Lightning protection studies in the cuban electric systems

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Resumen / *Abstract*

En el artículo se presenta una metodología para el estudio del comportamiento ante rayos de líneas de distribución y transmisión cuando se utilizan diferentes esquemas de protección y se consideran los aspectos técnicos y económicos. La metodología fue aplicada en algunas líneas del sistema eléctrico cubano. Los principales resultados fueron la recomendación de un nuevo arreglo del cable protector en las líneas de transmisión y el uso de cable protectores para las líneas de transmisión cubanas.
Palabras clave: Rayos, metodología, comportamiento ante rayos

This paper presents one methodology for the study of lightning performance of transmission and distribution lines with different protection schemes considering the technical and economic aspects. The methodology was applied in some lines of cuban electrical system. The main results were the recommendations of a new arrangement to the shield wire in the cuban transmission lines and the use of the shield wire for the cuban subtransmission lines.
Key words: Lightning, methodology, lightning performance

INTRODUCTIÓN

In the transmission and distribution electric power systems the interruptions of service result in low reliability and quality of the electric power with costs of millions of dollars for damages to equipment and energy undelivered. Likewise, the equipment and systems based on microelectronic (televisions, telephones, communication equipment and computer) are strongly affected by the electromagnetic interferences, originated by the incidence of electromagnetic change fields generated by lightning. The Cuba Republic have a high storm activity from 40 to 160 thunder day storms per year. The lightning is the main cause of the electrical interruptions in the cuban power system. Different methods have been developed and reported in the literature to study of lightning performance of transmission lines. Likewise, in the last two decades many studies on the lightning protection of the distribution lines have been carried out by different protection arrangements. Solutions that yield improved performance will vary from one line and another.

One methodology was developed in order to make predict studies on lightning performance of transmission and distribution lines with different protection schemes considering the several aspects that involved in the problem.

METHODOLOGY

The methodology is the following:

1. Evaluation of the necessity of the protection.

2. Evaluation of current state or perspective design.

2.1 Unshielded transmission lines**.**

2.1.1 Calculation due to direct lightning strokes, back flashover and total outages.
2.1.2 Evaluation of performance criterion.
2.1.3 Evaluation of improvements if it proceeds.
1.1.3.1 Economic and technical analysis of alternatives.

2.2 Shielded transmission lines.
2.2.1 Calculation of number outages due to shielding failures and back-flashover.
2.2.2 Evaluation of performance criterion.
2.2.3 Evaluation of improvements if it proceeds.
2.2.3.1 Economic and technical analysis of alternatives.

2.3 Distribution lines.
2.3.1 Evaluation of the protection for improvements insulation.
2.3.1.1 Verification of minimum and maximum insulation level.
2.3.1.2 Calculation of number outages due to direct and indirect strokes.
2.3.1.3 Evaluation of performance criterion.
2.3.2 Shielded distribution lines.
2.3.2.1 2 Calculation of number outages due to direct and indirect strokes.
2.3.2.2 Evaluation of performance criterion.
2.3.3 Evaluation of the protection for lightning arrester.
2.3.3.1 Selection of the lightning arrester.
2.3.3.2 Calculation of number outages due to lightning strokes on protected poles and the span between them and indirect stroke outages.
2.3.3.3 Evaluation of performance criterion.
2.4 Economic and technical analysis protection alternatives at distribution lines.

The models and methods are chosen according to the authors´s criteria. The main of them are:
- **Incidence model: Simplified Method. [1]**
- **Shielding failure outages: Simplified Method.[1]**
- **Back-flashover outages: Two Points Methods.[2]**
- **Calculation of induce voltage. Chowdhuris´s Method .[3]**
- **Calculation of indirect stroke outage in unshielded and improvement insulation lines: Chowdhuris´s Method.[4]**
- **Calculation of indirect stoke outages in shielded distribution lines: Simplified Method.[1]**
- **Calculation of indirect stoke outages in lightning arrester protected lines: IEEE Method.[5]**

Taking into account the different characteristics of the lightning parameters in tropical regions where ours countries belong, the methodology includes the results about the magnitude of the lightning current and the relationship between ground flash density and thunder day storms used in the reference 1.

