CASES 12-E-0201 & 12-G-0202

Exhibit __ (GCC-3)

Date of Request: September 5, 2012 Request No.: UIU- 3
Due Date: September 17, 2012

NIAGARA MOHAWK POWER CORPORATION d/b/a National Grid

Case Nos. 12-E-0201 and 12-G-0202 - Niagara Mohawk Power Corporation d/b/a National Grid Electric and Gas Rates

Request for Information

FROM: Department of State's Utility Intervention Unit

TO: Staff Consumer Issues Panel

Request: Low Income Program

Please clarify your statement on page 15 of your testimony asserting that the CIP "considered the size of the low income population, the economic conditions of the service territory, and the impacts on non participants" in determining your proposed monthly gas bill credit of $8.50.
a. In what way did the CIP consider these factors? Please provide all assumptions, both quantitative and qualitative, that support your proposal to increase the discount to $8.50 rather than to $10.00.
i. For example, what size of the low income population, economic conditions of the service territory, and impacts on non-participants would have to exist to support increasing the monthly bill credit to $10?
ii. To $12.50, as proposed by the UIU?
iii. To $15.00, as proposed by PULP?
b. How do the factors in Niagara Mohawk's service territory compare to the same factors in the other gas and electric service territories in New York. Please provide your analyses and work sheets.
c. Please state whether you weigh these factors equally or is one factor given less weight and one more? Please explain your rationale.
d. Please state and discuss whether an increase in the customer charge should be an additional factor considered.

Response:

a. We reviewed the following census and labor data, in comparison to the statewide averages: the average annual income in the Company's service territory from 2008 to 2010; the average unemployment rate in the service territory from 2009 to 2011, and the number of households living with incomes below the federal poverty line; along with other selected statistical data on low-income populations. We also reviewed the following Niagara Mohawk data: the annual total number of low-income disconnections from 2009 to 2011, the total number of reconnections in the historic test year, the average dollar amount and number of customers in arrears greater than sixty days for the historic test year 2011, and the percentage of revenues allocated to the low-income program. From our review of this data, we determined that an increase in the gas low income discount to $8.50 was appropriate. We did not consider what hypothetical scenario may have to exist in order to support an increase to $10, $12.50, or $15. Niagara Mohawk's service territory is geographically large and economically diverse. A specific formula for determining the size and scope of a low income program does not exist. As we indicated in the CIP testimony on pages 14-16, we believe that the $8.50 bill credit strikes a reasonable balance between the needs of low income customers and the costs of the program to ratepayers.

b. As shown in the attached table (UIU-3 Attachment), as a percentage of total sales revenue, Staff's proposed gas low income program, at 1.14%, would represent the highest percentage of total revenues of any major utility in New York State. On the electric side, at 0.52%, it is slightly above the statewide average of 0.50%.

For 2011, 16% of Niagara Mohawks customers had arrears due over sixty days, which is the highest in the State. In 2011, the percentage of accounts terminated was 3.5%, which is the statewide average.

Unemployment in the Company's service territory is slightly below the statewide average. In 2009, the unemployment rate in the service territory was about 7.8%, in 2010 it was about 8.1%, and for 2011, it was about 7.8%. The statewide average for those three years, were 8.3%, 8.6% and 8.2%, respectively.

According to Census Bureau data, the poverty rate in the service territory is about 13.5%, while the statewide average is about 14.2%.

c. We weigh these factors together in a comprehensive manner and strive to achieve the best balance of competing interests.

d. Niagara Mohawk has proposed an increase in the customer charge in this case, and the panel took this into consideration.

<u>Name of Respondent:</u>
Leonard Silverstein

<u>Date of Response:</u>
September 14, 2012

Utility-Based Low Income Programs

	2010 Number of Residential Customers		Estimated Number of Participants		% of Residential Customers		Annual Budget for Utility Low Income Programs		2010 Total Sales Revenues		Percent of Annual Revenues		2010 Customers		$/Cust/mo.			2010 Sales		cost per kwh or therm	
Utility	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric	Gas	Electric (kWh)	Gas (MMCF)	Gas (Th)(est.)	Electric	Gas
Central Hudson - Electric	237,920		9,450		3.97%		$2,077,700		$487,465,000		0.43%		277,984		$0.62		3,309,000,000			$0.00063	
Central Hudson - Gas		55,419		2,150		3.88%		$643,700		$132,367,000		0.49%		63,527		$0.84		11,559	119,057,700		$0.00541
Con Edison - Electric	2,807,485		375,000		13.36%		$38,750,000		$7,779,667,000		0.50%		3,308,063		$0.98		48,363,000,000			$0.00080	
Con Edison - Gas		803,108		165,000		20.55%		$6,400,000		$1,501,055,000		0.43%		1,062,140		$0.50		142,949	1,472,374,700		$0.00435
Corning		11,031		2,100		19.04%		$125,000		$16,387,000		0.76%		11,888		$0.88		1,473	15,171,900		
KeySpan NY		963,936		62,400		6.47%		$7,400,000		$1,646,647,000		0.45%		1,001,450		$0.62		149,287	1,537,656,100		$0.00481
KeySpan LI		453,225		30,400		6.71%		$4,800,000		$997,500,000		0.48%		495,001		$0.81		88,296	909,448,800		$0.00528
National Fuel Gas		586,324		29,084		4.96%		$6,400,000		$705,270,000		0.91%		619,217		$0.86		70,571	726,881,300		$0.00880
National Grid - Electric	1,224,605		125,000		10.21%		$11,850,000		$2,281,266,000		0.52%		1,327,095		$0.74		19,326,000,000			$0.00061	
National Grid - Gas		424,323		66,000		15.55%		$6,100,000		$537,338,000		1.14%		452,934		$1.12		48,076	495,182,800		$0.01232
NYSEG Electric	760,828		52,500		6.90%		$9,368,425		$1,292,704,000		0.72%		877,746		$0.89		21,738,000,000			$0.00043	
NYSEG - Gas		191,139		15,000		7.85%		$2,961,097		$308,184,000		0.96%		210,843		$1.17		27,395	282,168,500		$0.01049
O & R - Electric	193,070		12,000		6.22%		$1,000,000		$484,625,000		0.21%		223,911		$0.37		4,428,000,000			$0.00023	
O & R - Gas		116,765		6,700		5.74%		$823,000		$213,163,000		0.39%		128,301		$0.53		24,800	255,440,000		$0.00322
RG&E - Electric	325,421		36,800		11.31%		$4,179,916		$673,102,000		0.62%		365,515		$0.95		10,570,000,000			$0.00040	
RG&E - Gas		226,013		31,400		13.89%		$2,724,619		$270,450,000		1.01%		240,068		$0.95		23,467	241,710,100		$0.01127
St. Lawrence		13,825		2,200		15.91%		$132,000		$33,471,000				15,422				3,304	34,031,200		$0.00388
Total	5,549,329	3,845,108	610,750	412,434	11.01%	10.73%	$67,226,041	$38,509,416	$12,998,829,000	$6,361,832,000	0.52%	0.61%	6,380,314	4,300,791	$0.88	$0.75	107,734,000,000	591,177	6,089,123,100	$0.00062	$0.00632

Date of Request: September 5, 2012
Due Date: September 17, 2012

Request No.: UIU- 1

NIAGARA MOHAWK POWER CORPORATION d/b/a National Grid

Case Nos. 12-E-0201 and 12-G-0202 - Niagara Mohawk Power Corporation d/b/a National Grid Electric and Gas Rates

Request for Information

FROM: Department of State's Utility Intervention Unit

TO: Staff Consumer Issues Panel

Request: Low Income Program

The CIP asserts on page 12-13 of its testimony that "successful" low-income programs result in "reduced costs to the utility, and ratepayers."

a. Please identify those costs that are reduced for the utility (that is, shareholders) exclusively, those that are reduced for ratepayers exclusively, and those that are reduced jointly for both ratepayers and shareholders.

b. Please provide any analyses linking Niagara Mohawk's "special programs for its low income customers" to each specific cost reduction identified in the response to (a) above. These analyses should also include historical data, that is, the impacts on each specific cost reductions of the Company's low-income programs at the levels prior to the current Rate Plan.

c. Did the CIP perform any analysis of the impacts on the specific cost reductions of increasing the gas low-income program credit from $7.50 to $8.50, as proposed by the CIP, or from $7.50 to $10.00, as proposed by the Company? If yes, please provide. If not, why not?

Response:

1. a. We testified that, "these costs may be reduced by an effective program to assist low-income customers." Whether the savings inure to ratepayers or shareholders depends on other ratemaking factors. See our testimony page 11, line 14, through page 12, line 2, for a fuller discussion of how such costs and/or savings may be shared between ratepayers and shareholders.

b. Staff has not conducted any such analyses.

c. Staff did not conduct an analysis of the impacts on the specific ratepayer cost reductions of increasing the gas low-income program credit from $7.50 to $8.50, or from $7.50 to $10.00. We do not believe such a study was required to develop our proposal.

Name of Respondent:
Leonard Silverstein

Date of Response:
September 12, 2012

Date of Request: September 5, 2012
Due Date: September 17, 2012

Request No.: UIU- 2

NIAGARA MOHAWK POWER CORPORATION d/b/a National Grid

Case Nos. 12-E-0201 and 12-G-0202 - Niagara Mohawk Power Corporation d/b/a National Grid Electric and Gas Rates

Request for Information

FROM: Department of State's Utility Intervention Unit

TO: Staff Consumer Issues Panel

Request: Low Income Program

Please provide a citation to any documents indicating that the current monthly bill credit for electric-heating HEAP recipients is $10, as the CIP asserts on page 13.

Response:

See the Stipulation and Agreement Regarding Low Income and Economic Development (Case 10-E-0050-Exhibit 391), which was adopted by the Commission on January 24, 2011, in Case 10-E-0050.

Name of Respondent:
Leonard Silverstein

Date of Response:
September 12, 2012

Date of Request: June 13, 2012
Due Date: June 25, 2012

Request No. UIU-10E (SR-10E)
NMPC Req. No. NM-237

NIAGARA MOHAWK POWER CORPORATION

Case No. 12-E-0201 and 12-G-0202 - Niagara Mohawk Power Corporation d/b/a National Grid - Electric and Gas Rates

Request for Information

FROM: Saul Rigberg

TO: Rate Design - Electric

SUBJECT: Rate Design - Electric

Request:

10. Please provide the current monthly customer charge for all residential Service Classifications for both electric and gas.

Response:

10. The current monthly customer charges for the residential electric service classifications are:

Service Classification No. 1	$16.21
Service Classification No. 1-C (Optional Large Time of Use Rate)	$30.00

Income Eligible Basic Service Credit	$5.00
Income Eligible Basic Service Credit (Electric Heat Customers)	$15.00

The current monthly gas customer charges will be provided by the Gas Rate Design Panel in response to UIU-10G (SR-10G)

Name of Respondent:
Pamela B. Dise

Date of Reply:
June 18, 2012

Date of Request: September 12, 2012
Due Date: September 22, 2012

Multiple Intervenors Request No. 9
NMPC Req. No. ____

NIAGARA MOHAWK POWER CORPORATION d/b/a National Grid

Case 12-E-0201 and 12-G-0202 – Niagara Mohawk Power Corporation d/b/a National Grid

Request For Information

FROM: Multiple Intervenors

TO: Department of Public Service Staff Site Investigation and Remediation Panel

Request: On page 17 of its testimony, the Panel states that: "Staff's oversight and monitoring of the Company's SIR activities should further incent the Company to be vigilant in its duties and continue its efforts to minimize SIR costs." Identify all instances that Panel members are aware in which Staff advocated that utility SIR costs be disallowed as imprudent.

Response:

The SIR Panel is not aware of any instance in which Staff advocated that SIR costs should be disallowed as imprudent.

Name of Respondent:
SIR Panel

Date of Reply:
September 19, 2012

Date of Request: September 12, 2012
Due Date: September 22, 2012

Multiple Intervenors Request No. 7
NMPC Req. No. ____

NIAGARA MOHAWK POWER CORPORATION d/b/a National Grid

Case 12-E-0201 and 12-G-0202 – Niagara Mohawk Power Corporation d/b/a National Grid

Request For Information

FROM: Multiple Intervenors

TO: Department of Public Service Staff Site Investigation and Remediation Panel

Request: Has your review of Niagara Mohawk's proposed site investigation and remediation ("SIR") expense differed from that employed by Department of Public Service Staff in recent utility rate proceedings? If so, identify and explain all such differences.

Response:

The members of the Panel are familiar with Staff's review of SIR expense in the following recent rate proceedings: Cases 06-G-1185, 06-G-1186, 10-E-0362,and 11-E-0408. Our review of site investigation and remediation expenses in Niagara Mohawk's current utility proceeding did not differ from that employed in those listed proceedings.

