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INVESTIGATION OF THE TRANSIENT RESPONSE OF TRANSMISSION LINE TOWERS TO LIGHTNING STRIKES

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Abstract – Overvoltages developed between the phases and the metallic tower of a real line due to direct lightning strikes are simulated in order to evaluate the conditions for back flashover occurrence. Realistic environmental conditions and line component configuration were considered.

1 INTRODUCTION

Lightning is responsible for most of transmission line non-scheduled outages. Especially on high voltage transmission line, such occurrences are associated to direct strikes to the shielding cables. In Brazil, factors such as the very high lightning flash density, the long extensions of transmission lines and the non-favorable soil conditions, make such occurrences more critical and difficult to solve.

For high voltage lines that are usually provided with shielding cables, traditional protective actions intended to improve the lightning performance of line basically comprise two types of actions: (i) to reduce the tower footing resistance and (ii) the installation of line arresters devices to prevent flashover over line insulators. Besides that, there are other alternative practices that are also able to improve the line protection. Such practices usually explore the effects of those parameters that influence on the amplitude of overvoltage developed across insulator strings, due to lightning strikes to the line.

The authors have been working hard in investigations related to this topic. Some very interesting theoretical and practical results have bee obtained to specific lines placed at regions that have a very high lightning flash density, in the Amazon area [1]. The investigation comprises the calculation of overvoltages developed across insulator strings due to direct lightning strikes and the determination of practices to restrict the levels of such stresses to acceptable levels [1,2], in terms of its impact on the outage rate of lines.

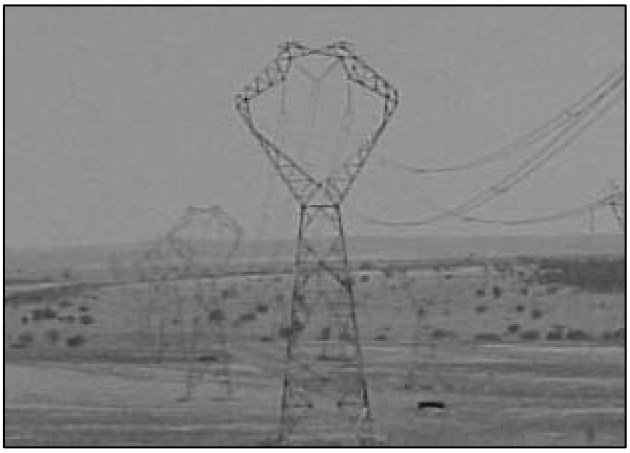


Fig. 1 – The studied line with its "racket" towers

Presently, the authors are working on a specific 230 kV line that present a large outage rate, placed in Mato Grosso state, Brazil. The line extends along a critical region, regarding the incidence rate and the soil resistivity and presents the so called racket configuration (figure 1).

In the proposed work, the authors intend to show the results of their evaluations about the response of such specific tower to direct lightning strikes and to present some potential solutions for improving the line performance.

2 THE PROBLEM ON FOCUS

The problem into investigation concerns the lightning related outages of transmission lines. According to the authors experience the lightning performance of most lines are conditioned by a few critical spots that are responsible by most of the line outages. The length of these spots are usually limited to less than 10% of the line extent, depending of the environment characteristic, mainly the altitude, the soil relief and soil resistivity.

Such critical spots are usually defined by a simultaneous unfavourable condition of a very high local lightning incidence rate and a very bad response of line to direct strikes. Bad response means that very high overvoltages are established across insulator strings in case of eventual lightning strikes, allowing the occurrence of backflashover across the insulators.

