Non-Conventionnal Measures for Improvement of Lightning Performance of Transmission Lines

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Abstract: This paper describes the evaluation of some non-conventional practices to improve the lightning performance of transmission lines, comprising the employment of auxiliary conductors and modification of grounding electrodes configuration. The results are obtained by simulation, employing a hybrid electromagnetic model to determine the amplitude of the overvoltage developed across insulator strings, due to direct strikes. The efficiency of such practices was evaluated for the actual conditions of a 230 kV line. Passed one rainy season since their implementation, the number of lightning associated outages was drastically diminished.

Keywords: Lightning performance of transmission lines, Non-conventional practices to improve line performance, Grounding behavior for lightning currents.

1. Introduction

Lightning is responsible for most of transmission line non-scheduled outages. The conventional practices for improving the performance of high voltage lines to lightning efforts usually comprises a limited set of actions. As these lines are usually provided with shielding cables, such actions basically comprise: (i) the reduction of tower footing resistance and (ii) the installation of line arresters devices to prevent flashover over line insulators.

Several energy utilities concentrate their efforts in the first action, due to the installation and maintenance costs for employment of line arresters. Nevertheless, the arresters are required in applications that involve non-favorable soil conditions, which inhibit the possibility of obtaining low value for grounding impedance of TL tower. Also some utilities extensively employ arresters in those applications where the continuity of energy delivery is essential.

There is a set of non-conventional practices that are able to intermediate the two presented actions. These practices explore the effects of those parameters that influence on the amplitude of overvoltages developed across insulator strings, when lightning flashes strike the line. Such parameters comprises the surge impedance and height of towers and the coupling effect between phase conductors and other metallic parts (shielding cables and tower structures).

The technical literature refers to some of these practices and suggests the possibility of employment of guy wires [1], of continuous counterpoise and metallic cables placed under phase cables and connected to towers (false shielding cables) as alternative solutions to improve the response of line to direct lightning strikes. In spite of these suggestions, the literature deals very poorly with the practical problems involved in their implementation and, mainly, with quantitative evaluations of their efficiency.

2. The motivation of this work

The authors are presently very involved with the problem related to the poor lightning performance of certain transmission lines [1,2] that cross distant locations at the Amazon Region. The region has typically very high lightning flash density and a large number of outages are verified for the local lines.

Usually, these lines have very long spans and frequently have their towers positioned at the top of hills. Very frequently, the earth layer that used to cover the hill is entirely removed by erosion effect along the years and the tower is positioned directly over rocks. So, extremely high values of grounding resistance are found for tower footing, even when very long counterpoise are employed. In this picture, despite the long length of these lines, a limited number of towers (critical spots) determines the whole lightning performance of it.

Due to the usual difficulties to access the towers for performing maintenance, mainly during rainy seasons, the use of line arrester devices is not very recommended. Therefore the authors have strongly dedicated their efforts to generated solutions to improve lightning performance of such lines, based on non-conventional practices.

In this work they describe the developments to achieve efficient solutions for a case study, a 230 kV line (~400km long). The provided solutions were recently implemented by the local energy utility and their practical efficiency was evaluated after the last rainy season.

3. Developments

3.1 Introduction

The evaluations of this work were done by simulation with the application of an elaborated model called HEM – Hybrid Electromagnetic Model [3]. This model is directly derived from application of field equations and circuit theory. It is suitable for calculation of electromagnetic transients in configurations of metallic structures (placed in air or soil) that can be represented by a set of cylindrical conductors. Its theoretical basis and details, including the comparison of experimental to simulated results and some applications, can be found in another publications [3,4,5].

The overvoltage developed across insulator strings due to direct strike was evaluated. Considering the basic configuration for typical towers, aerial conductors and grounding electrodes for the studied transmission line, such overvoltages were simulated employing the computational model.

In simulations, a current wave (2/70 μs ramp) was supposed to be injected into the tower top, assuming the presence of all conductors (shielding and phase cables), as indicated in Figure 1. Realistic parameters were adopted for the geometric configuration of tower, line conductors and electrodes. Also representative values for the constants of involved media (soil, conductors and air) were assumed.

