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Performance of Medium Voltage Overhead Distribution Lines Against Lightning Discharges

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SUMMARY

The lightning discharges are one of the main causes of interruptions of medium voltage overhead distribution lines, being the reason of great concern for the utility companies. Its destructive effects frequently extends to equipments and connected installations, with the possibility to cause personal injuries and material damages, beyond economic losses, due to out of income and the possibility of indemnities, penalties and fines.

With the beginning of the deregulation of the electric energy supply, some actions were been taken by the utilities for the prevention and minimization of the damages associated to the lightning discharges. However, as the lightning discharges are random events, consequently, difficult to predict, the majority of these actions does not follow a study or a detailed analysis of the problem.

By this way, in the majority of the cases the actions were taken based on the knowledge of the engineer in charge, or based in rules defined without any effective evidence, by means of studies or by laboratory tests. As a result, many of them besides of presenting high cost are not effective.

Among others, the distribution network reliability depends directly on its exposition to the lightning discharges. To determine the exposition level of the line, the designer should know the number of discharges to the ground per unit of area per unit of time.

The aim of this paper is to present the results of the performance study of medium voltage overhead distribution lines against lightning discharges, in the way to define methodologies to reduce the system failures.

The results were obtained within the partnership among the High Voltage Laboratory of the Federal University of Itajubá, AES Sul Utility Company and the University of Bologna.

Direct discharges and induced surges were simulated into real networks to identify the major factor of influence for network failures. Then commentaries on the relative performance and comparisons of different construction configurations of overhead lines are presented.

Once that the atmospheric discharges phenomena are random, this work considers that the parameter generation of the discharges follows the statistical data proposed by Anderson and Eriksson. The Monte Carlo Method is used for the incidence distribution of the discharges and the Electro Geometrical Model for the interception point of the discharge.

KEYWORDS

Performance, Medium Voltage, Distribution, Lightning.

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1. INTRODUCTION

The standard medium voltage distribution networks are subjected to the incidence of direct lightning discharges and induced surges. The majority of the damages to the distribution network are caused by direct discharges. However, they can be deviated by tall structures, such as towers, buildings, high constructions, and trees.
When the lightning strikes the network directly, they commonly cause permanent damages, because they are high intensity discharges with high growth rate. For this kind of damage, the network remains off until its repair.
Even when the lightning does not intercept the network, they induce surges that travel throughout the lines. These surges are able to cause many damages and interruptions to the distribution network. For that reason, this work presents the relations between induced surges and direct discharges.
The topology of the distribution network is the major factor of influence for analysis [1], and its density and distribution results in a greater or minor probability of incidence of direct lightning discharges.

2. DIRECT DISCHARGE AND INDUCED LIGHTNING SURGE

When 100 years of lightning discharges are simulated into a real urban distribution network, a low number of direct discharges intercept the network [1], mainly when the circuits are naturally shielded by tall structures, like buildings, towers, and trees. Between 2% to 16% of the lightning reaches directly the urban distribution network.
In complementary way, the amplitude of the average discharge currents that intercept the network stays between 12 and 23 kA.
The majority of direct discharge currents stay below 40 kA at urban systems, with 10% of probability of being surpassed.
Based on the median current intensities, it is possible to affirm that direct discharges intercepting the network results in dielectric failure of the system, and in the failure of not properly protected transformers.
As a result, the main factor of study for the performance improvement of urban distribution systems, front lightning, is induced surges. For this reason, this paper is focused on the assessment of the indirect-lightning performance of an AES 25 kV class standard medium voltage distribution line (see Fig. 1).

3. CALCULATION OF THE INDIRECT-LIGHTNING PERFORMANCE OF DISTRIBUTION LINES

The lightning performance of medium voltage overhead lines performed by means of statistical methods is based on the calculation of the flashover risk [3]. This last can be estimated when both overvoltage statistical distribution and insulation strength are known.
The analysis of the distribution networks response against Lightning Electro Magnetic Pulse (LEMP), requires the availability of accurate models of LEMP-illuminated lines. These should be able to reproduce the real and complex configuration of distribution systems including the presence of shielding wires and their groundings, as well as, surge arresters and distribution transformers. In addition to the accurate modelling of the overhead lines, the development of models of the entire distribution networks is clearly necessary. This should allow, in principle, to optimize the number and location of protective devices and then to minimize the number of outages.

