OPTIMIZATION OF SURVEYS FOR DETECTION OF ENERGIZED STRUCTURES TO ELIMINATE ELECTRICAL HAZARDS TO THE PUBLIC IN NEW YORK CITY

A Senior Scholars Thesis

by

ELIZABETH CHRISTINE WELLS

Submitted to the Office of Undergraduate Research
Texas A&M University
in partial fulfillment of the requirements for the designation as

UNDERGRADUATE RESEARCH SCHOLAR

April 2009

Major: Electrical Engineering

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ABSTRACT

Optimization of Surveys for Detection of Energized Structures to Eliminate Electrical Hazards to the Public in New York City. (April 2009)

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There have been many reports of individuals and animals in New York City coming in contact with electrically energized structures caused by “stray voltage”. The electric utility, Consolidated Edison (Con Ed), has been working hard to drive down the exposure rate of the public to dangerous electrical conditions by completing manual and mobile scans, or surveys, of above ground structures and repairing those structures once found. Con Ed engineers and external experts are researching ways to reduce the number of shock incidents.

This thesis presents an analysis of Con Ed’s past manual and mobile scans, or surveys, in order to determine the number of annual scans needed to drive down the exposure rate. Three methods of analyzing this data are discussed. First, there is an examination of the relationship between the scans and the number of energized structures and then the relationship between the detection of energized structures and the number of shock incidents. Next, a sensitivity analysis of the time of year of each scan is performed to determine whether climatic changes directly affect the number, frequency, or duration of stray voltage incidents. Two types of stray voltages are considered when examining the data: manifest and intermittent. The final analysis compares the actual data from surveys to three models of intermittent stray voltage to analyze the behavior of the stray voltage occurrences.

Three major conclusions are drawn. First, it is determined that the efficiency of energized structure detection is proportional to the duration of scans. In terms of cost and efficiency, fewer scans with longer durations would be more beneficial. Second, the generation rate is fairly constant throughout the seasons, indicating that the weather does not affect the generation rate. Lastly, the analysis reveals that the efficiency of energized structure detection is proportional to an increase in the duty cycle of intermittency due to annual conditions. The number of energized structures increases in the early spring and decreases in the winter. It would be more efficient in terms of cost and time to bias scanning toward the spring months and limit scanning in the winter months.

ACKNOWLEDGMENTS

No other utility has attempted to perform a study of this problem due to the unique nature of the Con Ed electric system. Because of this, there are no prior references other than the data and reports provided by Con Ed. Also, the equipment for the surveys performed by Con Ed was invented by Con Ed and no other utility has this equipment. The danger from electrocution and contact with energized structures is inherently obvious and is assumed to be a risk that must be avoided. General sources about grounding, the danger of electricity, and electrical hazards have been provided.

I would first like to thank my research advisor, Dr. B. Don Russell. Dr. Russell has provided me with the opportunity to gain knowledge beyond what my classes could offer. He has opened the door for my future in research and helped me along the way. His dedication to his students' learning has encouraged countless students to go beyond their coursework and make a difference. His contribution to the stray voltage problem in New York City is a selfless act truly deserving of praise.

I would also like to thank Con Ed employees, Steve Ierome, Sangeeta Noby, and Graciela Varela, for providing me with the information and data necessary to complete this project. I am grateful for their patience through all of the e-mails and numerous questions about the scans and reports.

I would also like to thank my parents for their support and encouragement. They have always pushed me to make the most of my education and have been more than willing to give a helping hand along the way.

NOMENCLATURE

ENE	Energized structures found during scanning
ESR	Electric shock report
τ	The amount of time an intermittent stray voltage is active
T	The period of an intermittent stray voltage
E	The number of detected ENEs per scan
E_o	The initial amount of ENEs on a route before scanning
S	The duration of a scan (days)
D	The distance of a scan route (miles)
G	The number of ENEs generated per day

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CHAPTER I

INTRODUCTION: A STRAY VOLTAGE PROBLEM

Background

The distribution of electricity in dense urban areas has always been problematic and has its own unique problems. Areas where electric lines can be carried on overhead poles and where load densities are sparse are relatively easy to serve and operate. By contrast, the dense electric loads in areas such as New York City, where all systems must be underground, create infrastructure maintenance and operational problems that are challenging. Any problems with the electric delivery system can create dangerous conditions for the public.

The largest concentration of electric load in the world served by a low-voltage underground distribution system is in Manhattan, New York City. The system dates from the 19th century and much of the infrastructure is decades old. The system is highly reliable because of a high level of redundancy where multiple sources of electricity serve, simultaneously, individual large loads. Consequently, the loss of an individual electric feeder or distribution line does not mean a loss of electric service to a specific individual load.

Because the electric system in New York City is underground, failures of the system are

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This thesis follows the style of *IEEE Transactions on Power Systems.*

difficult to locate and even more difficult to repair. Over the last several decades it has been noted that individual failures of distribution cables may go unnoticed since they do not individually affect the electric service to any given customer. The accumulation, however, of a number of cable failures can result in a highly degraded system that is both dangerous and extremely difficult to repair once total failure has occurred. In the last several years, very notable failures have resulted in large scale, long term outages that have created both political and public pressure on the electric utility, Consolidated Edison (Con Ed).

Throughout the past several decades, there have been numerous reports of individuals and animals coming in contact with energized structures including man holes and light poles in New York City. These have resulted in both injury and death. These energized structures have multiple causes that are collectively referred to as “stray voltage”. Stray voltage refers to voltage on an otherwise grounded structure due to some fault current or short circuit condition. Fault current and short circuits are usually caused by exposed wires due to corrosion, improper insulation, or bad connectors. Weather is also an important factor in stray voltage. The mix of snow, sludge, and salt that is spread over the streets and sidewalks in the winter creates a dangerous, conductive medium that can cause, exacerbate, or reveal stray voltage.

