Long Term Analysis Of Line Arrester Application Field Study

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***Abstract*— 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. In 1997 a field study was conducted to examine the impact of arrester spacing on lightning performance of a 12.5kV distribution system. Sixty of the worst performing 12 kV circuits, based on historical lightning performance, were analyzed, with half of the circuits upgraded to a test arrester configuration and the other half left alone for comparison. After the arrester upgrades were completed, a paper was published in 2001 to compare the two groups with three seasons of lightning and interruption data. In 2007, the analysis was updated with nine years of lightning and interruption data. This study presents the results of the long-term analysis.**

***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%." This improvement was calculated against a 1200 foot (360m) arrester spacing, which was the standard at the time. The 70% improvement was in the number of flashovers per year, not sustained outages.

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.

In 1995, ComEd conducted 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. Feeder upgrades to the new lightning arrester standard were completed in 1997. After three summers, the feeder performance was analyzed and the results were published in 2001 [1]. Statistical analysis of the results indicated that there was 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 Ground Strike Density) of the feeders constructed to the new lightning standard.

In 2007, the performance of the feeders was again analyzed, but this time there was nine years of data available to conduct the study. It was felt that updating the analysis with a much larger data sample would provide more definitive results for the field trial.

II. ARRESTER FIELD TEST PROGRAM

For the field trial, sixty 12 kV feeders with historical lightning interruptions were selected and broken into two groups of thirty feeders.

The two groups for the field test consisted of a control group and an 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 the 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.

The experimental group had arresters and ground rods installed to bring the entire feeder up to the new arrester standard. MOV arresters were installed every 180m and all non-MOV arresters were replaced with MOV arresters. The control group was left as is for comparison with the experimental group.

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.

The characteristics 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. In addition, the average pole height was

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less than that in the study, typically 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. 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.

III. ANALYSIS METHODS

The method used to analyze the two groups was to compare the number of sustained lightning interruptions (IEEE definition, > 5 minutes) per 100 km per Ground Strike Density (GSD is measured in number of lightning strikes per km^2). This method has been used in other studies [2,3].

To obtain the GSD and length data, the FALLS™ software, from Vaisala, Inc. (formerly 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.

Sustained lightning interruptions were extracted from ComEd's interruption database. These interruptions were 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, depending on the time of the interruption.

The date range that was used for the analysis of the original study was from May 9, 1997 to September 9, 1999. This provided 28 months of data for the analysis, which included 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 indicated that there was sufficient evidence, at a 95% confidence level, to expect a 16% improvement in the lightning performance of the experimental group feeders relative to the control group.

IV. THE LONG TERM STUDY

Before conducting the long-term study, we had to decide if a comparison of the experimental group feeders vs. the control group would still be valid. We were constrained to use the same feeders as the original study, since the experimental feeders are the only feeders on the system which have been so rigorously brought up to the new construction standard. Many years have passed since the field upgrade was completed, and our results may not be meaningful if there had been significant reconfiguration or reconstruction of many of the feeders.

A review of each feeder was made to compare it's present configuration to that of the original study. Of the 30 feeders in the control group, 21 are virtually identical to their original configuration. In the experimental group, this was also true for 20 of the 30 feeders. If we limit our analysis to those feeders that did not change, we felt we had a sufficient number to obtain a valid result.

The time frame of the study covered nine years, from 1998 through 2006. In that time, more than 550,000 lightning strokes were recorded within the buffered areas of the 41 feeders. The number of sustained 12kV lightning outages for all the circuits was 2,400.

A descriptive statistical summary of the data, for all lightning interruptions, is shown in the following tables. Table 1 contains data for the 21 feeders in the control group, and Table 2 contains data for the 20 feeders in the experimental group. This summary is for those interruptions that were indicated as being caused by lightning in the interruptions database. 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 average length of an experimental group feeder is about 25% longer than that of the control group. With all other things being equal, the number of interruptions, due to any and all causes, on the experimental group would be expected to be higher than that of the control group due to the increased exposure because of the greater length.

Next, the average ground strike density (GSD) is about the same for both groups. This indicates that the longer feeders would be exposed to more lightning strokes than the shorter ones, and consequently, more lightning challenges. Again, it would be expected that the number of interruptions would be greater in the experimental group due to their greater average length.

The actual results show, however, that for all interruptions that were considered to be caused by lightning, the experimental group experienced fewer interruptions than the control group. Also, for the number of interruptions per 100km per GSD, the experimental group's values were lower than the control group's for all outages.

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.