The statistical procedure used to infer the indirect lightning performance of the AES 25 kV class overhead distribution line is based on the calculation of lightning induced overvoltages by means of the models implemented in the LIOV code [5-8] and on the Monte Carlo method. The LIOV code allows for the calculation of lightning-induced overvoltages along a multiconductor overhead line as a function of lightning current waveshape (amplitude, front steepness, and duration), return stroke velocity, line geometry (height, length, number and position of conductors), values of termination impedance, ground resistivity and relative permittivity.

In particular, the LIOV code is based on the field-to-transmission line coupling formulation of Agrawal et al. [5], suitably adapted for the case of an overhead line above a lossy ground. The equations are numerically solved by a finite difference time domain (FTDT) approach [5, 9].

Concerning the statistical procedure, described in details in [12-14], it is based on the combined use of the Monte Carlo method and the LIOV code. The Monte Carlo method is applied to generate a significant number of events (al least 10^4). Each event is characterized by four random variables: the peak amplitude of the lightning current I_p, its front time t_f (whose statistical distribution is assumed correlated with that of I_p) and the two co-ordinates of the stroke location uniformly distributed within the surface around the line.

The lateral attractive distance expression adopted by the IEEE Working Group on Lightning performance of transmission lines is used to distinguish direct from indirect lightning events [3], only the latter being considered in this study.

The adopted parameters of the current peak and its front time lognormal statistical distributions are those proposed by Anderson and Eriksson [10], with a correlation coefficient equal to 0.47 [11]. These statistical distributions have been obtained by using experimental records collected by elevated structures.

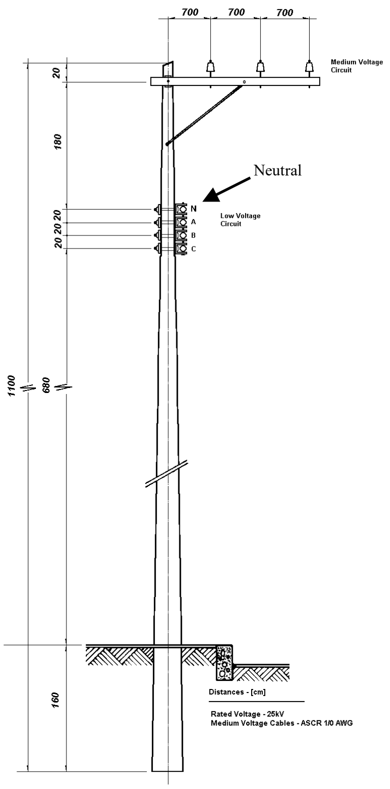

Figure 1 - Conductors geometry of the overhead line

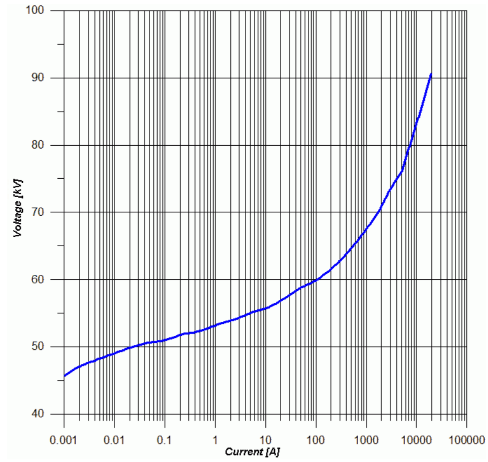

Figure 2 - V-I characteristic of the adopted standard medium voltage arrester

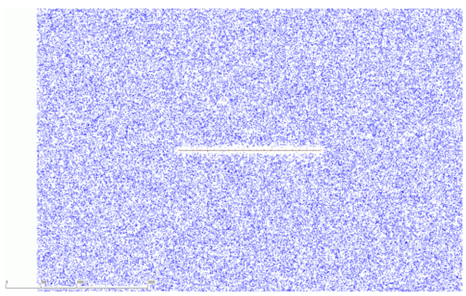

Figure 3 - Indirect stroke area to overhead line (top view)