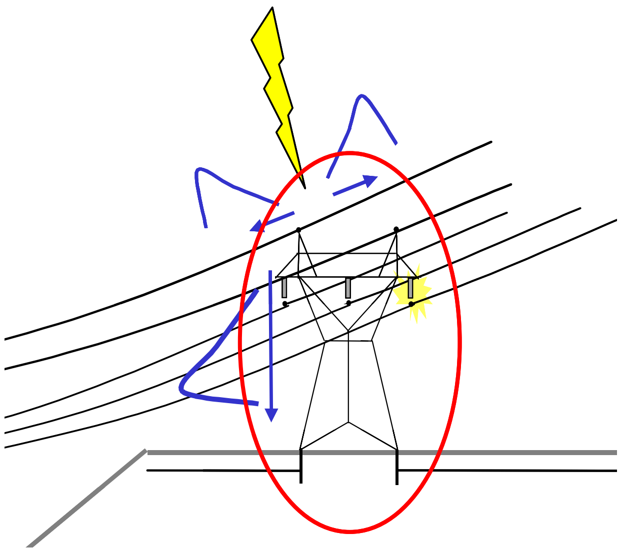

Figure 1 – Direct lightning strike to a tower

The provided results consist on the overvoltage developed across insulator strings due to the injection of such a ramp current wave at the tower top. The ramp waveshape was adopted only because it has very defined steepness and front time.

3.2 Case study

The case study consists on a 230 kV line. It comprises around 900 towers along 400 km. Their route crosses a region of very high lightning activity, with 500m long average spans. The indications of a fault location equipment allowed identifying 26 towers that were claimed to be responsible by most of lightning associated outages. All of them were situated over hills, with no earth coverture. Their bases were directly placed over rocks.

3.3 Evaluations for improvement of line performance

The first development was to evaluated the estimated value of developed overvoltage for a critical condition of incidence, assumed as a 50 kA peak current [6], considering the actual parameters of such towers. The grounding impedance of those towers ranged from 100 Ω to 500 Ω. As the insulation level of this line for impulsive voltages waves is estimated as 1.2 MV, it was verified that in all cases, this occurrence would develop overvoltages whose values would overpass the insulation level.

In order to evaluate the efficiency of non-conventional practices, some improvements were simulated and the developed overvoltage was quantified, assuming the towers to be stricken by the same current. The following conditions were simulated:

(i) tower configuration with no improvement (tower-footing impedance of 100 Ω);
(ii) additional shielding wires are placed below phase cables ("false shielding wires") at distances a little larger than the length of insulator strings;
(iii) installation of four guy wires, connected to counterpoises placed over the soil (rock), terminated by buried horizontal electrodes. The total parallel grounding resistance of buried electrodes was 100 Ω;
(iv) guy wires associated to very long cables placed directly over the soil surface (aerial counterpoises).

3.4 Results and analysis

Figure 2 shows the resultant overvoltage waves developed across the insulator strings for a typical tower of the 230 kV line (self-sustained, 30m high), due to a lightning strike to tower top, for the cited conditions. Voltages are presented in a kV per injected kA basis.

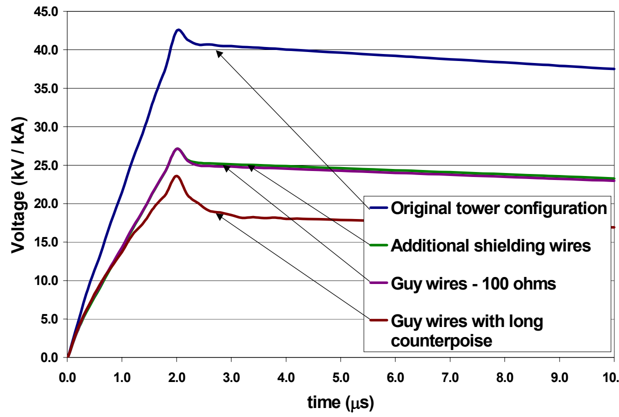

Figure 2 - Developed overvoltage across insulator string

Assuming, a 50 kA crest value for the current, in the curve corresponding to the original conditions of tower, the voltage is larger than 2.1 MV. Towers, whose equivalent grounding resistance exceeds the 100 Ω value, would have larger amplitude for this overvoltage.

