METHODOLOGY FOR THE UTILISATION OF COMPACT DISTRIBUTION LINES IN COASTAL AREAS

Arnaldo G. KANASHIRO
University of São Paulo – Brazil
arnaldo@iee.usp.br

Geraldo R. de ALMEIDA
Matrix Eng. em Energia – Brazil
grdealmeida@osite.com.br

Fernando H. MOLINA
CELESC Distribuição - Brazil
fernandohm@celesc.com.br

Gil F. VASCONCELOS
Matrix Eng. em Energia – Brazil
gil.vasc@matrixenergia.com.br

Sergio L. S. CABRAL
Matrix Eng. em Energia – Brazil
sergio.cabral@matrixenergia.com.br

Walter PINHEIRO
Matrix Eng. em Energia – Brazil
walter.pinheiro@matrixenergia.com.br

ABSTRACT

This paper presents the main results of a research project developed by the electrical utility CELESC, aiming at the preparation of a guideline for the utilisation of compact distribution lines in places with trees near the coast. Emphasis should be given to the development of an accelerated ageing test that would be able to reproduce, in the laboratory, the typical damage observed in polymeric material installed in places with heavy pollution. Different types of line spacers available in the Brazilian market were tested and the results of the investigation provided important information concerning the application of compact distribution lines in coastal areas.

INTRODUCTION

The utilisation of compact distribution lines with covered cables in places far from the sea has been an excellent option for the Brazilian electrical utilities, presenting many advantages and benefits when installed in urban areas. A more reliable energy supply is obtained in comparison to the conventional distribution lines with uncovered conductors, and good results are reached when compared to the lines with insulated cables, considering economic aspects.

However, since the radial electric field of the covered cable is not confined within the cable, in places near the coast leakage current can flow on the polymeric surface, and tracking and erosion can occur in the cable, line spacers and ring ties [1-3]. In the presence of pollution, the electric field can also provoke corona discharges where the covered cable is attached to the line spacer. As a consequence, fire can occur and the only alternative for the utility is to replace the damaged section of the covered cable.

With the objective of acquiring information in order to standardise the application of compact distribution lines in coastal areas, the electrical utility CELESC developed studies with the following main purposes:

- to develop and/or to adequate an accelerated ageing test methodology so as to reproduce in the lab the same conditions and damage observed in the field;
- to select better polymeric materials (covered cable, line spacers and ring ties) by using the accelerated ageing test;
- to prepare a guideline for the electrical design, installation and maintenance of the compact distribution lines in aggressive environments.

METHODOLOGY OF THE ACCELERATED AGEING TEST

The test methodology used in this research was based on the procedure standardised by the electrical utilities which are responsible for the distribution lines in Brazil [4]. The procedure intends to evaluate the dielectric compatibility among polymeric materials used in compact distribution lines, such as covered cables, line spacers, insulators and accessories.

Nevertheless, in this research, the basic idea was to reproduce, in the laboratory, the same critical conditions that could provoke tracking and erosion in compact distribution lines, as observed in the field due to the presence of marine pollution. Bearing this purpose in mind, it was necessary to make adjustments in some parameters of the standardised test methodology. Based on these adjustments, it was possible to study the behaviour of several polymeric materials. Also, this procedure resulted in the accelerated ageing test methodology adopted in this research.

The main conditions and parameters of the laboratory test methodology used in this work are mentioned below:

- installation of the covered cables horizontally, parallel to and under the salt fog sprays;
- induced electric current (60 Hz) in the conductor of the covered cable to maintain its surface temperature 60^{o}C;
- generation of fog during 5 minutes with precipitation rate of 1 mm/minute, followed by 10 minutes without fog;
- salt solution conductivity of 1000 μS/cm;
- voltage applied to the samples equals 16 kV, corresponding to about twice the phase-to-ground voltage of the distribution system.

For the purpose of verifying the validity of the methodology, tests were conducted considering line spacers which are most frequently used by the utility. The results provided helpful information for the next steps of this research, which is related to the methodology for the utilisation of compact distribution lines in coastal areas, considering environments with different degrees of severity (light, medium, heavy and extremely heavy). Background knowledge of the study described in [5], which applied similar line spacers exposed to heavy marine pollution, was also taken into account in this work. It is important to note that the line spacers of the study [5] presented tracking and erosion after being 8 months in the field.

It should be emphasized that the utilisation of the accelerated ageing test enabled the study of polymeric materials in the laboratory. Therefore, this test can be used as an important tool to evaluate the performance of different polymeric materials in aggressive environments. Figure 1 shows details of the typical kind of damage observed in the covered cable during the tests.

