STRAY VOLTAGE

- WHAT IS IT
- HOW TO ANALYZE IT
- WHAT TO DO ABOUT IT

Presented By:

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What is "Stray Voltage"?

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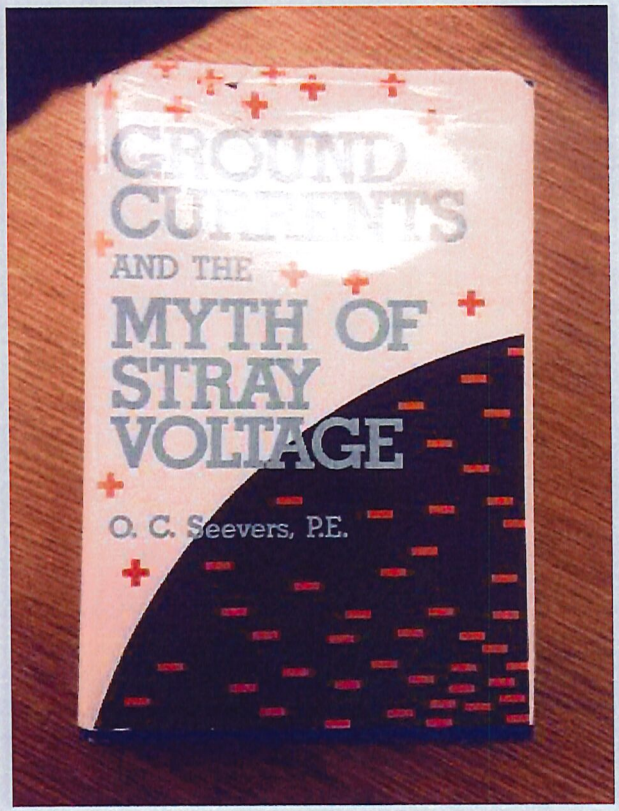
A very good reference on the subject is:

"Ground Currents and the Myth of Stray Voltage" by O. C. Seevers, P.E.



What is "Stray Voltage"?

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Mr. Seevers' book focuses on stray voltages in dairy farms, but the principles addressed apply to any stray voltage situation.

3 Important Comments

Mr. Seevers makes several important comments and observations:

- Stray voltage is "voltage which appeared where it had no business being".
- "There is no such thing as stray voltage! Voltage does not "stray". Voltage does not go anywhere. It exists at a location as electrical pressure between two points, A and B."
- "Nowhere in any of the horror tales which I have studied dealing with "stray voltage" have I seen that anyone looked at the distribution system and analyzed how it works. How primary neutral current returns to its source."

What Causes Stray Voltage?

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Simply stated, stray voltage is caused by current flowing in the earth.

Four Examples - Each Different reason.

Possible Reasons for Stray Voltage:

1. Faulty cable or equipment (Figure 1)
   - High impedance fault to ground
   - Resulting in low levels of ground fault current
   - Voltage of equipment frame, metal buildings, etc. in the fault path rises relative to remote earth - Neutral-to-Earth Voltage (NEV) *

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Figure 1 – High Impedance Fault