On January 16, 2004, Jodie S. Lane of Manhattan died from electrocution while walking her two dogs after coming in contact with an electrified metal plate embedded in the asphalt. Con Ed officials found exposed wiring and a short circuit beneath this metal plate. The current traveled through the cover because of the short circuit caused by erosion of insulation protecting power lines. Roger M. Lane, the father of Jodie Lane, created a foundation to find a solution to the stray voltage problem in New York. Together with a number of Con Ed engineers and external experts, they are researching ways to reduce the occurrence of these shock incidents. Research has led to discovery of hundreds of troublesome stray voltage spots around Manhattan, Queens, Brooklyn, the Bronx, and other areas [1-4].

Responsibility for public contact incidents is determined by who owns the energized structures and what caused the stray voltage. Non-Con Ed structures include customer equipment, awnings, fences, hydrants, and scaffolding. Con Ed structures include manholes, service boxes, and transformers. Streetlights are frequently owned by the City of New York, but Con Ed failures can affect these structures and cause stray voltage incidents. Finding failed electrical cables and repairing electrical cables or other infrastructure that is creating a public safety hazard or degrading the delivery of electricity to customers is a high priority for Con Ed, whether the structures are owned by Con Ed, the City, or private entities.

Objective

Techniques have been developed for measuring the presence of “stray voltage” on street lights, manholes, fences, or other above ground structures where this voltage is indicative of failed or failing equipment. However, the dependability and reliability of the measurement equipment and analytical tools currently used by Con Ed has not been fully evaluated with respect to the statistically large number of yet unknown energized structures.

The objective of this research project is to determine the optimal number of annual surveys of above ground energized structures in order to drive the public exposure of stray voltage down to the lowest practical levels and thereby improve public safety. Too few surveys and measurements will result in continued and possibly increasing exposure of the public to stray voltages. Too many surveys will result in a waste of funds that could otherwise be spent to improve the reliability of service or replace and update electrical infrastructure with new systems.

From the perspective of Con Ed, the number of surveys per year is a matter of economics and resource allocation versus public safety. While Con Ed needs enough surveys for the safety of the public, the expensive surveys compete with other programs for limited resources. The goal is the greatest possible safety for the time and money spent. The first question is how many surveys are sufficient to detect and reduce the number of stray voltage events to which the public is exposed, with the objective of ideally reducing the number to zero. Because of weather, there could possibly be fewer stray voltage events in the summer and more in the winter and spring. The next question is the sensitivity of occurrence to weather and time of the year, possibly affecting when surveys are run.

There were ten complete surveys in 2008. Investigation is required to determine whether there is a decrease in the number of accidents that indicates detection is at a higher rate than the occurrence rate of accidents. This issue is complicated because there are two types of possible occurrences. Stray voltage events can be continually manifest or intermittent. Manifest stray voltages are defined as existing energized sources that are, and will remain, detectable through manual or mobile testing. Intermittent stray voltages are transient energized sources, the detection of which is contingent on conditions localized in space or time. For example, an energized source that only becomes temporarily detectable or becomes a potential electric shock only under heavy rain, snow or adverse mechanical/chemical/thermal conditions is considered intermittent. This makes the generation rate most difficult to predict. Along with these two types of stray voltages, there is the possibility of a stray voltage being undetectable due to sensitivity or other limitations with Con Ed equipment. This can create false negatives in the data. For the purposes of this analysis, I will make the following assumptions:

1. Every stray voltage that Con Ed successfully detects, they will be able to locate and permanently correct the root cause.
2. Con Ed cannot perfectly detect every stray voltage due to intermittency and other factors, so there are some undetectable stray voltages.
3. Stray voltages are evenly distributed throughout the scanning route.

CHAPTER II

METHODS

An ideal experiment to test the behavior of stray voltages and find an estimation of the generation rate of both manifest and intermittent types could be designed. By partitioning regions prone to stray voltages, Con Ed engineers would be able to take regular measurements over several months, documenting stray voltage occurrences, without correcting the problems. Although this could provide the information needed, it would be very costly and would be a continuing hazard to the public. Because such an experiment is impractical and possibly unethical, only a graphical analysis of known behaviors from existing survey data can be considered. While imperfect, this method may provide insight into the questions previously posed.

Analysis of Con Ed’s scan results

To understand the behavior of the stray voltage occurrences and the efficiency of scans, Con Ed’s data must be examined. Con Ed has gathered information from surveys for each year starting from 2006. These give us various information from which we can approximate the effects of Con Ed scans. The data reveals the relationship between the number of scans, the number of electric shock reports (ESRs), and energized structures (ENEs). By looking at the relationship between these, predictions can be made about how many surveys it would take to reduce these events. The first step will be to compare the number of scans over time to the number of ENEs over time in order to determine if the amount of ENEs per scan is actually decreasing. The number of ENEs per scan will also be compared to the number of ESRs over time. A comparison is to be made to determine whether Con Ed’s increase in surveys from 2007 to 2008 had any affect on the number of shock events or if the generation rate of these energized structures is much greater than the rate of detection.