A possible approach to face the problem related to improving lightning performance consists in separating the problem into 2 stages. First it is necessary to investigate and to determine *where* to actuate. This means to find the critical spots. Following, it is necessary to determine *how* to actuate to improve the quality of the local response of the line to direct strikes. This is a complex question that is rather dependent on the local environment and on specific line characteristics. It requires a fine conceptual knowledge of the methodologies to reduce the overvoltage at insulator string. Both stages depend on the availability of resources for the specific case under analysis. For example, in the first stage, the availability of a lightning location system may allow identifying critical spots along the line, in terms of incidence frequency [3]. Unfortunately, there is no such a system covering the region crossed by the line studied. Thus, the authors look for a set of another type of indications that are also able to define the critical spots. Usually, registers related to the lightning associated outages of the relays (placed at substations) provide relevant information to delimit regions of major probability to include critical spots. Also physical indications at the towers related to the flow of short circuit current that follows a backflashover may be also identified by visual inspection. Figure 2 indicates positions along the metallic components where these damages may be found. Also the insulator string may provide such information as it is shown in figure 3. Maintenance registers are other valuable source of information, such as the communications of replacement of insulators and other pieces due to destructive effect of current flow. Finally, the knowledge of the value of tower grounding resistances complements information. This set of indications allows performing a consistent engineering evaluation intended to delimit the critical spots along the line.

In order to realize the second stage (definition of the improvement to be done), the first step consists on quantifying the overvoltage developed across insulator string for the specific tower configuration in the different conditions of the line. This allows defining the intensity of the action in order to limit the overvoltage to the insulation withstand. Following, the next step requires the definition of the type of intervention in the line in order to achieve the desirable overvoltage limitation. This step explores the possibilities to actuate in order to assure that the local intervention is able to limit the overvoltage. This requires a fine knowledge of such possibilities and the ability to develop them on the restrictive local environments conditions.

This paper is dedicated to the stage related to the quantitative evaluation of the overvoltage amplitude that is developed across insulator string due to direct strikes.

Fig. 2 – Visual inspection may reveal towers where backflashover have taken place

Fig. 3 – Damage due to destructive effect of current flow through the insulator following a backflashover (a corrosion process was initiated after the damage)

3 DEVELOPMENTS

The mentioned evaluation comprises the simulation of lightning strikes to the line shielding cable (A) and direct strikes to the tower (top: B and lateral: C). Figure 4 indicates the positions where strikes were considered. It also indicates the positions where the overvoltage wave generated by the simulated current wave was determined: 1 (tower top), 2 (support of upper insulator string), 3 (support of lateral insulator string), 4 (lateral 4) and 5 (lateral 5). These are points susceptible to backflashover occurrence.

The results were obtained by computational simulation, employing an elaborated model (HEM - Electromagnetic Hybrid Model). Details about this model are available in references [4,5]. Figure 5 indicates the simulated structure and Figure 6 shows the real configuration of the buried counterpoise cables of the line that were also considered in simulations.

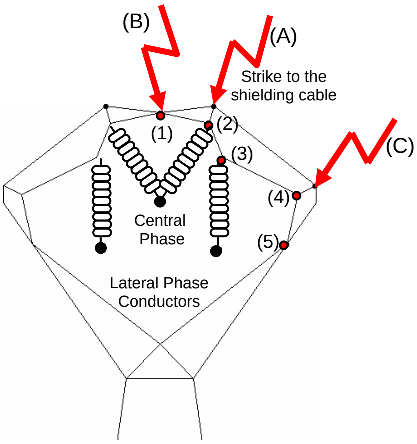
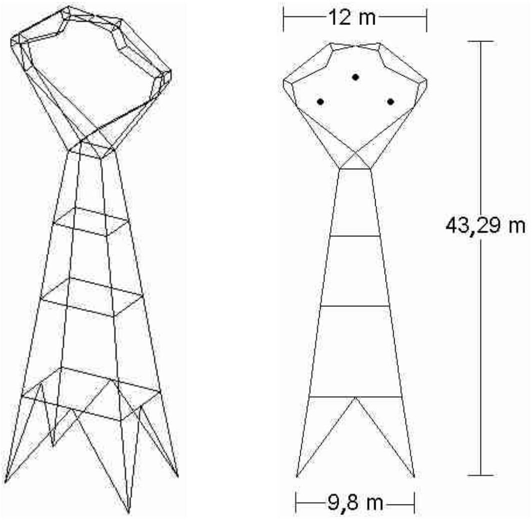