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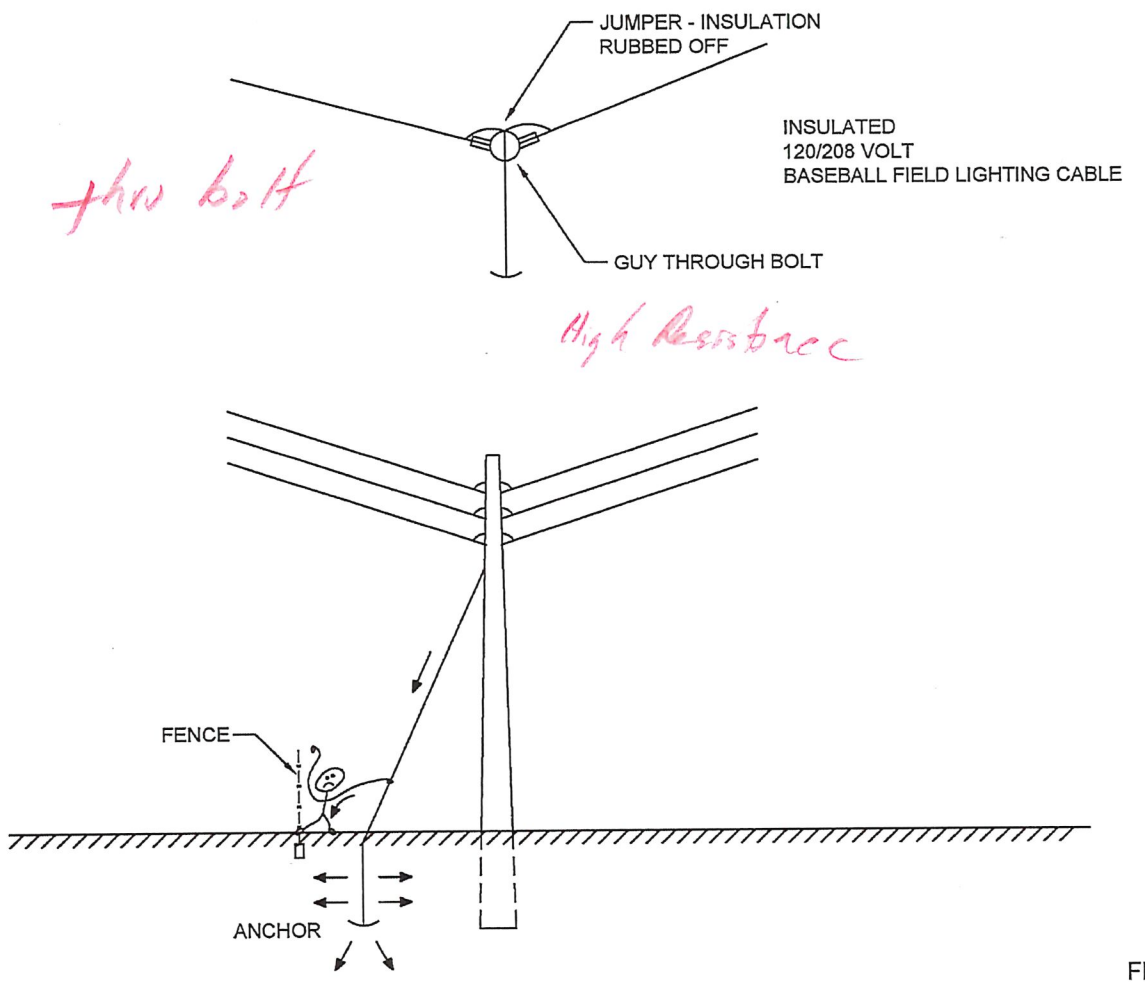

FIGURE 1

HIGH IMPEDANCE FAULT

What Causes Stray Voltage?

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NEV
Neutral-to-Earth Voltage

2. Transferred Potential *(Figure 2)
   - The voltage, or potential, of a point in an electrical system neutral is transferred to another point where the voltage is less
   - Fundamental 60 Hg
   - 3rd Harmonic 180 Hg
   - Other Harmonic currents

*The typical cause of stray voltage is transferred voltage resulting from neutral/earth current flow

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Figure 2 – Transferred Potential

