IMPROVEMENT OF THE LIGHTNING PERFORMANCE EVALUATION OF LINES WITH ARRESTERS

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Abstract: This paper presents a process in order to make the lightning performance evaluation of transmission lines with arresters in a more efficient way than it is commonly executed. The idea is to use the systematic switch of the ATP program so as to make a great number of simulations by running just once the ATP. It is necessary to vary both the lightning current amplitudes and the times to crest. The routine TACS has been utilized to make the conversion between the variation in time allowed by the systematic switches and the variation in statistical variables such as the current amplitude and time to crest. Some examples of the utilization of this process are shown and an analysis of the improvements in the lightning performance of transmission lines achieved with the application of line arresters is performed.

I. INTRODUCTION

The application of line arresters in parallel with the insulator strings in order to reduce the outage rates of transmission lines is becoming a common procedure for a great number of electrical utilities around the world. The line arresters have been proving to be a more efficient and economic technique than the classical methods of reducing the high tower footing resistances that generally exist in lines presenting high outage rates, and varying the shielding angles.

When the lines are subject to a great number of outages due to backflashovers, the classical alternative is to install counterpoises. Sometimes this installation is not feasible because the ground is too rocky. This is particularly true at the top of hills, where, in addition, the towers have their greatest exposure [1].

In the United States and Japan, several electrical utilities have been using line arresters since the last decade [1 - 3]. Mexico, Colombia and France are also some countries that are already using line arresters, but more recently [4 - 6].

In Brazil, two electrical utilities (FURNAS and CEMIG) are considering the installation of arresters in their electrical networks and the first application in lines presenting high outage rates will probably occur soon [7 - 9].

In order to determine how effective the line arresters may be on reducing the outage rates of transmission lines, it is necessary to calculate these rates when the arresters are installed and compare with those which the lines present prior to the arresters' installation.

The determination of the lightning performance of transmission lines without arresters is simpler than when there are arresters installed. The line can be considered as a linear system and it would be possible to define a tower top voltage per unity of the stroke current in case of a stroke terminating on the shield wires or the tower top. Then the phase conductor voltages may be determined through the coupling coefficients and the insulator voltages would be the difference between the tower arm voltages and the phase conductor voltages. The tower arm voltages may be determined by an interpolation between the tower top and the footing resistance voltages.

Once defined the tower top voltage per unity of stroke current, the outage rates are found through a Monte Carlo analysis taking under consideration the statistical distributions of current amplitudes and times to crest [10, 11]. A great number of lightning strokes are generated and with the current amplitude and the time to crest of each stroke, the insulator overvoltages which would appear are determined. They are then compared to the insulators CFO and if the CFO is exceeded, a discharge is supposed to have occurred. At the end of this process the outage rate of this particular line would have been determined.

When analyzing transmission lines with arresters, the determination of the outage rates becomes a more complex process, having as consequence a considerable increase in time consumption. In this case the transmission line becomes a non-linear system and it is not possible to utilize the tower top voltage method. The general procedure then is to determine the flashover current levels for each time to crest under consideration. The flashover current levels are those that would bring about the CFO for any insulator string of the line. The basic procedure to find these data is a trial and error process. The ATP program [12] was chosen to simulate the line so as to obtain these current levels. The transmission line must be modeled in detail, representing not only the ground wires but also the phase conductors. In this basic procedure the ATP program is executed in a shot by shot way, making it a very high time consuming process.

An alternative process was developed using the systematic switch of the ATP program and the routine TACS in order to make the evaluation of the flashover currents in a more efficient way concerning the time consumption.

Some examples of this procedure for a 138kV line with arresters will be presented together with an analysis of the improvements achieved through the installation of line arresters for different tower footing resistances.

II. IMPLEMENTATION WITHIN THE TACS

By using the systematic switch it is possible to execute just once the ATP and perform different simulations of an electric network. Therefore this switch is adequate for the task of searching the flashover current levels.

The process idealized is to automatically vary the lightning current amplitudes and the times to crest over an adequate range through the utilization of the systematic switch. Then the results are carried to the MATLAB program [13] to make the necessary post-processing analysis in order to obtain the flashover current levels for each time to crest.