When false shielding cables are placed below the phase conductors, this value is significantly decreased to around 1.35 MV. This reduction is explained by the capacitive coupling effect between cables.

The same value is obtained if false guy wires are placed, connecting the tower to anchors positioned in the soil (as indicated in Figure 3). In the case presented in this figure, each counterpoise leg has a 400 Ω grounding resistance.

Finally, the overvoltage crest is reduced to around 1.2 MV, if continuous counterpoises are connected to tower bases. Two aspects have to be considered to explain this reduction. First, the proximity of the conductors to soil surface (even for rocks) enlarges significantly the capacitance of the cable and therefore reduces its surge impedance. This promotes negative reflections for the incident voltage wave that contribute to diminish the overvoltage across insulators. On the other hand, the counterpoise length has to be significant, in order to avoid the effect of positive reflections of voltage wave at the counterpoise end. Actually, the length of counterpoise do not need to be extremely long, but has to be long enough to assure that the positive reflected voltage wave returns to tower top only after the peak voltage has already occurred. In practice, this length is determined by connecting the electrodes to the counterpoises of adjacent towers.

The results suggested that, if lower values were obtained for the grounding resistance at the termination of counterpoises, the overvoltage could have additional reductions. Therefore, new simulations were developed, considering different values for such resistances. The commented configuration is presented in Figure 3 and the results for a tower, whose original grounding resistance was 500Ω, are shown in Table 1.

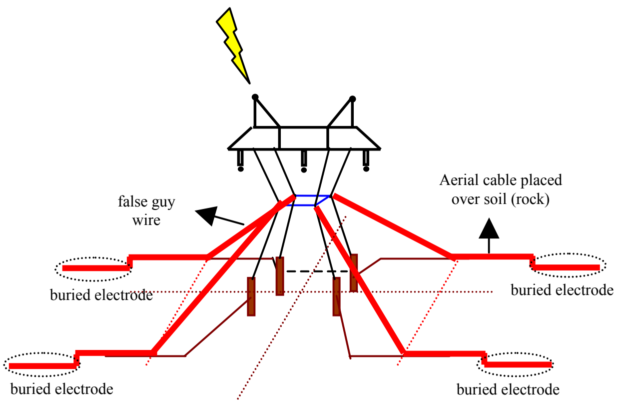

Figure 3 – False guy wires configuration

The results of Table 1 denote the high efficiency of such practice. They also allowed determining the limiting value of resistance that would keep the overvoltage amplitude lower than the insulation level for the assumed conditions, including current waveform and intensity. As indicated, the resultant resistance should be limited to 37.5 Ω (parallel of the grounding resistance corresponding to the four buried conductors).

Additionally, it was verified that, even when the termination is buried at a distant position, if its grounding resistance has low value, it is very effective to reduce the overvoltage across insulator string. It seems that the guy conductors contribute is this aspect, as they reduce the distance and therefore the transit time for the current reaching the buried termination.

This verification allowed the establishment of a criterion for assuring reduced overvoltages, as explained next.

Table 1 - Effect of reducing grounding resistance at the terminations of electrodes.

Configuration	Overvoltage developed across insulator strings (kV)
Original (Rg = 500Ω) counterpoises	2 225
False guy wires:	
R_1=R_2=R_3=R_4 = 200Ω	1 280
R_1=R_2=R_3=R_4 = 150Ω	1 180
R_1=R_2=R_3=R_4 = 100Ω	960
R_1=R_2=R_3=R_4 = 50Ω	870

R_i : Grounding resistance of the counterpoise i termination

4. Proposed practice

The proposed criterion comprises 3 steps:

(i) For each tower on focus, by local inspection, it is verified the existence of four regions around the tower, where the burying of electrodes could provide grounding resistance whose estimated value is around 150 Ω.

(ii) If such regions exist, the electrodes (four electrodes, as indicated in Figure 3) are buried and individually resistances are measured. If the parallel of such measured resistance provides a value lower than 38 Ω, then the buried conductors are connected to cables placed over rock, which connect them to the anchors, where the false guy wires (connected to the tower) arrive. Otherwise, longer length of electrode is buried until the desired resistance value of is achieved. The maximum distances around the tower should be limited to about 400 m from its base. When possible the four regions should be symmetrically positioned, as in Figure 3.

