Was the Stray Voltage Really Stray?

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Topics Covered

- Stray Voltage Causes
- Testing Protocol
- Hazard Levels
- Case Study
What is Stray Voltage?

- Stray Voltage is a voltage between neutral of the power system and earth
- Convention is $V_{ne}$
- Measure of Stray Voltage
  - Open Circuit = $V_{oc} = $ voltage seen with high Z voltmeter
  - Closed Circuit = $V_{ne\text{ loaded}} = $ voltage when an animal or human is in contact between neutral and earth (typically use a 500-1000 ohm load resistor to simulate contact)
What Causes Stray Voltage?

- The neutral carries current and therefore has voltage drop.
- Neutral will always be at some voltage relative to earth.
- If the voltage is high enough and the source “stiff” enough the body current can be objectionable.
What Causes Stray Voltage?

- Primary Cable Neutral Corrosion
- Causes increased $V_{ne}$ due to neutral impedance increase
- Significant Issue with older bare concentric cable
  (both direct buried and in conduit)
What Causes Stray Voltage?

- Neutral Current Unbalance – creates voltage drop in neutral
- Triplen Harmonics – these currents are additive in neutral – cause voltage drop in neutral
- Perfect 60 hz balance can still have high neutral current when harmonics are present
- Poor Neutral connections
What Causes Stray Voltage?

- Other sources can elevate earth potential relative to the neutral
  - Buried low voltage cable with cuts or bare exposure
  - Nicked street light cables a mile away have been found to energize water pipes and the earth near the pipes
Test Protocol

Determine Hazard Level by measuring Open circuit vs. Loaded neutral – earth voltage (Vne)

Is source Utility or Customer?
- Open customer main & check Vne
- Disconnect Utility neutral & measure Vne
  - Utility
  - Customer

If utility Vne is elevated check neutral current & Vne at various points on circuit back to substation.
- Sudden change at taps or neutral connections points to problem.
- Check connections by measuring voltage across connector.
Test Protocol

- Check neutral current with true RMS meter
- Most electronic relays read ONLY 60 HZ
- Excessive neutral current can be either balance or triplen harmonics
- Check neutral harmonic spectrum for excessive harmonics
Stray Voltage Hazard Levels

- Determined by Open Circuit vs. Closed Circuit Voltage tests
- How?
  - Loaded test allows calculation of maximum current
  - Assumes soil resistance is zero
  - Uses 500-1000 ohm resistance to simulate body resistance
Stray Voltage Circuit Representation

\[ V_{\text{oc}} \]

\[ + \quad V_{\text{loaded}} \quad - \]

\[ R_s \quad R_{\text{body}} \quad R_{\text{earth}} \]

\[ I_{\text{loaded}} \]
Calculation Example

- $V_{oc} = 26$ Volts  $V_{loaded} = 16$ volts
- $R_{load} = 500$ ohms
- $I = 16 / 500 = 32$ ma
- $R_s = (26-16) / 0.032 = 312$ ohms
- Thevinen Equivalent max current
  
  $= 26 / 312 = 83$ ma

Assumes no soil resistance
Human Hazard Assessment

- Reference = IEEE 80
- 1ma = Perception Threshold
- 1 – 6 ma = Let Go (unpleasant)
- 9 – 25 ma = No Let Go
  - 10.5 ma for women
  - 16.5 ma for men
- 60ma – 100ma = lethal
- The limits are statistical means for a population and vary with the individual
Where is Stray Voltage a Problem?

- **Milking Barns (cows)**
  - Milking machine is grounded – cow is standing on earth.

- **Swimming Pools**
  - entering or exiting pool, humans have simultaneous contact with the deck and pool water, ladders and other fixtures.