Name of Respondent:
SIR Panel

Date of Reply:
September 19, 2012

Date of Request: June 5, 2012
Due Date: June 15, 2012

Request No. UIU-1 (SR-1)
NMPC Req. No. 180

NIAGARA MOHAWK POWER CORPORATION

Case No. 12-E-0201 and 12-G-0202 - Niagara Mohawk Power Corporation d/b/a National Grid - Electric and Gas Rates

Request for Information

FROM: Saul Rigberg

TO: Electric Infrastructure and Operations Panel

SUBJECT: Regarding Testimony pages 31-32 & 66-68 of 116

Request:

1. Panel testimony, Exhibit ____ (EIOP-10), pages 43-44 of 154, and Exhibit ___ (EIOP-19), pages 101 and 298 of 684, present the Buffalo Street Light Replacement program, noting that the "program would address repetitive incidents of elevated voltage." The Panel further states:

> Elevated voltage testing on the underground street light cable system located in the Buffalo metropolitan area has identified stray voltage incident rates from 2 to 20 times the rates measured in other areas in the Company's service territory. Based on the success of a recent cable replacement program, a 10-year program to replace street light cable circuits in Buffalo is proposed ($2.5M each year for 10 years).

a. Please explain what is meant by the phrase "repetitive incidents of elevated voltage." For example:

    i. Is the Panel referring to instances where the same object became charged more than once even though the Company took measures to resolve the elevated voltage situation shortly after it had been identified?

    ii. Does "repetitive" mean at least twice or more than twice?

b. Please confirm that "elevated voltage" in this context refers to the same condition as "stray voltage"? If not, explain what is meant by "elevated voltage" and how it differs from "stray voltage."

c. Please explain the differences, if any, between "stray voltage" and "contact voltage." Which term is more accurate to use in the context of the Company's Buffalo infrastructure?

d. The Panel acknowledges that testing results indicate that the Buffalo stray/contact voltage incident rates are higher than the rates measured elsewhere in the Company's service territory.

   i. Please explain what type of testing, mobile scanning or manual, the Panel is referring to in making its comparisons.

   ii. Please provide the number of charged objects found in each of the mobile scans, categorized by voltage levels and identified by the dates the scans took place, that have been completed in Buffalo on behalf of the Company.

   iii. Please provide the number of mobile scans conducted annually and the cost per scan.

   iv. Is the Panel aware that Buffalo's stray/contact voltage incident rate per street miles is several times greater than New York City's stray/contact voltage incident rate per street mile? If yes, is the Panel able to explain why the incident rates are so different?

e. Panel testimony, in addition to the exhibits referred to earlier, indicates that the underground street lighting cables are more than 50 years old and that the Company proposes to replace about 14% of the cables over a 10-year period at a cost of $2.5 million each year.

   i. Please confirm that at the proposed replacement rate it would take more than 60 years to replace all of the (already more than 50 year old) "deteriorated street light cable in the Buffalo area."

   ii. Is the Panel aware of any studies or analyses showing the impact on safety and reliability, as well as on the frequency of failures or elevated voltages, of replacing deteriorated cable at the rate of 1.4 % per year versus any other rates? If so, please provide the studies or analyses.

   iii. Is the Panel aware of any studies or analyses showing the impact of replacing deteriorated cable at the rate of 1.4 % per year on the Company's levels of safety and reliability, as well as on the frequency of failures or elevated voltages, compared to other New York utilities? If so, please provide the studies or analyses.

   iv. How will the Company determine which cables to replace each year? That is, will the selection be targeted based on the results of mobile scans (or another method of discovery of elevated voltages), or will all cables in a particular area be replaced whether or not an individual cable is likely to cause a problem in the short-term or in the mid-term?

Response:

a.

i. The use of the term "repetitive" in this context refers to street light circuit cables that are deteriorated such that repairs to mitigate elevated or stray voltage from occurring at a location do not necessarily provide long term correction due to the existing circuit and cable condition.

ii. A street light circuit could be impacted twice or more due to deteriorated condition of the cables on circuits where repetitive incidents have occurred.

b. The use of the terms "elevated voltage" and "stray voltage" are considered equivalent in regard to the context of the question and definition provided in the NYPSC's December 10, 2008, Order Adopting Changes to Electric Safety Standards in Case 04-M-0159 (the "Order").

c. The existing definition from the Order (Appendix A, Section 1(c)) utilizes the term "stray voltage" defined as voltage conditions on electric facilities that should not ordinarily exist. The Order does not define "contact voltage."

d.

i. The Buffalo testing is completed twice per year utilizing a mobile scan.

ii. The results of the Buffalo mobile scans are provided below.

			Event/Hits			
Buffalo	2009	2010 Scan-1	2010 Scan -2	2011 Scan-1	2011 Scan-2	2012 Scan -1
Dates Inspected	10/02/2009 10/30/2009	06/07/2010 08/12/2010	08/30/2010 10/28/2010	06/06/2011 07/15/2011	08/17/2011 10/20/2011	05/07/2012 05/30/2012
Total Events	**2,677**	**931**	**837**	**714**	**566**	**316**
Events 4.5V and above	861	275	212	141	91	86
Events 4.4V and below	1,816	656	625	573	475	230

iii. The mobile scans for Buffalo occur twice per year at a current cost of $940,500 per scan.

iv. The panel has not studied the New York City incident rate per street mile scenario in the question.

e.

i. The Company did not propose to replace all street light cable in Buffalo, but rather zones where high incident rates of stray voltage have been experienced due to cable deterioration and configuration. The current plan to do this work is estimated at 10 years. The Company is not proposing a 60 year replacement program.

ii. The Panel is not aware of any studies showing the impact on safety or reliability, as well as on the frequency of failures or elevated voltages, by replacing deteriorated cable at the rate of 1.4% per year versus other rates. The Company is aware that the work planned over a 10 year period is projected to reduce the elevated voltage incident/mile ratio from 0.67 to 0.21. A study by the State University of New York at Buffalo ("UB") resulted in four recommendations:

    1. Continued mobile scanning to help identify issues within the street light circuit.
    2. Replacement of the old 3-wire system with the 4-wire system as discussed in the paper.
    3. Improved record keeping to assist in future trouble shooting.
    4. Increasing the current 1V limit to a more appropriate yet safe level of 8V.

    The UB study is provided as Attachment 1 to UIU-1(SR-1).

iii. The Panel is not aware of any studies or analyses showing the impact of replacing deteriorated cable at the rate of 1.4% per year on the Company's levels of safety or reliability, as well as on the frequency of failures or elevated voltages, compared to other New York utilities. Please see the response to question 1.e.ii, above.

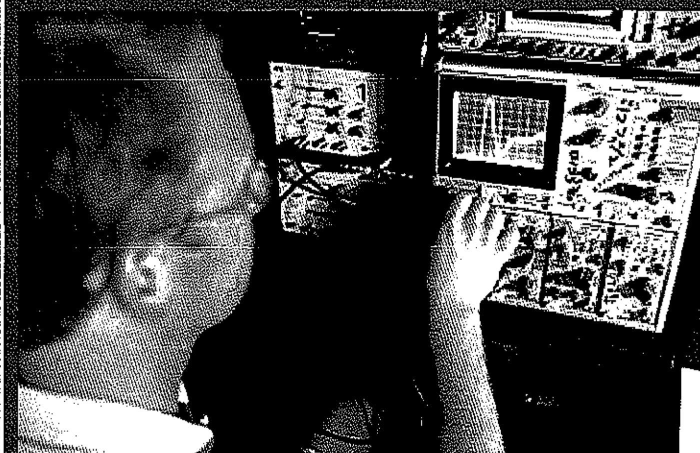
iv. The data from the mobile surveys can be utilized to determine areas for cable replacement. Zones for replacement will be prioritized based on the greatest impact where replacement will reduce the number of incidents. In the zones chosen for replacement, all cable will be replaced.

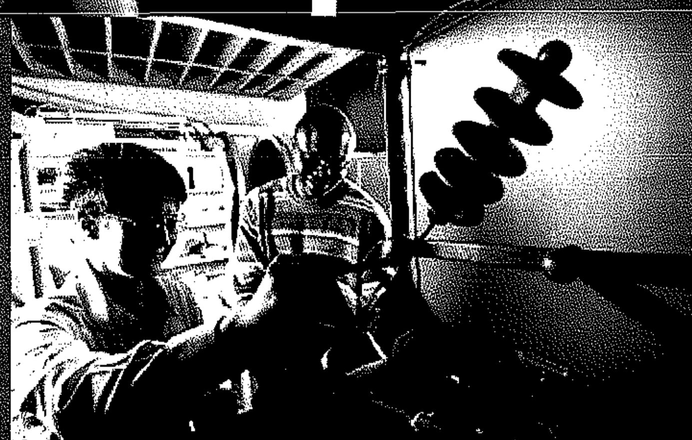
Name of Respondent:
Allen Chieco

Date of Reply:
June 14, 2012

Street Light Stray Voltage Investigation

Final Report





Energy Systems Institute
University at Buffalo
4/29/2011

Dr. Jennifer L. Zirnheld, Assistant Professor, Director
Dr. Kevin M. Burke, Adjunct Instructor, Deputy Director
Mr. T. Michael DiSanto, UB/National Grid Fellow

Energy Systems Institute
University at Buffalo
313 Bonner Hall
Buffalo, NY 14260
(716) 645-1033
zirnheld@buffalo.edu

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ABSTRACT

The University at Buffalo's Energy Systems Institute has investigated the occurrence of stray voltage in the City of Buffalo. The street light circuits have been the cause of many neutral-earth elevated voltages to develop on street light standards. In 2009 testing revealed 2556 occurrences, or light standards with voltages greater than 1V. In 2010, the same scanning area produced 931 occurrences. The causes of stray voltage were studied and analyzed using computer circuit modeling programs. The results of the computer simulations indicate that imbalances caused by corroded cabling, phase faults, and load mismatches result in neutral-earth elevated voltages on bonded light standards. The 4-wire system has been recommended as it solves many, but not all, stray voltage situations. A discussion on electrical safety is provided that aims to derive appropriate stray voltage limits. It was found that the variability in contact resistance (hand-light standard, foot-ground) plays a large role making it difficult to establish an explicit number. However, it was determined that current stray voltage limits have several safety factors built in, to the point that they may be excessively high. Other recommendations to the utilities include advanced record keeping to aid with future diagnostics and troubleshooting to reduce both down time and cost.

I. INTRODUCTION

The growth of the electrical utility distribution system over the years has not been without its complications. One issue that has gained some traction in recent years is neutral-elevated voltages (NEV), which is known more colloquially as stray voltage. The history of stray voltage extends back many years with the earliest complaints generated out of the mid-west farming industry. In response to farmers complaints of decreased milk production and the negative behavioral responses of cows in milking parlors, scientists conducted a study to investigate the effect that electrical current had on the cows [1]. The results corroborated the general mentality amongst the dairy farmers that the stray voltage was having an impact on the behavior of the cows. Armed with the results of the study, the dairy farmers lobbied the Wisconsin legislation which ultimately ruled in their favor by mandating that the utilities limit stray voltage to less than 0.5V on dairy farms [2]. Other states would soon enough sanction limits following similar law suits. Up to this point, the concern over stray voltage was seemingly isolated to dairy farmers; it was not until early in the 21st century that stray voltage discussion began in the context of metropolitan areas. The legislation of stray voltage on dairy farms was seemingly used as a precedent in much of the regulation the utilities face today regarding stray voltage in many of America's cities.

Stray voltage has been used as a general blanket term by the public, legislators, and even the utilities themselves to describe undesired voltages on objects that should not be energized. It is very important, however, to identify the appropriate nomenclature to avoid confusion. The Institute of Electrical and Electronics Engineers (IEEE) has established a working group to define stray voltage.

This group defines stray voltage as:

> ***Stray Voltage:*** *A voltage resulting from the normal delivery and/or use of electricity (usually smaller than 10 volts) that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public and/or their animals. Stray voltage is caused by primary and/or secondary return current, and power system induced currents, as these currents flow through the impedance of the intended return pathway, its parallel conductive pathways, and conductive loops in close proximity to the power system. Stray voltage is not related to power system faults, and is generally not considered hazardous.* [3]

Contact voltage is another type of elevated voltage that can occur on a metal object that is often confused with stray voltage. The IEEE working group on stray voltage defines contact voltages as the following:

> ***Contact Voltage:*** *A voltage resulting from abnormal power system conditions that may be present between two conductive surfaces that can be simultaneously contacted by members of the general public and/or their animals. Contact voltage is caused by power system fault current as it flows through the impedance of available fault current pathways. Contact voltage is not related to normal system operation and can exist at levels that may be hazardous.* [3]

Stray voltage can develop on any metallic object such as guard rails, street signs, man-hole covers, and street light standards. In the Buffalo metropolitan area, street light circuits have been the main cause of stray voltage occurrence. The analysis and discussion of this document will therefore be limited to street light related stray voltage.

The following section will discuss some of the main causes of stray voltage and several simulation cases are presented. An overview of government regulation of stray voltage is presented in section III which illustrates the history of legislation in many states. Much of the current legislation is based on a defined safety threshold. These safety thresholds are discussed in detail in section IV to shed light on what an appropriate safety limit should be from a regulation standpoint. Lastly, this work is summarized in V which provides some general recommendations based on the conclusion of this work.

II. STRAY VOLTAGE ANALYSIS

The root cause of many stray voltage issues are the result of an imbalance in the neutral return path of the light circuit. However, there could be several reasons why a circuit becomes imbalanced which makes diagnosing stray voltage problems particularly difficult. The imbalances can occur if the underground cabling becomes compromised in any way. Underground cabling is prone to the long term effects of multifactor stress aging which results in insulation breakdown and eventually failure. Corrosion also usually occurs at connection points within the light standard itself. The corrosion can raise the overall impedance of the connection which will change the characteristics of the overall circuit. Human factors also play a role in contributing to circuit imbalances, including construction or road crews that recklessly drive posts or signs into the ground causing faults or otherwise damage the cabling. Additionally, construction projects such as the addition or modification of roadways or walking paths sometimes require light standards to be relocated to other circuits. These modified circuits no longer match their original design and therefore could suffer from imbalances. Another, albeit continuously variable, contributor is environmental conditions. The moisture content, temperature, and composition of the soil will determine how conductive it is. A poorly insulated cable in cool and dry soil conditions will behave differently than if it were buried in an area that was warm and moist.

