Was the Stray Voltage Really Stray?

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What is Stray Voltage?

• Not presently defined by IEEE 100
• Used extensively in Media
• Two Types Proposed
  – Category 1: Neutral to earth step or touch voltage from normal steady state operation of the distribution system
  – Category 2: Voltage due to unintentional contact of an energized conductor with a conductive object
What is Stray Voltage?

• This case: 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 = $V_{ne}$ 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 cables (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
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
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 ohm resistance to simulate body resistance
Stray Voltage Circuit Representation

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

\[ R_s \]

\[ R_{\text{body}} \]

\[ R_{\text{earth}} \]

\[ V_{\text{loaded}} \]

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

- \( V_{oc} = 26 \text{ Volts} \quad V_{loaded} = 16 \text{ volts} \)
- \( R_{load} = 500 \text{ ohms} \)
- \( I = \frac{16}{500} = 32 \text{ ma} \)
- \( R_s = \frac{(26-16)}{0.032} = 312 \text{ ohms} \)
- Thevinen Equivalent max current
  \[ = \frac{26}{312} = 83 \text{ ma} \]
Assumes no soil resistance
Human Hazard Assessment

- Reference = IEEE 80
- 1 ma = Perception Threshold
- 1 – 6 ma = Let Go (unpleasant)
- 9 – 25 ma = No Let Go
  - 10.5 ma for women
  - 16.5 ma for men
- 60 ma – 100 ma = 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
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

- Voc = 26 volts
- Vloaded = 16 volts
- Rload = 500 ohms
- \( I = \frac{(26-10)}{500} = 32\text{ma} \)
  = 2 * let go current level
- \( Rs = 312 \text{ ohms} \)
- \( Isc = \frac{26}{312} = 83 \text{ ma} \)

This could be lethal!
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???
Mysterious Neutral Current

- Dead end of branch line is xfmr 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.
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 beginning work on standard for stray voltage
- Next S.V. W.G meeting at P.E.S. in Montreal
- C. Williams Chairman
TROUBLE-SHOOTING EARTH-TO-NEUTRAL VOLTAGE

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Stray Voltage Standards Website
http://grouper.ieee.org/groups/td/dist/stray/