4. GEOMETRY OF SIMULATIONS

All the simulations described in this paper refer to a 2 km line length with a distance between two subsequent poles equal to 100 m. The line conductor's geometry is one of the patterns adopted by AES Sul, where the grounded conductor corresponds to the neutral conductor shown in Fig. 1.
According to the indications reported in [4], the surge arresters were modelled using a V-I non-linear characteristic, which has been obtained by the standard 1.2/50 μs (see Fig. 2).
Two values of ground conductivities were considered, namely: 0.01 S/m and 0.0033 S/m. For each value of ground conductivity the following grounding resistances were assumed: 10Ω □and 40 Ω.
The randomly generated stroke locations in the area around the line ($80{\cdot}10^3$ events) are reported in Fig. 3. Such area is of 24 km² and the considered annual number of flashes per squared km per year is N_g=1. In the statistical procedure, the return stroke speed can be considered as a random variable, dependent to the return stroke current [12] or assumed with a fixed value. In these simulations, such a value is assumed constant and equal to $1.5{\cdot}10^8$ m/s.

5. SIMULATION RESULTS

Different line configurations, based on the same standard 2 km line structure, were considered. The cases differ for the soil conductivity, grounding resistance, number, position of surge arresters, grounding points and, finally, line boundary conditions.
Due to the predominant common mode coupling between LEMP and multiconductor lines, and to the identical height of the different line conductors, the number of events exceeding the BIL is practically the same for each phase. As a result, in a first approximation the calculations could be carried out for one phase only.
Laboratory tests have demonstrated that there is no effective dielectric improvement with the utilization of wood cross arms [15].

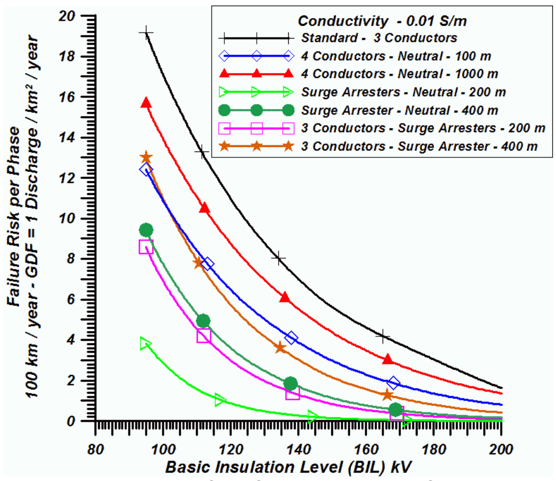

Figure 4 – Failure risk for influence distance of 20 poles, soil conductivity = 0.01 S/m and GDF = 1 fl/km²/Year

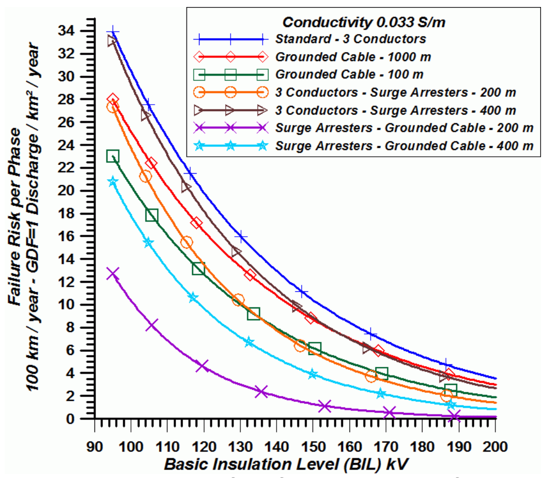

Figure 6 - Flashover risk for Influence Distance of 20 Poles, Soil Conductivity = 0.003 S/m and GDF = 1 fl/km²/Year

The results of Fig. 4 show that equivalent line configurations can be obtained. For instance, for system insulators having a BIL of 100 kV, the line configuration with surge arresters installed at each 400 m has a performance close to the line configuration with a grounded conductor at each 100 m.
Figure 4 can be used to support the selection of the appropriate line configuration. In order to provide an example, let assume as an acceptable risk level the value of 4 failures per 100 km per year, from Fig. 4 it is possible to select the equivalent configurations, as shown in Fig. 5.

