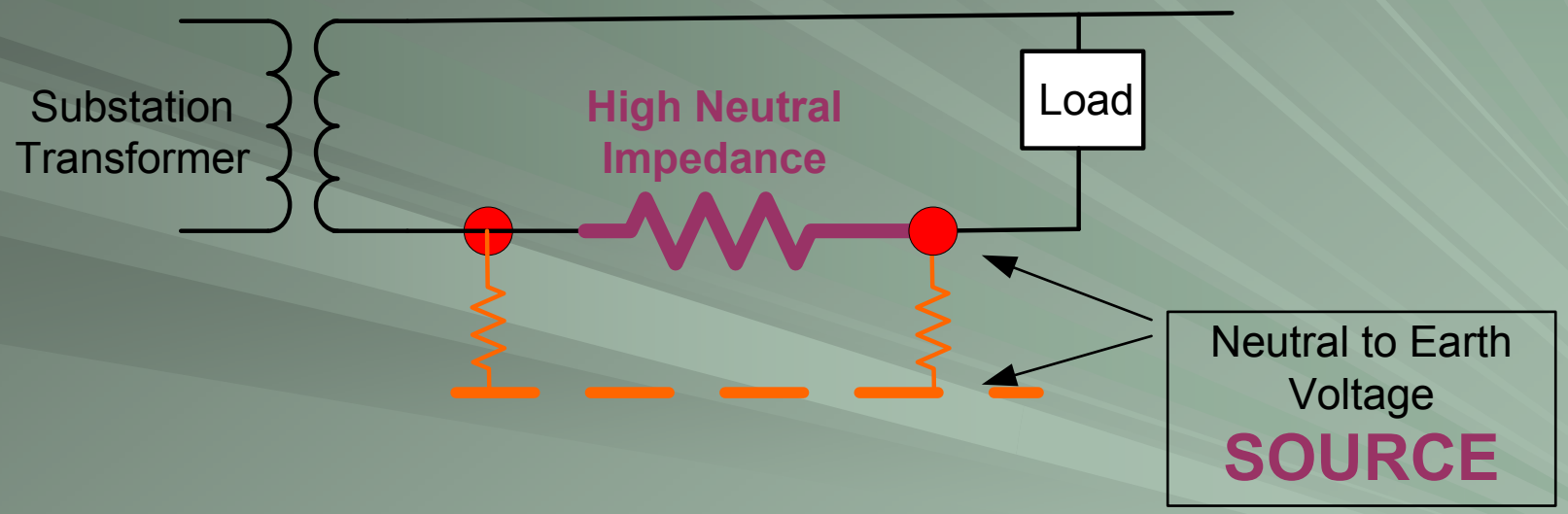
- Engineering Diagnostic Actions & Findings:
  - Location is near end of 1-ph Tap, distant from Substation.
  - Significant 1-ph loads downstream of this customer.
  - Stray voltage measurable at neighbors, but no complaints from them.
  - Previous reports from Construction of URD cable neutral corrosion in this area.
  - Impractical to replace all of this URD Cable, as not failing yet. (We do not replace due to neutral corrosion)

Case #1 - Outdoor Faucet

- Engineering Diagnostic Actions & Findings:
  - Location is near end of 1-ph Tap, distant from Substation.
  - Significant 1-ph loads downstream of this customer.
  - Stray voltage measurable at neighbors, but no complaints from them.
  - Previous reports from Construction of URD cable neutral corrosion in this area.
  - Impractical to replace all of this URD Cable, as not failing yet. (We do not replace due to neutral corrosion)
  - Verified that lifting the Service Neutral fixed the problem.

Case #1 - Outdoor Faucet

- Problem Cause (Classification)



Case #1 - Outdoor Faucet

- Remedial Actions Taken:
  - Installed 2nd ground rod near Customer Meter

    (Impedance went down, Current went up, No Voltage Change)
  - Installed 2nd ground rod at Pad Transformer

    (No significant affect)

Case #1 - Outdoor Faucet

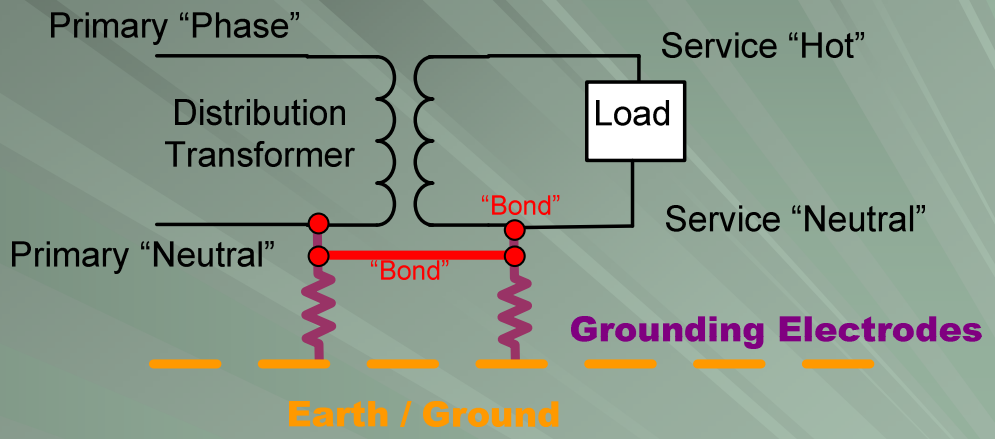
- Remedial Actions Taken:
  - Installed 2nd ground rod near Customer Meter

