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Evaluation of Distribution Line Spacers through the Leakage Current Monitoring

A. G. Kanashiro[1*], W. Pinheiro[2] and G. F. Burani[1]
[1]Institute of Electrotechnics and Energy / University of São Paulo
[2]Consulting Engineer
Av. Prof. Luciano Gualberto, 1289. São Paulo / SP. 05508-010. Brazil
*E-mail : arnaldo@iee.usp.br

Abstract: This paper presents measurements of leakage current aiming at the utilisation of this parameter to indicate the degradation of polymeric material of distribution line spacers and covered cables. Tests were performed at the laboratory in order to investigate the behaviour of the leakage current as function of the stage of degradation of polymeric material. The results showed that the leakage current can provide valuable information about the degradation, in particular, with the frequency of occurrence of the ratio of third harmonic (I3) to fundamental 60 Hz component (I_3/I_1). Investigations are being carried out in order to define reference values to be used in the field. A device is being developed and is intended for indication of maintenance in case of tracking and erosion of the polymeric material in distribution lines located near the coast.
Key Words: Leakage current, Pollution, Tracking, Erosion

INTRODUCTION

The utilisation of covered cable fixed to the insulator (conventional network) or to the spacer (line spacer), has shown an excellent option to the utilities in several countries, including Brazil, concerning technical and economical aspects. The main advantages are the low cost to build the network and the simplicity of its installation and maintenance procedures compared to the ABC (aerial bundled cable) distribution line and to the underground distribution. However, leakage current can appear on the surface of the covered cable as a result of the environment conditions. The presence of leakage current can accelerate the degradation of dielectric material causing tracking and erosion. In some cases, cables can rupture representing risks to population and interruptions of the electrical energy supplied. In case of advanced stage of degradation, there is only one alternative to the utility that is the replacement of the damaged section of the cable.

In order to minimise the consequences of ageing of cables, it is necessary to determine, by means of ageing tests, the initial process of degradation. Although the main factors (thermal, electric and mechanical stress and environment factors) that contribute to the degradation of covered cables are the same for the polymeric insulators, most of ageing test methods is directed to the polymeric insulators. Therefore, besides the determination of a laboratory test method representative of field conditions, it is also necessary to establish parameters that could indicate the stage of degradation of polymeric materials in service condition. This information could be used to elaborate the maintenance planning of the utility.

The University of São Paulo has developed an ageing test method directed to the covered cables fixed in polymeric insulators installed in wood crossarm. In this work, the same methodology was adopted to be used with line spacers although with some adjustments. Laboratory tests were performed with line spacers and cables in order to reproduce the problems observed in distribution lines (15 kV) located near the coast. During the tests, the leakage current of line spacers was measured through a resistor placed between the neutral, connected to the spacer, and the ground point. By means of Fourier analysis, the fundamental (I_1), third (I_3) and fifth (I_5) components of the leakage current were determined in order to get a correlation between the leakage current and the degradation stage of polymeric materials.

This paper shows results and analysis of laboratory tests aiming at the utilisation of the leakage current as a parameter to indicate the stage of degradation of polymeric material used in distribution lines located near the coast.

DEGRADATION PROCESS

The presence of industrial or salt pollution on the polymeric surface can reduce the superficial resistance of the material and leakage current can flow on the surface. The leakage current can cause dry-bands and arcs in the polymeric surface. As a consequence, the degradation of the material is initiated and this process can result in tracking and erosion. The mechanism that results in ageing of polymeric material is very complex because many parameters are involved in the phenomena.

In paper [1], the degradation process of silicone rubber was studied considering leakage current measurements. The evolution of degradation was correlated with the behaviour of the leakage current. The results showed good correlation with degradation and the leakage current pattern, the ratio of peak to rms current, third harmonic content and discharge duration. The leakage current showed a distorted waveform as the degradation increased. The ratio of peak to rms (I_{pk}/I_{rms}) current gradually increased while the degradation progressed, which means that the component of dry-brand arc current was increasing. This tendency showed good correlation with the variations of the harmonic ratio (I_3/I_1) and the maximum erosion depth.

