LINE ARRESTER APPLICATION FIELD STUDY

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Abstract— **Overall, lightning is one of the leading causes of interruptions on Distribution Systems, particularly for utilities that have a medium to high level of lightning activity. This study examines the impact of arrester spacing on the lightning performance of a 12.5kV distribution system. Sixty (60) of the worst performing circuits, based on historical lightning performance, were analyzed with half of the circuits upgraded to the test arrester configuration and the other half left alone for comparison. After the arrester upgrades were completed, three (3) seasons of lightning and interruption data were collected to compare the two groups. The lightning data analysis was performed with the use of FALLS™. To compare the performance of the two (2) groups, the number of interruption/length (km)/ground strike density was used.**

Index Terms—**Distribution Line, Distribution Line Lightning Protection, Lightning Performance of Distribution Lines, Surge Arresters**

I. INTRODUCTION

Lightning has been one of the leading reported causes of interruption on the distribution system, at the 4kV and the 12kV voltage levels. This has been the case since records of interruptions have been kept at ComEd, which has been recording data since 1982.

The number of lightning interruptions varies from year to year. This variation is due to the number of lightning strikes that occur each year. The number of lightning strikes best explains the variation in the annual number of lightning interruptions.

In 1992, a ComEd study was conducted. The goal of this study was to identify ways of improving the lightning performance of the distribution system. The study concluded that for a 12kV feeder, "by placing arresters every three spans (180m), reliability will be increased by more than 70% with only a 3.8% increase in cost." This 70% improvement was in the number of flashovers per year. Some of the assumptions for this study were: a 3-phase circuit with a length of 16km, a span length of 180m, 12m poles, ground resistance was 5 ohms, a 95 kV BIL (only the BIL of the insulators was taken into account), a ground flash density of 1.85 strikes/km^2 and no natural shielding. A recommendation of this study was that arresters should be installed every 180m on 12kV feeders.

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II. ARRESTER FIELD TEST PROGRAM

In 1995, ComEd decided to conduct a field trial using the arrester standard recommended by the study. The objective of this field test was to verify the expected performance of this arrester standard. Sixty (60) 12 kV feeders with historical lightning interruptions were selected and broken into two (2) groups of thirty (30) feeders.

The two groups for the field test consisted of a control group and an experimental group. The experimental group would have arresters and ground rods installed to bring the entire feeder up to the new arrester standard. MOV arresters were to be installed every 180m and all non-MOV arresters were to be replaced with MOV arresters. The control group would be left as is for comparison with the experimental group.

For selection of the feeders, interruption data from 1990 through 1994 was used. The feeders with the highest and most consistent number of lightning interruptions were chosen. These feeders were then ranked with the worst performer given the ranking of 1 and so on. These feeders were then alternated between the experimental and control groups. By alternating feeders, the two groups included feeders with similar historical performance. In addition, the two groups ended up being comparable in total length and in geographic distribution.

For the experimental group, installation of arresters began on 11/8/95. The installation of arresters was completed on the last of the feeders on 5/8/97. In all, approximately 40,000 arresters and 70,000 ground rods were installed on the 30 experimental feeders.

It should be noted that the condition of the experimental feeders varied vastly from the assumptions used in the 1992 computer analysis. For the experimental feeders, only 24% of the total length was 3-phase, while 16% was 2-phase and 55% was single phase. Also, the average pole height was less than that in the study, typical 10.5m poles for the 3-phase and 2-phase, while poles as short as 7.5m were found in some areas with single phase, while 9m to 10.5m poles were more the norm. The only condition that was the same was that the experimental feeders were mostly in open areas and would have a very low shielding factor. The computer analysis used a shielding factor of zero (0).

III. ANALYSIS METHODS

The method used to analyze the two (2) groups was to compare the number of lightning interruptions per 100 km per Ground Strike Density (GSD is measured in number of lightning strikes per km^2). This method has been used in several other studies [1,2].

To obtain the GSD and length data, the FALLS™ software, from Global Atmospherics, Inc., was utilized. To determine the GSD, a 1-km buffer was used around each of the feeders. A separate function returned the length of each feeder.

Lightning interruptions were extracted from ComEd's interruption database. These interruptions were then analyzed, with the use of FALLS™, to determine if there was lightning present at the time of the reported interruption. If there was lightning activity, up to 3 hours prior to the reported interruption, then the interruption was considered to be caused by lightning. The reason that the 3 hour time span was chosen was due to the methods for reporting interruptions, mainly customer calls, where a customer may not call in as soon as the interruption occurs or they may not be able to get through right away, especially if there is a storm at the time.