A. Simulations

In order to analyze how various imbalances produce stray voltage, various simulations were carried out. The circuit simulation and analysis package that was used was Orcad PSPICE® 9.2 Lite Edition. The physical layout of the circuit is shown in Figure 1 which shows a transformer feeding 8 street lights.

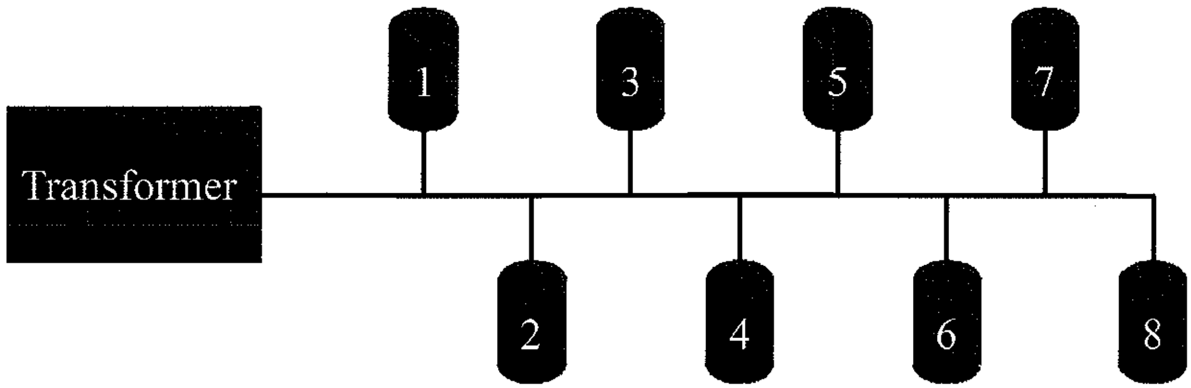

Figure 1: Physical layout representation of street light circuit.

The number of street lights was limited to 8 for all the simulations performed due to the constraints of the program. This layout is represented schematically in Figure 2.

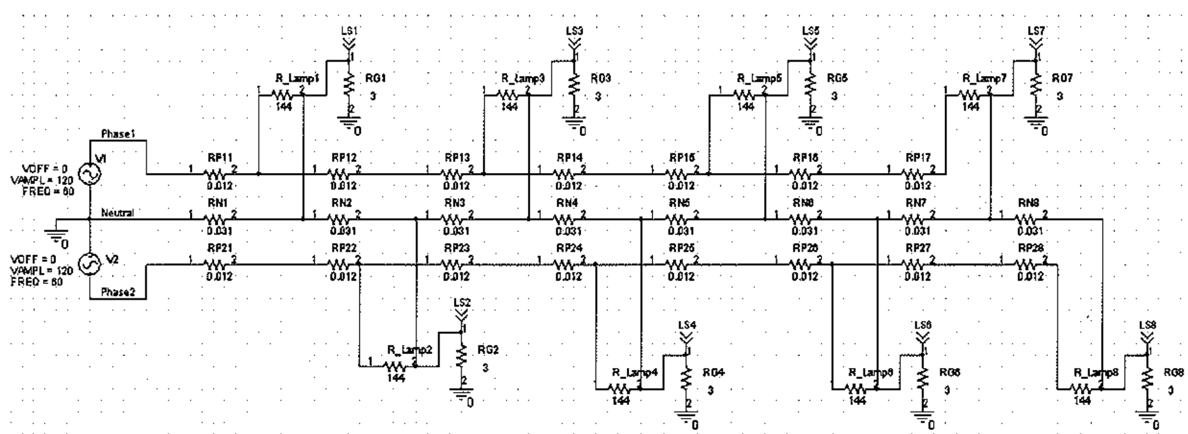

Figure 2: Schematic representation of a balanced street light circuit with 8 lamps

The center tap transformer feed provides two phases or "hot legs" which are 180° out of phase, and a grounded neutral. In an ideal case, every other street light would be powered of the same phase (ie lights 1,3,5,7 are on phase 1 and lights 2,4,6,8 are on phase 2). In this configuration the light circuit will be as balanced as possible. The simulation factors in the various cabling resistances which are shown in Figure 2. The cable resistances are based on the assumption that the length of cable between light standards is 50ft. The two phase cables are assumed to be 4AWG insulated copper with a dc impedance of 0.012Ω for the 50ft. length. The neutral cables are assumed to be 8AWG insulated copper with a dc impedance of 0.031Ω for the 50ft. length. The ground rod resistance was assumed to be 3Ω [4] which includes the ground rod/earth interface resistance. The voltage sources were set to 120V ac with a frequency of 60Hz and the lamps are assumed to be 100W units (144Ω impedance).

1. Sim case 1 - Balanced configuration

The balanced configuration was considered a baseline simulation case. The configuration was shown in Figure 1 and is considered the ideal case. The results of the simulation are shown in Figure 3 through Figure 6.

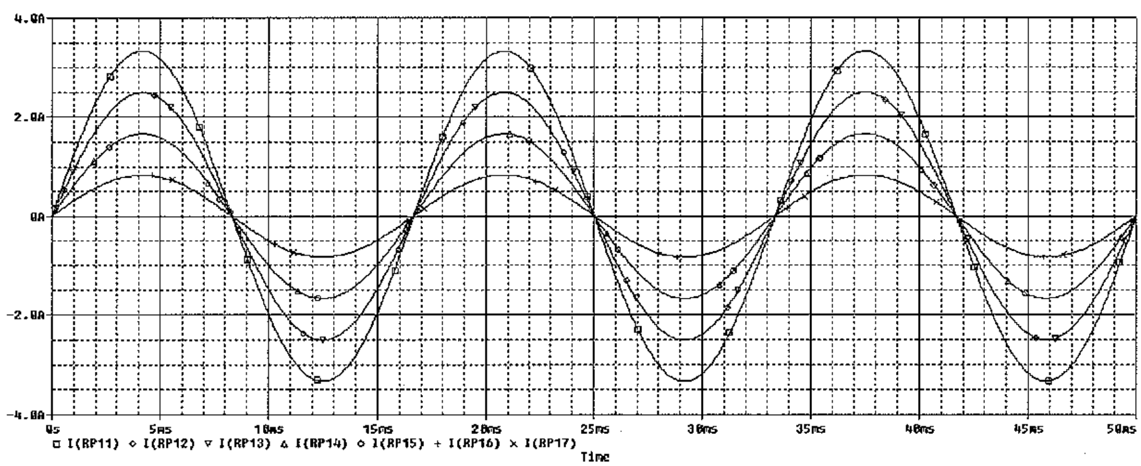

Figure 3: Sim case 1 (Balanced configuration) - phase 1 currents

Figure 3 and 4 show the phase 1 and phase 2 currents of the baseline simulation. The currents are nearly identical in magnitude and the light standards closest to the transformer have larger currents.

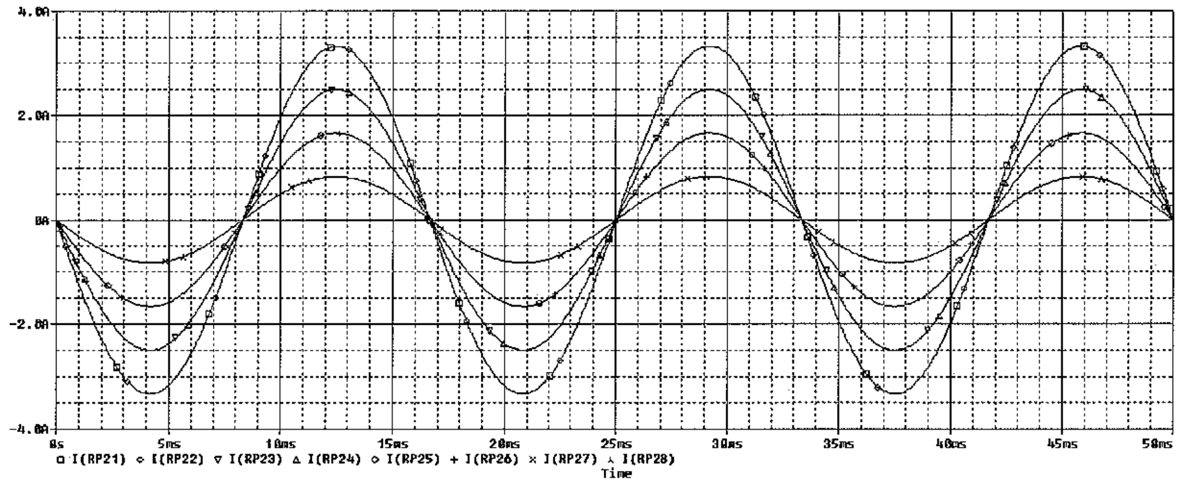

Figure 4 Sim case 1 (Balanced configuration) - phase 2 currents

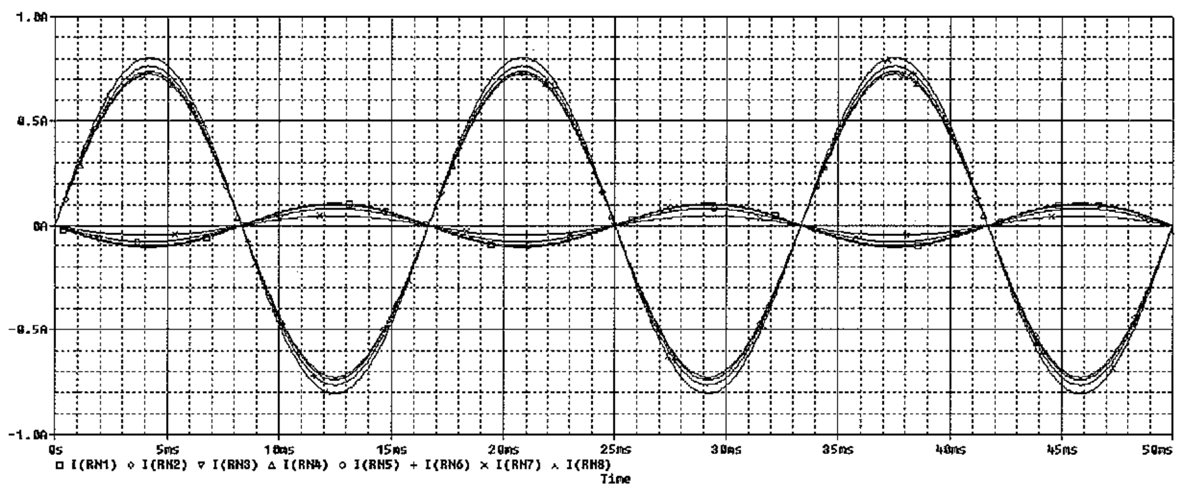

Figure 5 Sim case 1 (Balanced configuration) - neutral currents

Figure 5 and 6 show the neutral currents and the stray voltage on the light standard respectively. The neutral currents for the baseline configuration are approximately 0.75A for lights 2, 4, 6, and 8, and approximately 0.1A for lights 1, 3, 5, and 7. The light standards positioned closer to the transformer (ie lights 1, 2, 3) have lower stray voltages compared to the light standards furthest away (ie lights 6, 7, 8). All light standards however, are less than 90mV.

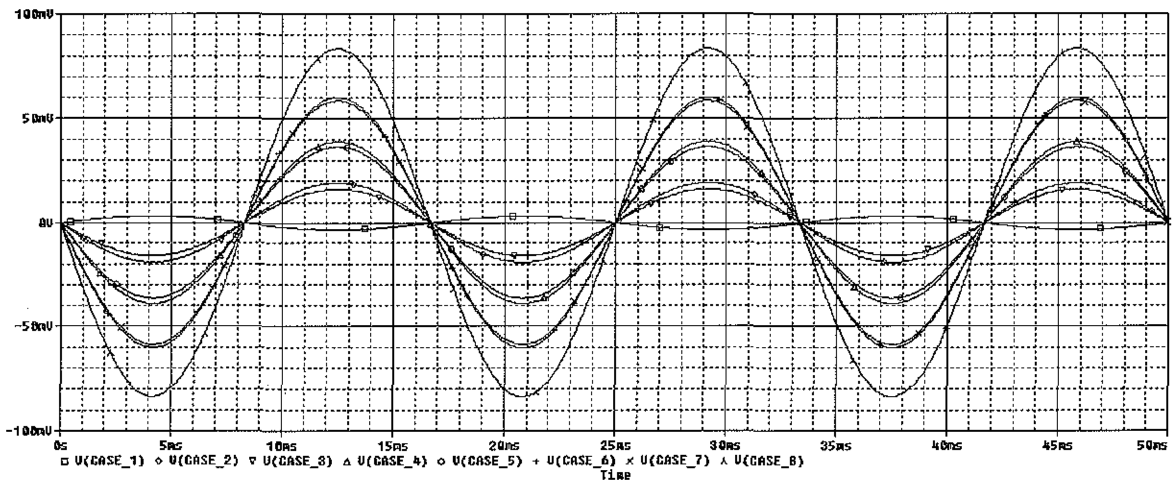

Figure 6 Sim case 1 (Balanced configuration) - voltage on light standard (stray voltage)

2. Sim case 2 - Unbalanced configuration

The unbalanced configuration is similar to that shown in Figure 1 except that lights 1-7 are powered off of phase 1 and lamp 8 is powered off of phase 2. This situation creates a "design imbalance" since the circuit has been hard wired in this configuration. These results are shown in Figure 7 through Figure 10.