Fig. 4 – Indication of positions and points of strike incidence



(a) Tower Configuration (b) Tower Dimensions

Fig. 5 – Simulated structure

The current supposed to be injected at the incident points was assumed as 1 kA amplitude ramp waveform (2/50 μs). The use of 1 kA amplitude is only intended to allow an analysis of the overvoltage in a kV/kA base. The chosen waveform is considered very conservative for a first stroke, that is the event of interest concerning backflashover at high voltage lines (median front time value around 4.5 to 7 μs [6]).

The simulations provided the overvoltage and current wave distribution in all points of interest. Particularly, the overvoltages developed across insulator strings and the critical overvoltage between cables and metallic components of tower were evaluated for different incidence conditions. The evaluations considered realistic parameters of the line and environment (original height of towers and different conditions for the soil: from 100 to 5000 Ω.m and realistic configuration and length of counterpoise cables: from 10 to 100 m) to perform sensitivity analysis in order to determine the quantitative level of influence of each parameter on the overvoltage amplitude.

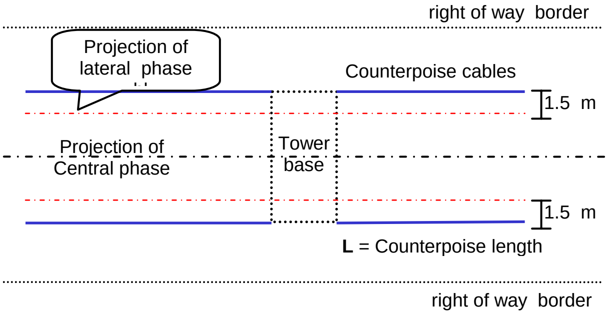


Fig. 6 – Configuration of counterpoise cables

3 RESULTS

The results were organized in terms of the developed overvoltage waves at points of interest. Figure 6 illustrates the primary type of results generated by simulations [5].

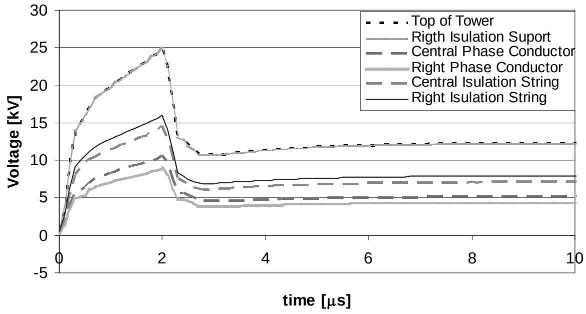


Fig. 7 – Overvoltage generated at different points (kV/kA)
Conditions: 1 k Ω.m soil, L= 30m

Systematic simulation provided a large amount of data about the response of towers to lightning strikes at different practical conditions. The results of real interest consisted in the overvoltage between those critical points that present larger probability to promote backflashover. Figure 7 illustrates this aspect for a 2000 Ω.m soil, considering four different counterpoise lengths.

The relevant results may be summarized. The incidence at the tower top generates practically the same amplitude of overvoltage generated by strikes to the shielding cables. The overvoltages generated by strikes to the tower lateral are a little different. Considering strikes to the tower, the maximum overvoltage is always verified between the lateral phase and point 3, where the phase insulator string is sustained. This overvoltage exceeds in about 10% the overvoltage developed between the central phase and point 2, where one of the central phase insulator strings is sustained (Figure 8). For strikes to the tower lateral this situation is confirmed and the difference is naturally increased. This should indicate this overvoltage as the critical one to promote backflashovers.