The methodology was implemented by LEL (Lightning in Electrical Lines). The LEL is a windows based software package.

STUDY OF 110 kV LINES

The 110 kV cuban transmission system consists of about 3 752 km of lines distributed in 90 circuits.

- **Historical performance.**

The first step in the evaluation process was to identify what lines had historically poorly performance under lightning conditions. To calculate the number of outages/100km/year at every line the momentary and permanent lightning fault in sunspot cycle were considered. The probable lightning outages from the unknown outages according to the method reported[1] in also were considered.

The main results were:
1. From 90 studied lines, 45 had a poor performance under lightning conditions with more than 6 outages/ 100 km/year.
2. The 83,33 % of the lines with poor performance were single circuits supported in concrete towers.

- **Field inspections.**

The second step was to conduct tower by tower, in some lines, field inspections to verify what factors were contributing to the poor performance. The problems found were:
1. High values of the ground resistance: the vast majority of the measurements on any lines were above 80 ohms. The ground system consists of ground rod.
2. Insufficient number of grounds: large sections of shield wire were found to be without any ground.
3. Insufficient shield angles: In many cases, the lines with poor performance had shield angle greater than 45 degree.

- **Analysis with LEL.**

The next step was to use the LEL to study the shielding failure outages to shield angle of each line and back-flashover outages for grounding resistance values measured.

Taking into account the keraunic and insulation levels and wind regions the shielding failure outages in the lines with poor performance were calculated. The main result was:
1. The shielding failure outages analytically obtained were too high beside high values of shield angle.

The back-flashover outages at every line considering the keraunic and insulation levels and values of the ground resistance in one range which included the measured values were calculated. In the analysis, the surge impedance was used. The calculus was made from the IEEE Methods to ground rod. The results were referred to a static ground resistance for comparative purpose with the measurements. The main result was:

1. The contribution more important in the lightning outages of the 110 kV lines in Benetti towers is due to the back-flashover outages.

- Solutions.

From to the results of study the solutions following were proposed:

1. A new arrangement to shield wire was implemented. It permitted values between 25 and 30 degree in different insulation and wind levels.
2. Improvements in the ground resistance were designed and implemented. Ground resistance values of 15 ohms to level keraunic of 100, 20 ohms to 80 and 30 ohms to 60 and below were obtained.
3. The shield wire was connected to ground at every tower.

The simulation of these improvements in LEL predicted, in all cases, lightning outage below 6. The lines where these protection improvements were applied were monitored closely. Taking into account the actual activity storms, the lightning performance in the last 3 years matched with the predicted results in the study.

STUDY OF 34,5 KV

In the last years, more attention has been paid to lightning performance on subtransmission and distribution lines. This is due to, in the other factors, lightning damages in the modern customer which have a high sensitivity to voltage fluctuations and momentary outages.

The cuban subtransmission system consists of about 9393 km of lines distributed in 301 lines. The study was carried out in 24 shielded lines supported in concrete poles in horizontal configuration and located in keraunic levels between 100 and 160 thunder day storms. They have installed insulators which Critical Flashover Voltage (CFO) is 340 kV.

The study in the 34.5 kV lines was made with the same steps that in 110 kV lines.

- Historical performance.

Values between 25 and 66 for 34,5 kV lines of lightning outages/100 km/year were found.

- Field inspections in the 34,5 kV lines.

The problems found were:

1. Inadequate application of protection: many sections without shield wire and high number of broken ground wire were found. This has already been identified that absence of ground on shield wire will render it inoperable. The unprotected section of line to grow worse lightning performance.
2. High ground resistance: more than 85 % of ground resistance measurements on any line were above 25 ohms. It has been also known that pole ground requirements are very strong due to the lower insulation level on these lines.
3. Clearance problems: clearances below standard dimensions were commonly found between the ground wire and energized pole hardware when bringing the ground wire down the pole. It reduces the BIL of that structure.
4. High induction effect: the practice of bult-wrapping the ground wire at the base of pole where it is connected to the ground rod was found. It known that wire wrapped around the pole creates an inductive effect that can increased the ground wire an the phase wire.