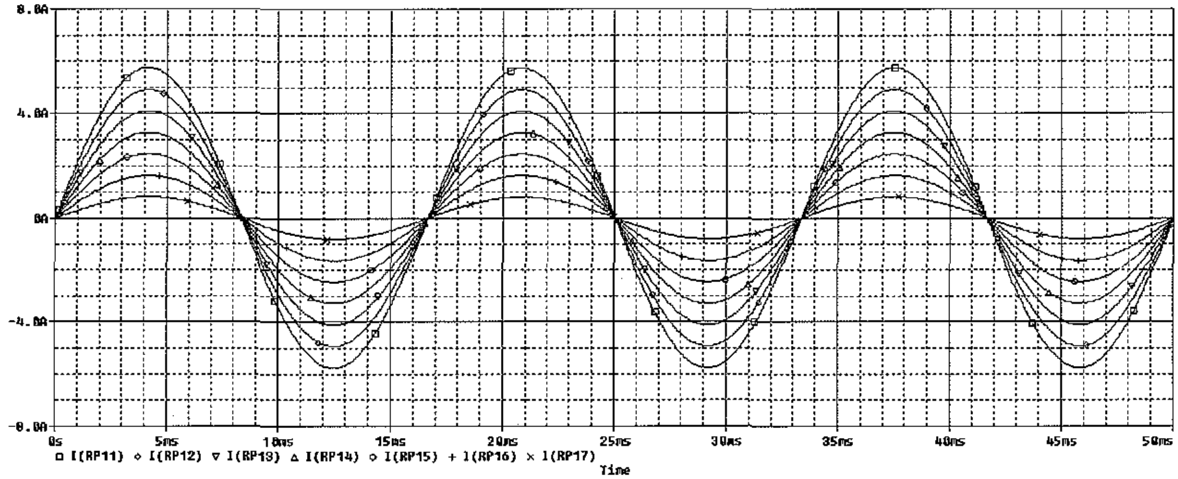

Figure 7 Sim case 2 (unbalanced configuration) - phase 1 currents

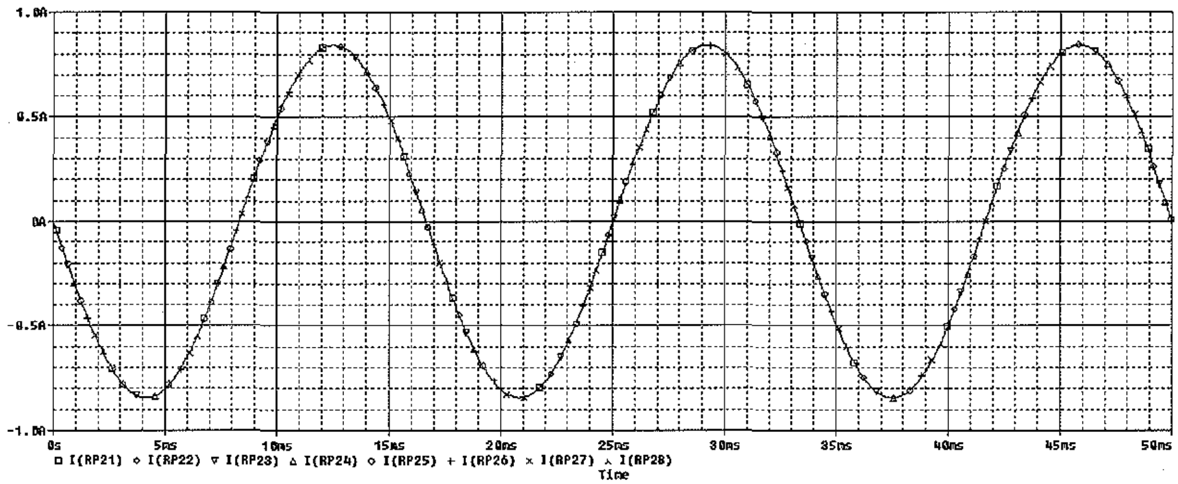

Figure 8 Sim case 2 (unbalanced configuration) - phase 2 currents

The phase 1 currents for the unbalanced configuration roughly doubled from the baseline case since it is powering almost all of the lights. Conversely, the phase 2 current was reduced since it was only powering one lamp.

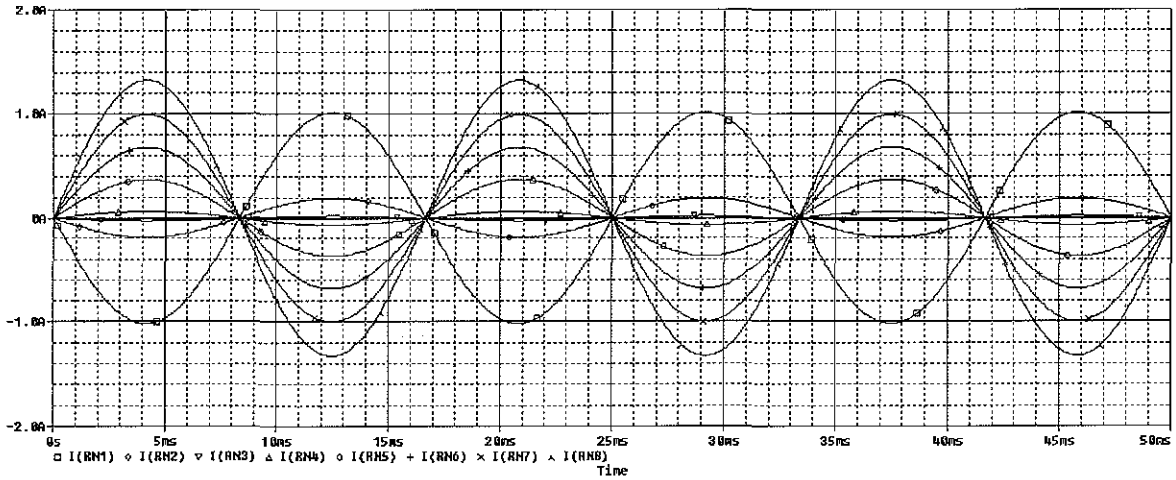

Figure 9 Sim case 2 (unbalanced configuration) - neutral currents

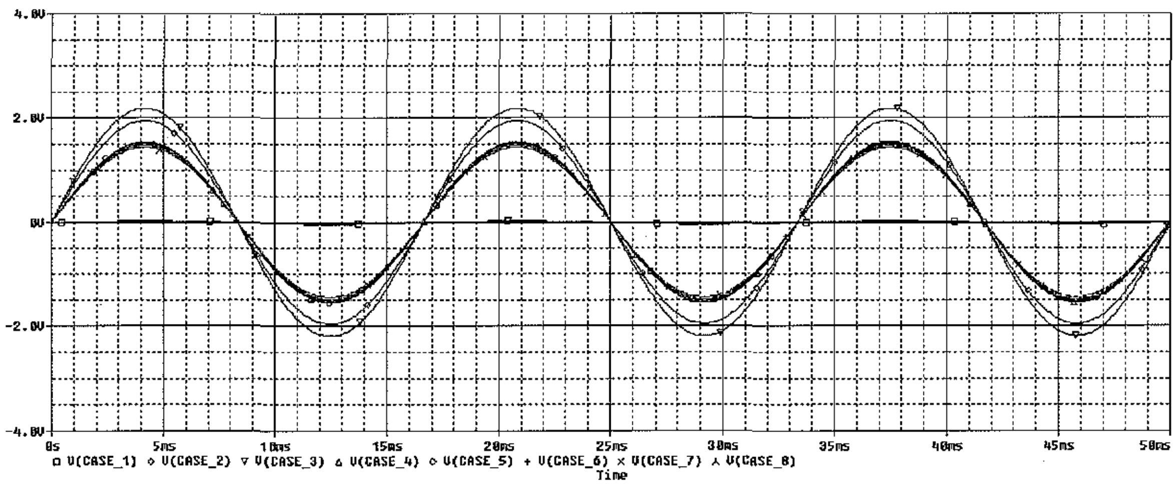

Figure 10 Sim case 2 (unbalanced configuration) - voltage on light standard (stray voltage)

The distribution of the neutral currents has changed significantly as well; the overall magnitudes have increased as well. The increase in the neutral currents has resulted in a voltage developing at the light standard. With the exception of the light standard closest to the transformer, the value of the stray voltages range from 1.5 - 2V on all other light standards.

3. *Sim case 3 - Corroded neutral (i)*

This simulation case represents situations where a section of neutral cable has corroded causing increased impedance for that particular length of cable. The corroded neutral impedance was assumed to be 100Ω and was positioned between light standards 1 and 2 as shown in Figure 11. The circuit is otherwise balanced; lights 1, 3, 5, and 7 are powered from phase 1 and the rest are on phase 2. The results of this simulation case are shown in Figure 12 through Figure 15.

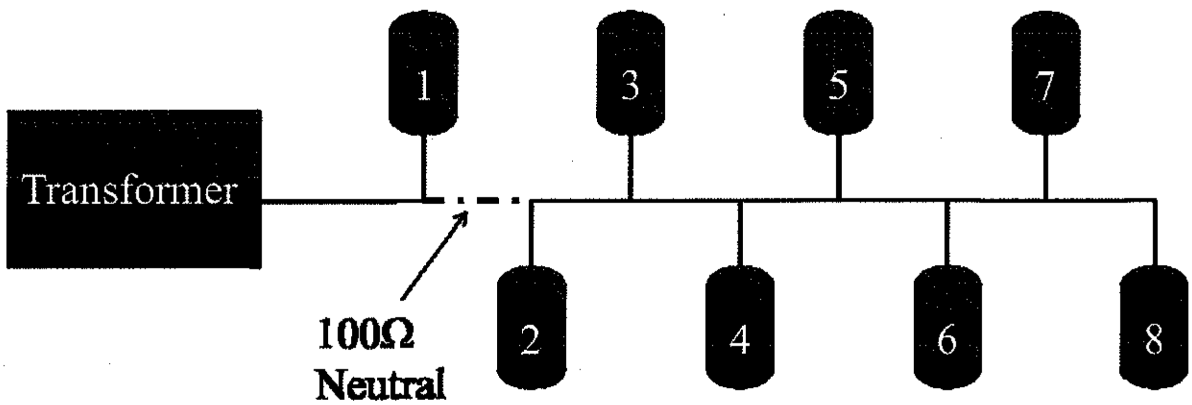

Figure 11 Representation of circuit layout showing the position of the corroded neutral.