Sensitivity analysis to weather

The previous analysis does not take into account many factors such as the intermittent nature of these stray voltage events and the impact of weather. The next step will be a sensitivity analysis of the same data considering such parameters as environmental conditions such as precipitation and temperature. As mentioned in the previous chapter, weather is an important factor in stray voltage. Precipitation, such as snow, rain, and salt that is spread over the streets and sidewalks in the winter creates a dangerous, electrically conductive medium. A sensitivity analysis may determine if the impact of seasons is large or insignificant.

Modeling of intermittency

The third step will be to model the intermittency of the stray voltages and compare these models to the collected data. “Binary” waveforms approximating the duty cycle of stray voltage events can model the intermittent nature of stray voltages. They are “on”, or active, for duration of time τ and “off” for the remainder of their period T. The expression τ/T represents the duty cycle, the fraction of time the stray voltage event is active. We will consider three models of intermittent behavior for ease in this analysis.

Model 1) Every intermittent voltage has the same frequency and duty cycle.

Model 2) Every intermittent voltage has the same frequency, but not the same duty cycle.

Model 3) Each intermittent voltage has a unique frequency and duty cycle.

Figures 1 through 3 show binary waveforms of these three models.

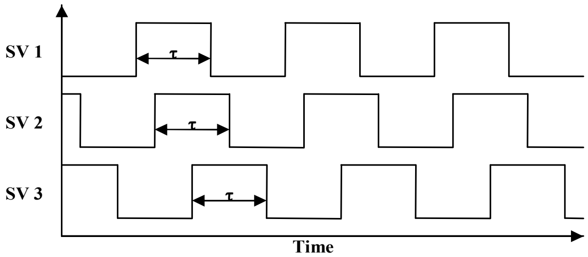

Fig. 1. Intermittent stray voltage model 1

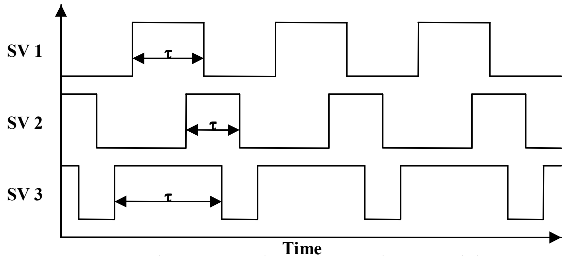

Fig. 2. Intermittent stray voltage model 2

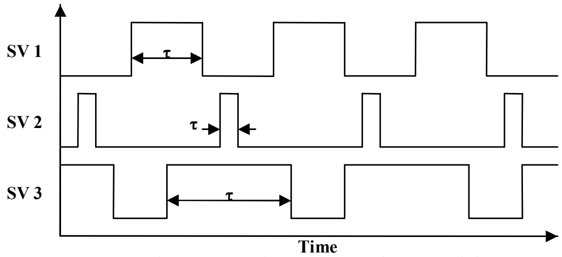

Fig. 3. Intermittent stray voltage model 3

The difficulty in examining these waveforms comes from the random nature of intermittent voltages. There is no way to predict the actual frequency or duty cycle; it may likely range from a few seconds to several months. However, approximate mathematical models will allow us to study the affect of intermittency on the efficiency of detection.

The manifest stray voltages can also be modeled as “binary” waveforms. In the previous chapter, I made an assumption that once detected, the source of each stray voltage can be corrected. At the time of each survey, the waveform will then be permanently “off” because the stray voltage will no longer be active. Figure 4 shows the binary waveforms for the manifest stray voltages.

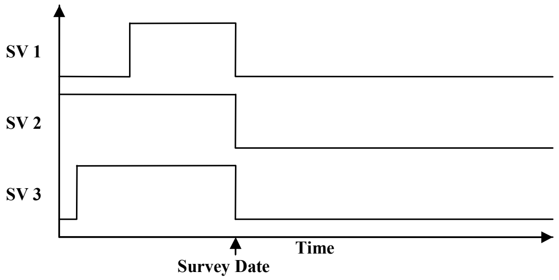

Fig. 4. Manifest stray voltage model

My first hypothesis is that, without consideration of intermittency, the efficiency and rate of detection of energized structures is directly proportional to the frequency of scans.

My second hypothesis is that the efficiency of energized structure detection is directly proportional to an increase in the duty cycle of intermittency due to weather and other annual conditions. The interaction and interdependency of these two hypotheses will also be studied.

CHAPTER III

ANALYSIS

According to Con Ed, if the stray voltage is more than 1 Volt as measured with a shunt resistor, voltage is considered substantiated. There are reports of ENEs and ESRs below this criterion, referred to as unsubstantiated. For all data collected from Con Ed, this analysis only considers substantiated ENEs and ESRs. The data includes Con Ed responsibility, customer responsibility, and New York City DOT responsibility in the count of ESRs and ENEs. All data is taken directly from Con Ed reports.

The past four years, Con Ed has performed multiyear surveys. In addition to the scheduled surveys, Con Ed performs surveys before each major parade and big event, as well as after each major weather event. Prior to 2007, Con Ed did not have a formal program in place to scan the system through mobile scans. In 2006, mobile scans were completed only to prove the technology [5]. However, manual scans have been done since 2004. Aside from the mobile scans in 2007 and 2008, manual scans were completed when Con Ed received reports of energized structures from customers and the public. These reports will not be considered in this analysis because of the incomplete nature of the data and its documentation.

2007 and 2008 scan results

In 2007, five scans were completed, two of which were storm scans. Table I shows the results from the 2007 scans [6-7].