According to paper [2], apart from the leakage current level, the leakage current waveform can provide useful information on the state of the insulator surface. When the insulator surface is hydrophobic, the leakage current is usually capacitive and the waveform is sinusoidal. Once the surface looses hydrophobicity, the leakage current becomes more and more resistive. This results in a deformation of the current waveform and an increase in the level of its harmonic content.

The mentioned studies aimed at to correlate the leakage current measurements with the degradation of the polymeric material. Based on the results, there are indications that the leakage current is a good parameter.
In this work, laboratory tests were performed considering spacer and cables of typical distribution lines aiming at the utilisation of this parameter in the field. The behaviour of the leakage current and the evolution of the degradation were investigated considering the third harmonic (I_3) and the harmonic ratio (I_3/I_1).

TYPICAL STRUCTURES

The basic structure of line spacer comprises three phase conductors and a neutral conductor. The neutral is not a covered cable. All the conductors are assembled on poles through metallic accessories and polymeric insulators. Figure 1 shows a typical structure with a line spacer. The phase conductors are made from aluminium or copper and are covered by a composite of crosslinked polyethylene (XLPE) and linear polyethylene (HDPE).

The polymeric material used to cover the cable is intended to reduce the leakage current in case of accidental contact of cable with earthed objects and to reduce the spacing between phase conductors. It is important to emphasise that the covered cable is not an isolated cable.

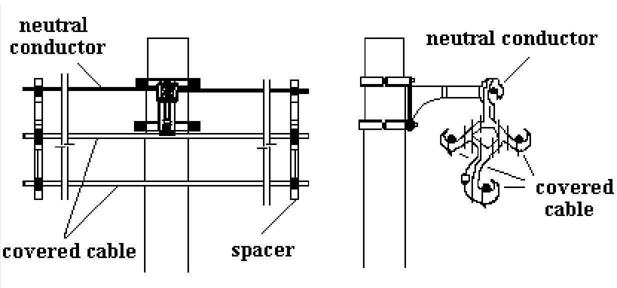


Figure 1 – Typical structure.

The streets near the coast are the most critical to distribution lines with covered cables. In those places, there are sections of lines assembled in a distance between 50 up to 150 m far from the beach. The main problems that occur with polymeric material in those places are:

- Degradation of materials (tracking and erosion);
- Corona effect;
- Rupture of polymeric accessories in the junction points of cables and spacers.

PRELIMINARY TESTS

Preliminary tests were performed in the laboratory with samples of covered cables HDPE (397.5 MCM) and two line spacers (1.5 m of distance between the spacers). The test voltage was 16 kV (phase–to-ground), 60 Hz, applied to the conductor. The temperature of conductor was kept in about 60^0, by using an alternating current of about 520 A. To provide salt-fog sprays directed to samples, nozzles were placed in tubes above the spacer/cables.

The parameters of test were determined aiming at reproducing the same problems observed in the field. Then, adjustments were done related to the concentration and flow of salt solution of the nozzles. Cycles with and without fog directed to the samples were also determined.

In the next step preliminary tests were performed and corona and superficial discharges were observed and, after a period of time, tracking and erosion could be verified in the surface of the cables. Then, the following parameters were fixed in order to correlate the leakage current with the degradation in the next laboratory tests:

- induced alternating current, 520 A, 60 Hz, in order to keep the temperature of the conductor in 60 ^oC;
- generation of fog of 5 (five) minutes, precipitation rate of 1 mm/min and conductivity of 1000 μS/cm, followed by 10 (ten) minutes without fog;
- voltage applied of 16 kV (about two times the phase-to-ground voltage.

