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Improvement of the transmission and sub-transmission overhead lines lightning performance using line arresters – Experience in Brazil

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SUMMARY

Lightning has been reported as the major cause of non-scheduled outages that occur in Brazilian's power system, being responsible for approximately 50 – 70% of the outages verified in overhead lines with rated voltages up to 230 kV and creating many issues for power supply utilities and consumers.

In agreement with the information of the National Institute for Space Researche (INPE) Brazil is the country with the largest incidence of lightning activities in the world, with about 50 - 70 million lightning outages a year somewhere in the country. With this considerable amount of lightning caused distubances, the resulting damages caused to the electric power systems are high such that the costs of losses and repairs exceed an annual value of 350 million dollars. This fact has been taken up by several power supply utilities and industrial consumers and caused them to invest in partnership with universities and research centers in the development of theoretical studies and the promotion of improvements along the critical sections of their overhead lines with poor lightning performance, thereby increasing their reliability. In many cases line arresters have been considered as the most effective method to improve the lightning performance.

In Brazil, the first application of line arresters was in the middle of the nineties and from this time on more than 3,000 units of gapless line arresters were installed on overhead lines from 34.5 kV up to 230 kV. The analysis and evaluation of overhead lines lightning performance before and after the line arresters installation have shown a good effectiveness, with average indexes for the improvement higher than 70%. Good field experience and the proven results obtained in the improvement of the overhead lines lightning performance after the line arresters installation have been encouraging more and more Brazilian power supply utilities and industrial consumers to develop studies to evaluate the line arresters application along their overhead lines presenting poorer lightning performance.

This paper presents information about the experience of the Brazilian power supply utilities as well as industrial consumers in the application of line arresters to improve the overhead lines lightning performance. Procedures used to optimize the characteristics of the line arresters, quantity and location along the critical sections of the lines; field experience as well as the lightning performance of the lines before and after the line arresters application are presented and discussed.

KEYWORDS

Line arresters, Overhead line performance, Lightning performance improvement

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INTRODUCTION

The quality and reliability of a power system is related to its ability to supply continuous and uninterrupted energy without significant momentary disturbances. Several factors may affect the indexes of energy quality, such as the system performance against lightning discharges, its configuration and operation characteristics. Lightning has been reported as the major cause of non-scheduled outages that occur in Brazilian's power system, being responsible for approximately 50 – 70% of the outages observed in overhead sub-transmission and transmission lines with rated voltages up to 230 kV. Some undesirable outages have been also observed in overhead transmission lines of 345 kV and 500 kV.

Although most of the non-scheduled outages have transitory characteristics, in many cases this is still deemed, creating many issues for power supply utilities and their consumers. Power supply utilities themselves have verified the load losses due to voltage sags on their systems from transitory outages caused by lightning activity and in some regions they have found serious permanent damages caused to the system itself due to these transitory disturbances occurring on important lines. Losses of power supply are critical for all modern industries now so reliant on sophisticated electronic equipment and especially production processes very sensitive to momentary disturbances on the system.

The Brazilian power system presents as particularity a great extension of transmission and sub-transmission overhead lines, with more than 180 thousand kilometres of extension, being more than 65% of this extension for overhead lines with rated voltage up to 230 kV. The consuming market concentrates mainly on the South and Southeast areas, which are the regions more industrialized.

In agreement with information from the National Institute for Space Research (INPE) Brazil is the country with the largest incidence of lightning activities in the world, with about 50 - 70 million lightning outages a year somewhere in the country. With this considerable amount of lightning caused distubances, the resulting damages caused to the electric power systems are high. Recent studies done by the Atmospheric Electricity Group (ELAT) from INPE show that losses and damages in the Brazilian power supply utilities caused by lightning exceed an annual value of 350 million dollars.

This fact has been taken up by several power supply utilities and industrial consumers and caused them to invest in partnership with universities and research centers in the research programs and field studies, aiming the development of theoretical studies and the promotion of improvements along the critical sections of their overhead lines with poor lightning performance, thereby increasing their reliability. Most of these studies are basically addressed in the optimization of the lightning protection for overhead lines; in the evaluation, better understanding and monitoring of the lightning activities in Brazil and their effects on overhead lines; and in the evaluation, better theoretical understanding and improvements of the grounding systems behaviour for fast transients.