- **Showers**
  - Human contact with grounded water fixtures while standing on earth (concrete floor) and drain pipes
Stray Voltage Thresholds

- Varies by person and situation
  - Can be affected by source impedance (high Z source produces little current)
- Once sensitized people and animals complain more
- “Let Go” current for 50% of population is 15 ma
Stray Voltage Case Study

Customer experiences shocking in shower

2009 Jodie Lane National Conference for Stray Voltage Detection, Mitigation & Prevention
Customer Site Observations

- Customer served from xfmr on dead-end pole
- CATV drop is new cable and not bonded to ground wire at service entrance
- Customer indicated CATV drop replaced about the time shocking started
- Voltage from CATV to neutral was 26 volts!
Check Voltage Levels

- \( \text{Voc} = 26 \text{ volts} \)
- \( \text{V}_{\text{loaded}} = 16 \text{ volts} \)
- \( \text{R}_{\text{load}} = 500 \text{ ohms} \)
- \( I = \frac{(26-10)}{500} = 32\text{ma} \)
  \[ = 2 \times \text{let go current level} \]
  \[ \text{Rs} = 312 \text{ ohms} \]
  \[ I_{\text{sc}} = \frac{26}{312} = 83 \text{ ma} \]

This could be hazardous to humans!
Check Neutral currents

- Branch line neutral current at tap = 5 amps
- Checks along branch line show neutral current increasing as we go out on the branch line!
- Neutral current at dead end = 65 amps!
- Where is the source of the current???
In = 5A

In = 70A

S/L Circuit

In = 5A
Mysterious Neutral Current

- Dead end of branch line is xfrmr station pole and has a secondary drop across the road to a lift pole at the edge of a lake.
- Lift pole has a secondary riser down the pole to a service pedestal. Pedestal serves a boat dock on the lake.
- AHA! – a wire on the dock must be contacting the lake and leaking current into the soil!
Check pedestal Currents

- None – nothing – zip NADA!
- Where is the current?
- A street light duplex cable circuit goes north along the lakeshore road.
- No street lights are burning
- Neutral of street light circuit measures 70 amps!!!!!!!
Mysterious Currents Continue

- Investigate street light circuit
- 4 spans north the SL hot leg circuit is open
- Lights farther out must be served by another source
- Followed SL circuit and it becomes open wire instead of duplex cable
- Source found about 0.5 miles away is a Y-Delta xfmr bank.
Y-Delta xfmr bank

S/L circuit
Mysterious Currents Continue!

- Check currents on SL circuit at xfmr
- Hot leg has 70 amps
- Neutral has nothing!
- Following circuit back we find 2 spans of duplex cable in the middle of an open wire circuit
- Upon inspection and tong ammeter checks the transition from open wire to duplex is reversed!
Mysterious Currents Found!

- During recent storm a tree downed SL circuit
- 2 spans of open wire replaced with duplex cable
- Connections at one end of duplex reversed to open wire conductors
- Hot leg bonded to neutral wire!!!!!
Mysterious Currents Found!

- Loop circuit distance was 0.85 miles
- Short circuit calc shows about 100 amps
- Current along branch line going to earth at driven grounds
- Results in decreasing neutral wire current as you get closer to source end of B/L
S/L Circuit Opened

- Vne at customer meter drops from 26 volts to 2 volts
- Source definitely found
- S/L circuit wiring corrected
- Problem Resolved
- CATV drop had burned up when power restored after storm
Was This Really Stray Voltage?

- No Definition in IEEE 100
- Not a temporary fault (wiring error was permanent)
- Not a true neutral to earth voltage from “normal” system operation
- A modified “contact voltage”?
What will the standard cover?

- Touch and Step Voltages due to steady state operation of the distribution system?
- Neutral as well as contact voltages?
Other Issues

- Gas Line Bonding and grounding?
- Substation grid potentials
- Use of Saturable reactors
- Phone & CATV bonding issues
- 2005 NEC Code changes for Swimming Pool Bonding
- Third Harmonics are +/- 50% of Neutral Currents = \( V_{ne} \)
Other Stray Voltage Mitigation

- Reduce Neutral Currents
  - Balance Loads
  - Install 3rd Harmonic Filter out on feeder
- Install “Blocker” reactor between primary and secondary neutral systems
- Must separate CATV and phone grounds from power neutral at service entrance
2005 NEC Code Changes

- Section 680.26
- New Item on Equipotential Bonding
- 12” x 12” Ground Grid required 3 ft out from Non Bonded Pools
References

- NETRAC Study
- EPRI STUDY
- IEEE PES working on standards for stray voltage
- C. DeNardo Chairman
Guides to stray voltage troubleshooting

- EPRI
- NETRAC
- IEEE Explore has several technical papers on Stray Voltage