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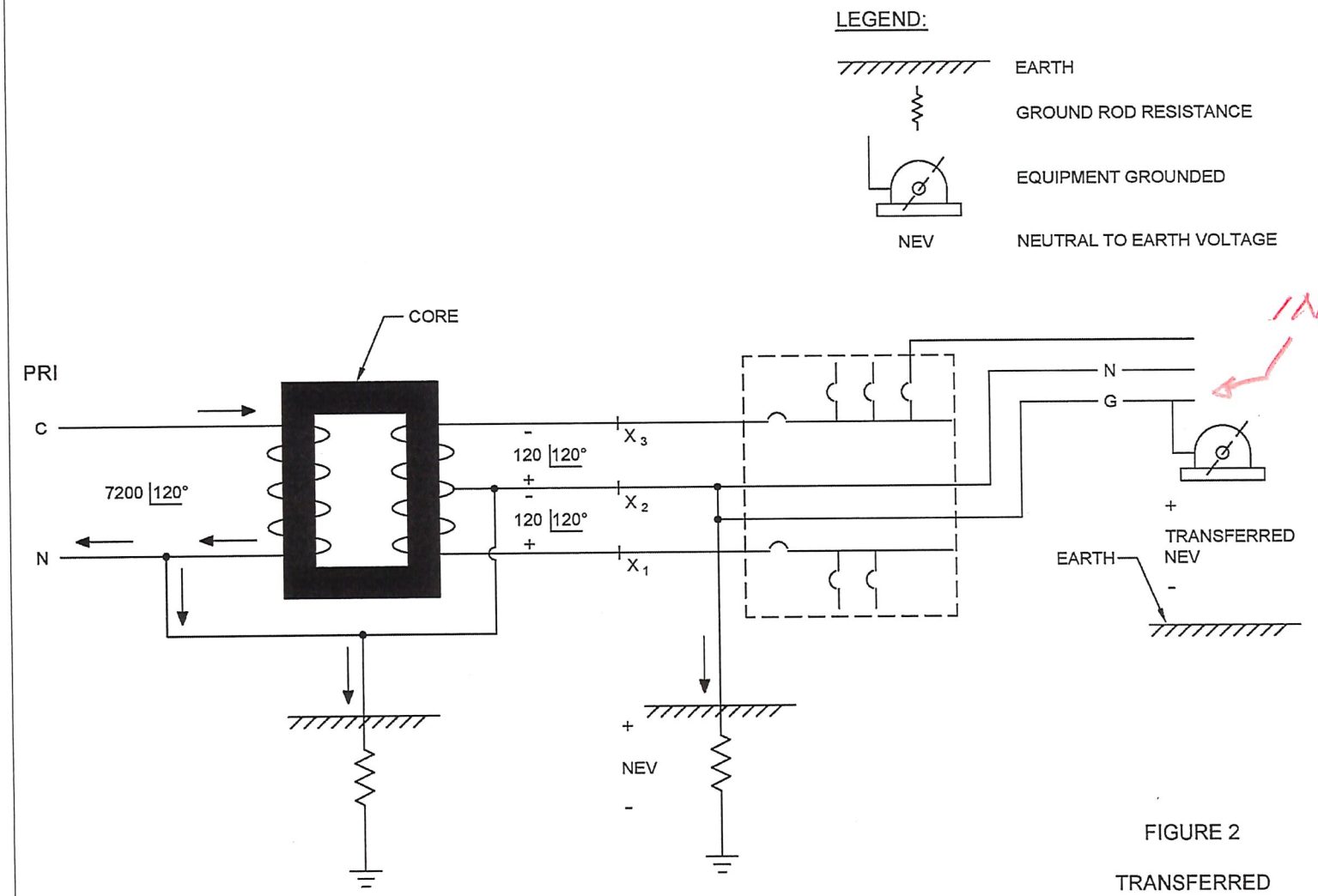

FIGURE 2

TRANSFERRED
NEV

What Causes Stray Voltage?

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3. High Resistance or Open Point in Utility Primary Neutral Conductor (Figure 3)