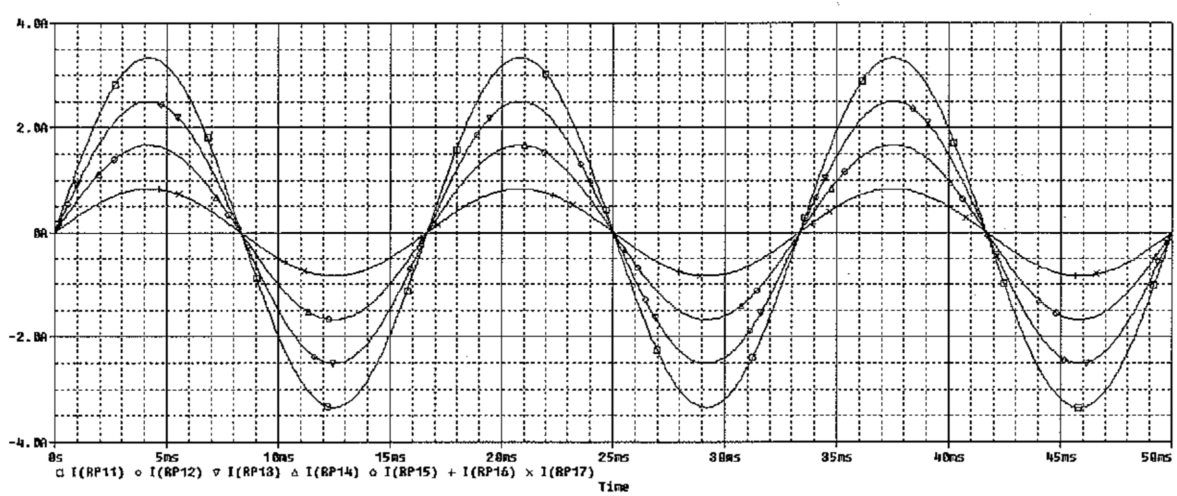

Figure 12 Sim case 3 (corroded neutral -i) - phase 1 currents

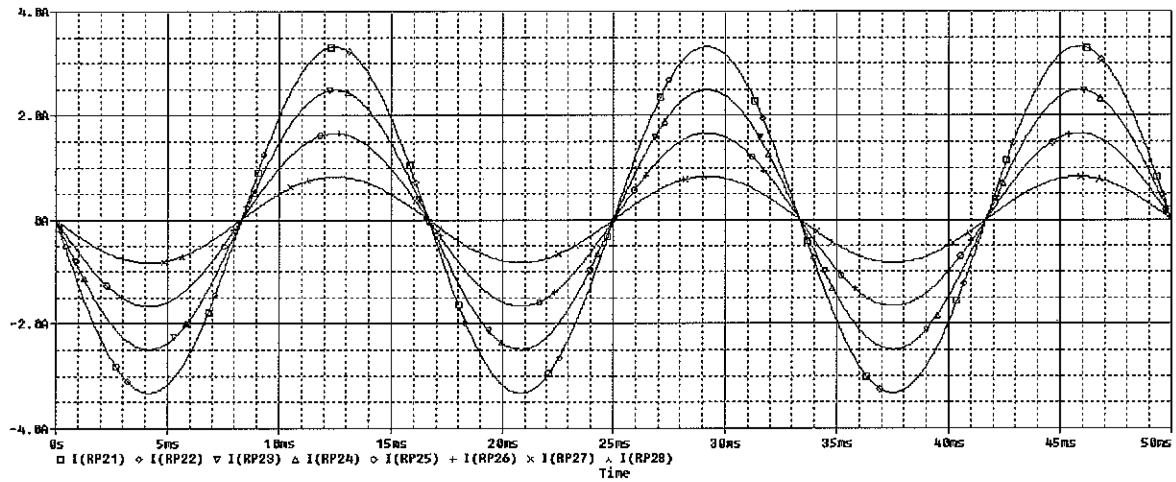

Figure 13 Sim case 3 (corroded neutral -i) - phase 2 currents

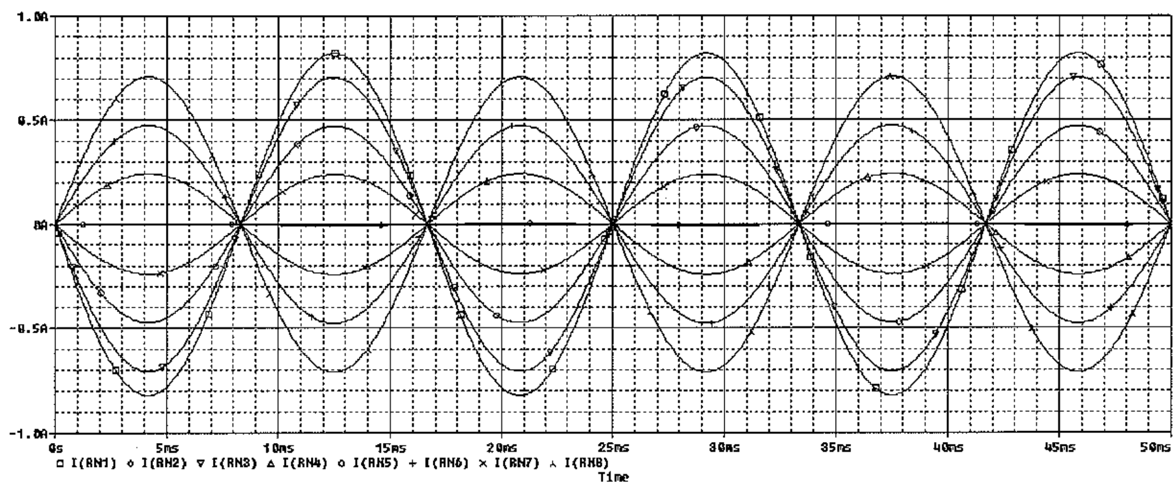

Figure 14 Sim case 3 (corroded neutral -i) - neutral currents

The phase 1 and phase 2 currents for this simulation case are nearly identical to the baseline case. However, since the corroded neutral was placed nearest the transformer, this has created a higher impedance path for the return currents. This resulted in the neutral current distribution to be more like sim case 2 rather than the baseline case, although the magnitudes are closer to the baseline case.

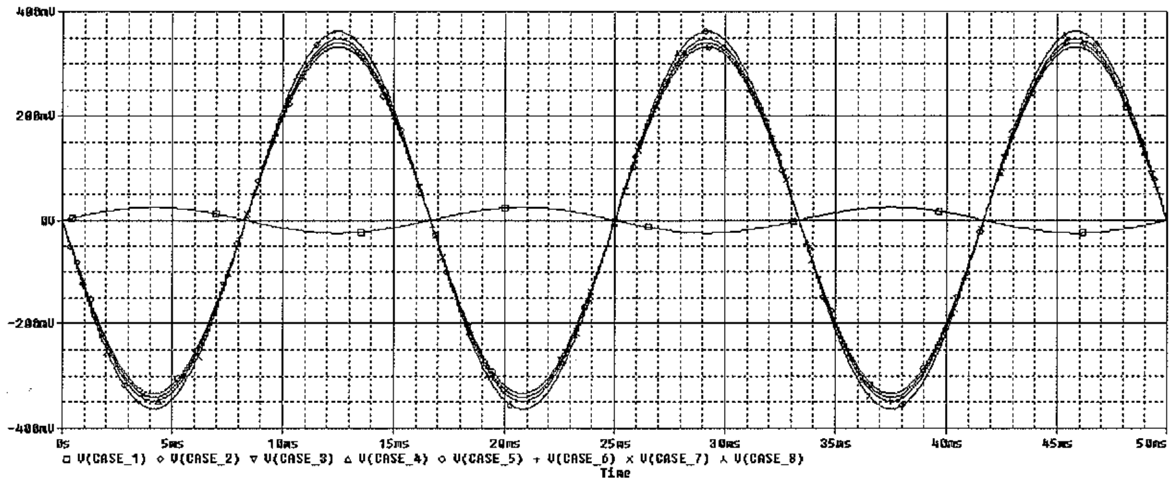

Figure 15 Sim case 3 (corroded neutral -i) - voltage on light standard (stray voltage)

The similar neutral current magnitudes resulted in the highest stray voltage value to rise from approximately 75mV in the baseline case to 350mV. The baseline stray voltage values, while lower, also decreased in magnitude with decreasing distance from the transformer. In this simulation case, the stray voltage present on all of the light standards located after the corroded neutral are of the same magnitude.

4. *Sim case 4 - Corroded neutral (ii)*

This simulation case is the same as simulation case 3 except the placement of the corroded neutral is placed between light standards 7 and 8 as shown in Figure 16.

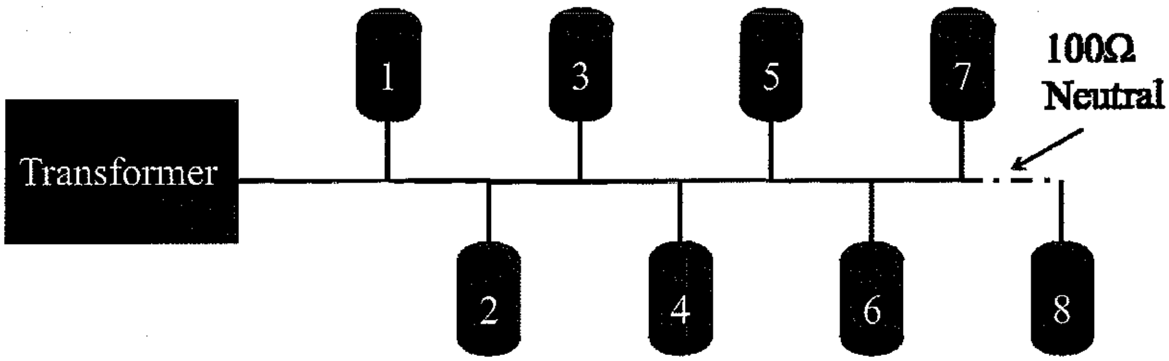

Figure 16 Representation of circuit layout showing the position of the corroded neutral.

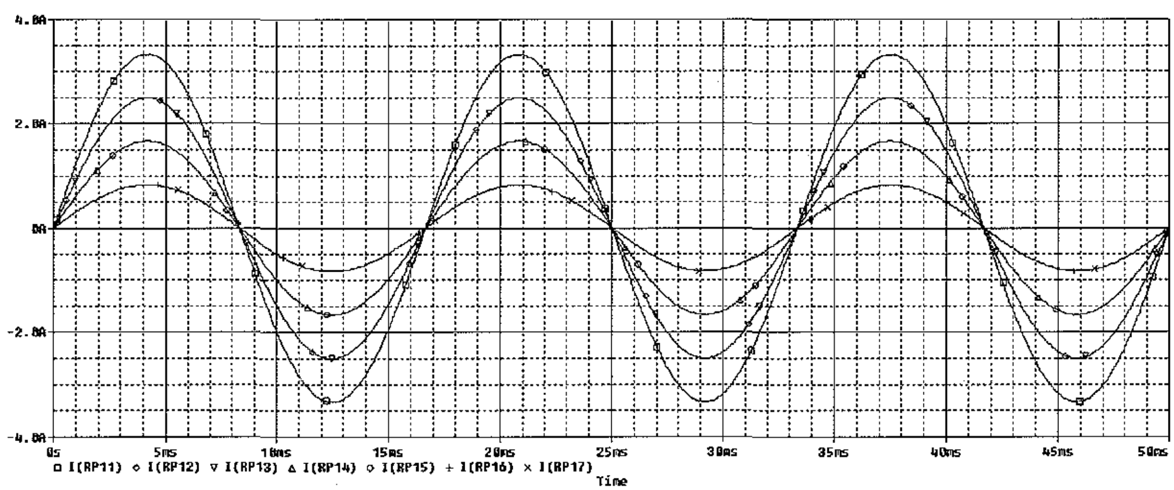

Figure 17 Sim case 4 (corroded neutral -ii) - phase 1 currents

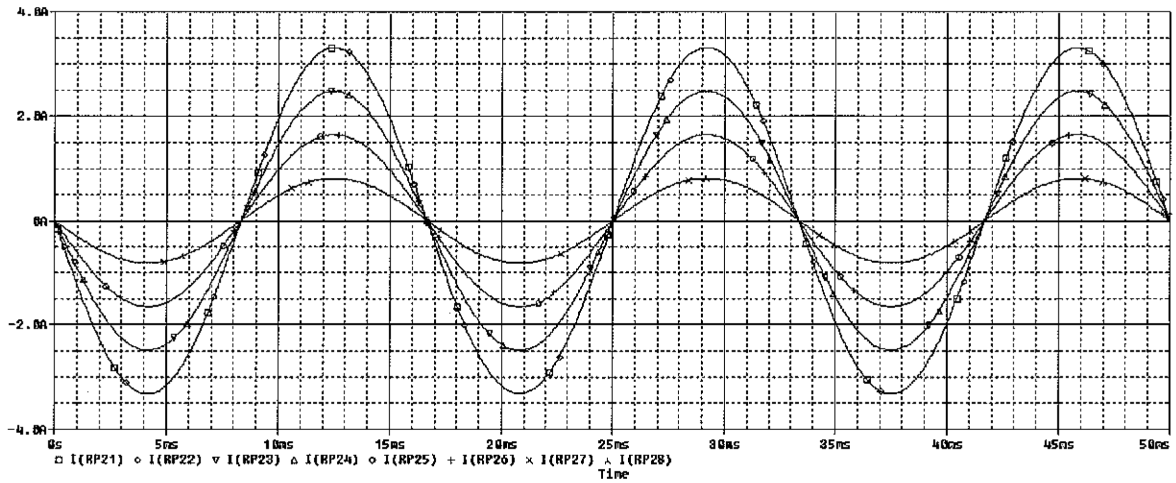

Figure 18 Sim case 4 (corroded neutral -ii) - phase 2 currents

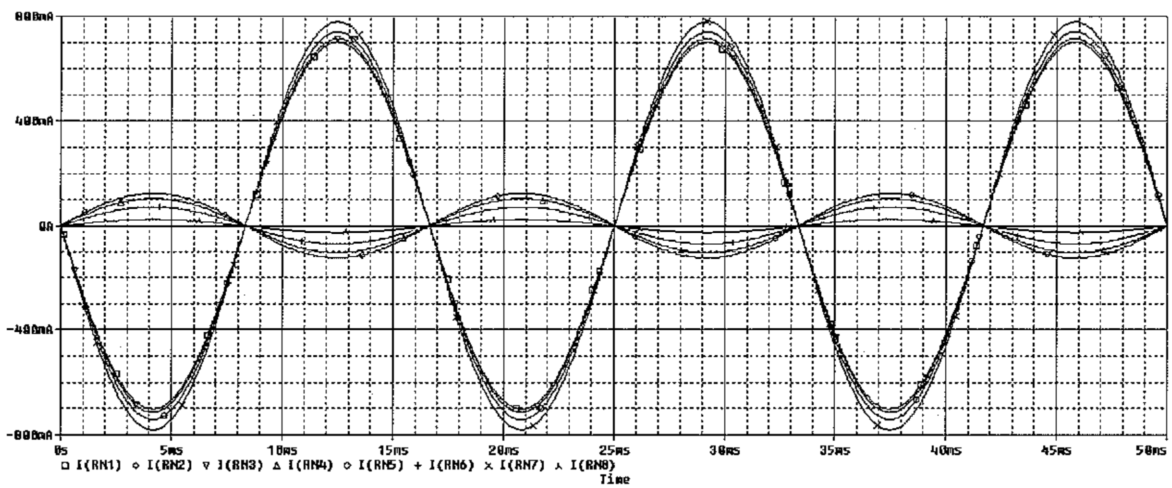

Figure 19 Sim case 4 (corroded neutral -ii) - neutral currents

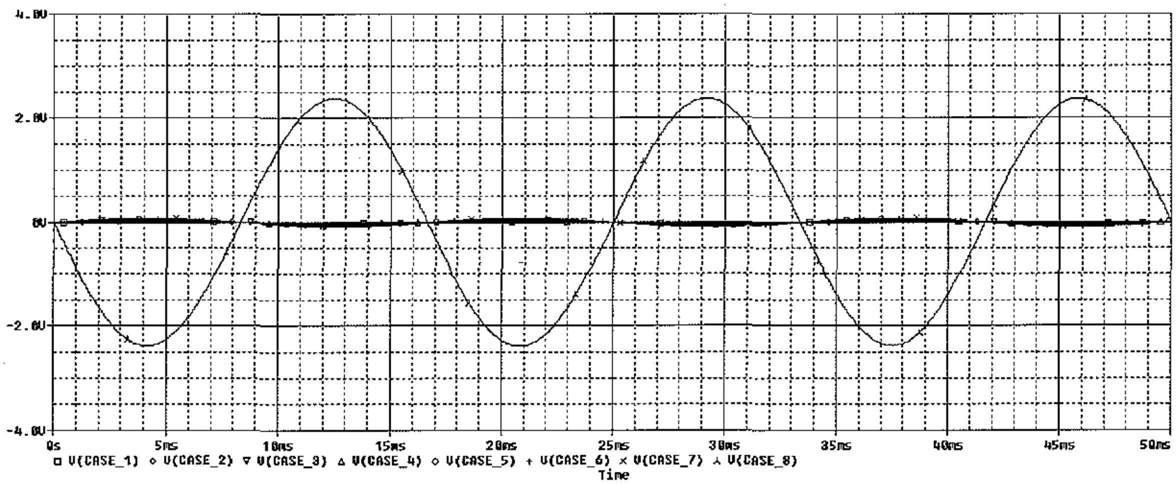

Figure 20 Sim case 4 (corroded neutral -ii) - voltage on light standard (stray voltage)

The phase currents again are the same as the baseline case and the distribution of neutral currents are closer to the baseline case rather than sim case 3. Since the location of the corroded neutral was far from the transformer the other neutral currents were not as affected compared to the previous simulation case. This translates into only a single elevated stray voltage on light standard 8 while the rest of the light standard voltages remain at low levels comparable to the baseline values.

