# Evaluation of Distribution Line Spacers Located Near the Coast

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*Abstract:* - An excellent option to the utilities has been the utilisation of covered cable fixed to the insulator or to the line spacer. However, distribution lines located near the coast are often exposed to marine pollution and then the superficial resistance of the polymeric material can be reduced and leakage current can flow on the polymeric surface. This paper shows the results of investigation considering covered cable and line spacers. By testing the polymeric material, the behaviour of the leakage current and the evolution of degradation were analysed, aiming the on-line monitoring of the leakage current of line spacers.

*Key-Words:* - covered cable, degradation, erosion, leakage current, line spacers, pollution, tracking

## 1 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 of the maintenance procedures, compared to the ABC (aerial bundled cable) distribution line and to the underground distribution.

However, distribution lines located near the coast are often exposed to marine pollution and then the superficial resistance of the polymeric material can be reduced and leakage current can flow on the surface. The leakage current can cause dry-bands and electrical arcs on 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 the polymeric material is very complex because many parameters are involved in this phenomenon.

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 covered cable. Therefore, it is very important to minimize the effect of pollution in coastal areas and to determine a parameter that could indicate the degradation of the polymeric material. The degradation process of silicone rubber was studied in [1], considering leakage current measurements. The results showed good correlation between the 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 (third to fundamental component) and the maximum erosion depth.

According to reference [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 studies mentioned before tried to correlate the amplitude and distortion of the leakage current, with the degradation of the polymeric material. Based on the results, there are indications that the leakage current is a good parameter. Other researches presented results of laboratory tests, considering the leakage current of polymeric materials [3,4,5]. Therefore, further investigations are necessary, considering spacers and covered cables of typical distribution lines.

Nowadays, it is very important to the utility to provide a high level of power quality to the consumers [6,7,8], then damages to the distribution line spacers should be avoided in order to reduce interruptions of the electrical energy supplied.

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 research, the same methodology was adopted, although with appropriate adjustments in the laboratory test.

In this paper, laboratory tests were performed in order to investigate the degradation of distribution line spacers and covered cables, and the respective behaviour of the leakage current. The evolution of degradation of polymeric material were investigated and the results were correlated with the fundamental ($I_1$), third ($I_3$) and fifth ($I_5$) harmonic components of the leakage current.

## 2 Distribution Line Spacers

Typical configuration of distribution line spacers comprises three phase conductors and a neutral conductor. All conductors are assembled on poles through metallic accessories and polymeric insulators. Typical configuration of a line spacer can be seen in Fig.1.

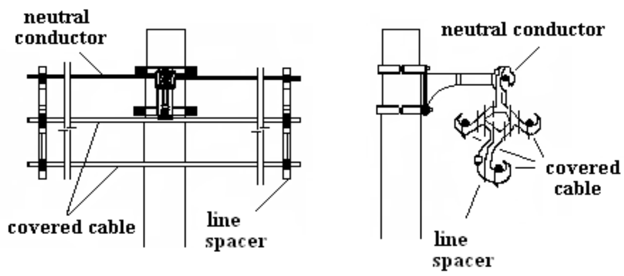
The neutral is not a covered cable. The phase conductors are made of aluminium or copper and are covered by a composite of crosslinked polyethylene (XLPE) and linear polyethylene (HDPE).

The polymeric material used to cover the cable is intended to reduce the leakage current in case of accidental contact (trees, for instance) and to reduce the spacing between phase conductors. It is important to emphasise that the covered cable is not an isolated cable.

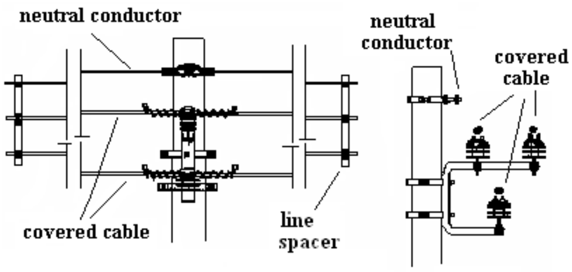
The most critical situation refers to distribution lines located near the coast. At this site, the main problems that occur with polymeric material are the following:

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

Two types of line spacers are commonly used, as shown in Fig.2. A distribution line situated near the coast is shown in Fig.3. The technical information and electrical characteristics of line spacers can be seen on Table I.

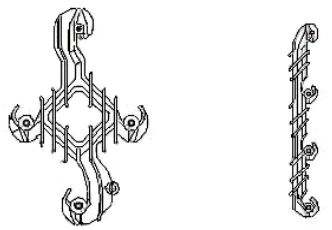



(a)




(b)

Fig.1 – Typical configuration of distribution line.



(a) lozenge                (b) vertical

Fig.2 – Types of line spacers.

Fig.3 – Distribution line near the coast.