    (Impedance went down, Current went up, No Voltage Change)
  - Installed 2nd ground rod at Pad Transformer

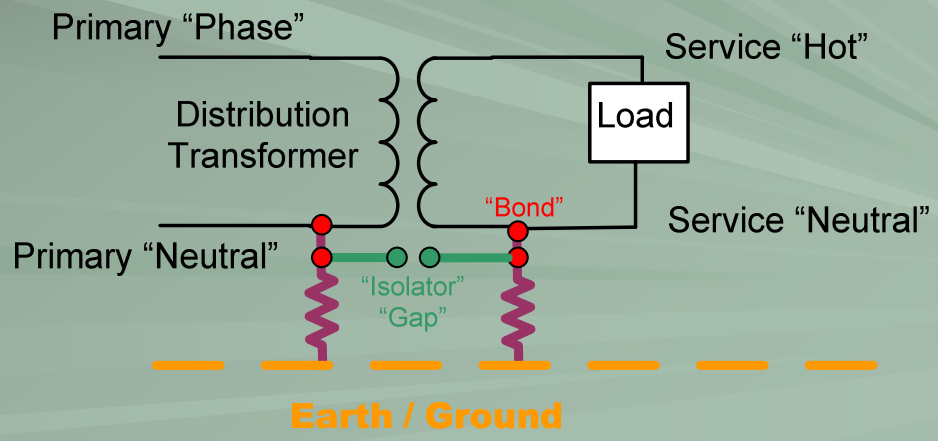
    (No significant affect)
  - **Learning what DOESN'T WORK**

Case #1 - Outdoor Faucet

- Remedial Actions Taken:

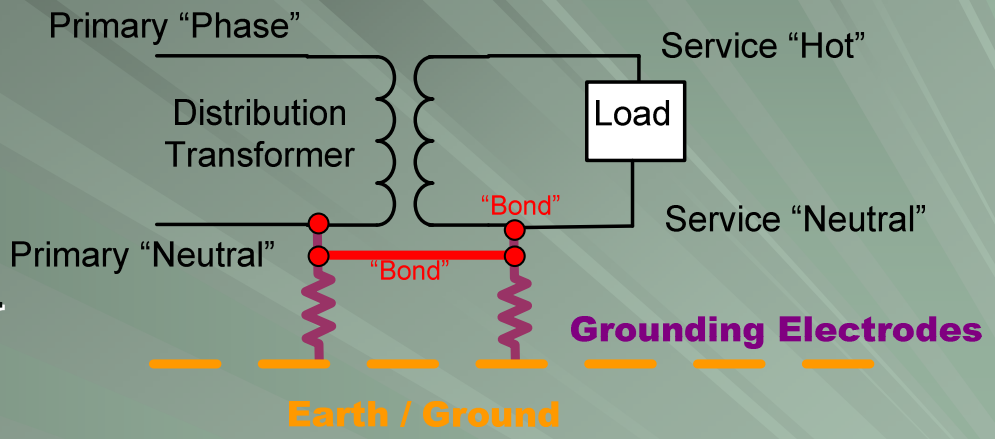


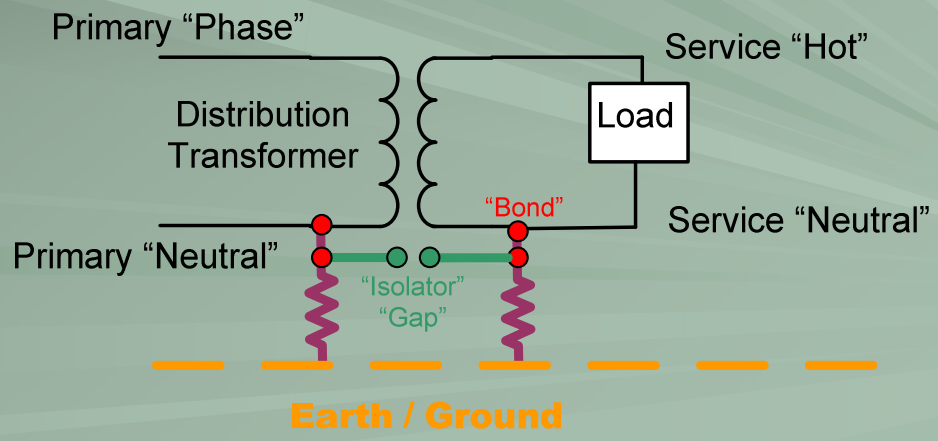
- Installed Neutral Isolator in Pad Transformer



Case #1 - Outdoor Faucet

- Remedial Actions Taken:
- Installed Neutral Isolator in Pad Transformer
- Cannot just leave neutral Open, as that results in a safety hazard and NEC Code Violation