Figure 3 – Neutral Open or High Resistance

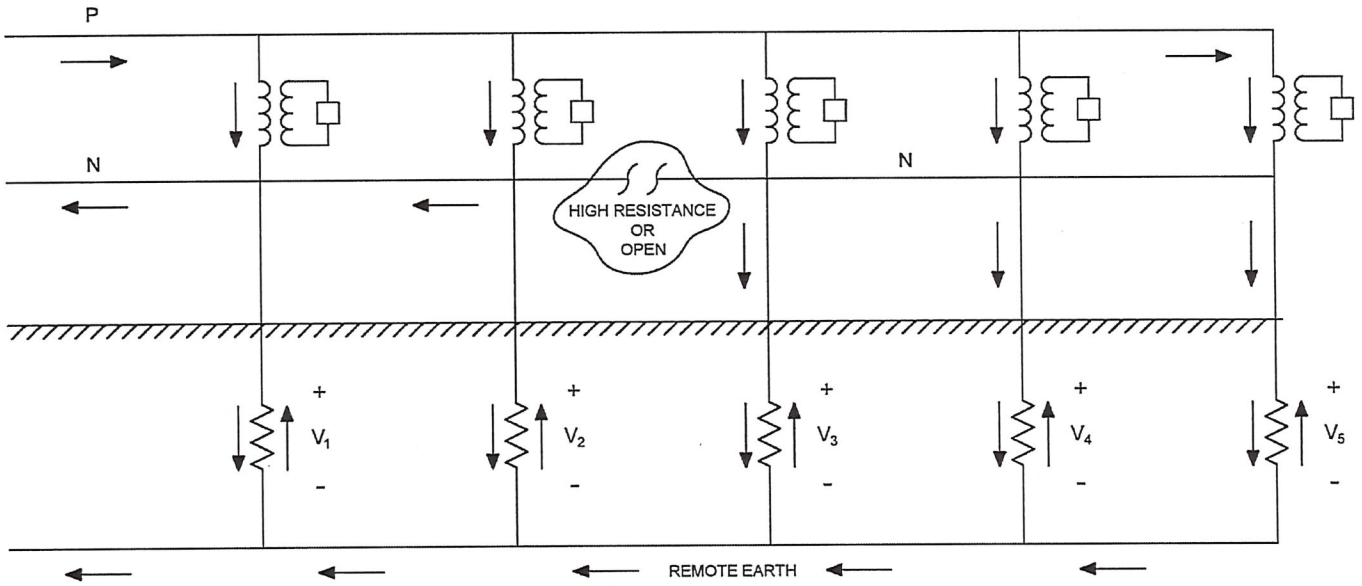


FIGURE 3

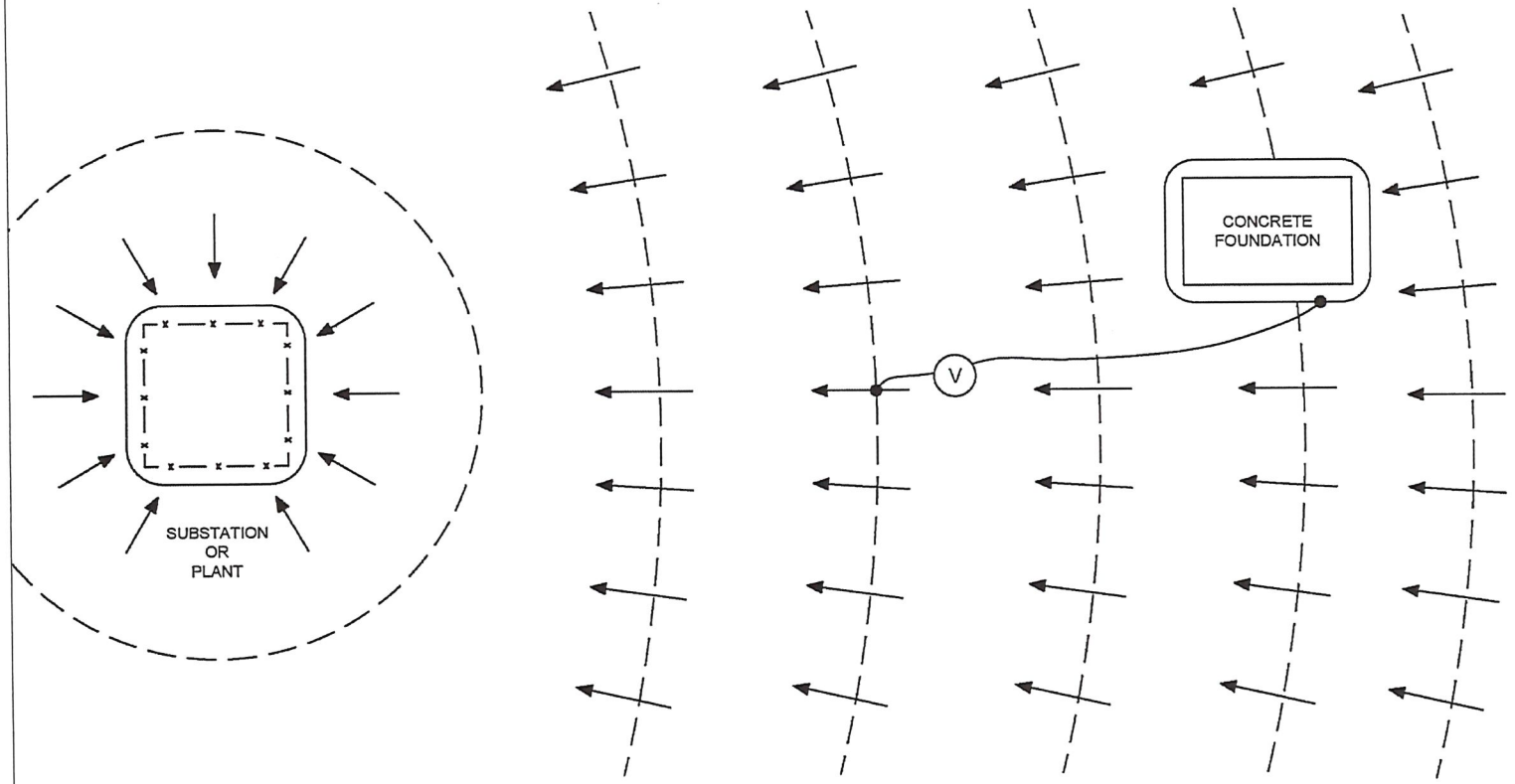
NEUTRAL OPEN
OR
HIGH RESISTANCE

What Causes Stray Voltage?

4. Ground Current From Outside Sources (Figure 4)

- Other Substation Circuits
- Other Utility Circuits
- Transmission Line Shield/Ground Currents
- Grounded Communication Circuits
  - DC
  - 60 Hz
  - Any Harmonic

Figure 4 – Current From Outside Sources



LEGEND:

- GROUND CURRENT FLOW
- EQUAL POTENTIAL LINES
- GROUND ELECTRODE
- (V) VOLTAGE MEASUREMENT

- Open Service Primary
- Open Primary Neutral before rod
- Measure Surface Potential

