Application of Line Surge Arresters in Power Distribution and Transmission Systems

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Brazilian production development of class 2 polymeric surge arresters for transmission line application (TLA)

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SUMMARY

CEMIG have been conducting studies in order to improve lightning performance of transmission lines since 1993, through the efforts of the Group on Performance Improvement, with the goal of providing better quality electrical power to their costumer, especially when reclosings became problematic.
Lightning performance improvement of TLs located in areas with high lightning discharge density and high soil resistivity have had unsatisfactory results trough traditional improvement measures.
If lightning performance improvement is defined as a priority, either due to consumer's claim or electrical system needs, the use of transmission line arresters (TLA) becomes mandatory.
CEMIG has studied and tested improvement measures in problematic TLs, always through the use of imported TLAs, due to the lack of brazilian manufacturers for this kind of arrester. By technical, operational and maintenance points of view, the results have been highly successful on those studies. The actual improvement results after those experiences are presented on this work.
Despite the success in this application, high costs of the arresters and issues in the acquisition process of imported items have made the massive applications on CEMIG lines practically impossible, which resulted in the decision from CEMIG's engineers to create a group of brazilian TLA development and manufacturing. This group was initially formed by CEMIG engineers, and three brazilian distribution arrester manufacturers. Only one has managed to accomplish all the development steps.
The development process has lasted for more than two years, with tests at CEMIG and Balestro labs, in which problems were spotted, but also solved, through the efforts of the whole group, until it was finally possible to give approval of the first brazilian polymeric TLA for 34.5 kV TLs, and after to give approval of a similar project by the same manufacturer for 69 kV and 138 kV lines as well.
In the field application, mechanical solutions were developed on the TLA prototypes in order to solve problems experienced in the past due to vibration and wind effects.
During the development phase, CEMIG has installed Balestro TLA prototypes on a problematic 34.5 kV line. After the final approval was given, other 81 units of 34.5 kV TLAs was installed, as well as 34 units on 69 kV lines and **265** units on 138 kV lines. The application on 138 kV systems has been more successful than in lower voltages, due to a more effective technical/economical balance.

KEYWORDS
Lightning outages, surge arresters, TLA, surge arresters development, lightning protection, transmission lines, line surge arresters

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1 INTRODUCTION

The protection against lightning discharges in transmission lines has for focus the direct discharges and is guaranteed by means of two complementary functions to be assured in the project. The first one of these functions is the capture of the discharges by the protection system, consisting of ground wire (also known as steel overhead ground or guard cable). The ground wires attract the discharges that, in the absence of the captor system, would be deviated to the phase conductors.
The second function consists of draining to the ground, through the proper metallic towers and their ground patches, the currents of eventual discharges caught by the ground wires. This must be made of such way that the resultant over-voltage on the tower body and, more accurately, over-voltage on the insulators strings, in function of currents circulation in the towers and the couplings between conductors phase and ground wires, are kept below the Basic Insulation Level (BIL) of the insulators strings, avoiding the transmission lines outages caused by disruptive discharges of return, also known as back flashover.

However, when the local conditions of ground resistivity are very unfavorable, associated with the lower Basic Insulation Level (BIL) (as in the case of 69 and 138 kV transmission line), it cannot be possible to assure the protection or the transmission line desired performance with conventional solutions, such as the use of ground wires and investments in the grounding patches. In this in case, the use of lightning surge arresters, installed in parallel with the insulators strings, is becoming an alternative increasingly more used currently.

CEMIG began to install lightning surge arresters in its transmission lines from the appearance of the polymer housing ZnO lightning arresters; however this equipment have been imported because these products didn’t exist in the national market. The price and the difficulty of acquisition of lightning surge arresters in the external market had motivated the development of this work.

2 DESCRIPTION

CEMIG Power Supply has about 21,148 km of transmission lines, at voltages that vary from 34.5 kV to 500 kV, where 16,119 km are constituted of 161 kV lines and below. The Minas Gerais State, region where CEMIG is located, has a high lightning discharges rate and ground flash densities that, associated with the high ground resistivities, affects negatively the operational performance of transmission lines. About 75% of transmission lines outages are due to this phenomenon.