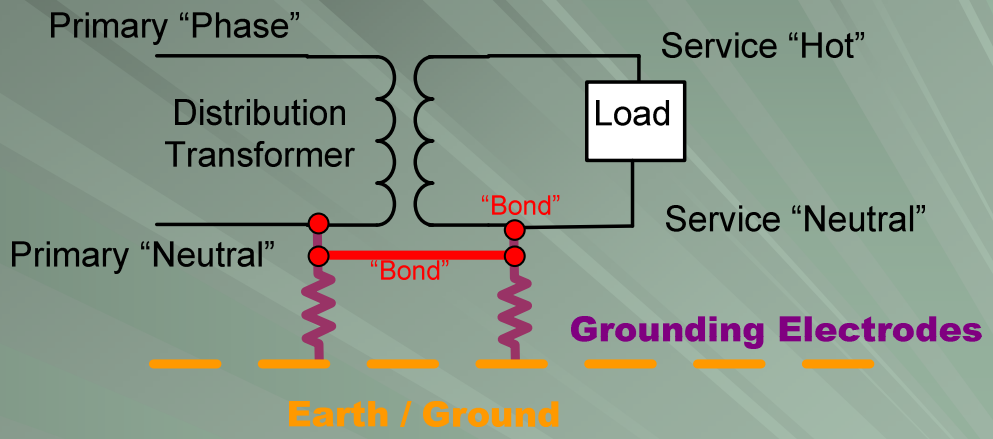


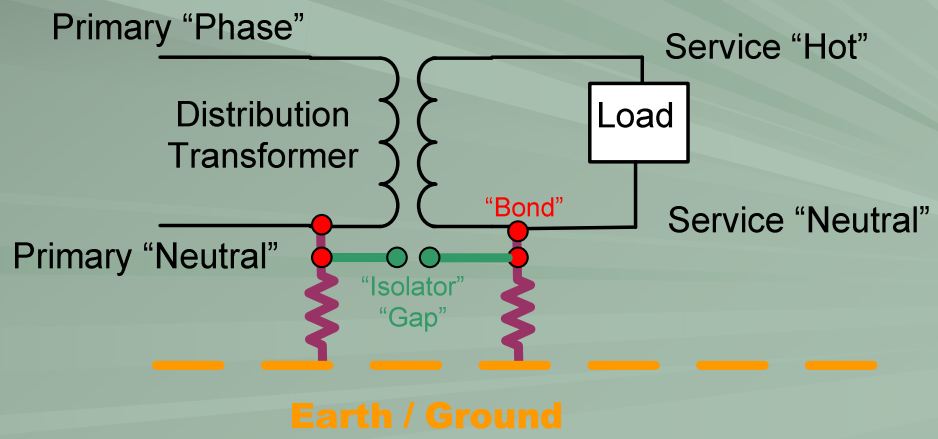


Case #1 - Outdoor Faucet

- Remedial Actions Taken:
- Installed Neutral Isolator in Pad Transformer
- Neutral Isolator can be:
  - Spark Gap Arrester
  - MOV Arrester
  - Saturated Core Reactor (Ronk Blocker)

Must Conduct any Ground-Fault Currents





Case #1 - Outdoor Faucet

- Remedial Actions Taken:
  - Installed Neutral Isolator in Pad Transformer
  - 120/240 Volt MOV Arrester

Case #1 - Outdoor Faucet

- Results
  - Voltage reduced to less than 1.0 VAC.
  - Declare success and “Walk Away”.

Case #1 - Outdoor Faucet

- Any Next Steps
  - Advise customer to call again if voltage re-appears next summer as loads go back up.

    (We did this in the Fall, and loads were way down from Peak)

Cases:

- #1 Outdoor Faucet
- #2 Basement Shower
- #3 Backyard Pool
- #4 Municipal Pool

Case #2 - Basement Shower

- Customer Complaint:
  - Rural home. Getting shocked in basement shower, when touch water valves. Started 2-3 weeks before investigation.

Case #2 - Basement Shower

- Previous Actions & Findings by Service Technician
  - Measured 6.4 – 7.0 VAC in shower, between water handles and metal drain cap in floor.
  - Disconnect hot leads at the meter (No Affect)
  - Disconnect service neutral at meter (No Affect)
  - So, call Engineering for assistance

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Verify measurement of 3.5 volts in shower
  - Measured ground impedance of 18 ohms and ground rod current of 0.194 amps (calcs to 3.492 volts)
  - Verified no affect from hot leg and neutral disconnections
  - Added water pipes to ground bond (No Affect)
  - Verified integrity of neutral connections (All OK)
  - Discussed situation with customer. Verified that problem started about same time as neighbor's electric problem.

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Pulled cut-out for the complaint location, with no affect.
  - Pulled cut-out for neighbor across street, stray voltage disappeared.

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Inspected neighbor's farm operation, no farm house
  - Farmer showed-up and offered to help

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - 4 branch circuits from meter pole

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Customer suggested overhead circuit, which had been torn down by a combine, and reattached by the farmer.

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - With aid of Troubleman, disconnected branch circuits one at a time and made measurements.
  - Confirmed that the overhead circuit was the source of the problem.
  - Checked wiring in that building, found everything OK.
  - Opening the breakers in that building, no affect.

Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Lights and garage door opener worked OK
  - Checked ground rod for good bonding
  - Could not get an impedance measurement (meter error)
  - 3-4 amps in ground rod, even with breaker open
  - Did NOT feel any voltage on the ground rod

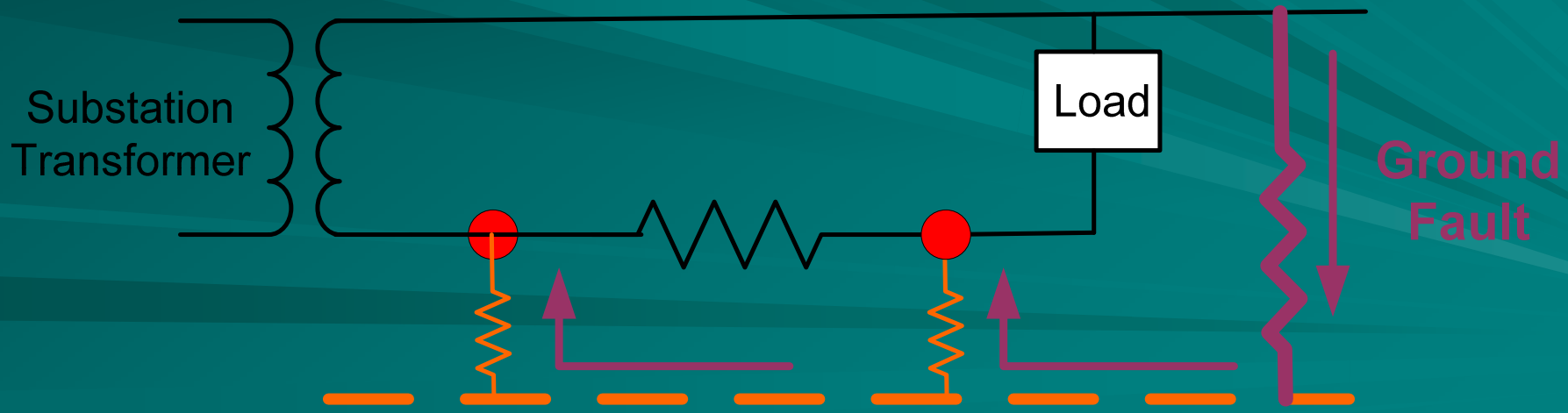
Case #2 - Basement Shower

- Engineering Diagnostic Actions & Findings
  - Checked continuity of the 2 branch circuit conductors
  - Verified that they had been REVERSED when reconnected by the farmer after the accident with the combine.

Case #2 - Basement Shower

- Problem Cause (Classification)

Ground Fault



Case #2 - Basement Shower

- Problem Cause (Classification)

  Ground Fault

- Initially investigated as a "Stray Voltage" type complaint
- Due to underlying cause, this would be classified as a "Contact Voltage" issue.
- The miswiring constitutes an ABNORMAL system condition.

Case #2 - Basement Shower

- Remedial Actions Taken
  - The overhead service wires to the barn were returned to their correct connections by the Troubleman.

Case #2 - Basement Shower

- Results
  - Measured voltage in the shower was reduced to 0.500 V AC.

Case #2 - Basement Shower

- Results
  - Measured voltage in the shower was reduced to 0.500 V AC.
    - Within expected voltage range for a customer on a long rural tap
    - Our “walk-away” level is 1.0 volts AC, so Case Closed

Case #2 - Basement Shower

- Any Next Steps
  - No follow-up actions were required

Case #2 - Basement Shower

- Pop Quiz
  - I left out one important bit of information
  - What is missing from the story?

Cases:

- #1 Outdoor Faucet
- #2 Basement Shower
- #3 Backyard Pool
- #4 Municipal Pool

Case #3 – Back Yard Pool

- Customer Complaint:
  - Newly installed in-ground pool
  - Immediately felt ‘tingling’ when using metal hand rail to exit the pool
  - Measured 1.5 – 2.5 VAC between hand rail and pool water

Case #3 – Back Yard Pool

- Previous Actions & Findings by Service Technician:
  - No field investigation was performed by Operations
  - Engineering was called immediately

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Met customer electrician at the site
    Quickly determined that he was not “Licensed”
  - Started to investigate multiple complaints:
    - GFI Breaker on pool pump would not stay closed
    - TV in house was recently damaged during a lightning storm
    - Tingling on pool hand rail

Case #3 – Back Yard Pool

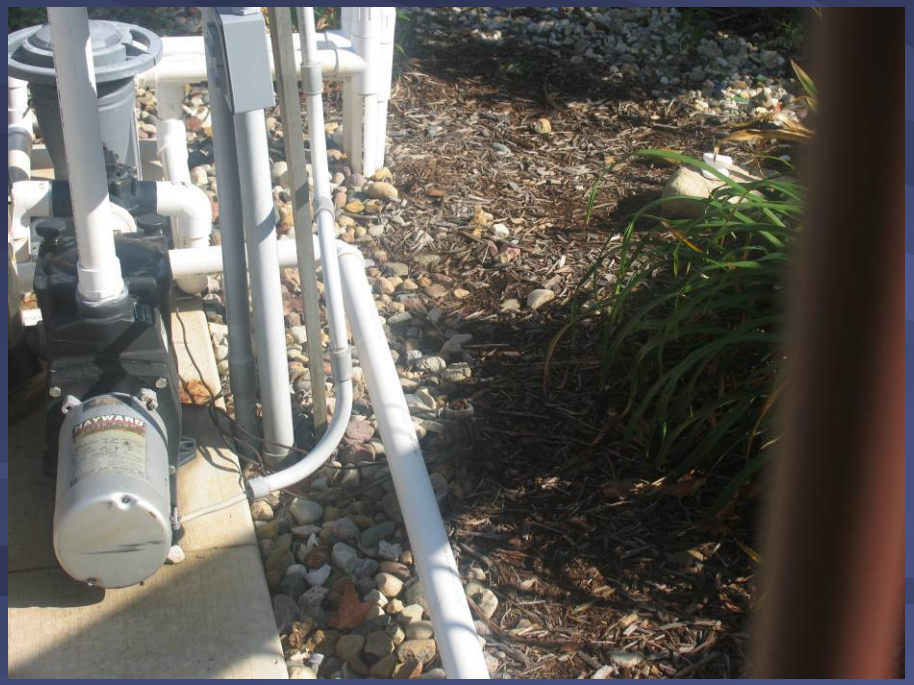
- Engineering Diagnostic Actions & Findings
  - Inspected wiring at main entrance panel and sub-panel at the pool.