The date range that was used for the analysis was from May 9, 1997 to September 9, 1999. This provided 28 months of data for the analysis. It also included data for 3 lightning seasons. The reason for the start date was that was the day after construction had been completed on all of the experimental feeders.

A statistical analysis of the number of interruptions per 100km per GSD of the control group versus the experimental group was performed. The analyses was to determine if there was sufficient evidence, at a 95% confidence level, to expect an improvement in the lightning performance of the experimental group relative to the control group.

IV. RESULTS

A descriptive statistical summary of the data, for all lightning interruptions, is shown in the following tables. Table 1 contains data for the control group and Table 2 contains data for the experimental group. This summary is for those interruptions that were considered to be caused by lightning. These tables show the average, minimum, maximum and standard deviation, of each group, for the number of interruptions due to lightning, the feeder length, the GSD and the number of interruptions per 100km per GSD. For the minimum and maximum statistics, the values for each measure are not necessarily for the same feeder.

A few observations can be made from this data. First, the length of the experimental group is slightly longer than that of the control group. This is the case for the shortest and longest feeders within each group and for the average length. With all things being equal, the number of interruptions, due to any and all causes, on the experimental group would expected to be higher than that of the control group due to the increased exposure because of the greater length.

Table 1

Control Group Statistics
For All Lightning Interruptions

	# of interruptions	Length (km)	GSD	Int's/100km/GSD
Average	14.43	150.7	21.27	0.457
Minimum	1	36	10.26	.040
Maximum	55	339	44.34	1.335
Standard Deviation	10.78	74.5	5.94	0.242

Table 2

Experimental Group Statistics
For All Lightning Interruptions

	# of interruptions	Length (km)	GSD	Int's/100km/GSD
Average	11.93	183	21.88	0.305
Minimum	1	49	12.29	0.108
Maximum	23	345	32.07	0.501
Standard Deviation	6.09	81.16	4.27	0.095

Next, the ground strike density (GSD) is about the same for both groups. This is especially true for the average and the minimum values. The big difference is in the maximum value, where the maximum GSD for the control group is almost twice as much as the experimental group. But, this difference in the maximum value of GSD is for only one (1) feeder and the rest of the feeders in the control group are in the same range as the experimental group. Therefore, if everything else were equal, then the number of interruptions due to lightning would expected to be roughly equal for each group.

For all interruptions that were considered to be caused by lightning, the experimental group experienced fewer interruptions on average than the control group. Also, the maximum number for the experimental group was less than half of the control group. The only unexpected result is with minimum number of reported interruptions, where the control group value was the same as that of the experimental group. Even with the shorter minimum feeder length in the control group than the experimental group, the difference is not enough to explain this difference. Besides that, the feeders with the minimum reported interruptions were not on the shortest feeders.

For the number of interruptions per 100km per GSD, the experimental group's average was lower than the control group's for all interruptions. This is also true for maximum number.

Statistical analysis of the results indicates that there is sufficient evidence, at a 95% confidence level, to expect a 16% improvement in the lightning performance (in terms of the average number of interruptions per 100km per GSD) of the experimental group relative to the control group. This for all of the interruptions that were due to lightning.

V. DISCUSSION

Figure 1 shows a graphical representation of each feeder's number of interruptions/100km/GSD for both the experimental and control groups. This is for all of the interruptions that were due to lightning. The mean for each group is also shown.

As shown in figure 1, the control group has a much larger range than that of the experimental group. The control group also has 8 feeders whose number of interruptions/100km/GSD is higher than the maximum for the experimental group, with 2 of them almost 3 times greater. But on the other end, the control group's and the experimental group's minimum value are equal. Also, most of the experimental group's points are below the average of the control group. The feeders that had higher numbers in the control group were expected since they were not upgraded to the current arrester standards, but those having same minimum value were not.