FIGURE 4

CURRENT FROM
OUTSIDE SOURCES

Is Stray Voltage a Problem?

At a minimum, stray voltage can be annoying.

At a maximum, stray voltage can be lethal.

Examples of Stray Voltage

1. Shock when in a swimming pool and touching the metal ladder to get out of the pool
2. Shock when touching a pole down guy wire
3. Shock to cattle when attached to a milking machine or feeding
4. Shock when touching grounded equipment in a rock quarry

Neutral-Earth-Voltage (NEV) Analysis

Example Typical 1-PH System (Figure 5)

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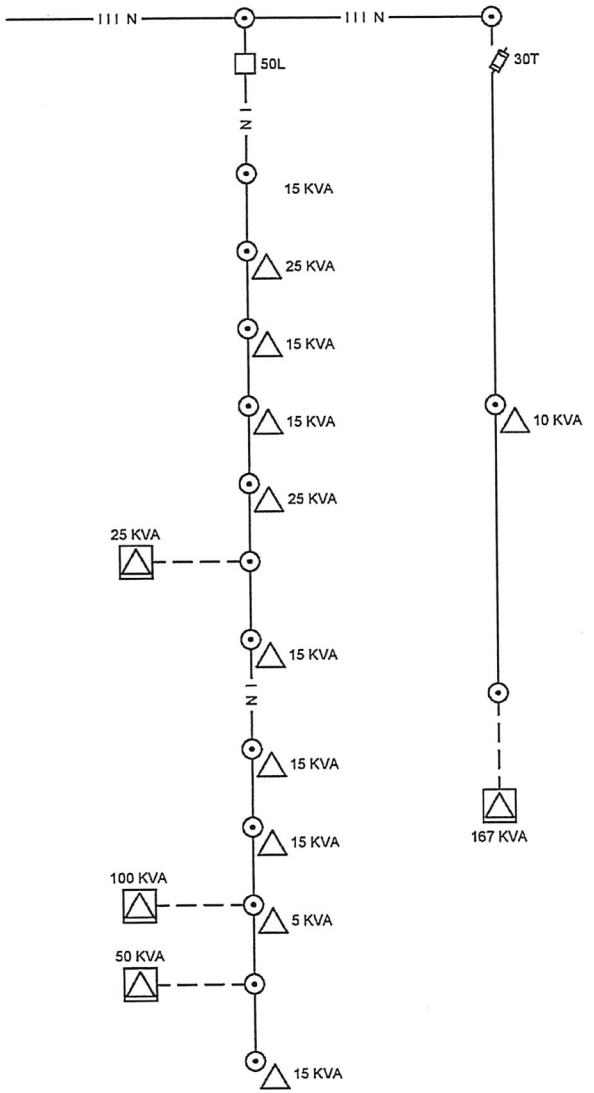
Figure 5 – Typical 1-PH 7.2 kV TAP