TABLE I
2007 Scan Results

Scan	SVD ENEs	Start Date	End Date	Scan Days	Scan Miles
1 (Before Storm1)	1086	01/04/07	02/13/07	41	4554
Storm 1	757	2/13/2007	2/27/2007	15	4690
2 (Before Storm 2)	240	03/05/07	03/16/07	12	4171
Storm 2	247	03/17/07	03/20/07	4	
2 (After Storm 2)	370	03/20/07	04/18/07	30	
3	779	04/10/07	08/06/07	119	4413
4	716	06/12/07	10/15/07	126	3740
5	243	09/13/07	11/25/07	74	1076

The first scan was interrupted by Storm 1. The second scan was interrupted by Storm 2, but completed after the storm. Usually scanning is only done on weekdays at night, but during Storm 1, vehicles were deployed around the clock until the entire system had been scanned. Table I shows the results from the 2007 scans. The scan miles for scan 2 and storm 2 are included in one number. Scan 4 and 5 were considered partial scans and not complete because they were less than 4000 miles. Figure 5 provides a graphical display of the number of ENEs per scan for 2007.

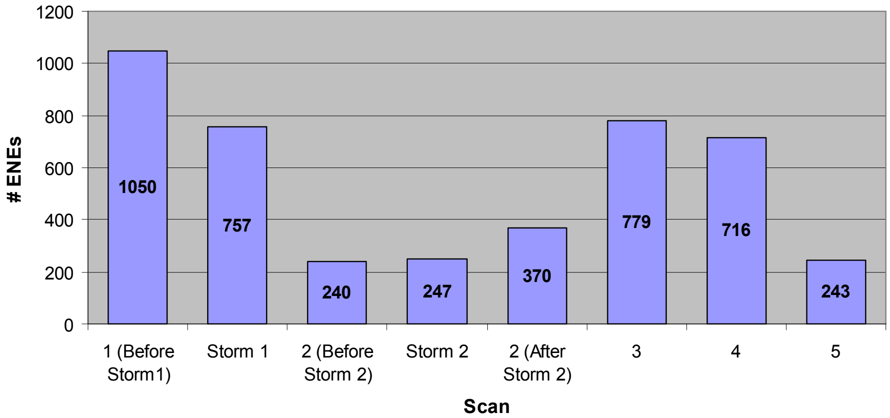

Fig. 5. ENEs detected per scan in 2007

In 2008, a total of 10 scans were completed. Table II shows the results from the 2008 scans [7].

TABLE II
2008 Scan Results

Scan	SVD ENEs	Start Date	End Date	Scan Days	Scan Miles
Routine108	599	01/03/08	02/25/08	54	4586
Routine208/308 (Partial Scan)	554	02/04/08	04/01/08	58	4380
Routine108-A	346	04/01/08	04/24/08	24	4725
Routine208-A	390	04/16/08	05/21/08	36	4875
Routine308-A + Heat Wave	474	05/09/08	06/26/08	49	5009
Routine408-A + 4th of July + All Star Game	717	06/05/08	08/22/08	79	5349
Routine508-A	413	07/30/08	09/10/08	43	5001
Routine608-A	347	09/02/08	10/06/08	35	5152
Routine708-A	304	09/24/08	10/30/08	37	4982
Routine808-A	236	10/21/08	11/24/08	35	5416
Routine908-A	285	11/18/08	01/06/09	50	5153

Routines 208 and 308 were partial scans and are combined into one scan. Figure 6 provides a graphical display of the number of ENEs per scan for 2008.

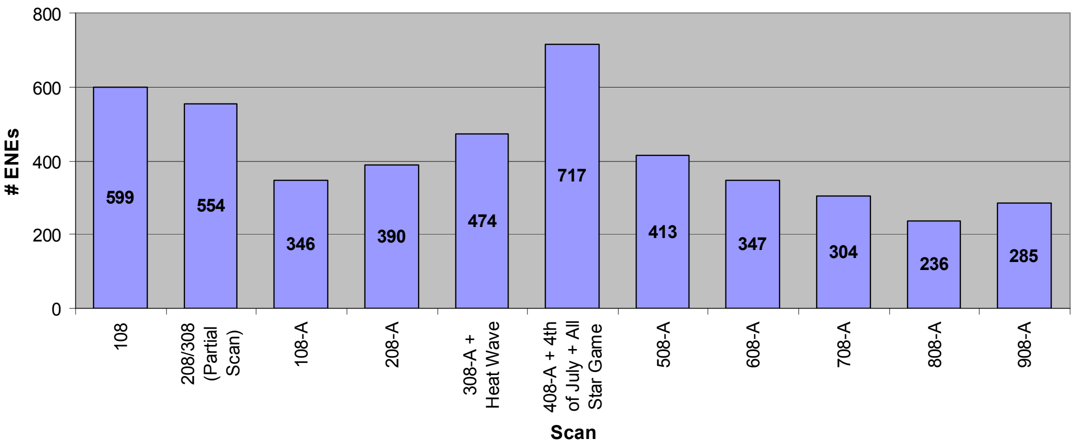

Fig. 6. ENEs detected per scan in 2008

The total number of detected ENEs was 4438 in 2007, and 4665 in 2008. There was about a 5% increase in detected ENEs from 2007 to 2008.

Distance of scans

Con Ed's trucks try to run at uniform speed and route during scans, but this depends on the weather, traffic, quality of road, road blocks, etc. Some areas are scanned more than one time due to street route pattern. The average distance of each scan in 2007 was 4457 miles excluding the partial scans, Scan 4 and 5. Figure 7 shows the distance of each scan in 2007.