As a consequence of Fig. 4, it can be observed that the increase of the system insulator's BIL results in a simplification of the line configuration with particular reference to the adopted protection systems.
Figures 4 and 6 show that the solutions involving the use of insulators with BIL greater than 200kV presents, as expected, reduction of flashover risks by induced surges. In these cases, even the most complex constructions, as the one that involves the use of surge arresters at each 200 meters and grounded cable, do not present significant differences related to the standard case, without surge arresters nor grounded wires.

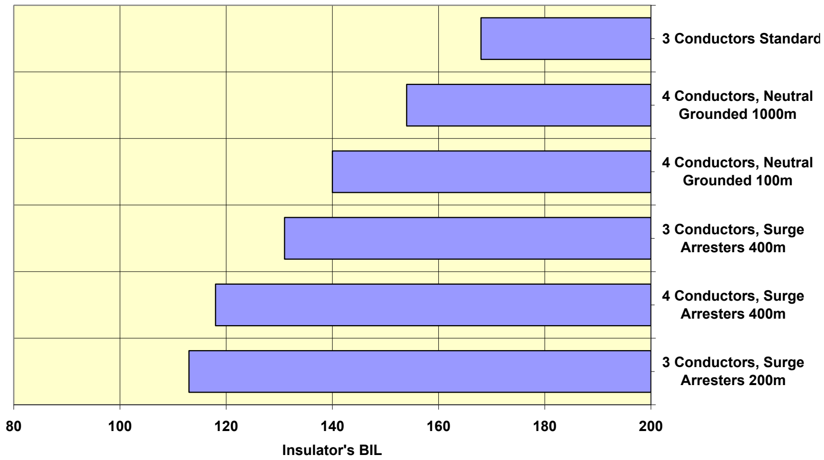

Figure 5 – Construction Comparison by Insulator's BIL

Based in Fig. 5, a construction cost comparison of the different alternatives can be made for the possible solutions, leading to the Table 1.

Table 1 – Construction Cost Comparison

Risk Level of 4 Failures per 100 km per year		
Construction	**Standardised Insulator's BIL**	**Cost US$/km**
3 Conductors, Surge Arresters 200m	125 kV	9,975.20
4 Conductors, Surge Arresters 400m	125 kV	10,482.47
3 Conductors, Surge Arresters 400m	150 kV	9,501.65
4 Conductors, Neutral Grounded 100m	150 kV	9,987.56
4 Conductors, Neutral Grounded 1000m	150 kV	9,638.47
3 Conductors Standard	170 kV	9,005.24

Table 1 shows that the simpler construction, only involving the standard 3 conductors, and without surge arresters nor grounded cable, but with insulator's BIL equal or above 170 kV, has the same performance as the other constructions but with a smaller cost.

6. CONCLUSIONS

The analysis has covered the influence of the presence of surge arresters and their spacing, and of grounded wires and the relevant grounding points on the indirect lightning performance of a typical AES 25 kV distribution line.
When an acceptable flashover risk is established, it is possible with the aid of some charts to choose the appropriate line configurations and to associate them with installation and maintenance costs. This is based on the assumption that the distribution system configuration can be described adequately as a single conductor overhead line, allowing taking decisions that capture important economic and technical aspects.