5. Sim case 5 - Phase to ground fault (i)

This simulation considers the situation when one of the phases is faulted to ground due to some sort of insulation failure. The impedance of the fault is assumed to be 10Ω. The phases are balanced similar to simulation case 1 with the fault on phase 2 as shown in Figure 21. The results of this simulation are shown in Figure 22 through Figure 25.

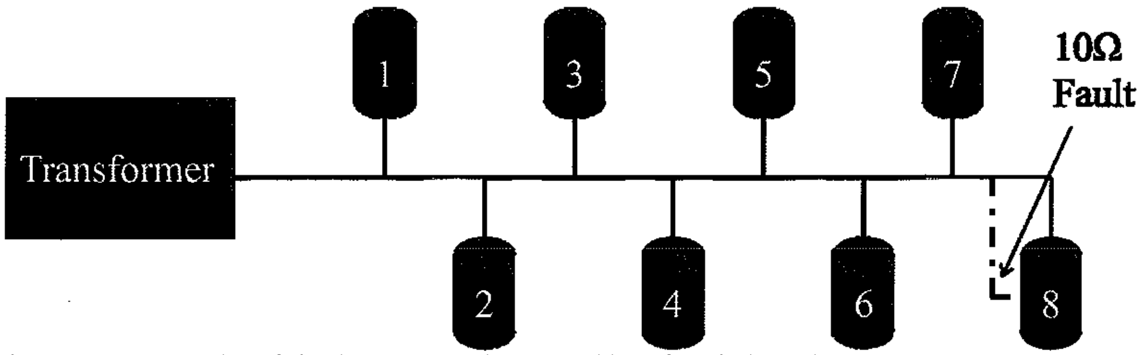

Figure 21 Representation of circuit layout showing the position of the fault on phase 2.

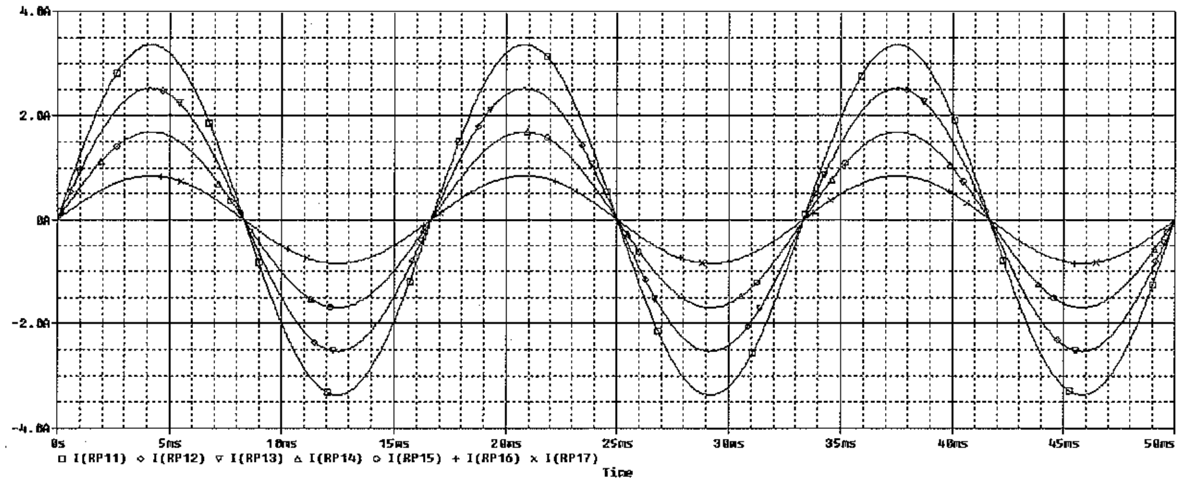

Figure 22 Sim case 5 (faulted phase -i) - phase 1 currents

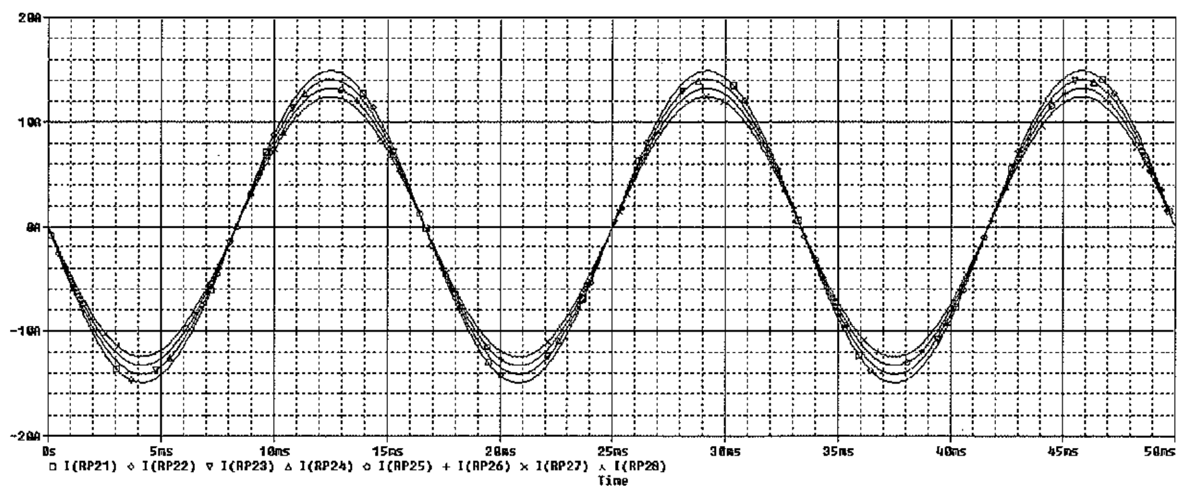

Figure 23 Sim case 5 (faulted phase -i) - phase 2 currents

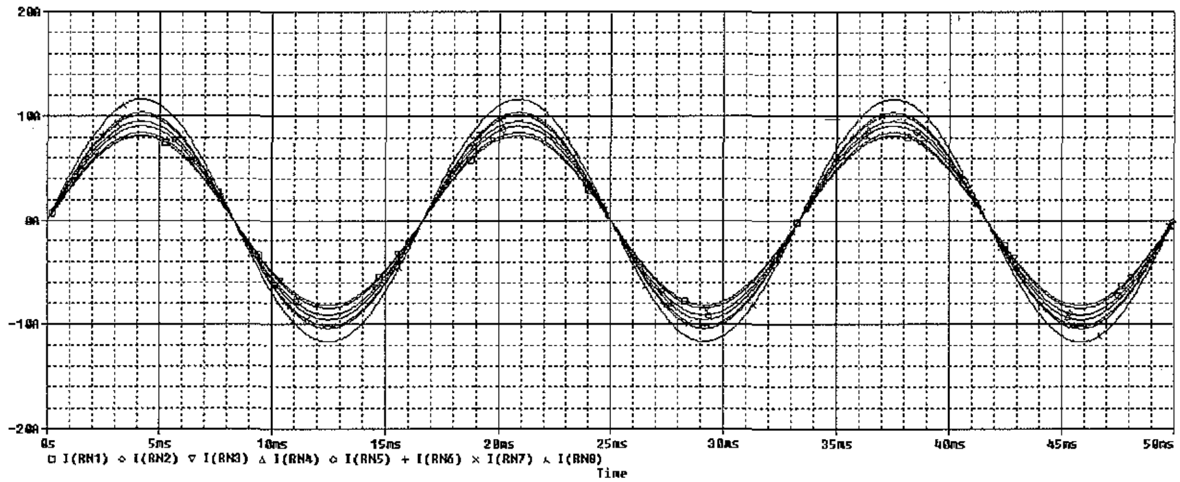

Figure 24 Sim case 5 (faulted phase -i) - neutral currents

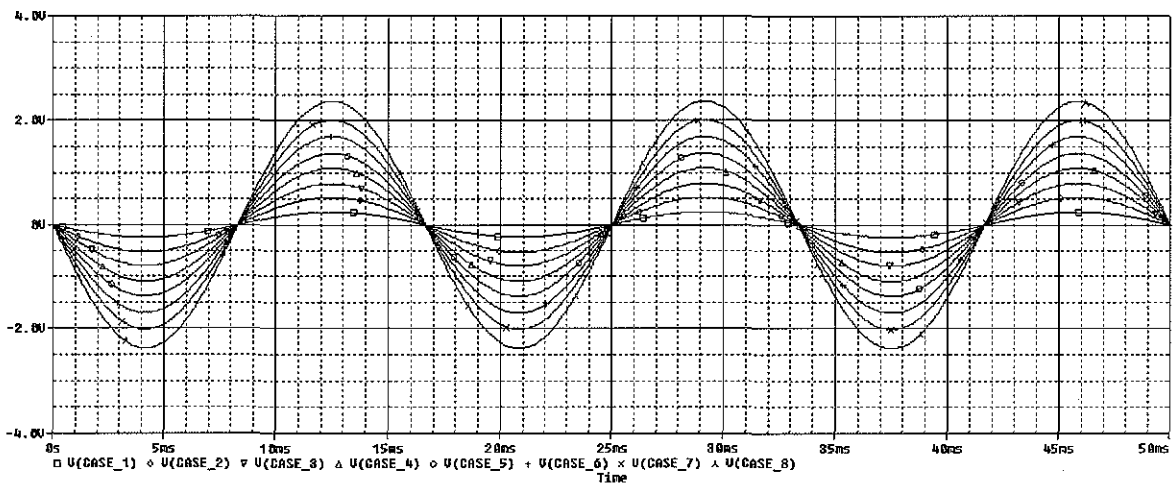

Figure 25 Sim case 5 (faulted phase - i) - voltage on light standard (stray voltage)

The phase 1 currents are unchanged from the baseline case as expected. The phase 2 currents are clearly higher due to the low impedance fault on phase 2. The neutral currents are therefore also considerably higher in magnitude as well with the average peak amplitude just under 10A. The amplitude of the stray voltage on the light standards is highest near the location of the fault with a peak value of about 2.5V, while the peak amplitude nearest the transformer is only about 250mV.