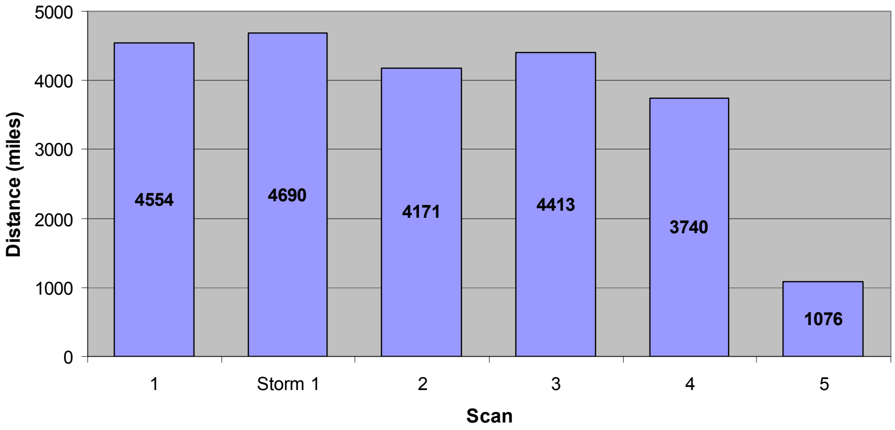

Fig. 7. Distance of scans in 2007

The average distance for each scan in 2008 was 5025 miles excluding the partial scans, Scans 208 and 308. Figure 8 shows the distance of each scan in 2008.

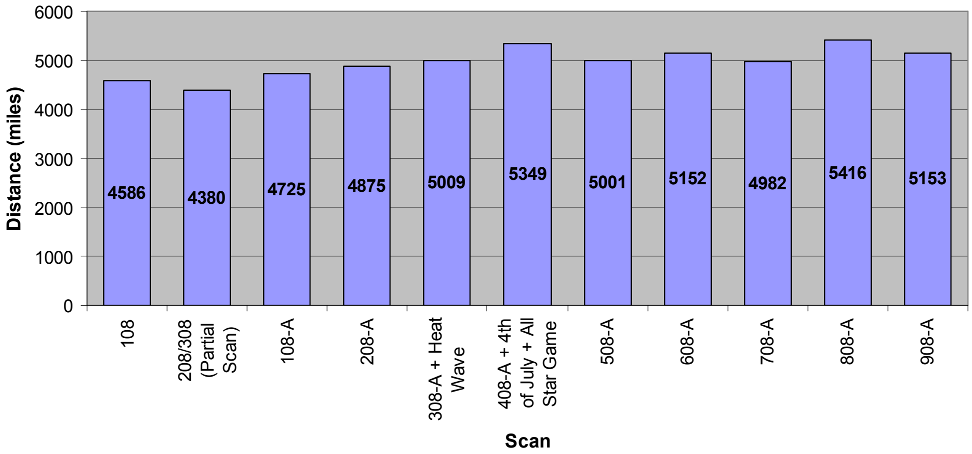

Fig. 8. Distance of scans in 2008

Duration of scans

Excluding the partial scans, the distances for each scan in 2008 were fairly constant, with a standard deviation of 258 miles. Because the distances were so similar, I have made the assumption that the distance per scan is constant for 2008.

During 2007 and 2008, each scan took a different amount of time to complete due to truck availability. Con Ed had less trucks running in 2007 than 2008, so the scans took longer to complete in 2007. Figures 9 and 10 show the 2007 and 2008 scan durations.

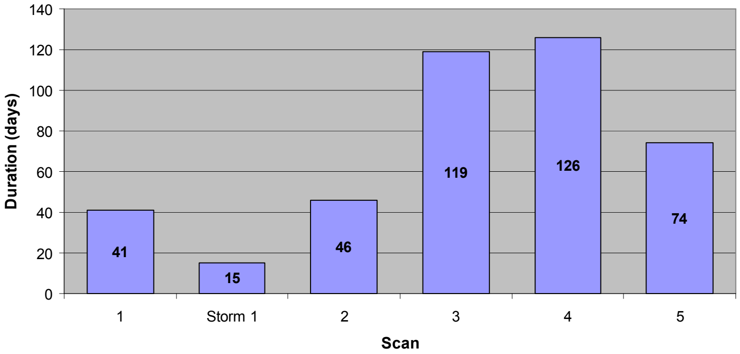

Fig. 9. Duration of scans in 2007

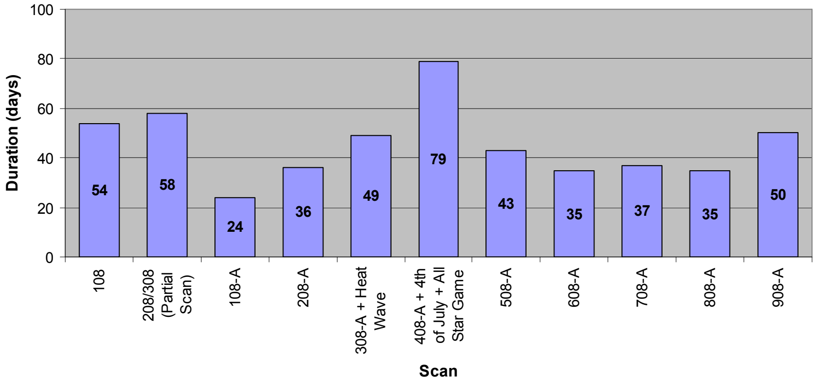

Fig. 10. Duration of scans in 2008

Because each scan has a unique duration, simply comparing the number of ENEs per scan would not provide a real image of what is happening. Variables such as duration and distance of scanning must be considered. The chart of the duration of scans reveals a very similar pattern to the plot of the ENEs per scan. Figure 11 shows the relationship between the number of detected ENEs and the duration of scans during 2008.