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings
  - Inspected wiring at main entrance panel and sub-panel at the pool.
    - "Amateur" electrician had bonded the neutral to the case ground at the pool sub-panel, creating a ground-loop. Lifting that illegal jumper fixed the GFI breaker problem
    - There were no bonds between the CATV service and the Electric service and the CATV was not grounded at all. Advised customer to call CATV company to get their service properly grounded, to avoid future lightning problems

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected the grounding and bonding around the pool



Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected the grounding and bonding around the pool
    - Observed ground rods at the meter, at the pump sub-panel, and at the far end of the pool.
    - Observed multiple grounding conductors attached to ground-rods around the pool
    - Were told by “electrician” that the pump, pool lights, powered pool cover, and all metal fittings and fixtures were bonded to this ground grid

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected utility service to the residence

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected utility service to the residence
    - Disconnecting hot-leads had no affect on Stray Voltage
    - Disconnecting neutral at meter lowered Stray Voltage, but not by enough to call it fixed.
    - All hot, neutral, and ground connections were restored and verified tight (No affect)
    - Two additional ground-rods were driven at transformer (No affect)

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected utility service to the residence
    - Disconnecting hot-leads had no affect on Stray Voltage
    - Disconnecting neutral at meter lowered Stray Voltage, but not by enough to call it fixed.
    - All hot, neutral, and ground connections were restored and verified tight (No affect)
    - Two additional ground-rods were driven at transformer (No affect)
  - Tested lines into subdivision (looking for Ground Faults or Bad Neutrals)

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected utility service to the residence
    - Disconnecting hot-leads had no affect on Stray Voltage
    - Disconnecting neutral at meter lowered Stray Voltage, but not by enough to call it fixed.
    - All hot, neutral, and ground connections were restored and verified tight (No affect)
    - Two additional ground-rods were driven at transformer (No affect)
  - Tested line into subdivision
    - Identified 2 cut-outs serving 2 sides of UG loop in subdivision
    - Opened cut-outs one at a time (Each time Stray Voltage went down to about half)
    - Checked neutral connections on OH line for 1.5 miles back to 3-ph main line (All connections good)
    - Measured phase and neutral currents on OH line
      - 14 amps phase current
      - Only 10 amps neutral return current

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Inspected utility service to the residence
    - Disconnecting hot-leads had no affect on Stray Voltage
    - Disconnecting neutral at meter lowered Stray Voltage, but not by enough to call it fixed.
    - All hot, neutral, and ground connections were restored and verified tight (No affect)
    - Two additional ground-rods were driven at transformer (No affect)
  - Tested service to neighbors (looking for Ground Faults)
    - Identified 2 cut-outs serving 2 sides of UG loop in subdivision
    - Opened cut-outs one at a time (Each time Stray Voltage went down to about half)
    - Checked neutral connections on OH line for 1.5 miles back to 3-ph main line (All connections good)
    - Measured phase and neutral currents on OH line
      - 14 amps phase current
      - Only 10 amps neutral return current
  - Conclusion:
    - High 1-ph loads at distance from substation was resulting in significant earth return currents
    - No observed or suggested neutral impedance problems, nothing to fix
    - What we were seeing was “normal” earth return currents situation

Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Systematically re-checked our measurements, observations, and what we had been told by the customer
  - Observed that pool water was at “Remote Earth” potential, but that the ground-rods were not. And, the three ground rods were not at the same potentials relative to remote earth.
  - Discovered that Stray Voltage went away when we added a bond between the pool hand rail and the nearest ground rod.