However the variation allowed by the systematic switch is on its close time and the desired variation is on the amplitude and time to crest of a function that represents the lightning stroke. Fig. 1 shows the basic curve used to represent the lightning stroke hitting a line.

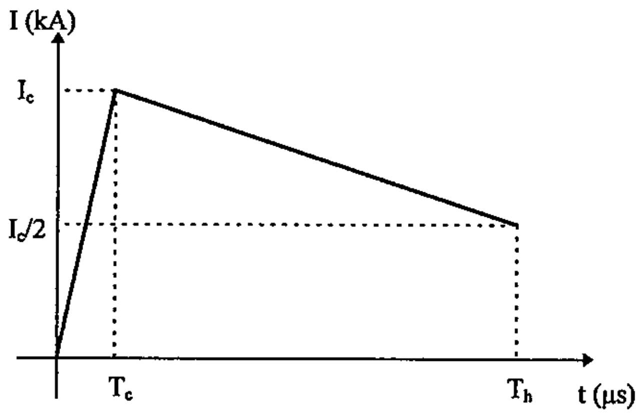

Fig. 1: Curve representing the lightning stroke

With:
T_c: time to crest
T_h: time to half value
I_c: crest current amplitude

The TACS routine was used to make the necessary adjustments in order to transform the variation of the close time of the systematic switch in the variation of T_c and I_c. Fig. 2 illustrates the block diagram of the routine implemented.

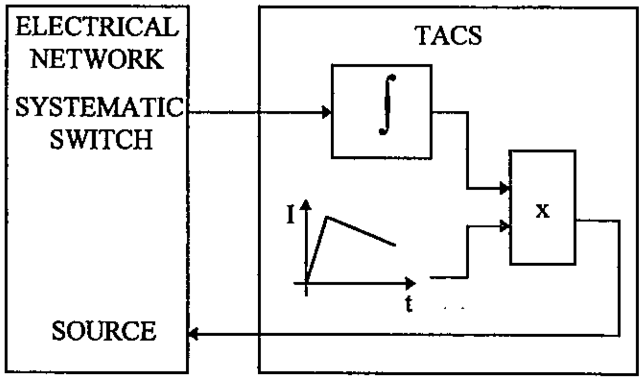

Fig. 2: Block diagram of the routine implemented

The signal coming from the systematic switch is integrated leading to a ramp signal which remains at a constant value when the switch is closed. The function shown in fig. 1 is then multiplied by this constant value.

The time to crest variation is performed by creating different functions for each time to crest desired. The functions are changed by using the TACS signal selector device.

The number of current amplitude evaluations can be varied as well as the times to crest for which the flashover current levels are desired.

The MATLAB program was used to make the necessary manipulations in the ATP output file in order to maintain only the required information for the evaluation of the flashover current levels. These are the highest overvoltages that occur for each lightning stroke in the phases and towers under analysis. With these results, a second order polynomial function representing the overvoltage values as a function of the current crest amplitude is created for each time to crest. The flashover current levels are then determined with the aid of these functions by evaluating which current would bring about the CFO for any insulator.

The pairs flashover current levels and times to crest are then carried to a lightning performance program based on the Monte Carlo method where they function as a data input to the program.

III. RESEARCH RESULTS

The line analyzed is of 138kV with a transmission tower structure typical of the Brazilian electrical utilities and represented in fig. 3