- Analysis with LEL.

The LEL was used for predict the performance of unprotected lines, and with shield wire and arrester protection.

- Unprotected lines.

In the study of unprotected lines the main results were:

1. In keraunic level of 100 (location of the majority of lines), 68,18 lightning outages/100 km/year were predicted.
2. The induced voltage outages were of 1,52/100 km/year. It permitted to affirm that for insulation level used (CFO 340 kV) the induced voltages aren't a problem in the cuban subtransmission lines.
3. The lightning outages for the unprotected lines are too high. It to require yours protection.

- Shield wire protection.

The study of protection for shield wire was carried out considering the following aspect:

1. The shield angle is 35 degree.
2. The shield wire exists in the total length of the line with ground at every pole.

3. The ground rods are used. The bult-wrapping the ground wire at the base of pole are eliminated.
4. The values of ground resistance were varied from 10 ohms to 100 ohms.

The main results were:
1. The shield wire decreases the lightning outages respect to unprotected line for any value between 10 ohms y 100 ohms of the ground resistance, e.g. 95,6 % (10 ohms), 85,96 % (20 ohms), 77,98 % (30 ohms) y 46,9 % (100 ohms).
2. The back-flashovers for direct strokes were the main cause of the outages. An adequate value of the shield angle and a low number of induced voltage outages were found.
3. The adequate lightning performance is obtained for values of ground resistance of 10 ohms and below.

- Lightning arrester protection.

The protection with lightning arrester was analyzed for different spacing between them with 10 ohms of ground resistance. The failure probability arresters in the total outages were included. The main results were:
1. The probability outage is 76 % of total strokes (50,28 outages/100 km/year) for lightning arresters installed each two poles.
2. The lightning arresters installed on every pole on every phase don't give a total protection from direct stokes due to that distribution class arresters experience a significant failure rate to excess energy dissipation.

In the lines studied the shield wire protection was reconfigured by solutions of the problems found in the field inspections. The same conditions, with 10 ohms of ground resistance that simulated in the analytical study were applied. The lightning performance of these lines, through five years, after of to implement the improvements were good.

CONCLUSIONS

1. The cuban 110 kV transmission lines can be correctly protected with an adequate arrangement of the shield wire.
2. The cuban 34,5 kV subtransmission lines with CFO of 340 kV, the induced voltage outages are minimal.
3. Direct strokes can discharge significant amounts of energy through lightning arresters. It can to cause a significant failure probability of lightning arrester due to excess energy dissipation. It is truer in countries of high activity storms.
4. In the cuban subtransmission lines located in open areas and with a high activity storms, the shield wire with 10 ohms ground at every pole is the best solution of lightning protection.

REFERENCES

1. Suárez, S.: **"Método para la estimación del comportamiento ante rayos de líneas aéreas eléctricas", Tesis Doctoral, Ciudad de La Habana, Cuba, 2001.**
2. Anderson, J. G: ***Lightning Performance of Transmission Line. Ch 12*, of Second Edition of Transmission Line Reference Book 345 kV and Above. EPRI, Palo Alto, California, 1982.**
3. Chowdhury, P. B. and E. T. B. Gross: **"Voltages Surges Induced on Overhead Lines by Lightning Stroke", *Proc. IEEE*, Vol. 114, No. 12, 1967.**
4. Chowdhury, P.: **"Estimation of Flashover Rates of Power Distribution Lines by Lightning Strokes to Nearby Ground", *IEEE Trans*, on PWRD, Vol. 4, No. 3, July, 1989.**
5. ***IEEE Guide for Improving the Lightning Performance of Electrical Ppower Overhead Distribution Lines*, IEEE Std. 1410-1997, pp. 39,New York, December, 1997.**

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