Table I - Technical information of line spacers.

| Type | Nominal voltage (kV) | Basic impulse level (kV) | Wet power frequency withstand voltage (kV) | Minimum creepage distance (mm) |
|---|---|---|---|---|
| vertical | 15 | 110 | 34 | 240 |
| lozenge | 15 | 110 | 34 | 260 |

# 3 Methodology

There are several diagnostic techniques for assessing surface degradation and the aim of these techniques is to determine when and how failure may occur and to prevent it [1]. The diagnostic techniques in use are surface conductivity, hydrophobicity, equivalent salt deposit density (ESDD), flashover voltage, leakage current, etc.

The leakage current measurement has an advantage of assessing on-line. In general, the leakage current monitoring could provide information about the average current, cumulative charge, current waveform and the number of peak pulses.

The aim of this research project is to study the behaviour of the leakage current and the evolution of degradation of the polymeric material, considering the harmonic components of the leakage current. Therefore, the first step was the development of a laboratory test method taking into account line spacers and covered cables used in distribution lines near the coast.

Initially, preliminary tests were performed in order to determine an adequate procedure, aiming to reproduce the same damages (tracking and erosion) observed in the field. Samples of covered cables HDPE (397.5 MCM) and two line spacers (1.5 m of distance between the spacers) were tested. The test voltage was 16 kV (phase–to-ground), 60 Hz, applied to the conductor. The temperature of the conductor, $60^{o}$C, was kept constant by using an alternating current of 520 $A_{rms}$.

To provide salt spray directed to the samples, spray nozzles were installed in tubes above the spacer/cables, as shown in Fig.4.

Cycles of salt spray occurred, periodically, during the test. After several experiments, similar damages were observed in the samples, as shown in Fig 5, being concluded that the test procedure was finally determined.

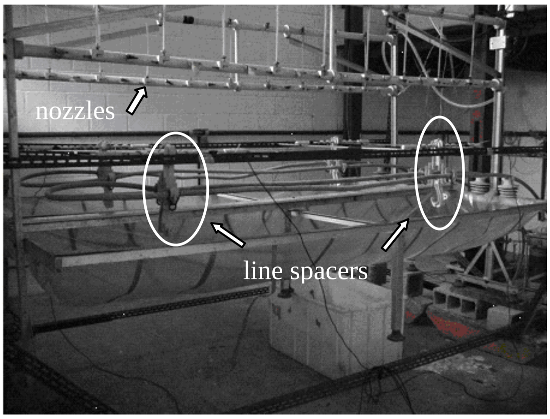
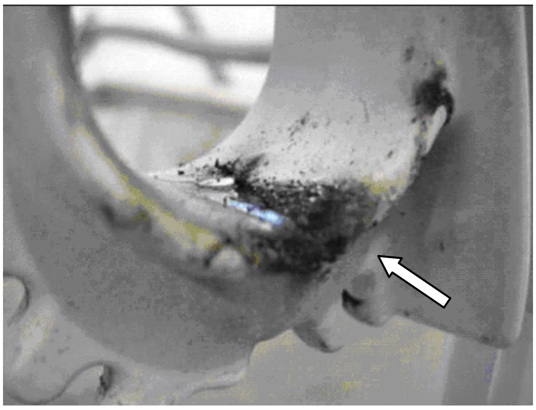
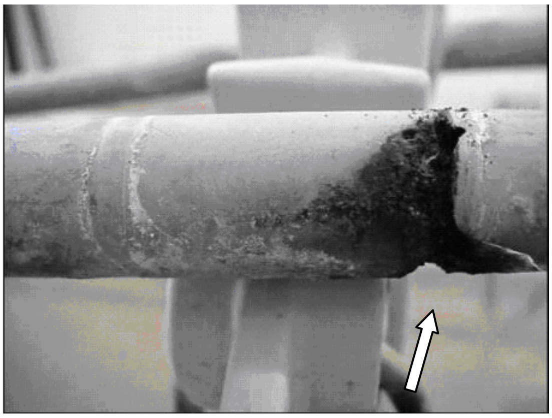



Fig.4 – Laboratory test.



(a) Line spacer



(b) Covered cable

Fig.5 – Tracking and erosion observed at the laboratory.

Then, adjustments in the laboratory facilities were done and they were related to the concentration of salt solution, besides the flow of air and of salt solution of the spray nozzles. The period of time, with and without salt spray (cycles of salt spray), was also determined, in order to be used in the following laboratory tests, named accelerated ageing test.

Once the procedure of the accelerated ageing test was defined, the next step was to investigate the initial process of degradation of the distribution line spacers and cables, bearing in mind the correlation between this phenomenon and the behaviour of the leakage current.

The following parameters were used during the accelerated ageing test:

- Test voltage of 16 kV (about two times the phase-to-ground voltage);
- Induced alternating current of 520 $A_{rms}$, 60 Hz, in order to keep constant the temperature of the conductor (60$^{o}$ C);
- Fog generation during 5 minutes followed by 10 minutes without fog;
- Precipitation rate of 1 mm/min;
- Conductivity of salt solution 1000 µS/cm.