BASIC CONSIDERATIONS ABOUT LIGHTNING INCIDENCE AND ITS EFFECTS ON OVERHEAD SUB-TRANSMISSION AND TRANSMISSION LINES

Lightning phenomena on transmission lines have important consequences in many safety and technical aspects. The problem has special importance in Brazil due to the high lightning activity and unfavorable electric parameters of soil in a large part of the Brazilian territory.

The frequency in which lightning discharges strike on overhead lines depends on some factors and has a strong influence of the environmental conditions: ground flash density level for the area crossed by the line; physical dimensions of the overhead line in special its height and length; presence of naturally shielding objects or other lines within the same corridor, etc. Besides, the transmission line lightning performance usually can vary at each year, depending on the lightning activities of the area.

Environmental conditions highly affect the power system reliability, and the lightning performance of the power installations seems to be unsatisfactory and disagree, sometimes, with conventional performance predictions and simulations [1]. Since the environment where the transmission line is inserted has a direct influence in the lightning activities and in the quality and reliability of the power supply, many technical publications have been presented aiming the monitoring of the lightning activities in Brazil and their effects on overhead lines [2-5].

The lightning detection aiming the monitoring in wide scale began in Brazil in 1988 in Minas Gerais state for initiative of CEMIG. Along the years, several institutions began the development of the similar activities, expanding the lightning monitoring area.

In 2005 three large lightning detection networks were in operation in Brazil [5]: (1) - the National Integrated Lightning Detection Network (RINDAT), that began its operation in 1998, covering the Southeast and some areas of South and Center-west regions of the country; (2) - the Integrated Information System based on a Lightning Detection Network (SIDDEM), that began its operation in the middle of 2005, covering part of the South and Center regions; and; (3) - the SIPAM Lightning Detection Network, that began its operation in the beginning of 2005 covering part of the North and Northeast regions. As a result of the effort of ELAT in partnership with several institutions in Brazil, it was possible to accomplish the integration of these three regional detection networks resulting in the Brazilian Lightning Detection Network – BrasilDAT. Nowadays BrasilDAT network is the largest network in the tropics and the third larger lightning detection network in the world, with detection efficiency (DE) of about 70 – 90% and location accuracy (LA) below 1 km. It provides good information for power supply utilities about the lightning incidence and their locations.

Most of the researches seeking the evaluation and the lightning improvement of the overhead transmission and sub-transmission lines have been done in Brazil using the Ground Flash Density map. Figure 1 shows the cloud-to-ground (CG) flash rate observed in Brazil from 1998 to 2005 by LIS data [5]. Since LIS sensor does not discriminate between CG and intracloud (IC) discharges, its information corresponds to total lightning data. Thus, the values presented in Figure 1 were computed based on IC/CG average ratios assessed by INPE in previous studies.

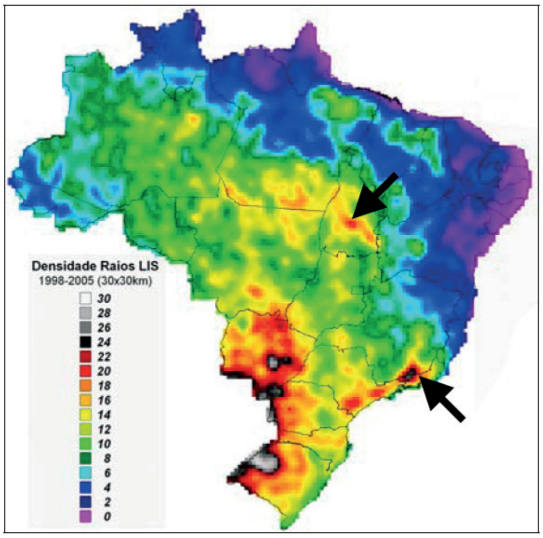

Figure 1 – Geographical distribution of the CG lightning in Brazil estimated from 8 years of LIS data

STUDIES FOR THE IMPROVEMENT OF THE OVERHEAD LINES LIGHTNING PERFORMANCE

The transient behaviour of an overhead line reached by lightning depends on several parameters and factors which need to be take into account during the theoretical studies to evaluate its lightning performance [6-8]: the discharge incidence point; the lightning current characteristic: its magnitude, wave shape and rise time; the transient response of the tower; the electromagnetic coupling among shield wires and phase conductors (for shielded lines); the distance from the tower reached to the adjacent towers; the grounding system response for fast transients; altitude of the tower reached by the lightning, etc. Overhead lines may present several different configurations for the towers, overhead conductors and tower-footing, which establish different transitory responses under lightning stress. Computatonal models and methodologies have been developed to evaluate the lightning transient response of overhead lines taking into account the interaction off all components presented in the line.