6. Sim case 6 - Phase to ground fault (ii)

This simulation case is the same as simulation case 5 except the fault impedance has been reduced to a value of 1Ω. The results are shown in

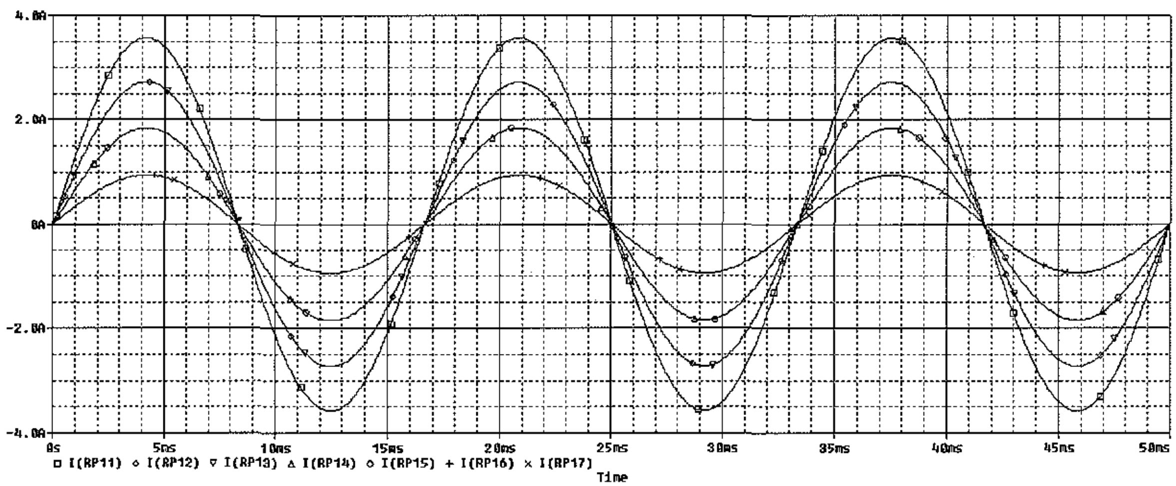

Figure 26 Sim case 6 (faulted phase - ii) - phase 1 currents

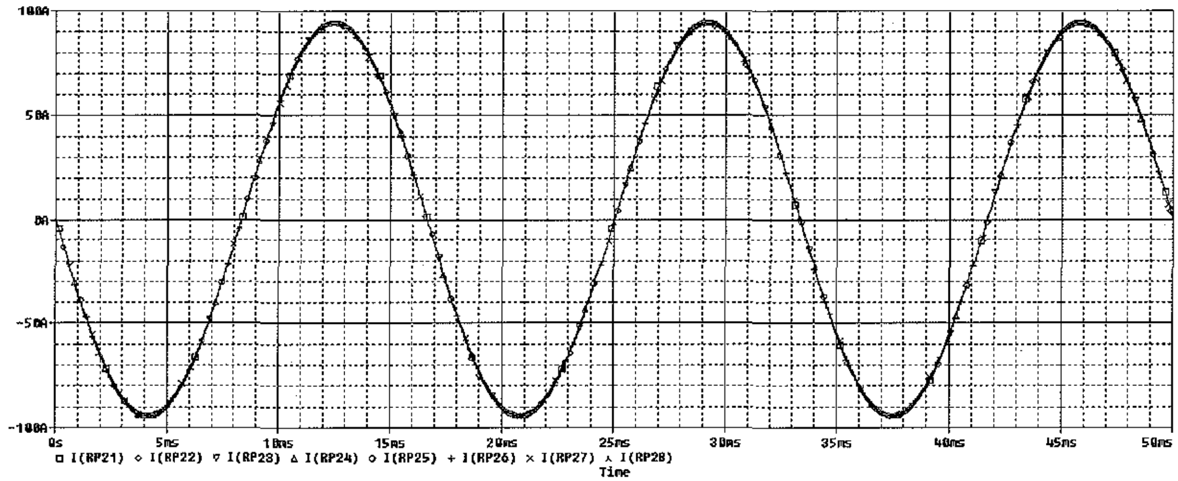

Figure 27 Sim case 6 (faulted phase - ii) - phase 2 currents

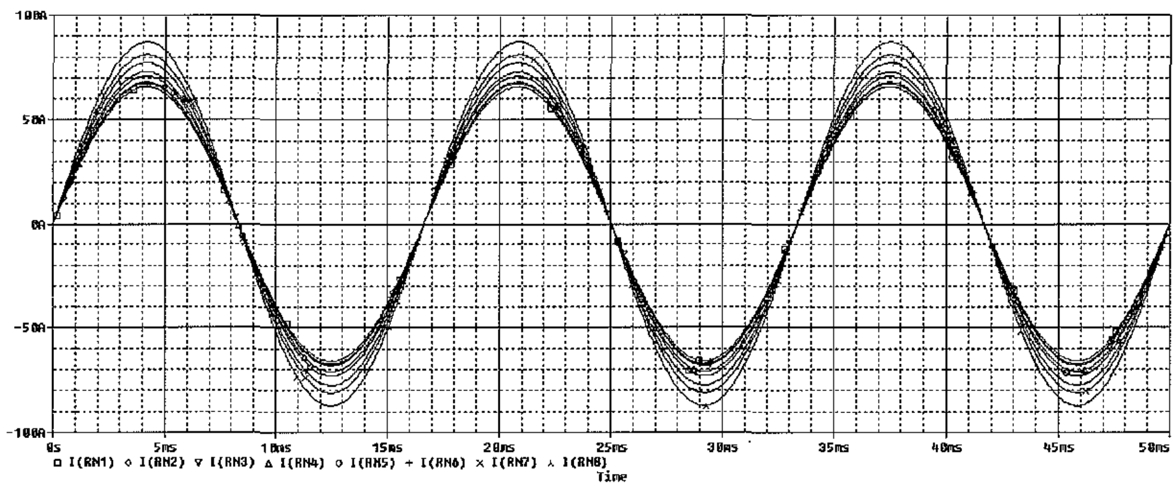

Figure 28 Sim case 6 (faulted phase - ii) - neutral currents

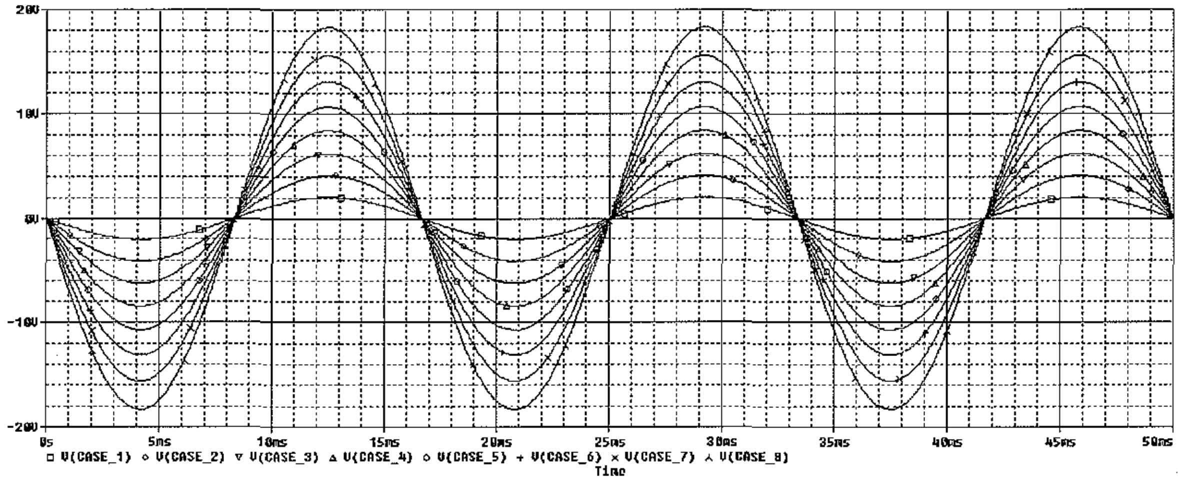

Figure 29 Sim case 6 (faulted phase - ii) - voltage on light standard (stray voltage)

The results of this simulation case follow the same trends and stray voltage distribution as sim case 5 only the magnitudes are higher. The phase 2 currents reported in the simulation are more than likely much higher than what would be allowed with the inline protection fuses. The simulation was done to show the effect of increased neutral currents on stray voltage.

The simulation cases presented in this section validate that various circuit imbalances can cause stray voltage. The circuit impedance values and other assumptions used in the simulations may not directly relate to what is seen in the field due to the variability of systems and of the surrounding environment. Therefore, the stray voltage values are shown only to demonstrate trends rather than absolute values under the simulation conditions detailed under each simulation case.

B. Stray voltage Mitigation methods

There are both short and long term corrective actions that can be taken to mitigate stray voltage. The short term fix is to remove the neutral-mechanical ground bond inside the light standard. This effectively isolates the light standard from the circuit. However, problems may still arise since the light standard is no longer grounded and may present a safety issue in the event of a line to standard fault.

A more appropriate long term solution is to use a 4-wire system (Figure 30). The fourth wire of this system is a mechanical ground that connects all of the local earth grounds at each light standard to the earth ground at the transformer. The advantage of this system is that the neutral no longer is bonded to the mechanical ground and therefore the light standard is not a part of the lighting circuit. However, safety is still maintained since the light standard still has a local ground rod attachment as well as a connection to earth at the transformer. The 4-wire system was not simulated because since there is no neutral-ground connection at each light standard, no stray voltage will develop under unbalanced conditions. This system essentially solves all stray voltage issues related to underground corrosion and insulation failure of neutrals and other imbalances in the circuit. Although, a line to light standard fault will still produce a voltage potential since a large current would be flowing along the mechanical ground wire. Inline fuses on the phase conductors should blow during excessive fault currents which would likely eliminate stray voltage occurrence during this type of fault condition. Additionally, circulating ground currents from other nearby sources could conduct to the ground rods connected to the light standard and produce a voltage.

Figure 30: Cut-away view of 4 wire system in a light standard.

III. STRAY VOLTAGE REGULATION [5]

The regulation of stray voltage started with legislation related to the dairy farming industry in Wisconsin. In 1987 Wisconsin state legislators passed Wisconsin Act 399 granting the Wisconsin Public Service Commission (PSC) authority to create stray voltage rules. Funding was provided to sponsor utility research to investigate the stray voltage issues on the local dairy farms. The scientific report concluded stray voltage was present and deemed counterproductive to dairy farm operations. Based on the recommendations of the report, the Wisconsin PSC mandated that mitigative action must be taken when voltage levels of 0.5V (1mA through 500Ω test resistor) or greater are detected. This decision was overturned in 1996 when another scientific study indicated that the 0.5V limit was too conservative because the 500Ω test resistor already includes a factor of safety. Concerns among dairy farmers in Vermont also resulted in legislative action in 1994. In response to the legislation, the Department of Agriculture, Food and Markets, the Department of Public Service, and the electric utilities worked together to investigate stray voltage and corrective actions. The group determined that should stray voltage levels over 0.5V be detected, neutral isolators be installed at the utilities expense. Similarly, Connecticut's Department of Public Utility Control (DPUC) found that stray voltage can cause physiological and behavioral changes in livestock, production losses, and financial loss and psychological stress for the farmer. The DPUC mandated that corrective action must be taken when stray voltage levels exceed 0.5V (1mA) in livestock contact areas and 1V between primary earth and neutral conductors. Minnesota's Public Utilities Commission (PUC) launched a scientific study which released a report in 1998 stating that they could find no credible scientific evidence that stray voltages cause poor health or milk production among dairy cows. As a result of the findings, the Minnesota PUC did not enact any stray voltage regulation.

Utility regulation in metropolitan areas is more recent. 15 years after the Wisconsin PSC established stray voltage regulations, the New Jersey Board of Public Utilities (BPU) investigated claims of nuisance shocking in pools and hot tubs. The NJBPU required the Jersey Central Power and Light to increase the size of the primary neutral conductors and to balance the loads of circuits to within 10% average and within 15% peak demands. They also were required to expand the ground area of substations. In 2004 the Massachusetts Department of Telecommunications and Energy (DTE) investigated reports of dog injuries and fatalities due to electrocution from man-hole covers. The DTE imposed stray voltage regulation that limited voltages between 8-20V. Utilities are required to immediately disconnect circuits that produce stray voltages greater than 20V, while voltages between 8-20V must be remediated within 24 hours. Stray voltage less than 8V is up to the discretion of the utility whether or not they address the issue. Lastly, in 2005 the New York Public Safety Commission (PSC) orders Consolidated Edison to test man-hole covers, street lights, service boxes, and vaults and report its findings. The effort was in response to the death of Jodie Lane in 2004; a New York City woman who fell on a live man-hole cover. After review of the utility report, the PSC specified 8-600V detection devices and adopted the National Electric Safety Code. Additionally, rate based fines were issued if utilities failed to implement the requirements. The current stray voltage limits imposed by the New York State PSC require voltages over 1V to be remediated. A timeline of these legislative and regulatory actions is illustrated in Figure 31.

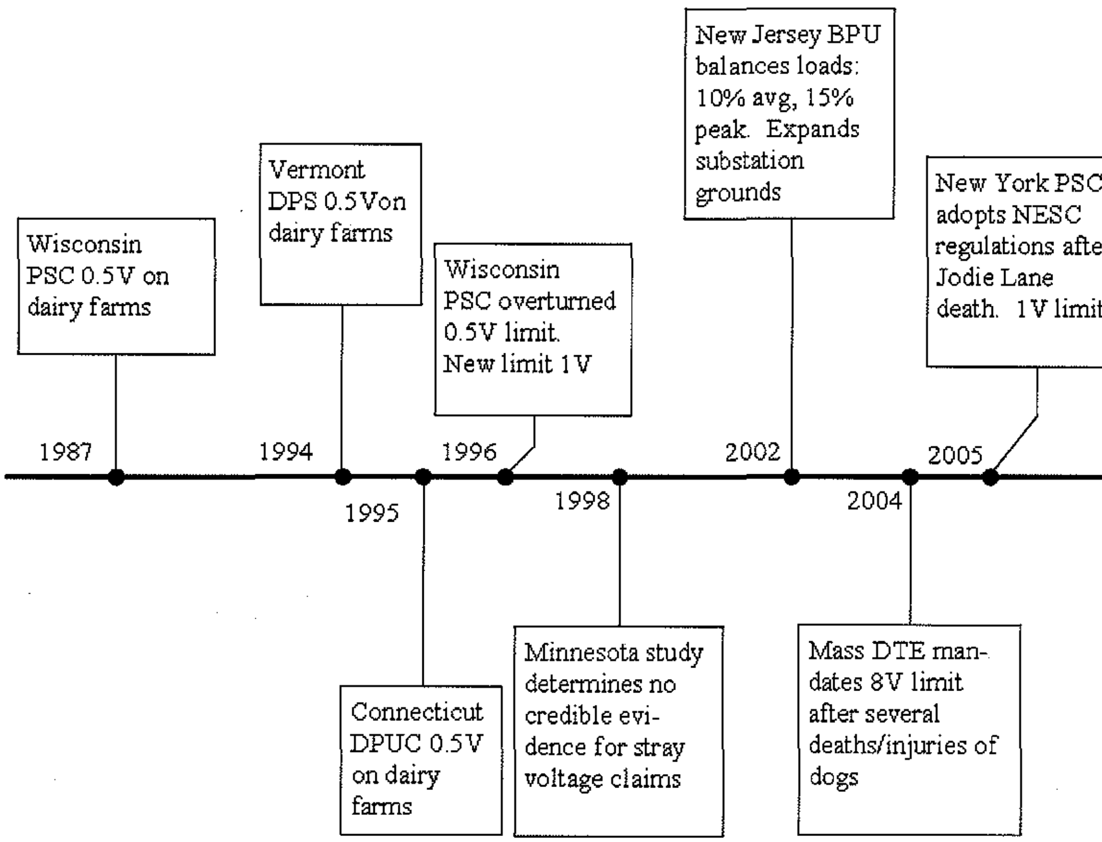

Figure 31: State regulation and utility response timeline for stray voltage.