The accelerated ageing test was performed considering four line spacers and covered cables. The leakage currents were measured through resistors placed between the neutral, connected to each line spacer, and the ground point of the laboratory. For each line spacer, the measuring system acquired the leakage current in intervals of 1 minute.

In each one of those intervals, one data file was generated and should contain the leakage current measured during 4 seconds (about 240 cycles of the supply frequency, 60 Hz).

Based on Fourier analysis, the fundamental ($I_1$), third ($I_3$) and fifth ($I_5$) harmonic components of the leakage current, were determined. When the surface of insulating material deteriorates, the leakage current waveform is distorted to such an extent that it gives rise to varying degrees of higher harmonics. However, significant variations can be seen concerning the third harmonic component.

As an example, Fig.6 shows the waveform of the leakage current and the respective harmonic components, when intense discharges occur on the polymeric surface.

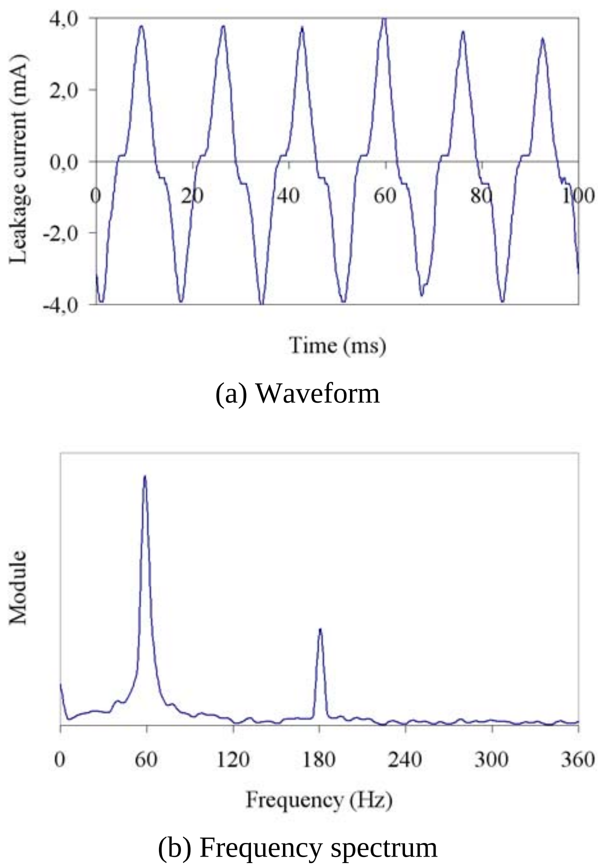



Fig.6 – Leakage current.

# 4 Results of Laboratory Tests

The accelerated ageing test was performed considering four line spacers and covered cables. They were tested during about 1000 h, being observed in most of the time, partial discharges on the surface of the line spacers and covered cables. In particular, intense electric arcs occurred periodically, in specific intervals, in which the nozzles were spraying the salt solution direct to the samples (cycles of salt spray).

In general, it was observed that the amplitude and distortion of the leakage current gradually increased while the degradation progressed. The leakage current waveform is a mixed form of the sinusoidal and the distorted waveforms. The sinusoidal waveform refers to the current that flows through the electrolytic conductivity and the distorted one refers to the dry-band arcs. Those arcs cause erosion on the polymeric surface.

The waveform of the current through the liquid film is an undistorted sinusoidal wave and the energy dissipated in this current is transferred to the surface, indirectly through the liquid film [1]. Then, it does not affect significantly the surface degradation.

Nevertheless, the arc current has a distorted waveform and the energy dissipated in the arc is large and is transferred to the polymeric surface directly. As a consequence, the degradation of the polymeric surface is much larger.

During the tests, the waveform of the leakage current was registered, as shown in Fig.7, by using a digital oscilloscope.

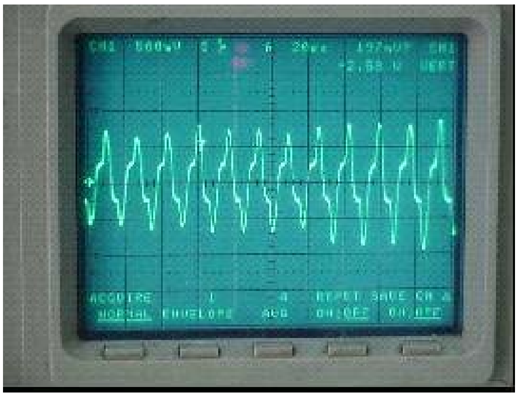


Fig.7 –Leakage current measurement using a digital oscilloscope.

The results of the leakage current measurements will be analysed considering the behaviour of each one of the harmonic components, $I_1$, $I_3$, $I_5$. Since the beginning of the accelerated ageing test, it was noticed that the behaviour of $I_1$, $I_3$, $I_5$ was stable with small variations in their respective amplitudes.