LEGEND:

⊙	NODES
15 KVA △	TYPICAL OH TRANSFORMER
100 KVA △	TYPICAL PADMOUNT TRANSORMER
— I N —	OH SINGLE PHASE 2ND NEUTRAL

Each Transformer is A Current Source into the neutral/ground, Not A Voltage Source.

FIGURE 5

TYPICAL
1-PH 7.2 KV TAP

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Neutral-Earth-Voltage (NEV) Analysis

1-PH System Nodal Circuit Model (Figure 6)

- Twenty-One Nodes 21
- Current Sources – Transformer Neutral Connections
- Admittance Matrix Elements
  - Neutral Conductor Sections
  - Ground Electrodes
- All Matrix Elements have both Real and Imaginary Components
- Admittance Matrix is 42 rows x 42 columns
- The "Unknowns" to be solved for are Node Voltages and Element Currents

$$[Y][E] = [I]$$

$$[E] = [Y]^{-1}[I]$$

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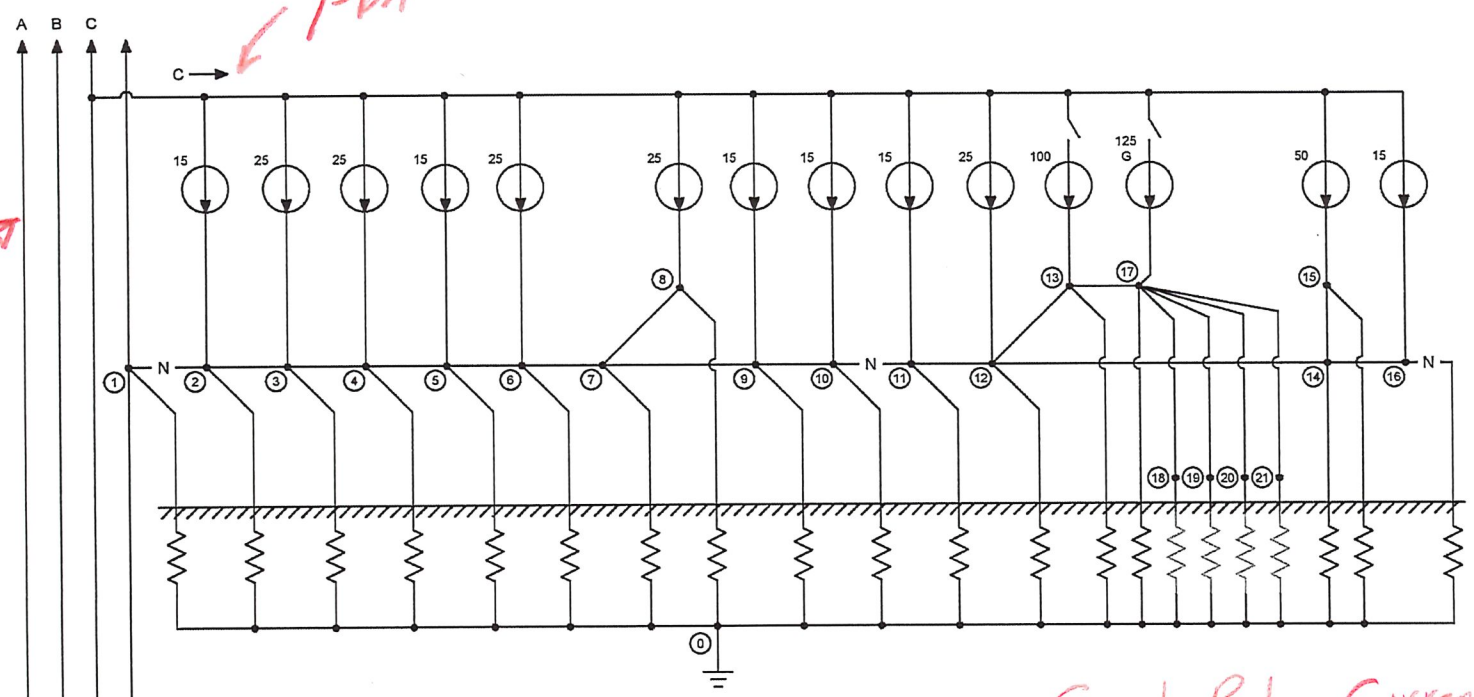
Figure 6 – 1-PH 7.2 kV TAP NEV CONCERN CUSTOMER AT NODE 13