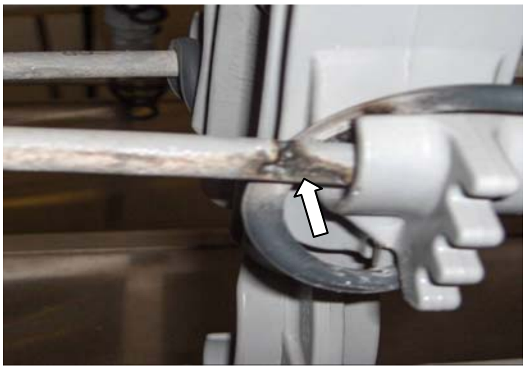

Figure 1 – Details of the typical kind of damage observed in a covered cable.

TESTS IN THE POLYMERIC MATERIALS

Accelerated Ageing Tests - I

With the aim of selecting polymeric materials for compact distribution lines, accelerated ageing tests were performed in sets which consisted of covered cables, line spacers and ring ties available in the Brazilian market. A very different behaviour was observed among the sets, which comprised line spacers made by the same manufacturer. The occurrence of tracking and erosion was very pronounced in some sets, whereas in others only small traces of degradation were observed.

Due to the above, it was decided that the reason for such different behaviours should be investigated. One possible explanation could be the own characteristics of the accelerated ageing test, because of the many parameters involved in the experiment, and a second reason might be the behaviour inherent in line spacers of the manufacturer in question.

Having in mind that corona discharges and electric arcs are well known as the main causes of degradation of polymeric materials, a study about corona discharges was carried out in the lab, aiming at the analysis of the correlation between their occurrence and the degradation observed in the accelerated ageing test. The first step in the procedure adopted in the investigation was to determine the initial voltage of the corona discharges (visual and/or audible) of different types of line spacers available in the Brazilian market. Three levels of severity were considered: light, medium and heavy. These levels correspond to a salt solution of 500, 750 and 1000 µS/cm, respectively, and are related to the severity in coastal areas. The determination of the initial voltage of the corona discharges was possible by applying sinusoidal voltage, 60 Hz, from $0{,}7V_0$ up to $2V_0$, being V_0 the phase-to-ground voltage. The results of two manufacturers are presented in Tables I, II and III. The occurrence of corona discharges was indicated by CV and CA, which mean visual and audible corona discharges, respectively.

Table I – Corona tests - salt solution 500 µS/cm.

LINE SPACER		AM1	AM2	AM3	AM4	AM5	AM6	AM7	AM8
MANUFACTURER "A", 15 kV (AM1, AM3, AM6 and AM8) MANUFACTURER "B" 15 kV (AM2, AM4, AM5 and AM7)	$0{,}7V_0$								
	$0{,}8V_0$								
	$0{,}9V_0$				CV				
	V_0				CV			CV	
	$1{,}1V_0$				CV			CV	
	$1{,}2V_0$				CV			CV	
	$1{,}3V_0$				CV			CV	
	$1{,}4V_0$				CV			CV	
	$1{,}5V_0$				CV			CV	
	$1{,}6V_0$				CV			CV	
	$1{,}7V_0$				CV			CV	
	$1{,}8V_0$				CV			CV	
	$1{,}9V_0$				CV			CV	
	$2{,}0V_0$				CV			CV	

Table II – Corona tests - salt solution 750 µS/cm.

LINE SPACER		AM1	AM2	AM3	AM4	AM5	AM6	AM7	AM8
MANUFACTURER "A", 15 kV (AM1, AM3, AM6 and AM8) MANUFACTURER "B" 15 kV (AM2, AM4, AM5 and AM7)	$0{,}7V_0$				CA			CA	
	$0{,}8V_0$								
	$0{,}9V_0$								
	V_0							CV	
	$1{,}1V_0$	CA	CA	CA	CA	CA	CA	CV	CA
	$1{,}2V_0$				CV			CV	
	$1{,}3V_0$				CV			CV	
	$1{,}4V_0$				CV			CV	
	$1{,}5V_0$				CV			CV	
	$1{,}6V_0$	CA	CV	CA	CV	CA	CA	CV	CA
	$1{,}7V_0$		CV		CV			CV	
	$1{,}8V_0$		CV		CV			CV	
	$1{,}9V_0$		CV		CV			CV	
	$2{,}0V_0$	CA	CV		CV	CA	CV	CV	CA

.