On the 22$^{nd}$ day of test (540 hours), it was observed erosion on the surface of the recovered cable, in the proximity of one of the line spacers, as shown in Fig.8 and Fig.9.

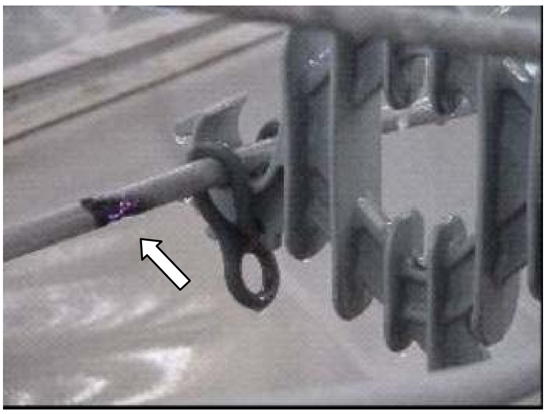


Fig.8 – Discharges and erosion.

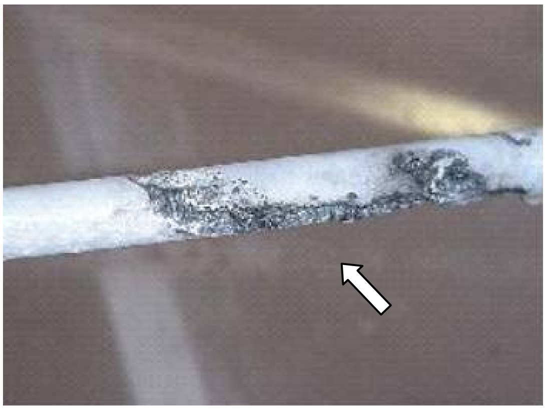


Fig.9 – Detail of the covered cable.

Afterwards, the leakage current of the degraded sample was analysed, trying to correlate the amplitudes of the harmonic components $I_1$, $I_3$, $I_5$ and the progress of the polymeric material degradation.

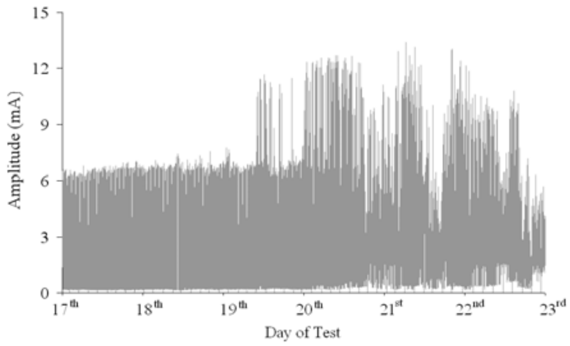
When the polymeric surface is hydrophobic, the leakage current waveform is usually sinusoidal. The occurrence of dry-band arcs causes an appearance of current spikes on the signal peak and the spikes can reach high intensities. Then, the deformation of the leakage current waveform increases due to the high values of harmonic content.

Thus, the largest variation of the amplitudes of the harmonic components $I_1$, $I_3$, $I_5$ occurred few days before the occurrence of erosion. Fig.10 shows the behaviour of the amplitudes of $I_1$, $I_3$, $I_5$, considering the 17$^{th}$ day up to 22$^{nd}$ of test.

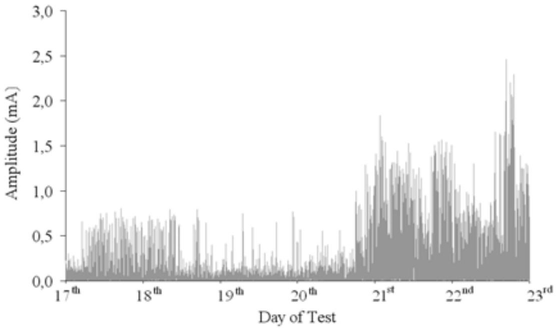
It can be seen that $I_1$ changed its behaviour on the 19$^{th}$ day of test. The behaviour of $I_3$ and $I_5$ components changed on the 17$^{th}$ and 20$^{th}$ day of test, respectively.

As mentioned before, the erosion of the covered cable occurred on the 22$^{nd}$ day of test. Specifically, this occurrence was observed at 4:00 pm. Fig.11 shows in detail the behaviour of the $I_1$ component, considering the time interval from the 19$^{th}$ day up to the 22$^{nd}$ day.