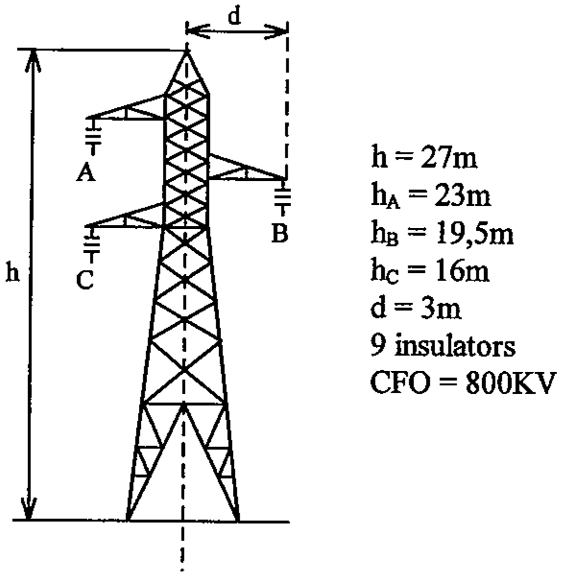

Fig. 3: Typical tower structure of the 138kV transmission line analyzed

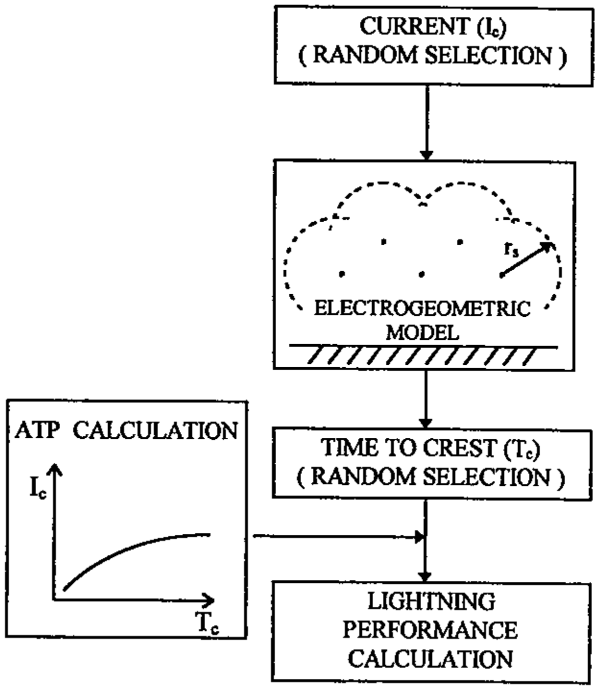

Fig. 4: Steps followed on the Monte Carlo evaluation

The transmission line has been represented with its parameters varying with the frequency [12, 14] and the tower arm voltages were determined by an interpolation between the tower top and ground voltages. The insulator overvoltages can then be defined more accurately by the difference between the tower arm voltages and the phase conductor voltages.

A model representing the variation of the gap withstand voltage in relation to the time to crest of the lightning impulse has been developed. Nevertheless the results presented in this paper consider the CFO as the voltage value which would cause the insulator discharge for any time to crest. In a future opportunity an analysis considering the gap model will be presented.

A corona model has not been implemented yet. As corona effect tends to reduce the outage rates, the results would show higher outage rates than if a corona model had been implemented. However, in order to compensate this influence, the line operating voltage which has the opposite effect was not considered in these simulations.

Fig. 4 shows the steps followed on the Monte Carlo evaluation:

The line arresters considered for analysis were of the gapless type with a nominal rating of 144kV.

Two alternatives of line arresters' position were analyzed together with the reference case (RC) of not installing any arresters. Alternative 1 is the option of installing only one line arrester per tower (on the lower phase) and alternative 2 is the option of installing two line arresters per tower (on the two lower phases). It is not necessary to perform any studies for the alternative of installing arresters in all phases as it would bring the outage rates to zero, if it is assumed that no arrester failures occur. The grounding resistances adopted were 20, 40, 70 and 100Ω for all the towers.

The analysis conducted in this research considers only backflashover occurrences. It is assumed that outages due to shielding failures are not of major concern when compared to those caused by backflashovers.

Fig. 5 to 8 show the flashover current levels for the alternatives and grounding resistances analyzed admitting that the stroke hits the tower top.