AGEING TESTS

Ageing tests were performed in sets of spacers and cables for about 1000 h, being observed superficial discharges during all the period of test causing tracking and erosion of the polymeric material. During the test the leakage current of each set was measured through a resistor placed between the neutral conductor, connected to the spacer, and the ground.

The measuring system acquired the leakage current in intervals of 1 minute, originating an archive of 4 seconds (about 240 cycles of the supply frequency). For each archive, the fundamental (I_1), third (I_3) and fifth (I_5)

harmonic components of the leakage current were determined.

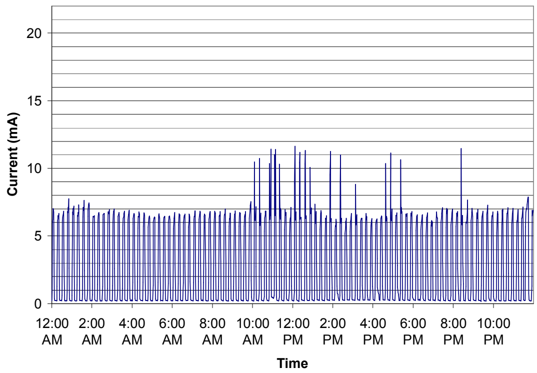
The behaviour of the harmonic components was analyzed in order to get correlations with the evolution of degradation of the polymeric material. Analysis was done considering I_1, I_3, I_5 and the ratio (I_3/I_1) of the harmonics components. Based on comparisons between the leakage current and the degradation observed in the material, it was possible to associate the degradation state of the material with the results of leakage current measurements.

The results to be present in this work refer to one of the sets tested. The degradation was observed after 540 hours of test (March 11). Figure 3 shows the spacer and the degradation of cable. Figure 4 shows the magnitudes of I_1 and Figure 5 shows the measurements of I_3 and I_5. The behaviour of the harmonic components can be observed as a function of the proximity of the degradation (erosion) of the cable occurred on March 11. Figure 6 shows results of measurements of the harmonic ratio I_3/I_1.

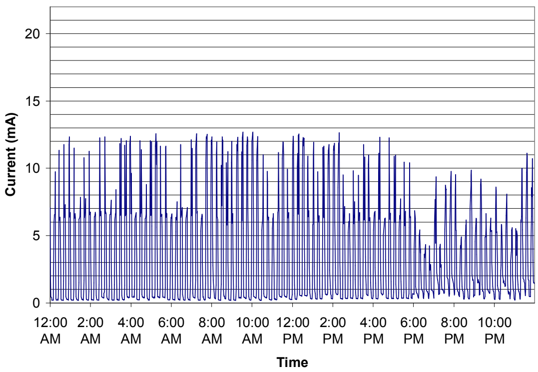
Based on results, the following aspects could be mentioned:

- Component I_1: the maximum magnitudes registered were of about 6 up to 8 mA until March 7. On March 8, peaks of 10mA up to 12mA were observed, showing changes in the behaviour. On the next days higher activities were observed until March 11. On this day, it was possible to observe that the amplitudes decreased at 4:00 pm, time when erosion was observed in cable;
- Component I_3: the maximum magnitudes were about 0.8 mA until 6:00pm of March 9. After this time, amplitudes higher than 1.0 mA were registered. The highest values were observed after 4:00 pm of March 11, when erosion on the surface of the cable was observed. On the other hand, values of I_5 were much lower than I_1 and I_3;

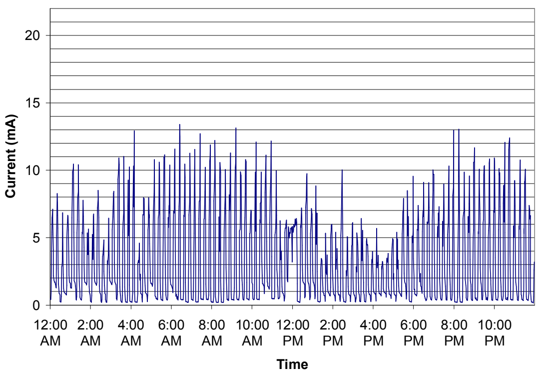
Figure 3 –Degradation after laboratory test.