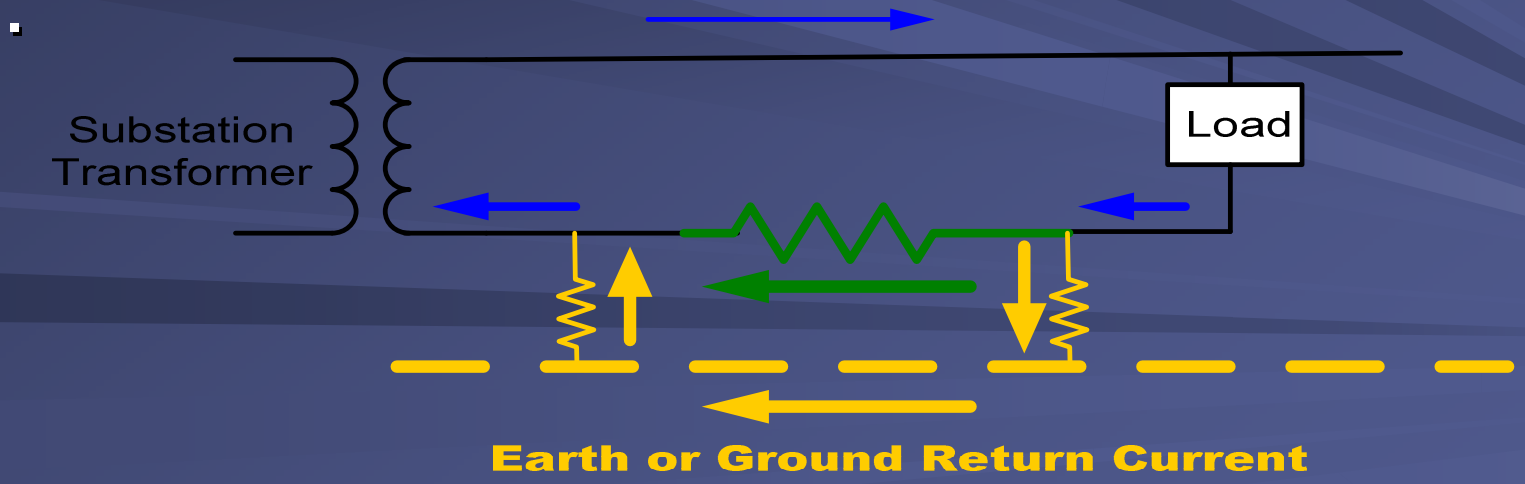
Case #3 – Back Yard Pool

- Engineering Diagnostic Actions & Findings:
  - Systematically re-checked our measurements, observations, and what we had been told by the customer
  - Observed that pool water was at “Remote Earth” potential, but that the ground-rods were not. And, the three ground rods were not at the same potentials relative to remote earth.
  - Discovered that Stray Voltage went away when we added a bond between the pool hand rail and the nearest ground rod.
  - CONCLUSION:
    The “Amateur” electrician and / or pool installer did not understand NEC requirements for pool area grounding and bonding.

    There was <u>no</u> equipotential grid around this pool.

Case #3 – Back Yard Pool

- Problem Cause (Classification)
  - This was not a Utility problem
  - It represented NORMAL electric operation
  - Nothing for us to fix.
    This is a Customer Problem.



Case #3 – Back Yard Pool

- Remedial Actions Taken
  - Nothing for utility to fix.
    - Neutral isolation would not fix problem.
    - Not practical to run 3-ph for 1.5 miles to balance and thus cancel earth return currents
  - Left our ‘temporary’ bonding conductor in place, so customer could verify our findings
  - Advised customer that it was his responsibility to bring his pool up to NEC Code Compliance.

Case #3 – Back Yard Pool

- Any Next Steps:
  - Advised customer to hire electrician to correctly bond all metal fixtures in pool area.
  - Advised customer to call back if that did not fix the problem

Cases:

- #1 Outdoor Faucet
- #2 Basement Shower
- #3 Backyard Pool

- #4 Municipal Pool

Case #4 – Municipal Pool

- Customer Complaint:
  - "Shocking" voltages felt in the Snack Bar
  - Closed pool for the season (Early)

Case #4 – Municipal Pool

- Customer Complaint:
  - Snack bar kitchen volunteers are getting shocked around the sink

Case #4 – Municipal Pool

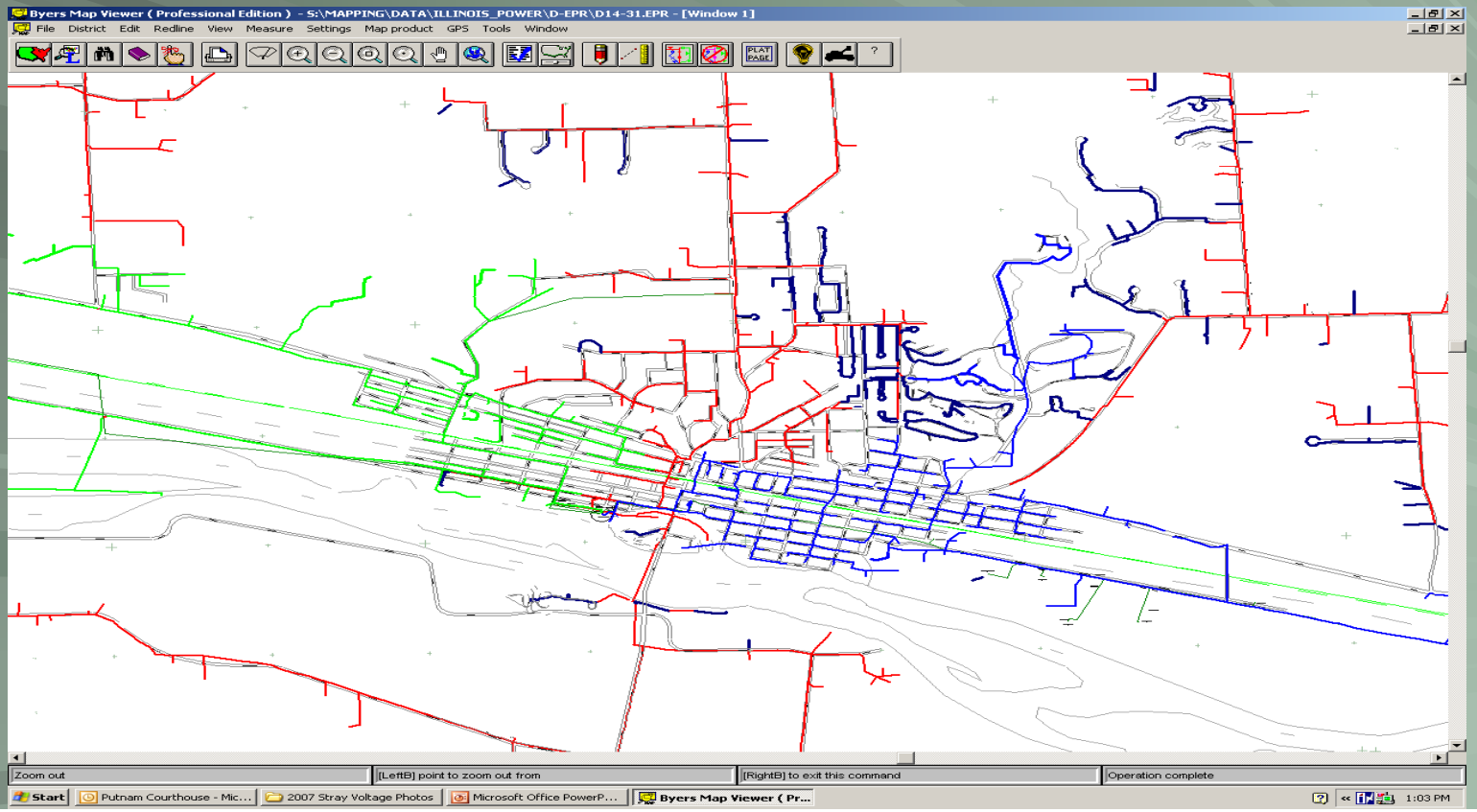
- Previous Actions & Findings by Service Technicians
  - Initial measurements between plumbing and metal electric conduits in kitchen were in the 8 – 10 VAC range.
  - Line crews found and fixed a nearby primary neutral connection, which reduced measurements to 2-3 VAC range.
  - Then called for Engineering assistance