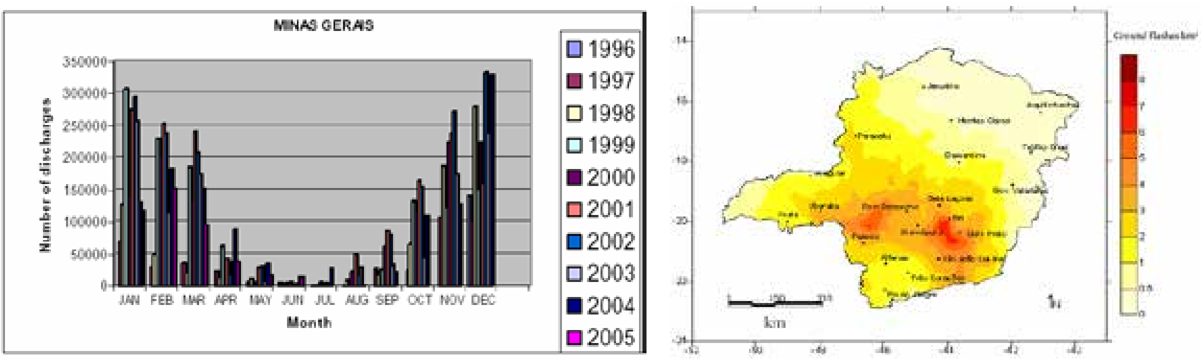

Fig. 2.1 – Lightning activity and ground flash density in
Minas Gerais state (data from Rindat LLS, Brazil)

In 1993, CEMIG created the Work Group of Transmission Lines Performance Improvement Studies.
Initially, the studies had defined the adoption of conventional measures (ground resistances improvement, insulation improvement, line shield, etc.) for lines performance improvement; however in many cases they had not been enough to get better power quality.
So, from 1996 CEMIG began to adopt alternative measures to improve lines performance with the installation of ZnO surge arresters of polymeric housing.

The high cost of the ZnO lightning surge arrester forced the Work Group to look for alternatives to give continuity to the lines performance improvement program.