Table 1

Control Group Statistics
For All Lightning Interruptions (21 Circuits)

	# of interruptions	Length (km)	GSD	Int's/100km/GSD
Average	60.8	148.6	104.8	0.390
Minimum	22	70	79.7	0.295
Maximum	137	288	157.8	0.588
Standard Deviation	29.33	58.9	21.43	0.072

Table 2

Experimental Group Statistics
For All Lightning Interruptions (20 Circuits)

	# of interruptions	Length (km)	GSD	Int's/100km/GSD
Average	56.2	185.7	105.5	0.291
Minimum	10	49	72.2	0.190
Maximum	114	320	159.9	0.414
Standard Deviation	27.27	73.2	28.71	0.069

V. DISCUSSION

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

As shown in the figure, all 21 of the feeders in the control group have a value of number of interruptions/100km/GSD which is higher than the average for the experimental group. At the same time, 18 of the 20 experimental group's points are below the average of the control group. For all feeder pairs, the experimental feeder has a lower int/100kM/GSD than the corresponding control group feeder.

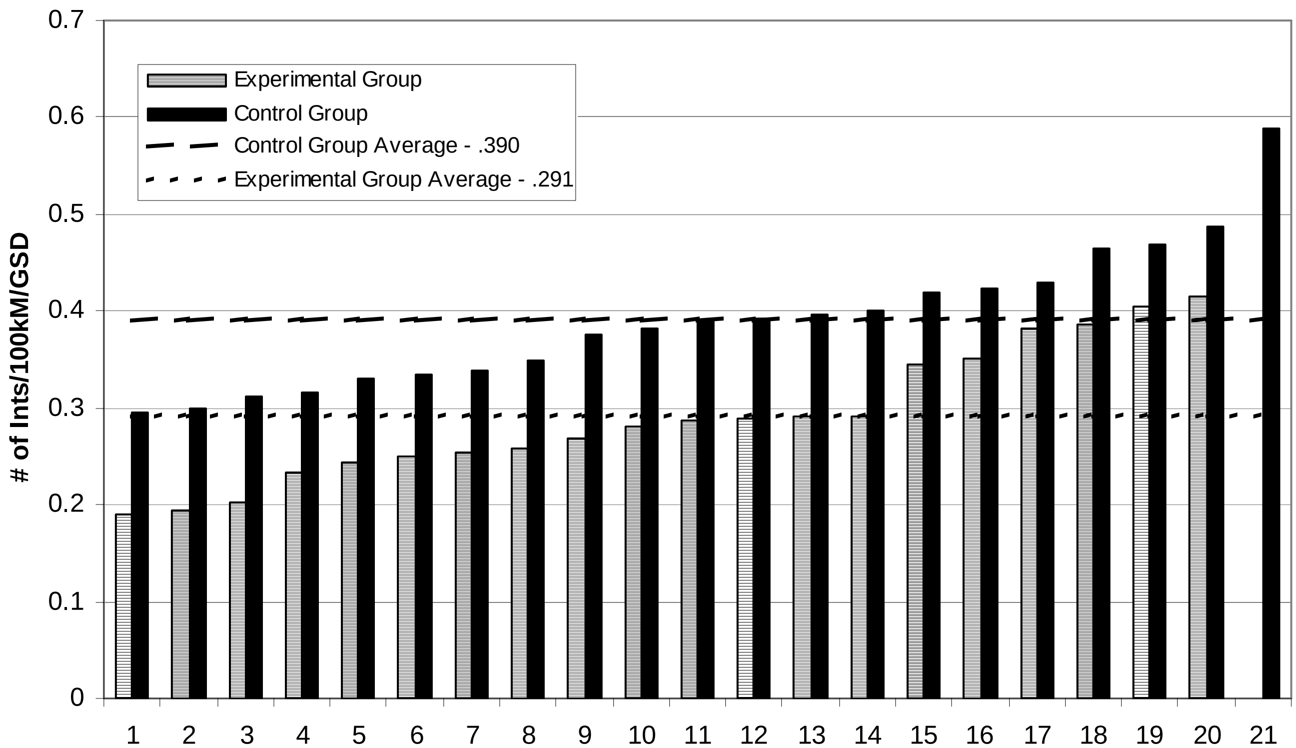

Figure 1. Individual Feeders Number of Interruptions per 100km per GSD

As stated earlier, there was 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 in the long-term study. This is identical to the findings of the original three year study. But even though the experimental group's performance improved 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. The following discussion summarizes some of the reasons why the results were not as expected.

The 1992 study predicted a 70% improvement in the number of flashovers whereas the field study is looking at sustained interruptions. 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 fault, and then reclose restoring 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 the effect of the reclosers on the performance of either the experimental group feeders or the control group feeders.

The performance improvement in the computer model was based on an arrester spacing of 1200 feet for the control group vs. 600 feet for the experimental group. In actuality, arrester spacing will not always be 1200 feet on the control group feeders. ComEd standards call for arresters at equipment poles (transformers, capacitors, etc.) and cable downfeed poles. Therefore, there are many areas where arrester spacing is much less than 1200 feet on the control group feeders.