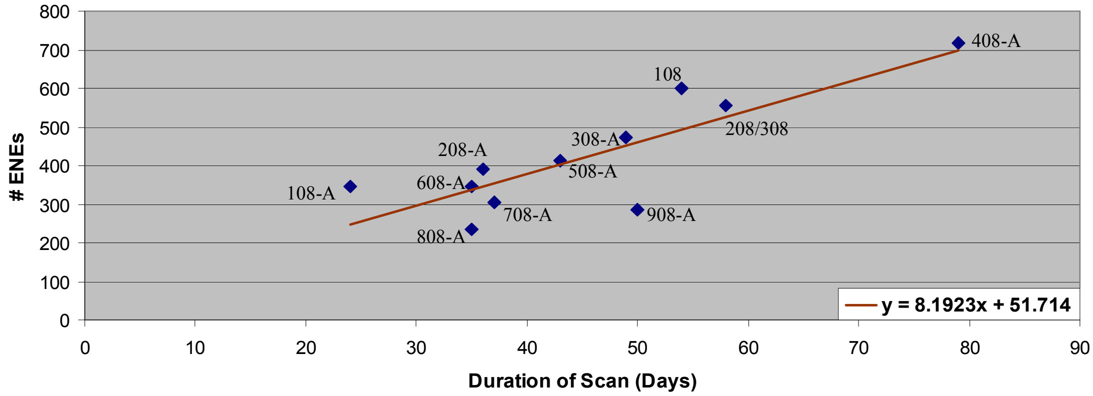

Fig. 11. ENEs vs. duration of scans for 2008

Derivation of the generation rate

Based on the data from 2008, the number of detected ENEs is linearly dependent to the duration of the scan. From this relationship of ENEs to duration, an estimated generation rate can be found by modeling the scanning process and the generation of ENEs. Three assumptions are made in order for this model to work:

1. ENEs are evenly distributed across the scanning distance.
2. The number of ENEs generated per day is constant.
3. All stray voltages are manifest.

Figure 12 shows this ENE model. In the model, a stretch of road of distance D represents the distance of the scan route performed by Con Ed. The initial number of ENEs on the road at the beginning of a scan is represented by E_o. G is the number of ENEs generated each day.

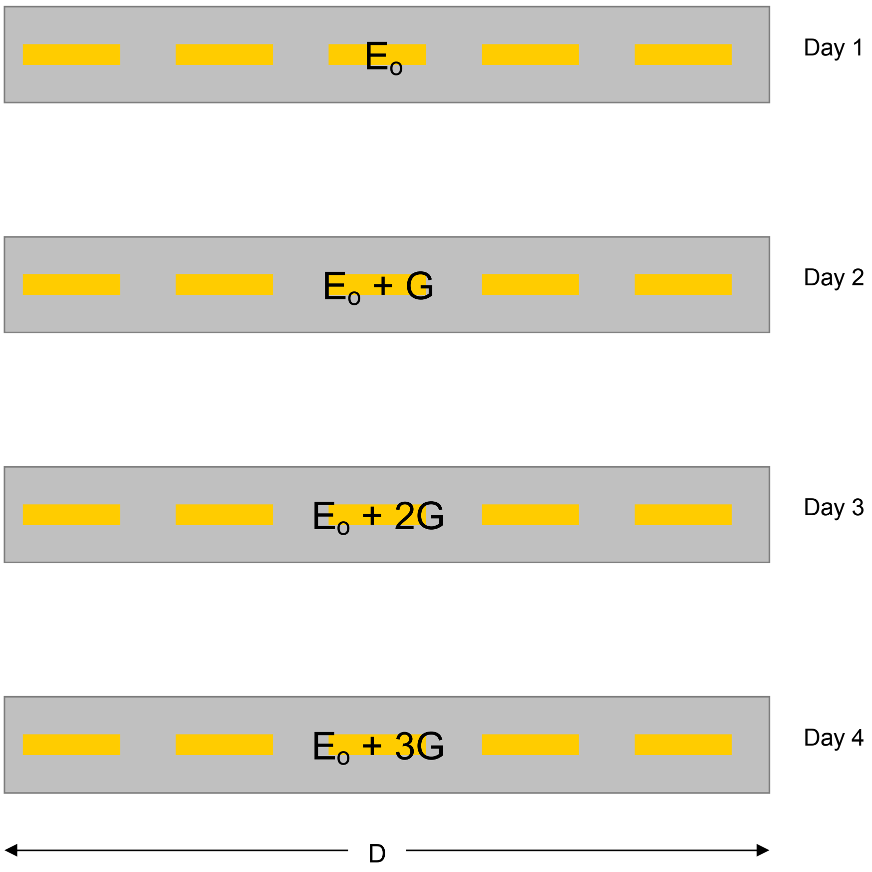

Fig. 12. Model of scans used to find generation rate

Table III shows the symbolic amount of ENEs detected for each duration of scan from one to four days. S is the duration of the scan in days.