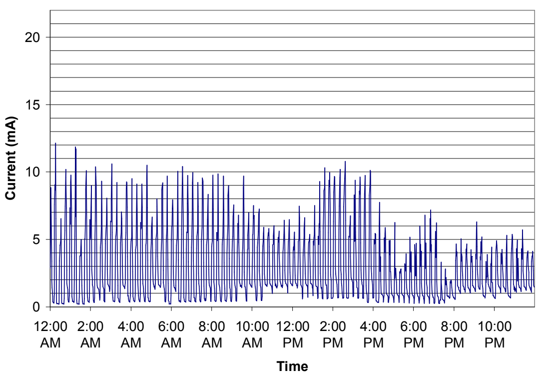
(a) March 8



(b) March 9

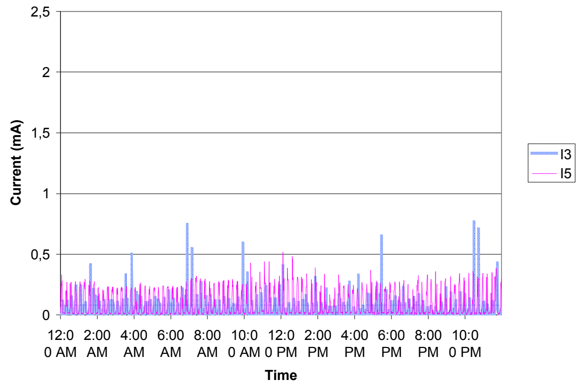


(c) March 10

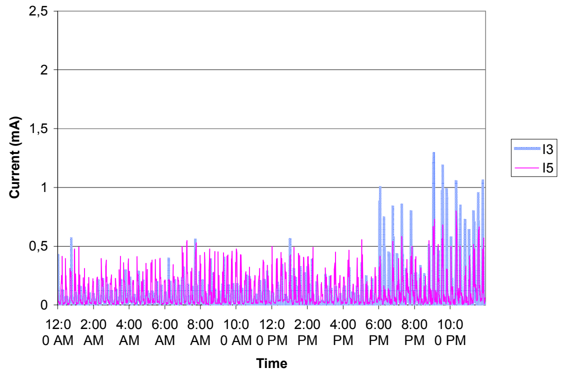


(d) March 11

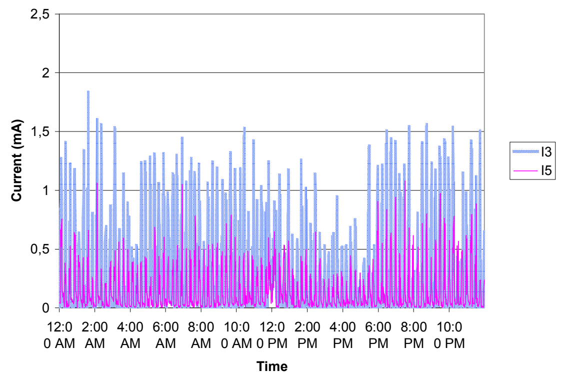
Figure 4 – Fundamental 60 Hz component (I_1).