Another factor that may have contributed to a lesser improvement might have been the field conditions versus the computer model. As stated earlier, 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. Computer studies that were performed for the 34kV system showed that taller poles are predicted to experience a higher flashover rate than shorter poles. The installation of additional arresters may have a greater effect on reducing the flashover rate, and thus improving the performance, of feeders with taller poles vs. shorter poles. No such 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 less than that predicted by the 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 BILs 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 more in line with the 16% improvement calculated for the Field Test.

Finally, the original study may have resulted in a calculated improvement that was too high considering the input parameters. Subsequent studies on other systems have indicated an estimated improvement of about 50%, when reducing arrester spacing from 1200 feet to 600 feet [4].

It should be noted that the Ground Strike Density (GSD) was much greater in the field study than the computer model. At the time the computer study was conducted, the only way to obtain GSD data was by using an Isokeraunic map. This method results in a rough estimate at best of lightning activity. A GSD value of 4.8 strikes per sq. mile per year was estimated from the map. Since that time, accurate lightning strike data can be obtained from the National Lightning Detection Network (NLDN) using the FALLS™ software described earlier. The actual average GSD for the 41 circuits, based on the NLDN, is approximately 30 strikes per sq. mile per year. While the increase in GSD will lead to a greater number of interruptions, or flashovers, for both groups, it will not necessarily 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%, which is less than what would have been expected based on the computer study. One reason 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, while in the field, over 50% of the circuits were single phase on poles as short as 7.5m. Also, the model assumed a 1200 foot spacing for arresters on the control group circuits. The actual spacing will be less than that in some areas due to arrester installations on equipment poles and cable downfeed poles.

The computer study calculated a 70% improvement, but this improvement was in the number of flashovers per year, not sustained interruptions. At the time of the computer study, and when the Field Test was proposed in 1995, the 70% improvement in flashovers was being equated to a 70% improvement in interruptions. With reclosers on the circuits in the study, not every flashover leads 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, for similar arrester spacing, a 250kV BIL line showed only a 30% improvement in the flashover rate, which is closer to the 13% improvement from the field test.

VII. ACKNOWLEDGEMENT

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VIII. REFERENCES

[1] J. McDaniel, “Line Arrester Application Field Study,” Transmission and Distribution Conference and Exposition, 2001 IEEE/PES, Volume 2, 28 Oct.-2 Nov. 2001 pp. 1025 - 1029 vol.2
[2] T. A. Short and R. H. Ammon, “Monitoring Results of the Effectiveness of Surge Arrester Spacing on Distribution Line Protection, *IEEE Trans. Power Delivery,* vol. 14 pp. 1142-1150, July 1999.
[3] J. Dougan, “Use of Lightning Flash Statistics Helps Utility Prioritize and Track Distribution Reliability Improvements,” presented at 1998 International Lightning Detection Conference.
[4] S. Meliopoulos and J. Kennedy, “Statistical Lightning Performance Evaluation of Overhead Distribution Lines,” Power Engineering Society Winter Meeting, 2000 IEEE, Volume 3, 23-27 Jan2000, pp. 2022-2028 vol. 3

VIII. BIOGRAPHIES

Wayne N. Zessin (M’2005) was born in Chicago, Illinois in 1949. He received the B.S.E.E. from the Illinois Institute of Technology in 1970. Wayne has been employed at ComEd for the past 37 years where he has worked in various departments, including Field Engineering and Capacity Planning. His present position is Senior Engineer in the Reliability Programs Department. Wayne is involved with the analysis of lightning, and other reliability data for ComEd, and the development of programs directed at improving the reliability for ComEd’s distribution customers. In addition, his work focuses on ComEd’s distribution automation efforts. Wayne is a member of the IEEE/PES Working Group on the Lightning Performance of Distribution Lines. Wayne participated as a Technical Advisor on the NEETRAC sponsored project, “Communications Infrastructure for Electric System Automation – Phase I and II.”

John McDaniel (M’1986) graduated from 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 National Grid in their Distribution Field Engineering group as a Reliability Engineer. He is responsible for overseeing the reliability work within National Grid’s New York Central Division. Previous to that, he was employed with Detroit Edison in their Distribution Planning department where he was for 6 years. His title was Senior Engineer - Planning. He was 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, and Planning. He is a Senior Member of the IEEE and his professional activities include work with the IEEE Distribution Sub-Committee and IEEE Lightning and Insulator Sub-Committee. John chair’s the IEEE/PES Working Group on the Lightning Performance of Distribution Lines and is the Vice Chair of the Distribution Subcommittee and the Distribution Reliability Working Group. He is also a corresponding member of CIGRE WG C4.4 (Lightning) and CIRED Joint WG C4.4.05 (Protection of MV and LV networks against lightning).