2.1 Statistical faults data

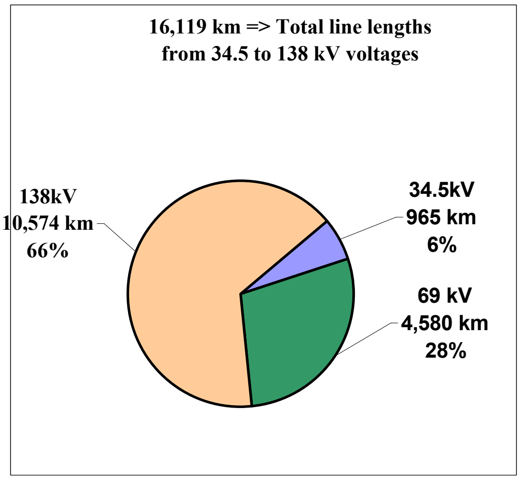

Fig 2.2 – Transmission line lengths

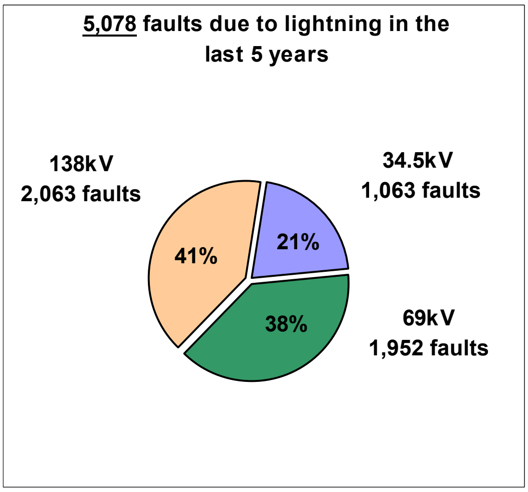

Fig. 2.3 – Faults in 34.5 to 138 kV transmission lines

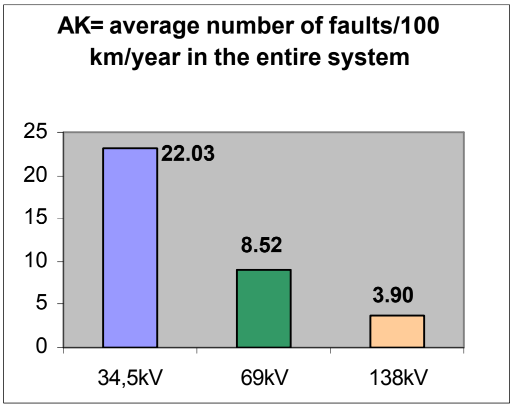

Fig. 2.4 – Average number of faults

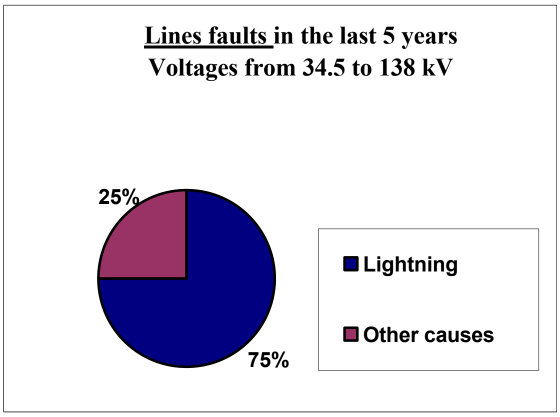

Fig. 2.5 – Overall faults causes

TRANSMISSION LINE	**Voltage (kV)**	**Length (km)**	**Installation year**	**AK before installation**	**AK – average value of the last 5 years**
Diamantina – Gouveia	34.5	31.6	1996	155.06	**44.30**
Ouro Preto 1 – Ponte Nova	138	66.5	1997	30.87	**6.32**
Ouro Preto 2 – Mariana 1/Samarco/Alegria	138	38.9	1998	40.94	0.00 **1.03*** **
Itutinga – Minduri	138	44.6	1998	19.40	**3.59**
Peti – Sabará	69	61	1998	43.64	**5.24**
Itutinga – Três Corações 2	138	87.0	1999	16.2 *	**1.61**
Araxá - Jaguara	138	60.9	2006	24.0 *	**0.00**
Monte Sião – Ouro Fino	138	30.7	2007	25.0 *	**6.50 ** **

Fig. 2.6 – Lines performance improvement where lightning surge arrester were installed

AK = number of faults/100 km/year due to lightning
* Estimated AK – Improvement studies made during the transmission line project
** First year (last raining period)
*** Before and after the transmission line configuration change.

3 PERFORMANCE IMPROVEMENT STUDIES

In general, using an adequate protection offered by lightning ground wires and with a correct size and type of ground electrode, it is possible to get an improvement in the reducing of outages number caused by lightning discharges in transmission lines. Currently, the use of zinc oxide lightning surge arresters (ZnO) has allowed the attainment of significant performance improvement of transmission lines especially in places of high operational diversity. These performance improvements of transmission lines in operation and project at CEMIG, with regard to outages caused by lightning discharges, has been executed in two stages, as per follows:

3.1- Application of Conventional Measures for Lines Transmission Performance Improvement

It consists of transmission line performance evaluation through ground resistances measurements and its improvement through the installation of counterpoise and application of resistivity reducing (bentonite). The type of industrial process and the consumer demand are considered in the analysis of transmission lines operational performance. When the conventional measures are not enough to attain a good performance of the TL, the alternative measures are used (ZnO).

3.2- Application of Alternative Measures for Transmission Line Performance Improvement

Aiming to get the desired improvement in the TL performance, alternative measures as the installation of ZnO lightning surge arresters are adopted. They are analyzed under the approach of cost x benefit to be proportionate to the TL performance.
In this in case, critical sections of the TL are raised initially, considering:

· The higher points of the TL profile are identified;
· The registers of faults localization from the disturbance digital recorder;
· Mapping of locations of ground flashes in the TL route in the last five years;
· Ground resistance measurements of the most exposed towers on the TL.