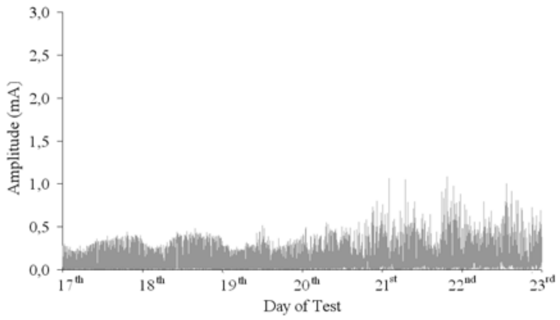
The behaviour of $I_3$ and $I_5$ are also presented in Fig.12, considering the same period. In order to have additional information and better correlation with the degradation, the ratio of the third harmonic to fundamental ($I_3/I_1$) was calculated and the results can be seen in Fig.13. The reference [1] showed good correlation with the variations of the harmonic ratio (third to fundamental component) and the maximum erosion depth.




(a) $I_1$




(b) $I_3$

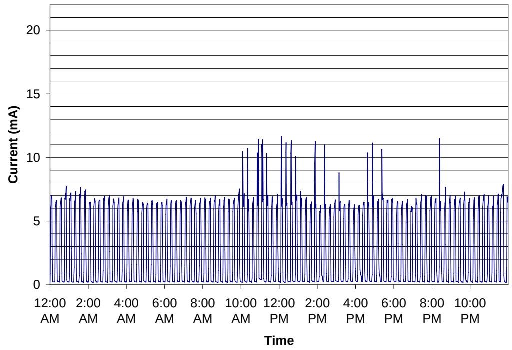



(c) $I_5$

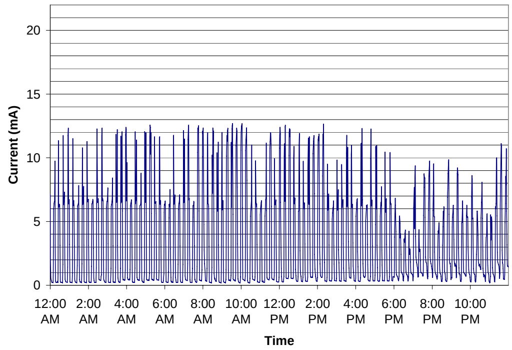
Fig.10 – Leakage current: $I_1$, $I_3$, $I_5$ components.

According to the measurements, it was observed that the amplitudes of $I_1$ component were from 6 mA up to 8 mA until the 19th day of test. On this day, the behaviour changed and values of 10 mA up to 12 mA were also measured.

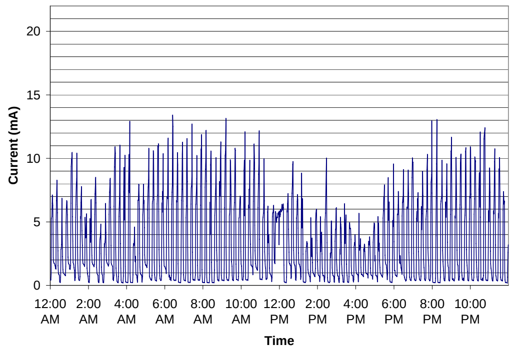
On the 20th day, higher activities were observed until the 22nd day of test, in which the amplitudes decreased at about 4:00 pm, when erosion was observed on the covered cable.



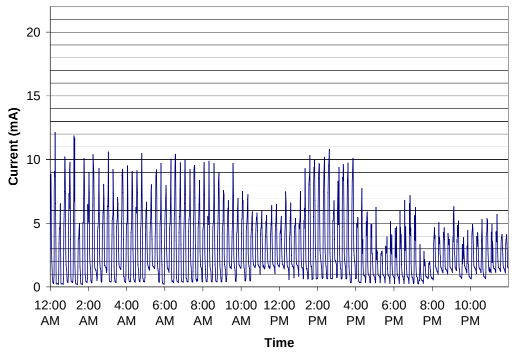

(a) 19th day




(b) 20th day

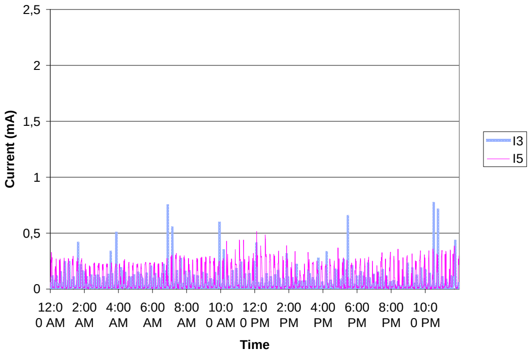



(c) 21st day

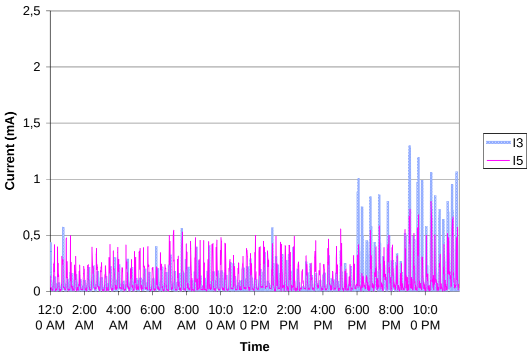



(d) 22nd day

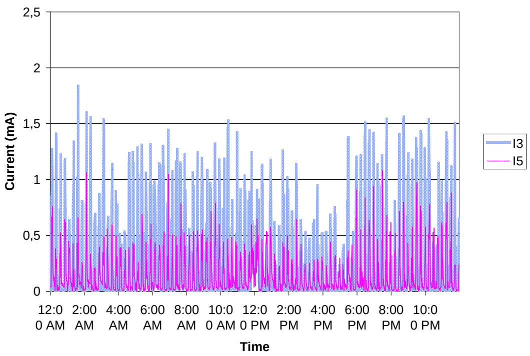
Fig.11 – Fundamental component ($I_1$).