(iii) If such possibility does not exist, the counterpoises are extended from the anchors and connected to the counterpoises of both adjacent towers, which have probably buried conductors with low resistance values, that will contribute to reduce overvoltage at the first tower.

Therefore, in this criterion, the implementation of the grounding design does not depart from the tower, but is determined from the local environment in the region around the tower.

5. Implementation of the proposed practice

This idea was implemented for the 26 critical towers along the mentioned line. After a whole rainy season, the usual number of lightning associated outages of this line was decreased from 7 outages/year to 0.

6. Conclusions

In this work the authors quantified the efficiency of some non-conventional practices intended to reduce the developed overvoltage across insulator strings, due to direct lightning strikes.

The results allowed establishing comparative analysis about the efficiency of such different practices.

Particularly, for the analyzed conditions, the employment of additional shielding wires placed below phase cables was able to provide a decrease of overvoltage to about 70% of its original value.

The use of continuous counterpoises allowed reducing suc overvoltage to about 60% of its original value.

The most promising results were obtained by providing low grounding resistances at the terminations of long counterpoises (over soil), connected to false guy wires. This practice allowed decreasing the overvoltage to about 40% of its original value.

The alternative techniques were evaluated separately. Though it was not evaluated, for critical conditions it would be possible to simultaneously adopt more than one of such practices to achieve additional overvoltage reductions.

The last mentioned practice (Figure 3) was evaluated in details. Considering the line insulation level, it was possible to determine the acceptable limit for the equivalent value of the distributed grounding resistance, able to assure a good expectation of performance to lightning strike.

Additionally, for those conditions where it is not possible to locally respect this limiting value, it was verified that an alternative practice could be efficiently adopted: the connection of the tower counterpoises (placed over soil) to the electrodes (or counterpoise) of adjacent towers. This would work very well if the adjacent towers satisfy the limiting value for resistance.

The application of the proposed method to the line under study seemed to be very satisfactory, after one rainy season. Nevertheless, it is considered prudent to wait for complementary periods of experience, before definitely concluding about the method efficiency.

Although the method was employed only to this specific 230 kV line, as a principle, it can be applied for lines of different voltage levels and configurations. Of course, other limiting values would result for the acceptable resistance of towers. Anyway, the method seems to be efficient and feasible to improve the lightning performance of transmission lines.

7. References

[1] S. Visacro, M. A. Felipe, R. Z. Oliveira, "*Non-Conventional Methodology To Improve the Lightning Performance Of Transmission Lines*" , Proceedings of GROUND'2002 – International Conference on Grounding and Earthing & Workshop on Atmospheric Electricity, pp. 267-270, Rio de Janeiro, Brazil, Nov. 2002.

[2] S. Visacro, R. N. Dias, C. R. Mesquita, "*Novel Approach for Determining Spots of Critical Lightning Performance along Transmission Lines*", Accepted for publication, IEEE Power Delivery, Feb. 2004.

[3] S. Visacro F., A. Soares Jr., M. A. O. Schroeder, "*An interactive computational code for simulation of transient behavior of electric system components for lightning currents*", in Proc. 2002 International Conference on Lightning Protection, Crakow, Poland, 2002.

[4] A. Soares Jr., M. A. O. Schroeder, S. Visacro F., "*Application of an electromagnetic model for calculation of transient voltages in transmission towers*", in Proc. 2002 International Conference on Lightning Protection, Crakow, Poland, 2002.

[5] A. Soares Jr., M. A. Schroeder, S. Visacro, "*Transient Voltages in Transmission Lines Caused by Direct Lightning Strikes*", Accepted for publication, IEEE Power Delivery, Feb. 2004.

[6] Visacro S., Schroeder, M. A. O., Soares A. J., Cherchiglia L. C. L., Sousa V. J., "*Statistical Analysis of Lightning Current Parameters: Measurements at Morro do Cachimbo Station*", Journal on Geophysical Reserach, v. 109, NO. D01105, 1-11, 2004.