LEGEND:

- 100 — TRANSFORMER MODELED AS CURRENT SOURCE TO NEUTRAL, KVA SIZE NOTED
- 125 G — 240 VOLT STANDBY GENERATOR
- GROUND ELECTRODE RESISTANCE
- POSSIBLE GROUND ELECTRODE RESISTANCE
- (17) — CIRCUIT MODEL NODE NUMBER, TYPICAL
- EARTH SURFACE

Ground Rod Current Flow
Ground Voltage Drop
Thevinins Law — Loop Voltage = 0
Kirchoffs Law — Node Current = 0

FIGURE 6

1-PH 7.2 KV TAP
NEV CONCERN
CUSTOMER AT NODE 13

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Nodal Matrix Solution

Nodes	Node Voltage - Volts	Node Voltage Ang - Deg	Line Sect Neut Current - Amps	Line Sect Neut Current Ang- Deg	Gnd Rod Curr - Amps	Gnd Rod Curr Ang - Deg
1	7.006	179.275			0.02217	179.275
2	7.026	179.169	0.21454	-84.068	0.02223	179.169
3	6.961	179.664	0.80715	86.846	0.02203	179.664
4	6.901	179.910	0.61057	103.900	0.02184	179.910
5	6.832	-178.500	1.84394	60.970	0.02162	-178.500
6	6.761	-177.240	1.50807	68.152	0.02140	-177.240
7	6.749	-174.142	3.32654	46.686	0.02136	-174.142
8	6.792	-175.085	2.41979	-135.328	0.02149	-175.085
9	6.636	-170.123	5.25958	45.769	0.02100	-170.123
10	7.723	176.860	17.78179	-102.615	0.02444	176.860
11	7.851	173.364	4.47996	-129.335	0.02484	173.364
12	7.989	169.766	4.69853	-132.431	0.02528	169.766
13	7.954	169.791	0.71525	91.985	0.02517	169.791
14	8.316	167.241	4.42182	-108.746	0.02632	167.241
15	8.307	167.359	0.39559	33.590	0.02629	167.359
16	8.329	165.731	2.00046	-149.572	0.02636	165.731
13	7.9539845	169.7914939	0.715250078	91.98481055	0.025170837	169.7914939

1-Phase Circuit (Figure 6)