Case #4 – Municipal Pool

- Engineering Diagnostic Actions & Findings:
  - Confirmed neutral to ground voltage in 2-3 VAC range
  - Inspected customer wiring panels for proper ground-neutral bonds and proper grounding
  - Found a REAL MESS.
    - Looked like the work of multiple ‘volunteers’
    - Conductor color-coding was non-existent
    - Neutrals and safety grounds all tangled
    - Advised customer to call-in a licensed electrician and bring up to Code before someone got hurt

Case #4 – Municipal Pool

- Engineering Diagnostic Actions & Findings
  - Identified complaint location to be very near Substation with lots of downstream 1-phase loads.



Case #4 – Municipal Pool

- Engineering Diagnostic Actions & Findings
  - Formed a Hypothesis:
    - Likely more bad neutral connections on circuit
    - Likely downstream from this location
      Could be anywhere on a LONG feeder
    - Time and effort required to find and fix all of them would be prohibitive, with relatively small payback.
    - Remaining voltage was measurable, but not a safety hazard and likely not noticeable in ‘dryer’ locations

Case #4 – Municipal Pool

- Engineering Diagnostic Actions & Findings
  - Formed a Hypothesis:
    - Likely more bad neutral connections on circuit
    - Likely downstream from this location
      Could be anywhere on a LONG feeder
    - Time and effort required to find and fix all of them would be prohibitive, with relatively small payback.
    - Remaining voltage was measurable, but not a safety hazard and likely not noticeable in 'dryer' locations

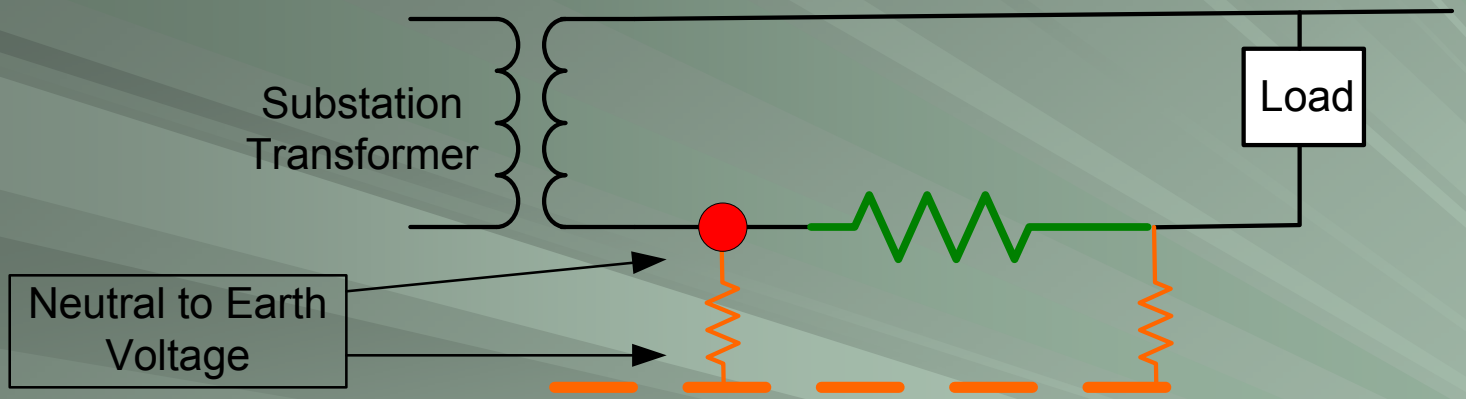
    - Lifted the service neutral and verified that the Stray Voltage disappeared.