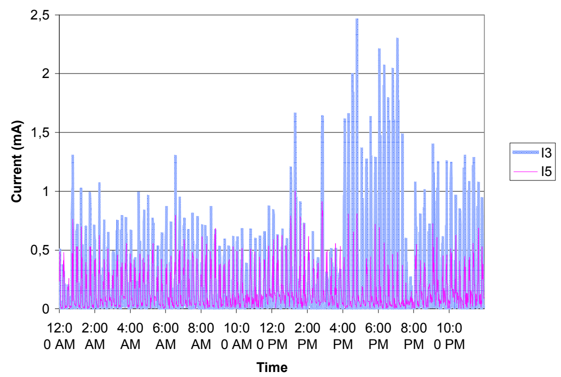
(a) March 8



(b) March 9

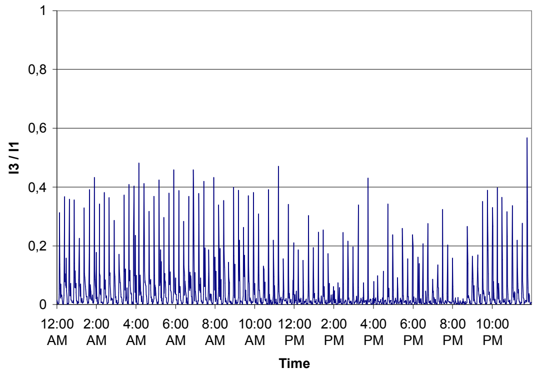


(c) March 10

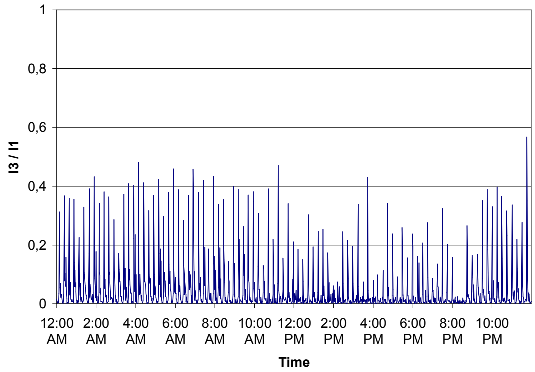


(d) March 11

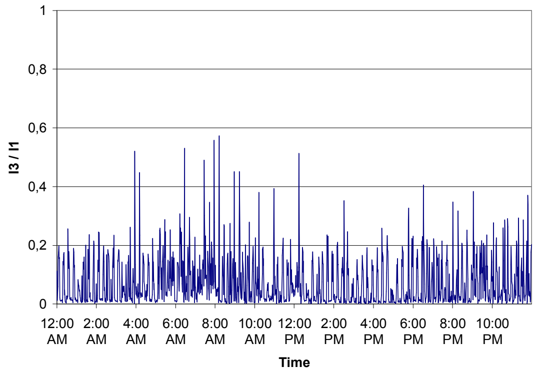
Figure 5 – Harmonic components I_3 and I_5.



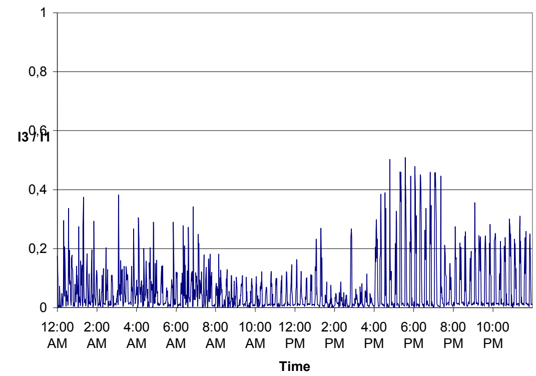
(a) March 8



(b) March 9



(c) March 10



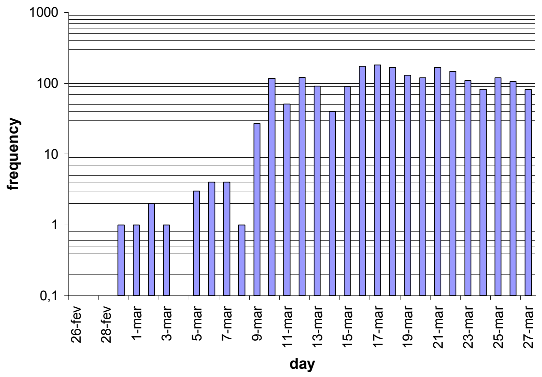
(d) March 11

Figure 6 – Harmonic ratio I_3/I_1.