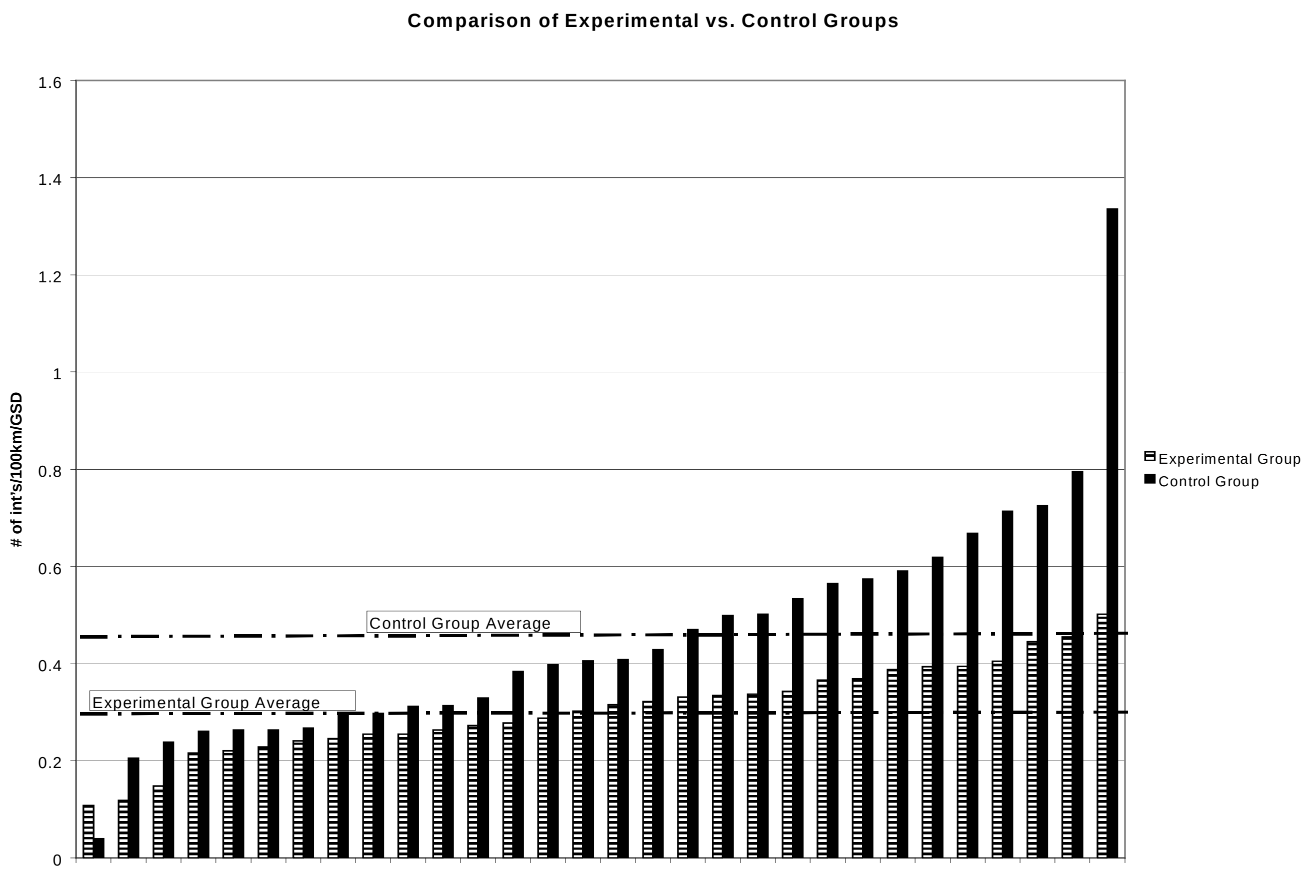

Figure 1. Individual Feeders Number of Interruptions per 100km per GSD

In figure 1, the mean for the control group is higher than that of the experimental group. The standard deviation for the control group is larger than that of the experimental group. The range of the experimental group is also much more compacted than that of the control group. All of these results would have been expected and they indicate an improvement of the experimental group over that of the control group.

Even though the experimental group's performance has improved, on average, over that of the control group, the improvement was not as great as expected. This should not be looked on negatively, as there was improvement in the performance. Of course, there are many reasons why the results were not as expected.

The original study predicted a 70% improvement in the number of flashovers whereas this study is looking at sustained interruption. Every feeder in this study is a rural circuit with multiple reclosers. With a recloser, a flashover would not necessarily lead to a sustained interruption. The recloser would sense the flashover, open up, clear the flashover and then reclose and restore service. As there is no remote indication on these reclosers, there is no way to determine what the number of operations were, especially during thunderstorms, and therefore no way to determine what the improvement in flashovers was for the experimental group.

Another factor that may have contributed to a lesser improvement might have been the field conditions versus the computer model. The model used for the computer simulations was a 3-phase main line circuit on 12m poles, while over 50% of the length of the experimental group circuits was single phase circuits with poles as short as 7.5m. While computer studies that were performed for the 34kV system showed that pole height affected the performance (a larger improvement for taller poles), no studies were conducted for 12kV, so it can only be inferred that with the shorter poles the improvement of the experimental group would have been slightly reduced. As the software that was used is no longer usable, the actual field conditions cannot be put into the model to see what the revised expected performance would be.