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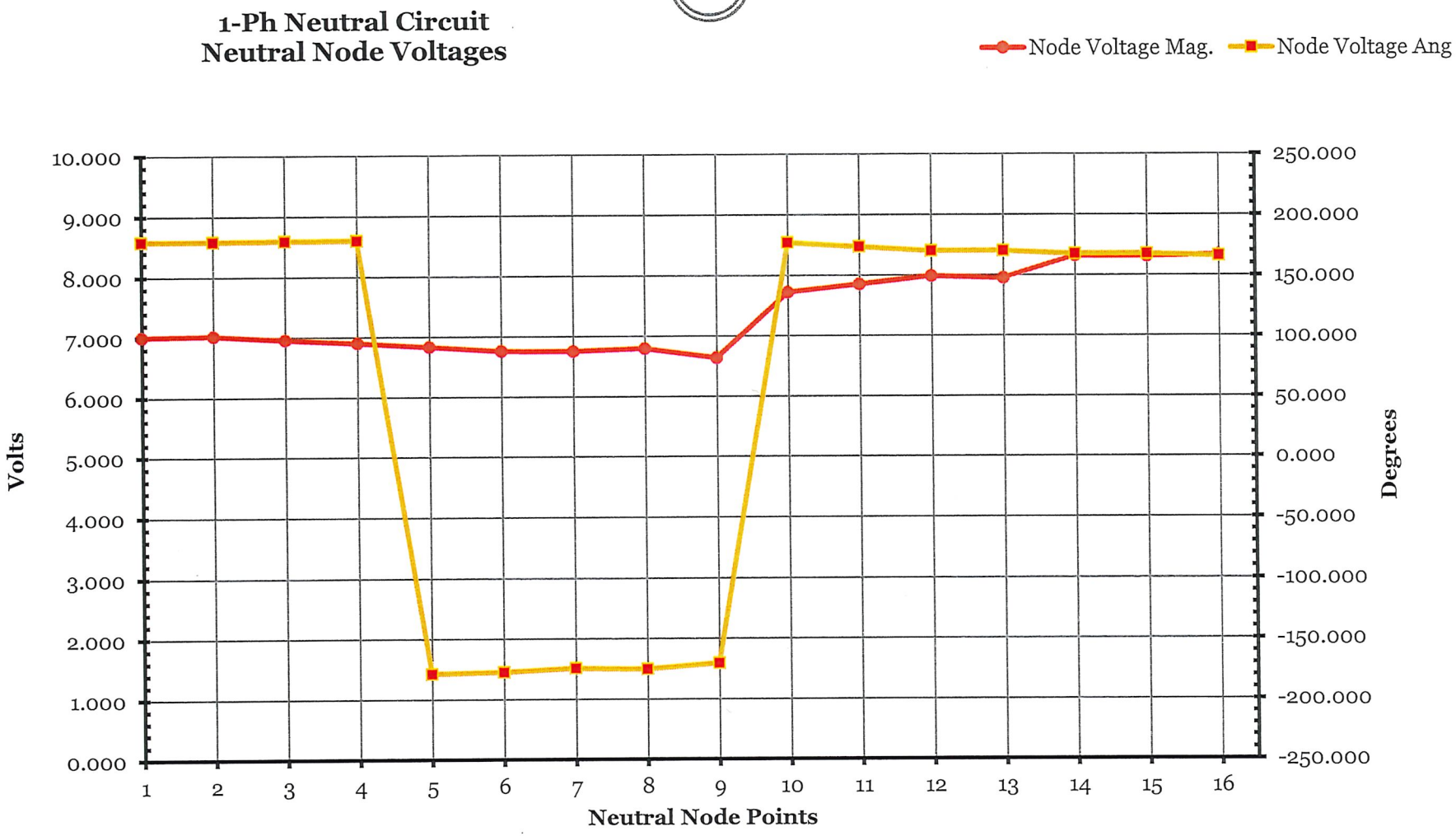
Nodal Matrix Solution

Picture worth 1000 Words



1-Phase Circuit (Figure 6)

Analysis Findings

1. The current flowing into the neutral/ground system is a constant and is not changed by increasing neutral conductor size or adding ground rods

   At any one point in time

2. Modifying the neutral conductor size, adding ground rods, or modifying ground rod resistance will change current flow in the neutral/ground system and therefore will modify NEV

3. Adding ground rods at the problem point will reduce ground rod resistance which will increase ground current into that point, and may increase NEV

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Analysis Findings

4. Voltage blocking devices are commercially available that will electrically separate the utility neutral from the customer service ground

5. Electrically separating the utility neutral from the customer service ground can significantly reduce customer NEV

6. When using neutral voltage blocking devices, the customer service ground must be separated from the utility ground rod by more than 10 feet

7. For three-phase circuits, balancing load among phases will minimize neutral/ground current NEV

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QUESTIONS & DISCUSSION

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