As demonstrated, the surge arresters installation to each 400 meters is not an efficient solution, mainly when compared with solutions where the insulators BIL are greater than 170kV. In this way, systems where the insulators BIL are lower than 125kV and protected by surge arresters each 400 meters, presents greater flashover risk than the systems constructed without surge arresters and with insulators BIL above 170kV.
As a first result of this study, the solution for 3-conductors construction line without surge arresters nor grounded wire and BIL greater than 200 kV seems a valid alternative worth of additional studies. This alternative presents economic potential, as much for equipments as for hardware, however with a bigger cost with regard to the standard insulators.

BIBLIOGRAPHY

[1] M. A. M. Saran, M. L. B. Martinez, H. R. P. M. de Oliveira "Performance of Medium Voltage Urban and Rural Distribution Lines Front Lightning Discharges and Induced Surges" (GROUND'2006 & 2nd LPE, November 2006, Maceió, Brazil)

[2] M. A. M. Saran, R. R. Bonon, M. L. B. Martinez, H. R. P. M. de Oliveira, C. A. Nucci, M. Paolone "Performance of Medium Voltage Overhead Distribution Lines Against Lightnitning-Induced Voltages: A Comparative Analysis" (GROUND'2006 & 2nd LPE, November 2006, Maceió, Brazil)

[3] IEEE working group on the lightning performance of distribution lines "Guide for improving the lightning performance of electric power overhead distribution lines" (IEEE Std 1410, 2004)

[4] IEEE Fast Front Transients Task Force "Modeling guidelines for fast front transients" (IEEE Trans. on PWRD, Vol. 11, No. 1 , pgs. 493 – 506, Jan. 1996)

[5] Agrawal A.K., Price H.J., Gurbaxani S.H. "Transient response of a multiconductor transmission line excited by a nonuniform electromagnetic field" (IEEE Trans. on EMC 22-2, 1980, 119-129)

[6] Nucci C.A., Rachidi F., Ianoz M. and Mazzetti C. "Lightning-induced voltages on overhead power lines" (IEEE Trans. on EMC, Vol. 35, February 1993)

[7] Rachidi F., Nucci C.A., Ianoz M., Mazzetti C. "Influence of a lossy ground on lightning-induced voltages on overhead lines" (IEEE Trans. on EMC, Vol. 38, No. 3, pgs. 250-263, August 1996)

[8] Rachidi F., Nucci C.A., Ianoz M., "Transient analysis of multiconductor lines above a lossy ground" (IEEE Trans. on PWDR, Vol.14, No.1, pgs. 294-302, January 1999)

[9] Paolone M., Nucci C.A., Rachidi F. "A New Finite Difference Time Domain Scheme for the Evaluation of Lightning Induced Overvoltage on Multiconductor Overhead Lines" (Proc. 5th Int. Conf. on Power System Transient, vol. 2, Rio de Janeiro, Brazil, 2001, pgs. 596-602)

[10] Anderson R.B., Eriksson A.J. "Lightning parameters for engineering application" (Electra, No. 69, 1980)

[11] Chowdhuri P. "Estimation of flashover rates of overhead power distribution lines by lighting strokes to nearby ground" (IEEE Transactions on PWDR, Vol. 4, No. 3, pgs. 1982-1988, July 1989)

[12] Borghetti A., Nucci C.A. "Estimation of the frequency distribution of lightning induced voltages on an overhead line above a lossy ground: a sensitivity analysis" (in Proc. International Conference on Lightning Protection, Birmingham, United Kingdom, September, 1998)

[13] Borghetti A., Nucci C.A., Paolone M. "Statistical Evaluation of Lightning Performances of Distribution Lines" (Proc. of the International Conference on Power System Transient 24-28 June 2001, Rio de Janeiro, Brazil)

[14] Borghetti A., Nucci C.A., Paolone "An Improved Procedure for the Assessment of Overhead Line Indirect Lightning Performance and its Comparison with the IEEE Std. 1410 Method" (in press on IEEE Trans. on PWRD)

[15] De Salles, C., Figueira, A. D., Violin, A., Martinez, M. L. B., Oliveira, H. R. P. M., Oling, R. "Insulation Coordination for a 23 kV Medium Voltage Distribution" (Powertech, Bologna, Italy, June, 2003)