IV. ELECTRICAL SAFETY

Electrical safety is a topic that is both studied and regulated by many organizations. The regulations may be specific to a certain occupation or they may be general regulations that are adopted nationally. Therefore, the safety limits do not always coincide because of this variability. Interestingly enough, the safety thresholds (Table 1) of various national and international regulatory bodies are considerably higher than the stray voltage limits set by several states. These thresholds represent the maximum voltage that is still considered safe, or in other words, the maximum voltage that will not result in bodily harm. These thresholds are concerned with human safety rather than human comfort.

Table 1: Other national and international electrical safety regulations [6, 7]

Regulating Body	Thresholds
OSHA Occupational Safety Health Administration	50Vac (shock hazard)
NESC National Electric Safety Code	50Vac
NEC (dry/wet) National Electric Code	50Vac/15Vac
ARRL Amateur Radio Relay League	35Vac
UL-60950 Underwriter Laboratories	42.4Vac dry
IEC 479-1 International Electric Code	25Vac clearly safe (1kΩ)
IEC 479-1 International Electric Code	50Vac marginally safe (shock hazard) (1kΩ)
NFPA 70E National Fire Protection Association	30VRMS (500Ω) (shock hazard)
IEEE std. 80 Institute of Electronic and Electrical Engineers	60Vac for 4 sec @ 1kΩ
USDA United States Department of Agriculture (Stray Voltage)	1Vac
NYS PSC New York State Public Safety Commission (Stray Voltage)	1Vac

The discrepancy in safety thresholds between many reputable safety organizations and the stray voltage limits set by state legislators only leads to an interesting conundrum: what is a safe stray voltage limit? In order to investigate this it is important to break down the problem into three parts: an acceptable current level, human body resistance, and the voltage potential across the body. Once the first two parts are known, finding the voltage potential is a matter of simple algebra.

It is universally accepted that electrical current and not voltage is what is harmful to the human body. Therefore, it is crucial that an appropriate current level be established. The body's reaction to an electrical current can be characterized as perception, startle, and fibrillation [7]. Some literature suggests that human perception to electrical current can occur at values as low as 0.1mA [8]. Underwriter Laboratories (UL) research concludes that 99% of the population will not have a startle reaction to currents less than 0.5mA [7]. This value has an inherent safety factor built in and the author suggests that this corresponds to a conservative voltage level of 15V [7]. That same study concluded that 2.2mA was borderline hazardous [7]. Fibrillation is the most concerning human reaction to excessive electrical currents. Fibrillation can occur with approximately 67mA for adults and 30mA for children. It is important to note that no documented deaths caused from electrical fibrillation have occurred with voltages less than 50V [7].

The electrical impedance of the human body is very difficult to quantify due to many variables. The contact mode is important to consider: hand to hand, hand to foot, foot to foot, etc. The wetness or dryness of the contact surfaces also comes into consideration. Commonly accepted impedance values range from a conservative 300 ohm value to 2000 ohms.

Figure 32: Impedance contact values for a human-street light interaction scenario.

Consider the diagram in Figure 32 which shows the contact resistances of each component along the path of conduction. The contact resistance of the light standard itself could range from ohms to mega-ohms. The standard could have a layer of paint, corrosion, or other foreign material buildup that acts to impede the flow of electricity. Conversely, the standard could have areas where the paint or other coating has been scratched or chipped off which would result in a very low contact impedance. The hand brings into play another set of variables. What are the conditions of the skin: hard, dry and callused, or soft and moist? In the situation shown in Figure 32 we are concerned with a hand to foot contact path. The body impedance, as previously mentioned, can assumed to be anywhere between 300 and 2000 ohms. The electricity must then find a path to ground through the foot. The foot to ground interface also has a range of values which can span from hundreds of ohms to mega-ohms. The lowest impedance most likely would be achieved with an individual standing barefoot on a metal object such as a drain grate or manhole cover which is submerged in water. Higher impedances values would occur with a dry rubber soled shoe standing on asphalt or concrete. These equivalent impedances are shown in circuit form in Figure 33.

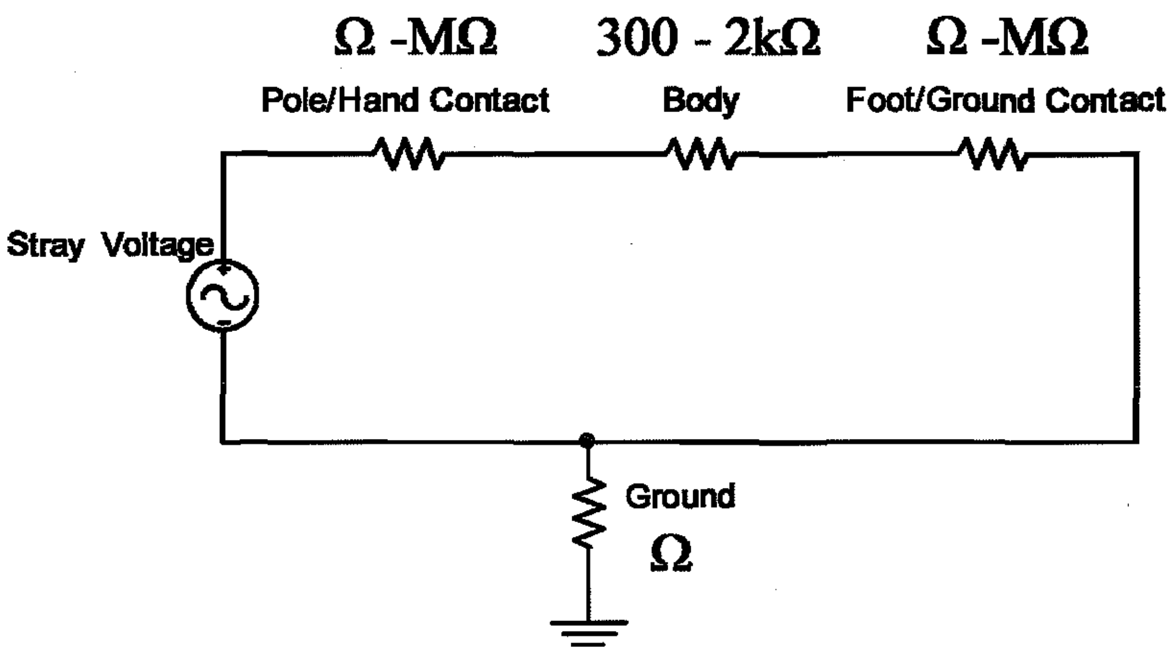

Figure 33: Circuit diagram illustrating different components and ranges of contact impedances for the individual touching a light standard in Figure 32.

With the circuit diagram in Figure 33, it is now possible to calculate the acceptable stray voltage value if the three impedance values are known. If low conservative values are assumed for the pole/hand contact impedance and the foot/ground contact impedance then the body impedance value will dominate. This would result in a stray voltage range of 0.6 - 4.4V for the 2.2mA reaction hazard threshold stated earlier. It is important to note that the 2.2mA was considered borderline hazardous because the reaction from that current could cause someone to injury themselves through other means (falling off a ladder, etc.) rather than the current itself being hazardous. For situations related to touching a street light, higher contact impedances are a likely scenario. While it is feasible that hand-light standard impedances can be low, it is likely that the foot-ground interface will be substantially higher. This could put the overall effective impedance at a value of a few thousand ohms or more. For a value of 4000 ohms, the stray voltage limit would be 8.8V.

Clearly, defining a stray voltage limit is a difficult task because one must assume an equivalent human body impedance for a vast array of situations. Perhaps what could be more appropriate would be to define a lower limit for higher risk areas such as pools and hot tubs. An individual submerged in water reaching out to grab a metal ladder or pole would likely result in what is termed a "nuisance shock" with stray voltage values as little as a few volts. However, an individual touching a street lamp is not completely submerged in water like in the case of the swimmer, and is most likely fully clothed. It would therefore be appropriate to have more relaxed stray voltage limits in these type of settings.

It is interesting to see the large discrepancies in electrical safety thresholds defined in Table 1 compared to the limits established by state legislators in section III, while the safety values derived in this section fall somewhere between. One possible explanation for the discrepancy between the stray voltage limits and the electrical safety thresholds is that much of the of the stray voltage research was concerned with how electrical currents affected the behavior, health and milk production of cattle. It is quite evident that the threshold to disrupt the normal behavior of the cows is much different from the threshold that will cause injury to the cow. The claims from dairy farmers was never based on the notion that cows were being injured, but rather that the cows were behaving erratically in milking parlors and that overall milk production had decreased. When talking about stray voltage in metropolitan areas and specifically with street lights and other metal structures, it is important to focus on the safety of the public rather than their comfort. It is evident that many of the regulatory bodies were concerned with safety rather than comfort which is why their electrical safety thresholds are considerable higher.

V. RECOMMENDATIONS

Based on the review of the stray voltage phenomenon and its history, we have the following recommendations.

Scanning - The remote scanning should continue to help "sniff" out issues within the street light circuit. In 2009, the Buffalo metropolitan area overseen by National Grid had 861 hits that were over 4.5V [9]. Some of these hits could be dangerous and lethal contact voltage and must be discovered and corrected. The scanning provides a quick way to detect these dangerous voltages as well as elevated stray voltage.

Upgrade Investment - Generally speaking, the electrical utility network is very old. The street light circuits in older neighborhoods are several decades old and the buried underground cable is approaching end of life. It would be beneficial to replace the old 3-wire system with the 4-wire system discussed previously during upgrades. The insulated wire that is currently being used in new installs is far superior to the older coaxial style with lead neutral and should continue to be used. Care should be taken when installing new cabling such that it is isolated from the earth as much as possible when buried and should not be routed in areas that are high risk for being damaged from construction or other means. When laying out new or upgrading existing lighting networks, the circuits should be balanced (ie number of lights on each phase are as close as possible).

Record Keeping - Superior record keeping will help aid with future troubleshooting and will save money in the long run. Documentation should include not only the magnitude of the stray voltage but the position of the light standard within the circuit. The corrective solution should also be noted as well. For example, simulation case 3 and 4 in section II illustrates the importance of noting the position where the stray voltage occurred. In simulation 3 a corroded neutral was placed at the beginning of the light circuit (nearest the transformer) which produced an elevated stray voltage on all seven light standards located after the corroded cable. Conversely, in simulation case 4 the corroded neutral was placed between light standards 7 and 8 which resulted in a neutral to earth elevated voltage only on light standard 8 while the rest of the light standard voltages remained similar to the baseline case. Statistics and analysis similar to this can be a very powerful cost saving tool. When crew members identify these types of relationships they can very quickly identify, locate, and correct stray voltage issues which will result in smaller work crews, less overtime, and an overall cost reduction.

Stray Voltage Thresholds Re-defined - There seems to be a conflict of numbers between many electrical safety authorities and many state legislators. Much of this is due to several safety factors implemented in the stray voltage limits as well as these limits being translated from studies done on dairy farms. The focus of the thresholds should relate to human safety rather than comfort. Massachusetts DTE stray voltage limits seem very appropriate. Any stray voltage limit detected that is under 8V is up to the discretion of the utility to correct. While it would behoove the utility to be prudent and correct whatever is causing the stray voltage before it gets to a possibly dangerous level, this voltage level is harmless as corroborated by the standards shown in Table 1. The Massachusetts DTE requires voltages between 8 and 20V to be corrected within 24 hours and anything over 20V must be disconnected immediately. The 8V threshold fits more appropriately with much of the current research that defines stray voltage as "...usually less than 10V" and "...considered harmless" [3]. The utilities should push to have the current 1V limit raised to a more realistic and appropriate, and yet safe, level of 8V.

VI. SUMMARY

The Energy Systems Institute at the University at Buffalo has investigated the stray voltage issues occurring in many of the street light circuits in the Buffalo metropolitan area. The history of stray voltage occurrences stemming from the dairy industry has been reviewed as well as the legislative history. Many northeast states in the US have adopted stray voltage limits which were reviewed and presented in this work. A full analysis of what factors cause stray voltage was carried out and it was determined that various forms of imbalances are the dominant factor. A discussion on electrical safety provided insight into the difficulty of establishing stray voltage limits. It was determined that many factors of safety are built into many of the stray voltage limits, including New York State, and the limits may be grossly conservative. Several recommendations have been suggested to the utility that can help them detect, correct, and mitigate stray voltage now and in the future.

VII. REFERENCES

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