Table III – Corona tests - salt solution 1000 µS/cm.

LINE SPACER		AM1	AM2	AM3	AM4	AM5	AM6	AM7	AM8
MANUFACTURER "A", 15 kV (AM1, AM3, AM6 and AM8) MANUFACTURER "B" 15 kV (AM2, AM4, AM5 and AM7)	$0{,}7V_0$				CV			CV	
	$0{,}8V_0$				CV			CV	
	$0{,}9V_0$				CV			CV	
	V_0				CV			CV	CA
	$1{,}1V_0$				CV			CV	
	$1{,}2V_0$				CV			CV	
	$1{,}3V_0$				CV			CV	
	$1{,}4V_0$				CV		CV	CV	
	$1{,}5V_0$	CA	CA	CA	CV	CA	CV	CV	CA
	$1{,}6V_0$				CV			CV	
	$1{,}7V_0$				CV			CV	
	$1{,}8V_0$				CV			CV	
	$1{,}9V_0$				CV			CV	CV
	$2{,}0V_0$	CA	CV	CA	CV	CA	CV	CV	CV
	$1{,}9V_0$				CV				
	$2{,}0V_0$	CA			CV	CA	CA		CA

The following aspects can be pointed out:
- As the severity of the salt solution increased, high activities of visual and audible corona discharges were observed and, in some line spacers, the initial voltage of the discharges occurred in lower values;
- The behaviours presented by the line spacers from the same manufacturer were very different among themselves. Corona discharges did not occur in some sets, while in other samples audible and visual corona discharges were observed. These results reasonably explain the different behaviour obtained in the accelerated ageing tests with line spacers of the same manufacturer.

Figure 2 shows the typical corona discharges, where the covered cable is attached to the line spacer.

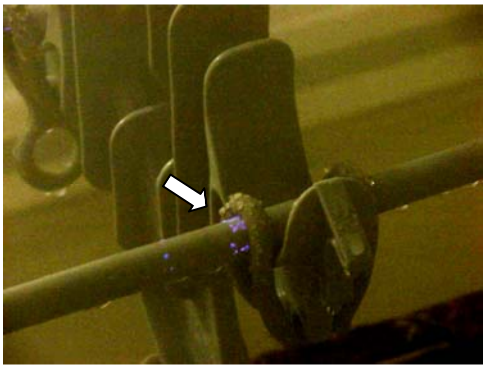

Figure 2 – Typical corona discharges where the covered cable is attached to the line spacer.

Accelerated Ageing Tests - II

Based on the discussion above, it was decided that the next step would be to investigate a possible correlation between the performance of line spacers in the accelerated ageing test and their behaviour in the corona test. The purpose was to check if the sets that presented corona discharges with high intensity in the corona tests would be the first to show degradation during the accelerated ageing tests.

Therefore, the accelerated ageing test was performed in line spacers, class 15 kV, of two manufacturers. These line spacers were first submitted to the corona test. Figure 3 shows details of the degradation which happened in the tests. The results can be seen in Table IV.

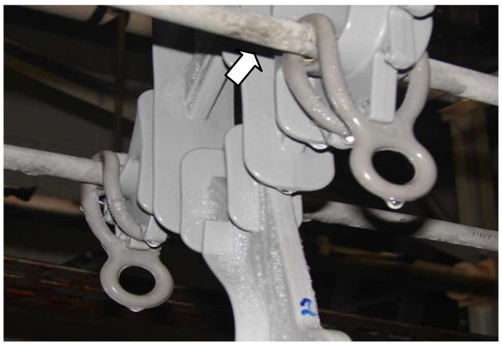

Figure 3 – Tracking and erosion in a covered cable.

Table IV – Behaviours of the sets in the accelerated ageing test - salt solution 1000 µS/cm.