Many technical research programs have been developed in Brazil in order to obtain a better knowledge of the transient phenomena associated with the lightning striking on shielded and unshielded overhead lines. Most of these studies are basically addressed in the optimization of the lightning protection for overhead transmission and sub-transmission lines; In the evaluation, better understanding and monitoring of the lightning activities in Brazil and their effects on overhead lines; and in the evaluation, better theoretical understanding and improvements of the grounding systems behaviour for fast transients. Some publications written with basis in these studies until September of 2006 are shown in the references of the technical papers [9-10]. From September 2006 on, technical reports and publications have been published starting from the results obtained in these researches [11-13].

In agreement with the Brazilian Organ Electricity Regulator, the maximum number of transmission lines outages due to lightning depends on the voltage level: one outage per a hundred kilometres a year for voltages equal to or higher than 345 kV; and two outages per a hundred kilometres a year for overhead lines with rated voltage of 230 kV. For overhead lines with rated voltages of 138 kV and below doesn't exist defined yet a maximum number of outages due to lightning. In this case, the maximum number of outages admitted for a specific overhead line is defined by the power supply utility, and depends basically on the importance of the line for the reliability of the whole system and on the economical effects of its outages on the loads connected to the overhead line.

Starting from the results obtained in the theoretical studies and knowing the target number of outages desired for the line evaluated, it is possible to define the methods and procedures more appropriate to improve the lightning performance of the line considered. A technical evaluation should be usually followed by an economical analysis, allowing to the user to analyze and optimize the cost – benefit balance. Among the methods used to improve the overhead lines lightning performance, line arresters have been usually considered in most of the cases as the most effective. Sometimes, its effectiveness and cost – benefit balance increases with the improvement of the grounding systems for fast transients associated with line arresters application.

FIELD EXPERIENCE OF THE BRAZILIAN UTILITIES WITH LINE ARRESTERS APPLICATION

The first application of line arresters in the Brazilian system was in the middle of the nineties, to improve a 34.5 kV overhead radial distribution line from CEMIG. From this time on more than 3,000 units of gapless line arresters were installed on overhead distribution, sub-transmission and transmission lines with rated voltages from 34.5 kV up to 230 kV. From this total, more than 75% were applied in the improvement of the lightning performance for 69 kV and 138 kV lines.

Approximately 70% of all the gapless line arresters installed in Brazil are in the area under concession of CEMIG, located at Minas Gerais State. Besides CEMIG, FURNAS, Ampla, Light, CFLCL, UTEJF, Escelsa, RGE, CEEE, Porto Primavera Transmissora de Energia – PPTE and one industrial consumer - CVRD have been already installed or acquired line arresters to install along their 34.5 kV to 220 kV overhead lines. Details of the line arresters installed are shown in Figures 2 to 4.

The selection criteria used by these utilities to define arresters quantity and location were based on the evaluation of overhead lines or their sections with poorer lightning performance even after the improvement of the grounding systems, and by consumer complaints. Line arresters have been installed in parallel with the insulators strings and the number of line arresters per tower has been depending on the protection philosophy used by the users. In order to obtain good solutions in the technical and economical point of view, lightning performance estimate studies have usually been performed to select the appropriate line arresters characteristics and to optimize the quantity and location of the line arresters along the more critical sections of the overhead lines [14-18].

Figure 2 – Line arresters installed on 34.5 kV line – CEMIG [1]

Figure 3 – Line arresters installed on 69 kV lines: Left CEMIG / Right Ampla

Figure 4 – Line arresters installed on 138 kV lines: Left – CEMIG / Right - UTEJF

The analysis and evaluation of the Brazilian's overhead line lightning performance expressed as the average number of outages per a hundred kilometers a year before and after the line arresters installation have shown a good effectiveness, with average indexes for the improvement higher than 70% for overhead lines with rated voltages from 34.5 kV to 138 kV. Recent publication [19] has shown for CEMIG averages indexes for lightning performance improvement after line arresters installation of approximately 70%, 83% and 90% for overhead lines with rated voltages of 34.5 kV; 69 kV; and 138 kV, respectively. These indexes obtained are in reasonable agreement with the indexes shown in Mexican and Japanese systems.