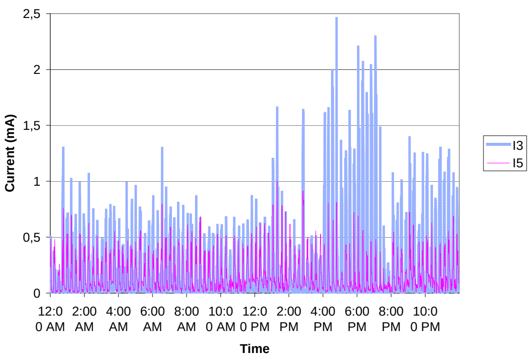

(a) 19th day




(b) 20th day

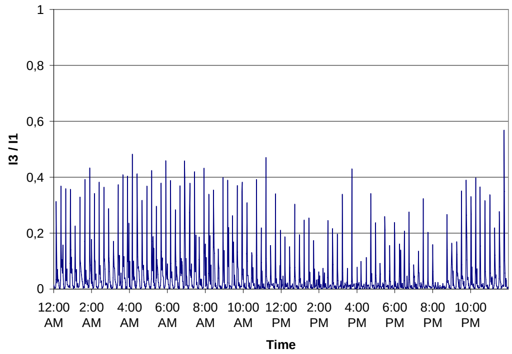



(c) 21st day

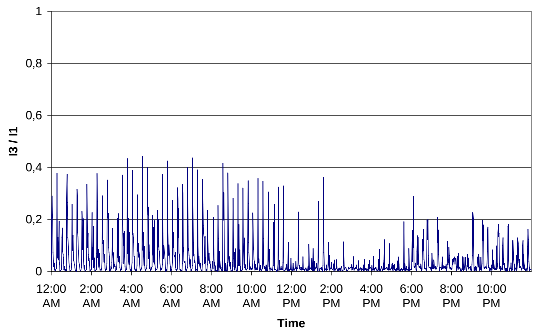



(d) 22nd day

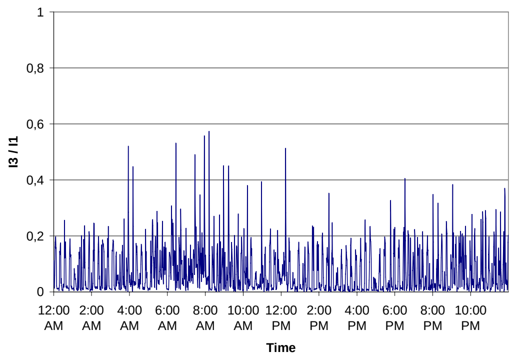
Fig.12 – Harmonic components $I_3$ and $I_5$.



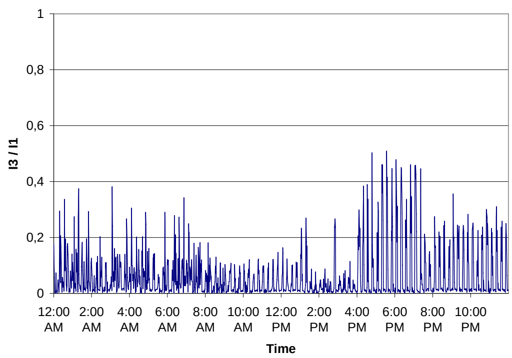

(a) 19th day




(b) 20th day




(c) 21st day




(d) 22nd day

Fig.13 – Harmonic ratio $I_3/I_1$.

The $I_3$ component changed its behaviour on the 17th day of test, when values of 0.8 mA were measured. At about 6:00 pm of the 20th day, the amplitudes of $I_3$ increased and their values were higher than 1 mA. On the 21st day, higher activities were observed. Amplitudes in the range of 2 mA up to 2.5 mA were observed in the time interval of 4:00 pm and 6:00 pm of the 22nd of test, when erosion on the surface of the cable was observed.

The behaviour of $I_5$ component changed on the 20th day of test and presented amplitudes of 1 mA on the following days. The amplitudes of $I_5$ are much lower than those observed for $I_1$ and $I_3$.

Concerning the $I_3/I_1$ ratio, the highest values were about 0.6 on the 19th day. This behaviour was similar on the 20th and 21st days. On the 22nd day, values of ratio $I_3/I_1$ were lower and, at about 4:00 pm, higher amplitudes were registered.