TABLE III
2008 Scan Results

Duration S (Days)	Number of Detected ENEs E
1	E_o
2	$E_o + {}^{1}/_{2}G$
3	$E_o + G$
4	$E_o + {}^{3}/_{2}G$

Using Figure 11, with an average distance of 5025 miles for 2008:

$E = 8.1923 \times S + 51.714$

For S = 1,

$E = 8.1923 + 51.714 = E_o$

For S = 2,

$E = 8.1923 \times 2 + 51.714 = 8.1923 + E_o = E_o + {}^{1}/_{2}G$

${}^{1}/_{2}G = 8.1923$

Therefore, G = 16.3846 ENEs per Day for 5025 miles,

So, G = .0033 ENEs per Day per Mile for 2008

The generation rate found with the graph in Figure 8 is about .0033 ENEs per Day per Mile. This is an estimation only for the 2008 scans that assumes a uniform distance for each scan. If this same method were used for 2007, it would not be a good estimation due to the large fluctuation in distances for the scans. In order to compare the relationship between ENEs and duration of scans for both 2007 and 2008, the distance of scans needs to be considered. I multiplied the distance of the scans for both 2007 and 2008 by the duration of the individual scans. Figure 13 shows this new relationship.

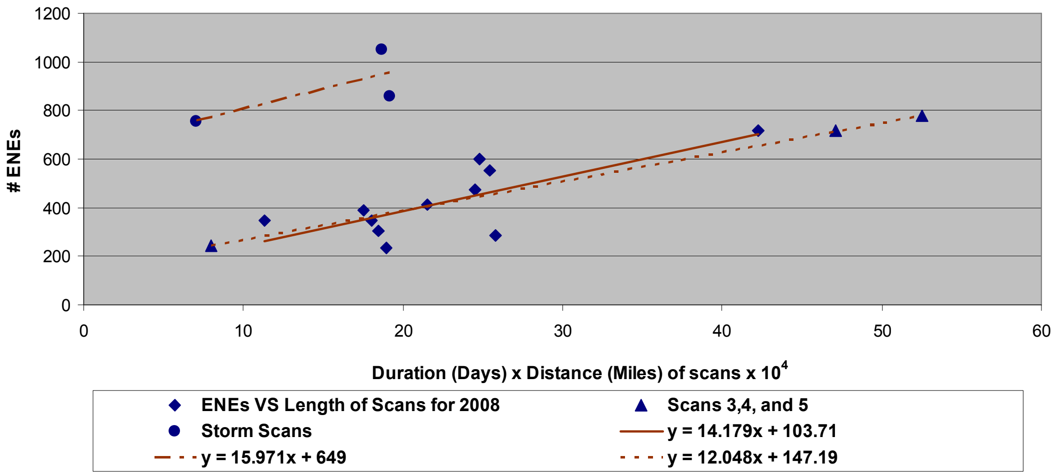

Fig. 13. ENEs vs. duration × distance of scans

Aside from the storm scans in 2007, the normal scans from 2007 and 2008 reveal approximately the same linear relationship between the ENEs, duration of scans, and distance of scans. The slope of the approximated line reveals the same generation of ENEs for both 2007 and 2008. This generation rate can be found by using the same method as earlier.

Using Figure 13, for 2007,

$E = 12.048\times10^{-4}\times D\times S + 147.19$

For S = 1,

$E = 12.048\times10^{-4}\times D + 147.19 = E_o$

For S = 2,

$E = 12.048\times10^{-4}\times 2\times D + 147.19 = 12.048\times10^{-4}\times D + E_o = E_o + {}^1/_2G$

${}^1/_2G = 12.048\times10^{-4}\times D$

Therefore, $G = 24.096\times10^{-4}\times D$ ENEs per Day for a given distance D

So, G = .0024 ENEs per Day per Mile for 2007

Using Figure 13, for 2008,

$E = 14.179\times10^{-4}\times D\times S + 103.71$

For S = 1,

$E = 14.179\times10^{-4}\times D + 103.71 = E_o$

For S = 2,

$E = 14.179\times10^{-4}\times2\times D + 103.71 = 14.179\times10^{-4}\times D + E_o = E_o + {}^1/_2G$

${}^1/_2G = 14.179\times10^{-4}\times D$

Therefore, $G = 28.358\times10^{-4}\times D$ ENEs per Day for a given distance D

So, G = .0028 ENEs per Day per Mile for 2008

The estimated generation rates are.0024 ENEs per Day per Mile for 2007 and .0028 ENEs per Day per Mile for 2008.

Sensitivity analysis to weather

In 2007, the storm scans revealed a much higher rate of ENEs per duration. By following the same procedure as above, the generation rate can be found as $G = 2\times10^{-4}\times15.971 =$ .0032 ENEs per day per mile. The generation rate is still similar to that of scans 3, 4, and 5, with only about a .0008 difference in ENEs per day. Since the generation rate is not much different, the initial number of ENEs present before the scans must be higher. The initial ENEs present for the storm scans is about 649 – 147.19 = 501.81 ENEs higher than that of scans 3, 4, and 5. This reveals that damp conditions result in an increase in detection of stray voltage events.

In 2008, Routines 108, 208/308, and 108-A all occurred in the spring. Using the data in Table II and the equation generated in Figure 13, the estimated number of ENEs for Routine 108 should have been:

$$\begin{aligned} E &= 14.179\times10^{-4}\times D\times S + 103.71 \\ &= 14.179\times10^{-4}\times4586\times54 + 103.7 \\ &= 454.8 \text{ ENEs} \end{aligned}$$

However, Routine 108-A actually resulted in the detection of 599 ENEs, giving a percentage error of 24%. The expected detected ENEs for Routine 208/308 and 108-A, resulted in percentage errors of 16% and 23%, respectively. This reveals a bias in the detection of stray voltages towards season. In the month of April, the melted snow mixes with sludge from the streets and can cause a very wet and salty medium. This medium is very conductive and may explain the increase in ENEs.