Case #4 – Municipal Pool

- Engineering Diagnostic Actions & Findings
  - Formed a Hypothesis:
    - Likely more bad neutral connections on circuit
    - Likely downstream from this location
    - Time and effort required to find and fix all of them would be prohibitive, with relatively small payback.
    - Remaining voltage was measurable, but not a safety hazard and likely not noticeable in 'dryer' locations
  - Conclusion:
    - Good candidate for "Fix the Symptom"
    - Recommended installing a Neutral Isolator

Case #4 – Municipal Pool

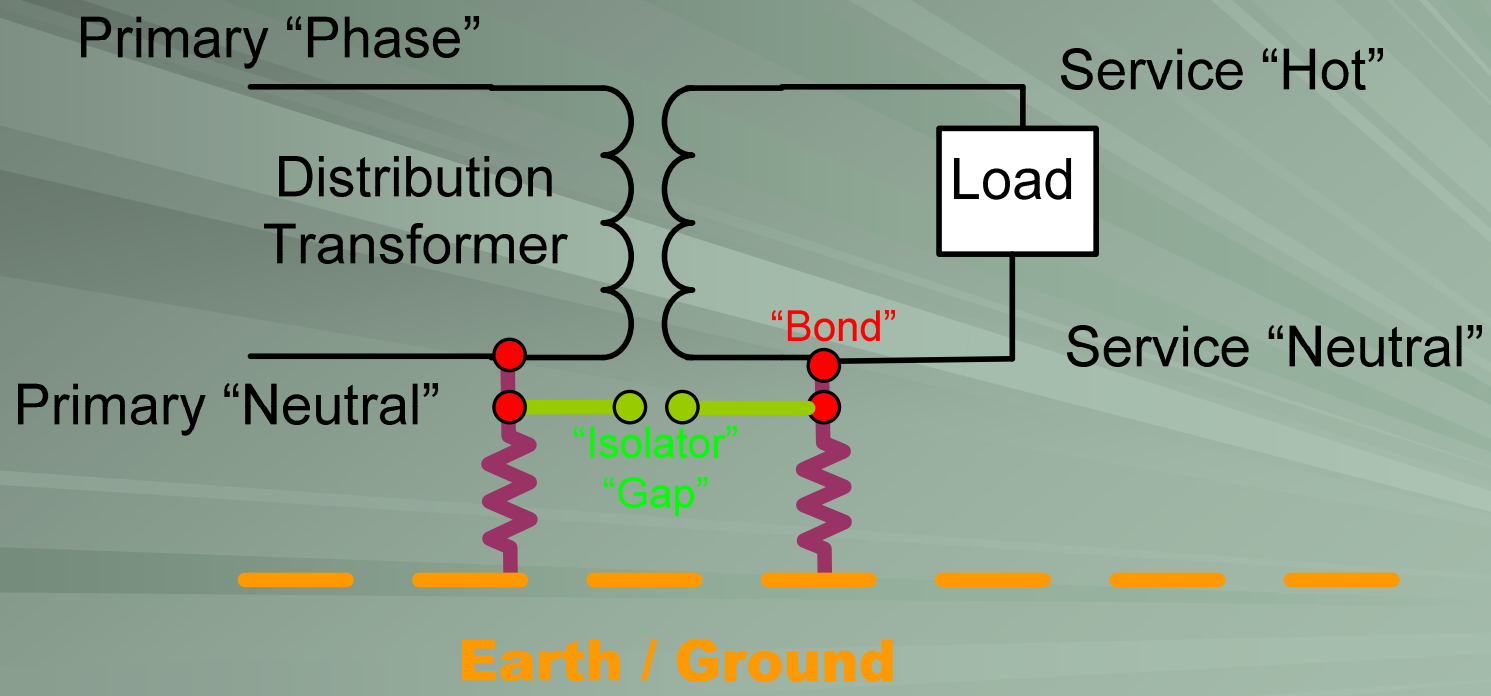
- Problem Cause (Classification):



- Earth currents returning to neutral near substation

Case #4 – Municipal Pool

- Remedial Actions Taken
  - Crew installed neutral isolator.



Case #4 – Municipal Pool

- Results
  - Measured voltage reduced to 0.3 to 0.5 VAC range.
  - Our “Walk-Away” voltage is 1.0 VAC so we declared success and quit.

Case #4 – Municipal Pool

- Any Next Steps:

- Recommended customer electrician bring wiring up to Code.

- Told customer to call back if problem returned when the Pool re-opened next Spring

In Summary

We Discussed 4 Case Studies:

- Outdoor Faucet (Bad Neutral)
- Basement Shower (Ground Fault)
- Backyard Pool (Excess Ground Return Current)
- Municipal Pool (Bad Neutral)

Closing Summary

- Presented a Really Simplified Electric Model
- Discussed some Likely Sources of Stray & Contact Voltages
- Discussed Proposed Format for Case Studies
- Presented Example Case Studies

Closing

- Presented a Really Simplified Electric Model
- Discussed some Likely Sources of Stray & Contact Voltages
- Discussed Proposed Format for Case Studies
- Presented Example Case Studies

Questions or Discussion ??