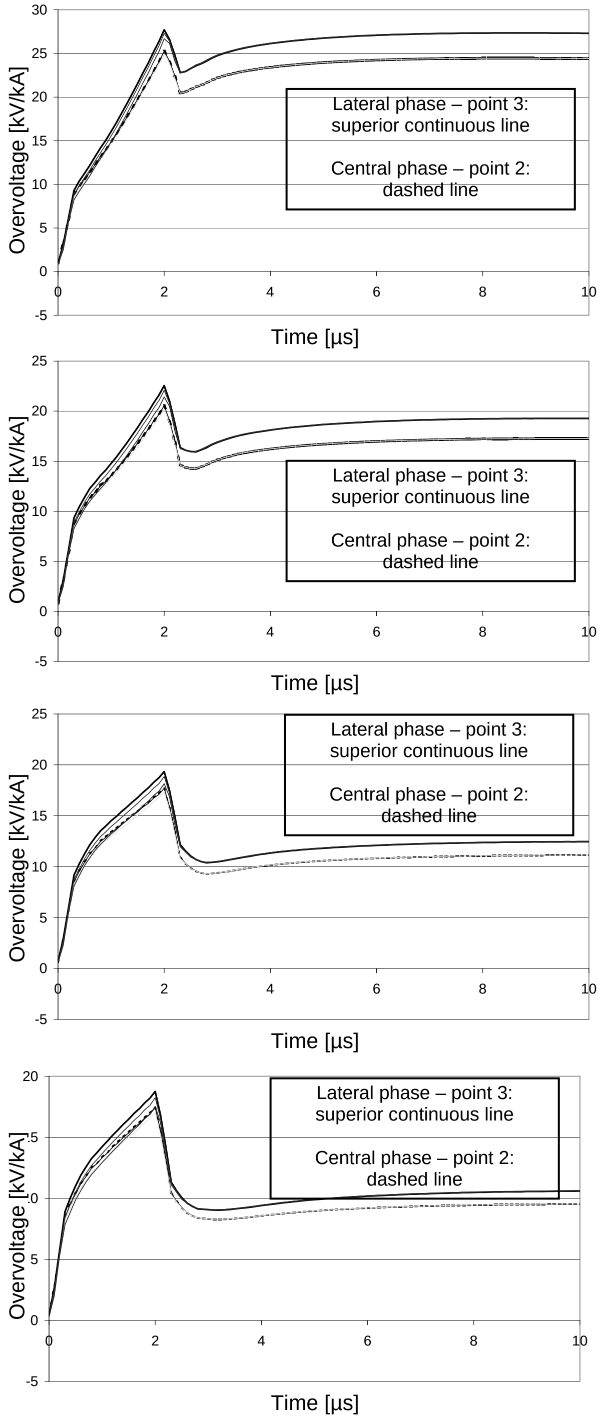


Fig. 8 – Overvoltage between critical points due to a strike to the shielding cable (kV/kA) - Conditions: 2 k Ω.m soil, L= 10, 20, 40, 50 m (in sequence)

Nevertheless, it is necessary to consider the parallelism between the insulators that sustain the central phase that decreases its voltage withstand. Besides, the different positions of insulators strings may lead to different levels of pollution deposition over the insulators. This is also able to influence on the insulator strings withstand.

The previous figure shows that for the 2000 Ω.m soil and a 50kA peak current [2,6], for counterpoise lengths of 10, 20, 40 and 50 m, the critical overvoltage (lateral phase to point 3) would have respectively the amplitudes 1.38 MV, 1.2 MV, 950 kV and 900 kV. Due to the insulation level of this line BIL, estimated in 1,140 kV, at least 40m of counterpoises would be required to avoid insulation failure, for this representative condition. On then other hand, beyond 50m it is not efficient to increase the electrode length, once the effective length for a 2000 Ω.m soil is just around 50 m. Similar evaluations were performed for soils from 100 to 5000 Ω.m. A very interesting result found from the systematic simulation was the limiting value of grounding impedance to be observed in order to avoid overpass the line insulation level. This was estimated as 26.5 Ω, independently of the soil characteristic.

4 CONCLUSION

These preliminary results provide some contributions to support proposals for improvement of the lightning performance of the studied transmission line. The investigation continues under development.

5 REFERENCES

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