Sets		Corona	11 days	20 days	52 days
MANUFACTURER "A"	1	CA	Salt accumulation	Salt accumulation	Starting point of the tracking cable/ring ties and line spacer Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Increased whitening of the cable near the ring ties (traces of discharges)	
	3	CA	Salt accumulation	Salt accumulation	Traces of discharges cable/ring ties Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Increased whitening of the cable near the ring ties (traces of discharges)	
	6	CV	Salt accumulation	Salt accumulation	Tracking and erosion cable/ring ties Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges) Traces of tracking near the ring ties	Increased whitening of the cable near the ring ties (traces of discharges) Increased tracking near the ring ties	
	8	CV	Salt accumulation	Salt accumulation	Starting point of the tracking cable/ring ties Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Traces of tracking near the ring ties	
MANUFACTURER "B"	2	CV	Salt accumulation	Salt accumulation	Starting point of the tracking cable/ring ties Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Increased whitening of the cable near the ring ties (traces of discharges) Traces of tracking near the ring ties	
	4	CV	Salt accumulation	Salt accumulation	Starting point of the tracking cable/ring tie Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Increased whitening of the cable near the ring ties (traces of discharges)	
	5	CA	Salt accumulation	Salt accumulation	Starting point of Tracking cable/ring tie Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges)	Increased whitening of the cable near the ring ties (traces of discharges)	
	7	CV	Salt accumulation	Salt accumulation	Tracking and erosion cable/ring ties Tracking in the cable outside the ring ties
			Whitening of the cable near the ring ties (traces of discharges) Traces of tracking near the ring ties	Increased whitening of the cable near the ring ties (traces of discharges) Increased tracking near the ring ties	

CV = visual corona CA = audible corona

The accelerated ageing test showed that line spacers that present corona discharges in the corona test will present tracking and erosion in the accelerated ageing test. Then, the corona test is an important tool to be used in the choice of polymeric materials that should be submitted to the accelerated ageing test.
Regarding the methodology applied in this study, it should be stressed that the corona test is not intended to replace the accelerated ageing test. In the former, the aim is to verify if the electric field can provoke corona discharges in the critical part of the sets; in the latter, the purpose is to evaluate the intrinsic strength of the polymeric material used in the compact distribution lines.

CONCLUSION AND RECOMMENDATIONS

The corona test can be an important tool during the selection of the polymeric materials to be submitted to the accelerated ageing test, which reproduced in the laboratory the aggressive conditions observed in coastal areas.

Based on the results of this research, it can be said that the utilisation of compact distribution lines in places with heavy pollution is not advisable. For other locations, the following can be recommended:

- New installations: it is necessary to verify the pollution severity of the environment. Some aspects should be taken into account:
. proximity to the seashore and characteristics of the beach with or without strong winds;
. existence (or not) of physical barriers between the sea and the supposed site for the installation of the line (buildings, trees, etc.);
. pollutants investigation results, indicating the severity level where the line is intended to be installed;
. history of occurrences of tracking and/or erosion in materials of compact lines installed in places with similar environment aggressiveness to that present in the supposed site for the installation of the line;
. previous occurrences of interruptions due to flashovers of insulators.

- Homologation of polymeric materials (cables, line spacers and ring ties) which can be used in places with light and medium pollution levels, making use of this research's test methodology according to the guidelines bellow:
. preselect the most suitable sets (covered cables, line spacers and ring ties) to be used, performing a test which is adjusted to the expected pollution degree (light 500 μS/cm and medium 750 μS/cm) and which identifies the initial level of corona discharges, giving preference to the sets with the greatest values of initial corona voltage;
. conduct an accelerated ageing test in the pre-chosen line spacers so as to select those which present greater resistance during the test.

An aspect of the results of this research that should be mentioned is related to the covered cable, which presented the worst performance, being the weak point of the set (covered cables, line spacers and ring ties) used in the compact distribution lines. The covered cable degraded first, contributing to the degradation of the other polymeric materials. Thus, a careful selection of the covered cable is recommended aiming at a better performance of the compact distribution lines.

REFERENCES

[1] ABRADEE (CODI-3-2-18-24.1)., Specification of line spacers and accessories for the compact distribution lines 13.8 kV and 34.5 kV (*in Portuguese*), Rio de Janeiro, s.d.
[2] FERNANDO, M. A. R. M. and GUBANSKI, S M., 1999, Leakage current patterns on contaminated polymeric surfaces, IEEE Transactions on Dielectrics and Electrical Insulation**,** v. 6, n.5, p. 688-694.
[3] NADERIAN, A.; SANAYE-PASAND, M.; MOHSENI, H., 2004, A review of artificial contamination withstand test methods of high voltage outdoor insulators. In: International Symposium on Electrical Insulating Materials, Proceedings. ISEIM 2004, Piscataway: IEEE, 2004 p. 284-287.
[4] YAMAMOTO, H. et al., 2005, IEC 5000h multi-stress test on polymeric insulators In: International Symposium on Electrical Insulating Materials, Kitakyushu. Proceedings ISEIM 2005, Piscataway: IEEE, 2005, p.v.3 / 580-583.
[5] MELLO, D.R. et al., 2003, Evaluation of compact distribution networks. In: XIII ISH, 2003, Delft. XIII International Symposium on High Voltage Engineering.