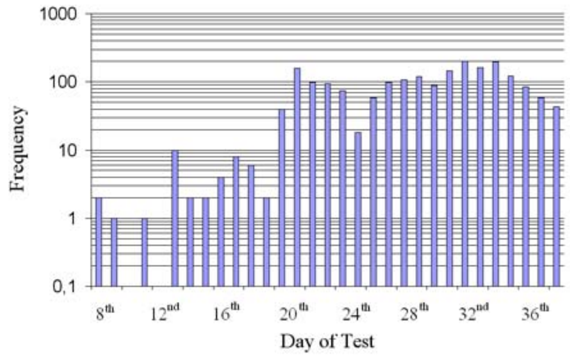
Results obtained in this experiment showed that there were changes in the behaviour of $I_1$, $I_3$, $I_5$ components while the degradation progressed. This is an important point that could be used in order to have an indication about how close the proximity of degradation of the polymeric material is. Nevertheless, it is very difficult to determine limit values of $I_1$, $I_3$ and $I_5$, having in mind their application in the field.

On the other hand, the correlation of the ratio $I_3/I_1$ as a function of the evolution of degradation on the covered cable is not an easy task due to the dispersion of their values.

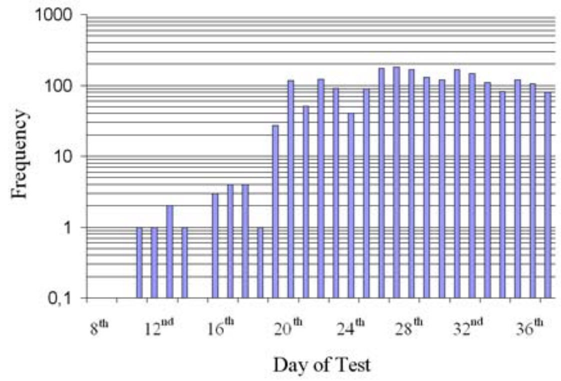
In order to define a parameter that could be used in the field, it was decided to investigate the frequency of occurrence of ratio $I_3/I_1$ for several ranges of values. This procedure was based on the following facts, observed during the accelerated ageing test:

- as the degradation increases, the distortion of the leakage current increases;
- the frequency of occurrence of distorted leakage current waveform also increases.

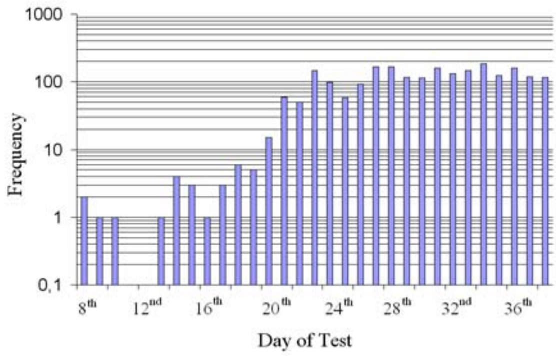
Fig.14 shows the values of $I_3/I_1$ ratio in the ranges of 0.10 up to 0.15, 0.15 up to 0.20, 0.20 up to 0.25 and 0.25 up to 0.30.



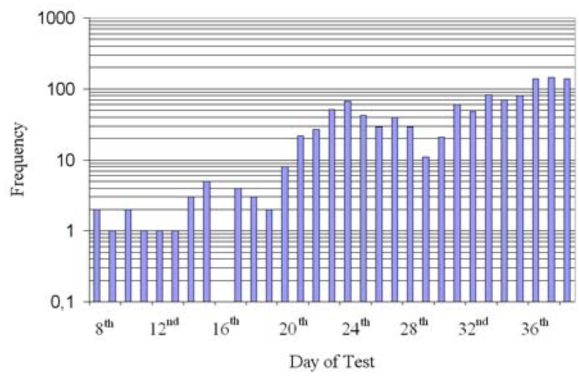

(a) range 0.10 – 0.15




(b) range 0.15 – 0.20




(c) range 0.20 – 0.25




(d) range 0.25 – 0.30

Fig.14 – Frequency of the harmonic ratio $I_3/I_1$.

The frequency of occurrence of $I_3/I_1$ ratio shows a reasonable correlation with the evolution of the degradation of the polymeric material.

The erosion on the surface of the covered cable occurred on the 22nd day of test. After this day, the frequency of occurrence, in the ranges showed in Fig.15, presented small variations.

All ranges are being analyzed in order to determine reference values to be used as a warning limit in distribution line spacers.

## 5 On-line Monitoring

Aiming the monitoring of the leakage current of distribution line spacers, a device capable of acquiring the leakage current and to determine the ratio $I_3/I_1$ is being developed. The aim is the indication of the stage of degradation of the polymeric material used in the distribution line spacers.