Yet another factor which may have led to the less than predicted improvements may be the differences in lightning parameters used in the computer model versus what exists within the service territory. The only parameter that may have been close was the lightning wave rise time: the study used a 2µs risetime, which is probably close to that of natural lightning even though an IEEE Task Force is working on a new standard risetime for subsequent strokes of 0.1µs. The computer study stated that program calculated and used the minimum current that would result in a flashover, which is probably greater than the average current of 22.1kA from the actual field conditions. The differences in the lower lightning current in the field conditions probably helped lead to the lower improvements from the field conditions to what was modeled in the computer study.

Also, the computer study used just the BIL of the insulators and ignored the insulating levels of the cross-arms and poles, which would raise the flashover level. The typical distribution pole has a Critical Flashover level (CFO, which is combination of the BIL's of all of the components in the flashover path) in the range of 250kV to 300kV. From notes from the computer study, a 12kV line with a BIL of 250kV would only have roughly a 30% improvement in the flashover rate, which is only slightly greater than the 16% improvement in the Field Test.

As the feeders in this study have very minimal shielding, any lightning in the vicinity of the feeder should terminate on the feeder. If the lightning does not strike the feeder, it should strike far enough from the feeder so as not to induce a voltage that would cause a flashover. Therefore, any flashovers, or interruption, on these feeders would be the result of a direct strike due to lightning

With the feeders being in open areas, any lightning interruption would likely be due to a direct lightning strike. With all of the lightning interruptions being the result of direct lightning strikes, it appears that there is minimal improvement of the experimental group (arresters every 180m) over the control group (arresters assumed every 360m). As already stated, there is a 16% decrease in the average number of interruptions/100km/GSD. These results are in line with a study that was done by Power Technologies, Inc. (PTI) which showed roughly a 10% improvement, in the number of flashovers, going from a spacing of every 360m to every 180m [3]. The PTI study showed that the only way to greatly reduce the number of flashovers, which would lead to a reduction in sustained interruption, was to install arresters on every pole, especially if the circuit had no natural shielding, which is the case with the feeders in this study.

It should be noted that the Ground Strike Density (GSD) was much greater in the study than the computer model. While the increase in GSD will lead to a greater number of interruptions, or flashovers, for both groups, it will not lead to a difference in the percent improvement. The flashover rate increases linearly with an increase in GSD and therefore the percent improvement between the groups would be the same.

VI. CONCLUSIONS

There is an expected improvement in performance by installing arresters every 180m instead of every 360m. From the Field Test, there is an average improvement of 16%. The reason that the results of the Field Test were less than those predicted in the study is due to the parameters that were used in the studies model. The greatest difference in the model from the field conditions was that the model used a 3-phase circuit on 12m poles and in the field over 50% of the circuits were single phase on poles as short as 7.5m. Also, the model was looking at flashovers, which do not necessarily lead to interruption, and this study was looking at sustained interruption.

The improvement in the performance of the experimental group was not as good as predicted. The original study expected a 70% improvement, but this improvement was in the number of flashovers per year, not sustained interruption. At the time of the study and when the Field Test was proposed, the 70% improvement in flashovers was being equated to a 70% improvement in interruption. With the number of reclosers on the circuits in the study, not every flashover would lead to a sustained interruption. Without knowing the trip counts on all of the reclosers, there is no way of determining the flashover improvement of the experimental group over the control group. Also, it should be noted that from the original computer analysis, a 250kV BIL line showed only a 30% improvement in the flashover rate, which is only slightly larger that the 16% improvement from the field test.

There is also a better predictability in the experimental group versus the control group. As was shown in figure 1, the spread in the number of interruptions/100km/GSD is much less experimental group than the control group (reduced variance). Also, in the experimental group the high-end number of interruptions/100km/GSD does not exist.

VII. REFERENCES

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VIII. BIOGRAPHIES

John McDaniel (M’1986) graduated from the Michigan Technological University with a B.S.E.E. and M.S.E.E. in Electrical Engineering, majoring in power systems. John is employed with Detroit Edison in their Distribution Planning department where he has been for the past year. His present title is Senior Engineer - Planning. He is responsible for distribution planning and reliability planning. Prior to that, John was employed at Commonwealth Edison for 10 years, most recently in their Reliability Analysis Department. He has held several positions in both engineering and operations. His areas of interest include Lightning Protection, Reliability Analysis, Planning and Special Engineering Studies and Problem Analysis. He is a Member of the IEEE and his professional activities include work with the IEEE Distribution Sub-Committee and IEEE Lightning and Insulator Sub-Committee.