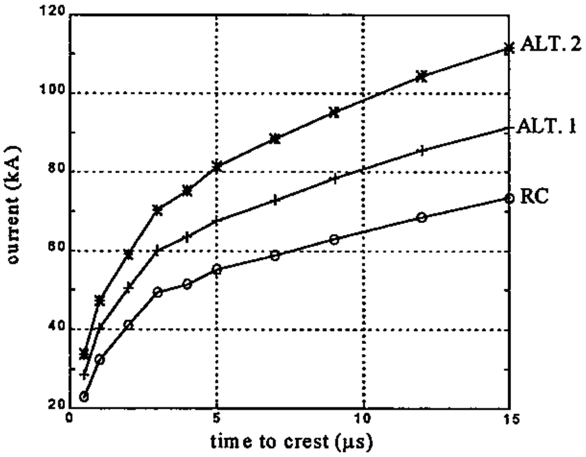

Fig. 5 Flashover current levels vs. times to crest (Stroke on the tower top and grounding resistance of 20Ω).

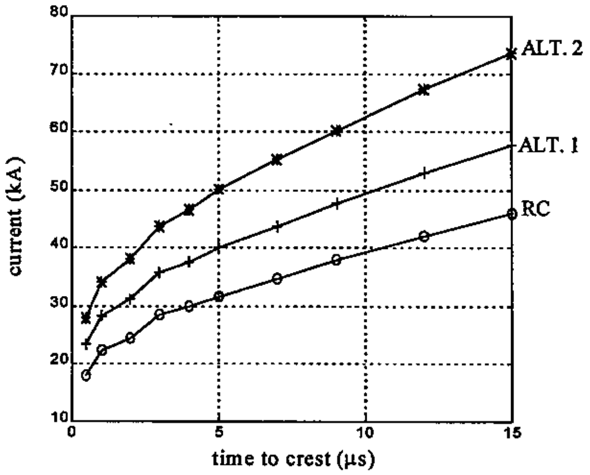

Fig. 6 Flashover current levels vs. times to crest. (Stroke on the tower top and grounding resistance of 40Ω).

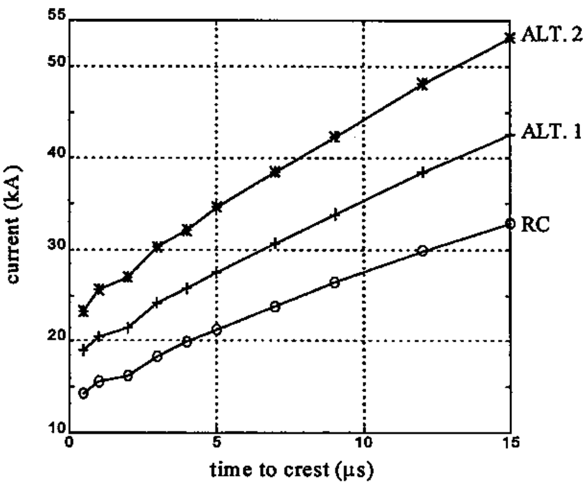

Fig. 7 Flashover current levels vs. times to crest. (Stroke on the tower top and grounding resistance of 70Ω).

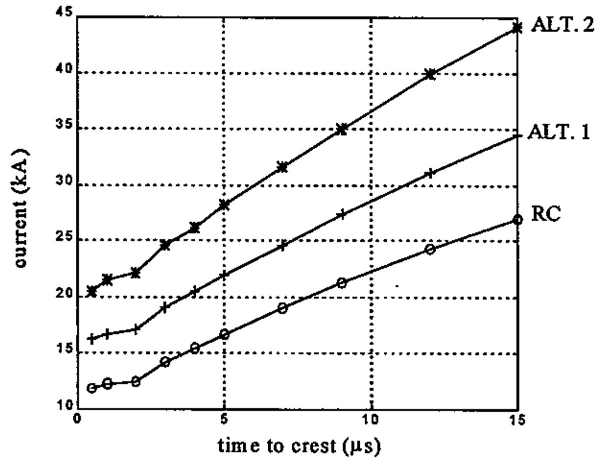

Fig. 8 Flashover current levels vs. times to crest. (Stroke on the tower and grounding resistance of 100Ω).

Fig. 9 shows the flashover current levels for a grounding resistance of 70Ω considering that the stroke hits the midspan.