In 2008, Routines 708-A, 808-A, and 908-A all occurred in the fall. These scans revealed a lower than average rate of ENEs per day by 23%, 58%, and 65% respectively. Once again, seasonal conditions appear to affect the number of ENEs.

Intermittency

Stray voltages are caused by failures in the system, such as corroded wires and improperly grounded structures. Weather only causes these stray voltages to become detectable, or "on". These stray voltages must be intermittent if they are not "on" at all times, as this defines manifest stray voltages. By comparing this behavior to the three models for intermittency shown in Figures 1-3, it becomes apparent that model one would not be applicable in this situation. If the stray voltages have a constant duty cycle and frequency throughout the year, there would not be an increase in intermittent stray voltages in the spring months. The duty cycle is most probably increasing as a result of the conductive atmosphere. Models 2 and 3 would both explain this behavior. However, if model 3 were the correct model in this situation and weather affected the frequency of intermittent stray voltages, then we could conclude that the increase in frequency would result in a large increase in generation rate. This is not the case. The generation rate is fairly constant throughout the season. For this reason, model two seems to best fit the results of Con Ed's scans.

Efficiency of scans and ESRs

While the number of detected ENEs has decreased from 2007 to 2008, a total of 4,438 in 2007 and 5,025 in 2008, the efficiency of detection has decreased. The ratio of ENEs to miles scanned was .196 in 2007 and .085 in 2008. This ratio has decreased because the scans in 2007 were drawn out over more days than in 2008. As discussed earlier, the number of ENEs is proportional the duration of scans, not the distance.

Table IV shows the ESRs per year from 2004 to 2008 [6-7]. Since the report was written in December, the number of ESRs had not yet been reported for December 2008, so the number of ESRs reflected in the table for 2008 is based on an eleven month period.

TABLE IV
ESRs per Month for 2004-2008

Year	ESRs	ESRs/Month
2004	285	23.750
2005	230	19.167
2006	198	16.500
2007	133	11.083
2008(only over 11 months)	87	7.909

The number of ESRs is decreasing each year due to manual and mobile scanning. Figure 14 shows the amount of ESRs per month for 2004 through November of 2008.

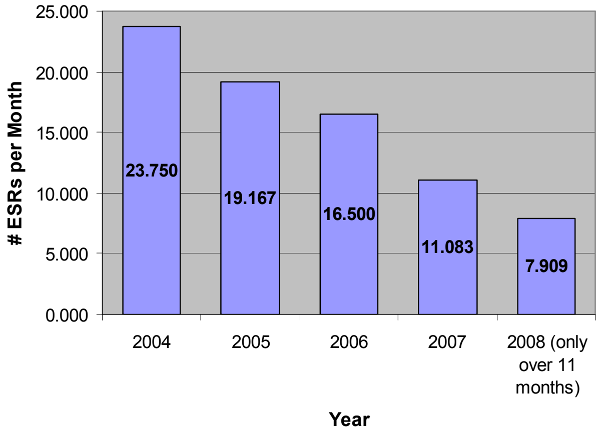

Fig. 14. ESRs per month for 2004-2008

After an increase in mobile scanning in 2007, ESRs decreased from 2006 to 2007 by 32.8%. From 2007 to 2008, ESRs decreased by 28.6%.

CHAPTER IV

CONCLUSIONS

Summary

Without consideration of intermittency, the efficiency of detection of energized structures is not directly proportional to the frequency of scans, as predicted. Instead, the efficiency of detection of energized structures is proportional to the duration of scans. Longer scans result in detection of more ENEs. While increasing the number of scans and the miles per scan does slightly increase the number of ENEs detected, it is much more efficient to have a longer duration. As discussed in the results, efficiency in 2008 decreased by 50%. In 2007, there were fewer scans, but with twice as long durations. In 2008, there were more scans, and thus more miles, but the scans were very short. The amount of miles scanned doubled, but the number of ENEs found only increased by about 5%. In terms of cost and efficiency, it would be beneficial to have fewer scans, but each with longer duration.

The generation rate for 2007 was found to be about .0024 ENEs per day per mile, and the generation rate for 2008 was about .0028 ENEs per day per mile. These are very low generation rates relative to the number of ENEs found per day. The generation rate is fairly constant throughout the seasons, indicating that the weather does not affect the generation rate.

As predicted, the efficiency of energized structure detection is directly proportional to an increase in the duty cycle of intermittency due to weather and other annual conditions. In the spring, there is an increase in the detection of ENEs as a result of the weather conditions during that time. Weather does not cause stray voltage, but rather causes it to "show up". In the spring, the snow is beginning to melt, causing moisture. This moisture mixes with the salt and sludge on the streets from winter and creates a very conductive medium. We postulate that the intermittent stray voltage is no longer undetectable and quiescent as it was during dry conditions; the duty cycle of this intermittent stray voltage has increased. Because there is about a 20% increase in ENEs in the months of January through April, it would be beneficial to bias scanning toward the spring by about 20%. Increased scanning in the spring would result in energized structures being found and fixed that would normally be undetectable, thereby increasing public safety. Since there was a decrease in the expected number of ENEs in October though December by about 50%, it would be more efficient to limit the scanning done in the fall in order to save money and time.

Future work

The data in this analysis only represents two years of scans, one of which was mainly storm scans. In order to produce more reliable results, the 2009 scan results should be used in order to verify the generation rate model and gain a better understanding of the effect of seasonal changes.

The number of ESRs is decreasing each year, but at a much faster rate than ENEs are being detected. This relationship is not yet understood and requires further study. It is suggested that future data be used to determine why these ESRs are decreasing much faster than detection of ENEs is occurring.

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