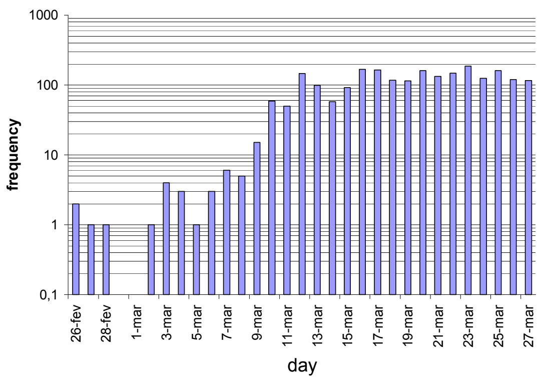
- The highest values of ratio I_3/I_1 on March 8 were about 0.6. On March 9, the highest values registered were about 0.4 until 2:00 pm. On March 11, values of ratio I_3/I_1 increased at the time that the erosion on the surface of the cable was observed (4:00 pm).

Results obtained in this experiment showed that there were reasonable correlation between the behaviour of I_1 e I_3 and the evolution of the degradation of the cable, although, due to the dispersion of their magnitudes, it is very difficult to establish limit values concerning the utilization of I_1 e I_3 in the field. The values of the ratio I_3/I_1 didn't increase as a function of the evolution of degradation of the cable. This fact can be due to the characteristics of the acquisition system as described before.

In order to choose a parameter able to be used in the field, it was decided to investigate the frequency of occurrence of ratio I_3/I_1 in the various ranges obtained in the tests. This procedure seemed to be more adequate because it was observed that after the date of degradation (11 of March), the frequency of occurrence in some ranges showed higher magnitudes. Figure 7 shows, as an example, the values of ratio I_3/I_1 in the ranges of 0.15 up to 0.20 and 0.2 up to 0.25. All ranges obtained in the tests are being analyzed in order to determine reference values to be used in the field as a warning limit.



(a) range 0,15 - 0,20



(b) range 0,20 – 0,25

Figure 7 – Frequency of harmonic ratio I_3/I_1.

Aiming at the monitoring of the leakage current of line spacers in the field, it is being developed a device capable of acquiring the leakage current and determine the ratio I_3/I_1. The calculated ratio I_3/I_1 is compared with a reference value. If the measured value is higher than the reference value, then the device shows a visual indication in order to warn the necessity of maintenance of the cable. Figure 8 shows an example of installation in the field.

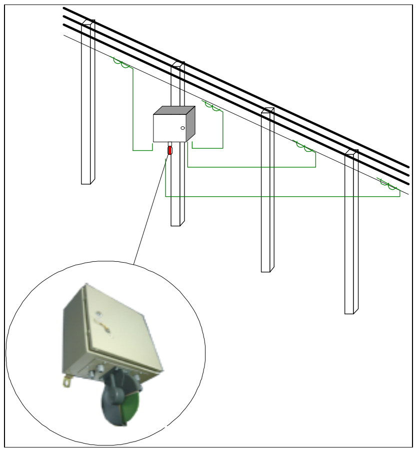


Figure 8 – Installation in the field.

CONCLUSIONS

This work showed results obtained in a research concerning distribution line spacers located near the coast. The final aim is the use of the leakage current in the field in order to indicate the degradation of polymeric material of spacer/cable in aggressive areas. Based on results from the laboratory tests, the utilisation of the leakage current is a viable alternative, in particular, the frequency of occurrence of the ratio I_3/I_1. Investigations are being done in order to confirm the feasibility of this parameter and to define reference values to be adjusted in the device under development. The device is being tested in order to install it in distribution lines near the coast to indicate the necessity of maintenance in case of tracking and erosion of the polymeric material.

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