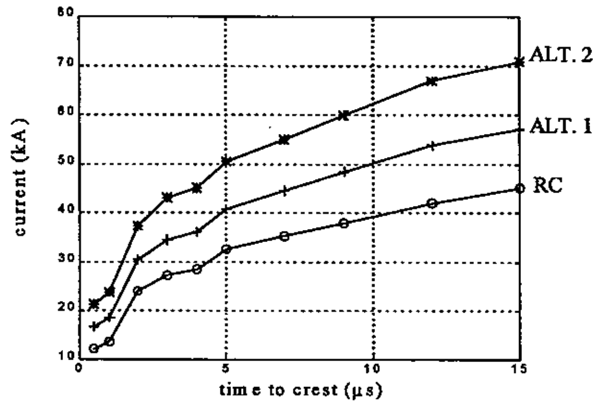

Fig. 9 Flashover current levels vs. times to crest. (Stroke on the midspan and grounding resistance of 70Ω)

Table 1 shows the outage rates obtained considering a 60% probability of the stroke hitting the tower top and a 40% probability of hitting the midspan. The keraunic level adopted was 70 thunderdays per year with a ground flash factor of 0.1.

TABLE 1 - OUTAGE RATES / 100km /YEAR FOR THE ALTERNATIVES AND GROUNDING RESISTANCES ANALYZED EXPRESSED IN TERMS OF THE ABSOLUTE AND RELATIVE VALUES

	alternative		
R_g (Ω)	RC	1	2
20	13.9 (1.0)	7.5 (0.54)	3.9 (0.28)
40	40.6 (1.0)	27.4 (0.67)	16.5 (0.41)
70	64.8 (1.0)	50.4 (0.78)	36.3 (0.56)
100	75.2 (1.0)	64.3 (0.86)	49.9 (0.66)

Where
R_g: grounding resistance
RC: reference case - without arresters
1: alternative 1 - arresters on the lower phase
2: alternative 2 - arresters on the two lower phases

All these results have been determined in a considerable lower time than if they had been obtained by the traditional analysis of finding the flashover current levels through the trial and error process.

It can be verified that the application of line arresters is especially effective when conjugated with low tower footing resistances providing reductions that vary from 46% when applying only one arrester to 72% when using two arresters per tower in the case of a grounding resistance of 20Ω.

On the other hand, if the towers have a grounding resistance of 100Ω, the reduction is not significant, reaching only 14% with one arrester and 34% with two arresters per tower.

This is due to the fact that lower footing resistances provide an increase in the flashover current levels necessary to make the insulator voltages reach their CFO.

The outage rates depend on the joint probability areas of current amplitudes and times to crest. When the application of line arresters shifts the curve "flashover current levels vs. times to crest" to a region where both variables have low probability occurrences, the possibility of a line failure reduces. This is the case of a grounding resistance of 20Ω.

Besides the differences in the outage rates supplied by the application of one or two line arresters per tower, some consideration should be given to the energy stresses on the arresters. In trying to reduce the possibility of an arrester failure due to an overstress in its energy dissipation capability, the application of at least two line arresters per tower is a more secure alternative. In this case the energy dissipation is shared between the two arresters so that each of them does not become subject to a very high energy stress.

IV. CONCLUSIONS

A process in order to make the lightning performance calculations of a line equipped with arresters in an efficient way has been presented.

The routine proposed has been implemented in the ATP program using as aids the systematic switches and the TACS subroutine.

This process is particularly helpful when line arresters are installed in towers with different grounding resistances. In this case the number of simulations necessary to achieve a reliable outage rate would increase at a great proportion because it would be necessary to evaluate the outage rates for each tower. By using the process proposed in this paper the time consumption may be greatly reduced.

Also the MATLAB program was used to make the necessary manipulations on the ATP output files so as to calculate the flashover current levels.

As a conclusion in what concerns the efficiency of applying line arresters, it can be seen that when this application is conjugated with the reduction of the tower footing resistances the relative gain compared to the reference case without arresters is higher than when the grounding resistances are high. In a grounding resistance range from 20 to 40 or perhaps 50Ω the application of line arresters in only one or two phases per tower together with conventional methods of installing counterpoises where possible to improve the interface tower-ground may be more economic than installing arresters in all phases. On the other side, for higher grounding resistances it is probably more economic to install arresters in all phases.

V. REFERENCES

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