3.2.1 - Definition of the number of ZnO lightning surge arresters for structure

For each critical section defined in item 3.2 is simulated, through ATP Program and SIGMA SLP Program, the installation of ZnO surge arresters, varying their number for structure in function of the reduction of the expected rate of TL outages. The analysis is completed with the relation cost x benefit that the number of surge arresters / structure in the sections will improve the TL performance.

3.2.2 - Analysis of the energy and class definition of the ZnO lightning surge arrester

Some TL spans are simulated in ATP Program, considering the ZnO lightning surge arresters installed in the phases, varying number of surge arresters for structure, however keeping the same number for each structure in the section. The objective of this simulation is to define the energy levels to be absorbed by the lightning surge arresters in view of the limit of energy absorption capability of the equipment. The absorption capability of surge arrester is evaluated for indirect and direct discharges.

From the point of view of energy class, the lightning surge arrester of CLASS 2 has attended the expectations of operational performance for the systems phase to phase voltages of 34.5 kV, 69 kV, 138 kV and 230 kV for discharges currents limits of 100 kA, whose probability of being exceeded is of 4%. In some cases, a joint improvement of ground resistance of some structure it makes necessary to reduce the energy to be absorbed by the surge arrester, in TL with lightning ground wires.

4 DEVELOPMENT AND WORK GROUP ACTIONS

From experimental installations studies we verify the viability and effectiveness of the technique, however CEMIG still faced the financial problem to make possible the widespread application of lightning arresters in its problematic lines. The costs of these lightning arresters until then were much raised and necessarily imported; this became the acquisition process very long.

Objectifying to make possible the application of this type of lightning arresters in CEMIG lines, the work group, in partnership with national manufacturers of lightning arresters, as focused in this material development using national manufacture components, with the exception of the ZnO varistor, aiming to reduce costs and to mitigate the operational difficulties of acquisition.

During a period of approximately two years, the work group had meetings, and the result was the adequacy of the CEMIG technical specification, contemplating all the necessary characteristics to manufacture the lightning arresters to attend the lines necessities. From this specification, an industrial partner developed and manufactured lightning arresters for transmission lines (TLA) on the voltage range from 34.5 kV to 138 kV, class 2.

Fig. 4.1 - A 36 kV Ur Balestro TLA in test at LEMAT/CEMIG

The prototypes development, tool rack adequacy, polymer injection system, automatic disconnector and production line for lightning arresters manufacture, were implemented only after the laboratory results analyses, always accomplished in the laboratories of the industrial partner and LEMAT/CEMIG.

In this first stage it was looked for evaluate the developed project in relation to the fulfillments of all normative requirements contained in the 02.118-CEMIG-0684 technical specification and IEC 60099-4 standard.

Moreover, special attention was given to the consolidation of a project capable to support the mechanical forces proceeding from the proper application and a cage type system; with the objective to contain the active part (varistors) against short-circuits forces.

Also, during the project stage, solutions for correction the problems detected in the lightning arresters upper terminals had been presented, developing an articulated connection in this terminal, reducing the risk of terminal breaks due to fatigue.

5 PILOT MANUFACTURE, HOMOLOGATION AND TESTS

Finished completely the project stage and the production line adequacies, the industrial partner produced a pilot lot of lightning arresters with 36 kV rated voltage. These lightning arresters was tested at LEMAT/CEMIG and installed in a line located in a region with high lightning discharge density, to check in field performance, at Diamantina region.

At the end of this development process, the industrial partner won an open CEMIG utility tender to supply a significant amount of lightning arresters, in the rated voltages of 36 kV, 75 kV and 120 kV, however this had the CEMIG requirement of lightning arresters previous homologation and the accomplishment of all type tests and acceptance tests.

The lightning arresters homologation process was constituted of three stages, the first one was the technical industry evaluation, the second was the samples choice for test and the third was the accomplishment of the type and acceptance tests. The main goal of technical industry evaluation was to evaluate the production capability, the manufacture uniformity, the quality control during productive processes and the electric and physical chemistry laboratory test facilities. The next step was the accomplishment of the samples manufacture for homologation tests. Before these samples manufacture, CEMIG selected and identified varistors made by an European (Switzerland) manufacturer, in enough quantity for all tests required. These varistors had been selected in a bet of approximately 2,500 varistors, as previous agreement. CEMIG accomplished all the stages of arrester's samples production and tests, cared on prorated section complete lightning arrester, housing and automatic disconnector carried out in the laboratories of Balestro, LEMAT/ CEMIG, IEE - USP and CESI - Italy, in accordance with CEMIG and IEC standards.