These indexes can be higher for overhead lines more protected with line arresters. An example is the "Ouro Preto - Mariana", 138 kV overhead line from CEMIG, which presents a high ground flash density level and towers with high tower foot resistances values. Before the installation of the line arresters this line had an average outage index of 41.0 outages per hundred kilometers per year. A partnership project between CEMIG and its industrial consumers fed by this line was developed, and in 1998 line arresters were installed on three phases and on all towers. From 1998 on no outages due to lightning were recorded in this line.

Few registrations of electric and mechanic failures in the line arresters have been observed and detected. Electric failures were attributed to the higher energies absorbed by line arresters during the lightning, while mechanic failures were attributed to the disconnection of some line arresters due to failures in the flexible cable and in the links connection (eye screw) caused by the incidence of strong winds. This mechanic problem was solved by the utility through the reinforcement of the flexible cable and links connection using a steel cable in parallel with the flexible cable connection. This procedure has been applied for the user in the installation of news line arresters and in case of the occurrence of mechanic failures in the arresters already installed. No mechanic fails were observed by the user in the line arresters using this new mechanical configuration.

More detailed information about line arresters performance in the field and their effectiveness in the improvement of the overhead lines lightning performance in the Brazilian's systems have been reported in [1; 10; 16, 19-21].

Good field experience and the proven results obtained in the improvement of the overhead lines lightning performance after the installation of line arresters, have been encouraging more and more Brazilian power supply utilities and industrial consumers to develop studies and research programs to evaluate the line arresters application along their overhead lines with poor lightning performance.

In way to diffusing the technical information referring to the criteria used in the studies seeking the improvement of the overhead lines lighning performance; to increase the line arresters application field and its reliability; as well as to encourage more users and researchers in the participation of lightning studies, the Brazilian CIGRÉ Working Group A3.17 – Surge arresters has created the Task Force A3.17-05 - studies for application of line arresters, whose basic objectives are: (1) - to evaluate the influence of the quantity and the location of the line arresters; the magnitude and wave shape of the discharge current; the grounding impedance; and the multiple strokes on the energy absorbed by the line arresters; (2) - to evaluate the statistical behaviour of the energy absorbed by line arresters and its failure probability in function of the critical energy absorbed, taking into account the magnitude and wave shape of the discharge currents flowing through the line arresters; (3) - to evaluate the electric and mechanic performance of the line arresters in the field; (4) - to give more detailed information about the overhead lines lightning performance in the Brazilian system after the application of line arresters or other method to improve the lightning performance; (5) - to analyse and evaluate special applications for line arresters, such as: compact lines; control of the switching overvoltages; up grade in the system voltage of the line; etc;

This Task Force has been working in the development and elaboration of an application guide and has as main objective to define the basic guidelines regarding to the technical analysis and evaluation of the methods and procedures used for the improvement of the overhead lines lightning performance, with emphasis in the application of line arresters and its dimensioning and selection criteria.

CONCLUSIONS

- Lightning has been reported as the major cause of non-scheduled outages in Brazilian's power system, creating many issues and damages for power supply utilities and their consumers. Losses and damages in the Brazilian power supply utilities caused by lightning exceed an annual value of 350 million dollars.
- Power supply utilities and industrial consumers with partnership with universities and research centers have been establishing and developing research programs seeking the lightning - performance improvement of their overhead transmission and sub-transmission lines.
- Among the methods used to improve the overhead lines lightning performance, line arresters have been usually considered in most of the cases as the most effective. Sometimes, this effectiveness and cost – benefit balance increases with the improvement of the grounding systems for fast transients associated with line arresters application.
- Studies about overhead lines lightning performance shall be done through computational simulations, in way to optimize the quantity and the best location of the line arresters along the line. Usually an economical analysis allows to the user an optimized solution. At same time, studies to estimate the maximum energy absorbed by the line arresters during lightning shall be done in order to get a good field arrester performance and increase its reliability. These studies allow the utilities to estimate arresters fail rates, based on most critical lightning occurrence and grounding impedance conditions for fast transients.
- Brazilian's transmission system has more than 3,000 units of gapless line arresters installed along overhead lines from 34.5 kV up to 230 kV. The analysis and evaluation of lightning performance before and after the installation of line arresters have shown a good effectiveness, with average indexes for the improvement higher than 70%.
- Good field experience and the proven results obtained in the improvement of the overhead lines lightning performance after the installation of line arresters, have been encouraging more Brazilian power supply utilities and industrial consumers to develop studies and research programs to evaluate the line arresters application along their overhead lines with poor lightning performance.

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