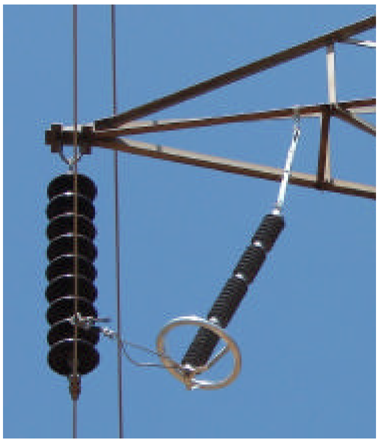

Fig. 5.1 – New arm installation

During these lightning arresters installation, the CEMIG Maintenance coordination and Engineering Management team identified that the installation of the lightning arresters directly in the transmission lines towers arms was, in some cases, better than suspended in the line conductor, however this meant that the automatic disconnector would be submitted to an inadequate continuous torsion load, out of its project conception.

The manufacturer shown solution, observing this new type of installation, was to modify the automatic disconnector installation position, using a device to allow that the disconnector would be only submitted to tension loads, not to the torsion ones. Further studies also demonstrates that, in old installations, the connection flexible cables broke due to vibration, and the solution to this was the use of a chain to make the mechanical connection, bypassed by a cooper cable to the electrical joint. The new solution includes the installation of the disconnector on the live line clamp. And, of course, as the potential side is in the bottom of the arrester, the grading ring had to be installed in the opposite position to be connected to the line potential.

6 FIELD INSTALLATION

Brazilian ZnO TLA class 2 were installed in the transmission line Diamantina 1 – Paraúna

In 2006 81 Brazilian ZnO lightning surge arresters, Ur = 36 kV class 2, were acquired and 16 Brazilian ZnO lightning surge arresters, Ur = 36 kV class 1, were received as industrial partner samples, for installation in the LT Diamantina 1 - Paraúna (US) 34.5 kV. The acquired lightning surge arresters were installed in the section Diamantina 1 - Gouveia 2 with the goal to improve its performance against lightning discharges, while the lightning surge arresters samples were installed for tests in the section Gouveia 3 - Paraúna. The services of installation of the lightning surge arresters were done successful, having been fulfilled the programming foreseen, with the installation executed with the transmission line off.

The performance of the TL Diamantina - Gouveia and the lightning surge arresters physical conditions will be followed, in the next rainy periods, with the aim to verify the performance of the Brazilian surge arresters in transmission lines. These line is unshielded, and after this last arresters installation the total ammount of protected structures is about 65%. All structures are exposed to high lightning activity, as show in section 2 above. A really good in field lab for surge arresters. In the last year (2007) this 31.6 km line outages due to ligthning was about 16 times, instead of about 50 times/year in the past, before the arresters installation.

Fig 6.1 – 36 kV Brazilian ZnO TLA

Fig 6.2 – 36 kV Brazilian ZnO TLA

Acquisition of 105 Brazilian ZnO lightning surge arresters, Ur = 120 kV - class 2, for installation in the new LT Araxá - Jaguara 138 kV

At the end of 2006 were installed 105 Brazilian ZnO TLAs in the LT Araxá – Jaguara, following project studies orientation. The installation passed yet for two rainy periods, not presenting any problems of surge arresters functioning. Figures of the installation:

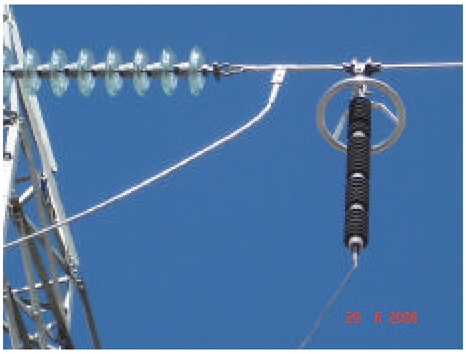

Fig 6.3 – 120 kV Brazilian ZnO TLA

Fig 6.4 – 120 kV Brazilian ZnO TLA

The only abnormality occurred until the moment was the actuation of a ZnO lightning arrester automatic disconnector due to a short circuit through the external part of the polymer cover caused by Curicaca bird streamer. The lightning arrester was removed from TL, tested in laboratory and, later, reinstalled in the TL. The occurrence of Curicaca bird streamer outages is verified on CEMIG lines in [10].

Fig 6.5 – Curicaca bird on a 138 kV tower

7 CONCLUSIONS/RECOMMENDATIONS

- Performance improvement studies carried out by CEMIG have brought excellent benefits for the TL lightning performance, with consequent improvement of energy quality supplied to the consumers, this was clearly proved by more than 2,500 units in operation;
- In new projects and system increasing, CEMIG has looked for contemplate performance improvement actions in TL to be constructed;
- Due to the high costs of the application, the utility researched and found a good alternative to guarantee the continuity of the project of TL performance improvements;
- A work group was formed involving CEMIG and manufacturers with the aim to develop the Brazilian surge arresters manufacture and to look for their cost reduction;
- The presented nationalization of the ZnO surge arresters manufacture by CEMIG and Balestro, resulted initial good results with future perspectives of profits with the product more accessible and of lower cost.
- It is important to point out that using vanguard technology and the partnership, the project aim was reached and today we have in Brazil a product with high quality and nationalization index, making possible its installation in new transmission lines with a favorable cost-benefit relation, especially in the 138 kV voltage. The local production of those arresters as show other advantages, as for example the fast response to the adaptations in the installation;
- Large power consumers in Brazil reveal today interested in financial participating in works for transmission lines performance improvement, aiming to reduce their operational losses caused by outages. This is happening on CEMIG system in the mining region of Mariana.

8 BIBLIOGRAPHY

[1] A. Schei, et al, “Application of Metal Oxide Surge Arresters to Overhead Lines”. *Working Group 11 of CIGRE Study Committee 33. Electra n. 186. October 1999.*

[2] L. C. L. Cherchiglia, A. Cazetta Fº, R. J. dos Reis, G. E. S. Amorim, “CEMIG Experience in Improving Transmission Line Lightning Performance using a Lightning Location System”, *Cigré, Paris, session 2002, group 33-207.*

[3] "*Guide to Procedures for Estimating the Lightning Performance of Transmission Lines* ". CIGRE Working Group 01 of SC 33, October 1991.

[4] "*IEEE Guide for Improving the Lightning Performance of Transmission Lines”,* IEEE PES Std 1243-1997

[5] A. C. Guará Bezerra, “Diagnostic of the Performance of Transmission Line in Design Phase, Under the Action of Atmospheric Discharges with Installation of ZnO Surge Arresters”, *Cigré Symposium, paper 400-01, CAIRNS,Australia, 2001*

[6] A. D. Andrade, R. L. Markiewicz, “Experiência da Cemig na Instalação de Pára-Raios de ZnO em Linhas de Transmissão – Aspectos de Manutenção”, *Cigré, XVI SNPTEE, Group X, Campinas, Brazil, October, 2001*

[7] A. D. Andrade, A. C. Guará Bezerra, R. L. Markiewicz, “Melhoria de Desempenho de Linhas de Transmissão sob a Ação de Descargas Atmosféricas*”, Cigré, VI SBQEE, Belém, Brazil, October, 2005*

[8] EMTP/ATP Program – Electromagnetic Transients Program.

[9] SIGMA SLP Program – Version 1.1, *Sadovic Consultant, France, 1999*

[10] R. L. Markiewicz, et al, “Influência do Comportamento de Pássaros no Desempenho De Linhas de Transmissão”, *Cigré, XVIII SNPTEE, Group III, Curitiba, Brazil, October, 2005*

[11] R. J. dos Reis, C.W.G.A. Coelho, “Estudo de tempestades com descargas atmosféricas na CEMIG” – CEMIG/Puc Minas – *on Rindat LLS Workshop at Furnas, Rio de Janeiro, July, 2005*