The device should be able to acquire the leakage current on-line and to determine the fundamental and the third harmonic components. The frequency of occurrence of the $I_3/I_1$ ratio should be calculated considering line spacers of a distribution line located near the coast.

The 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 covered cable.

The device has four modules: conditioning, CPU, signal indication and supply, as shown in Fig.15.

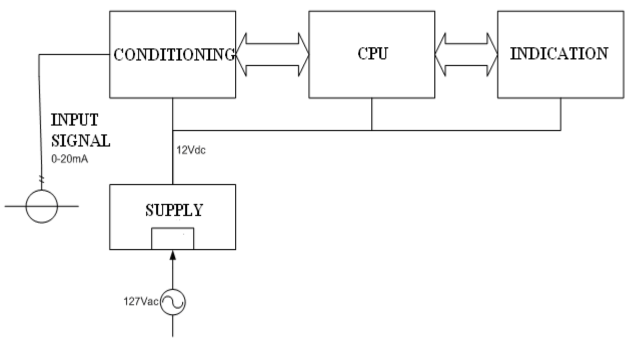



Fig.15 – Block diagram of the device.

It should be emphasized that the module, concerning the signal indication, has an electromechanical component with a cylinder that shows a colour indication, as a function of the $I_3/I_1$ ratio values and the operation of the device.

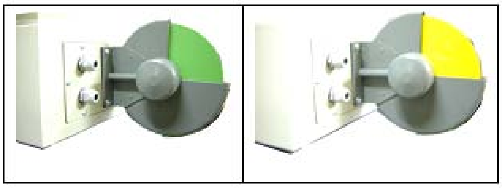
In Fig.16 the electromechanical indication is shown, being possible to know the status of the device and of the $I_3/I_1$ ratio values. The meaning of the colours is described below:

- Green: normal operation of the device. Also, values of the $I_3/I_1$ ratio are less than the reference value;

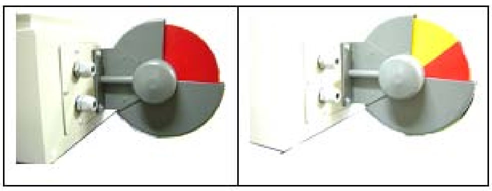
- Yellow: normal operation of the device. However, the values of the $I_3/I_1$ ratio are increasing and the utility has to evaluate them in order to decide the necessity of maintenance;

- Red: normal operation of the device and the polymeric material are presenting values of leakage current that can degrade the covered cable and/or line spacer. Maintenance procedures must be adopted by the utility.

- Between Yellow and Red: failure of the device, being necessary replacement or maintenance.



(a)



(b)

Fig.16 – Visual indication of the device.

Details of installation in distribution lines can be seen in Fig.17 and Fig.18, where the device and the line spacer are shown.

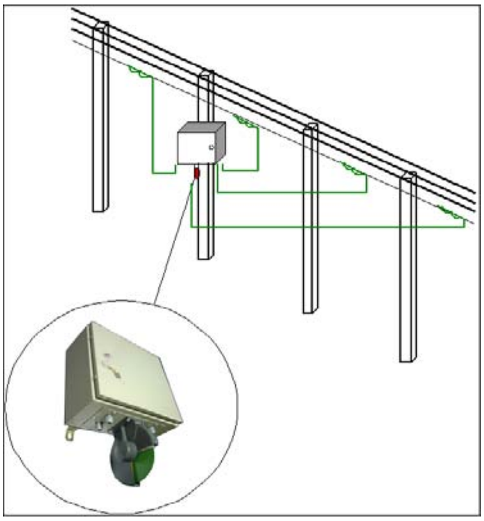


Fig.17 – Installation of the device in distribution line.

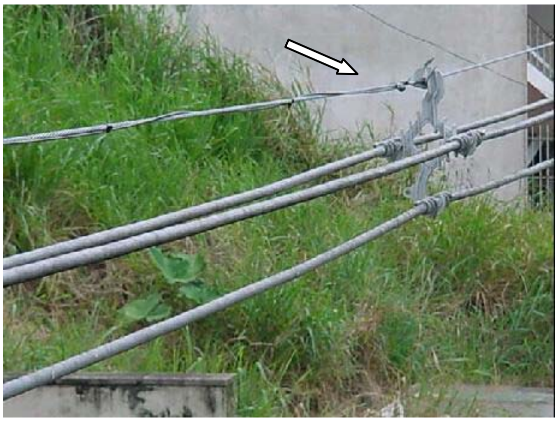


Fig.18 – Details of installation in distribution line.

# 6 Conclusion

This work showed results of a research project concerning distribution line spacers and covered cables located near the coast. The aim was the investigation aiming the utilization of the leakage current to indicate the degradation of the polymeric material of distribution line spacers and covered cables, situated near the coast.

A reasonable correlation was obtained between the stage of degradation of typical polymeric material used in distribution lines and the leakage current. In particular, the ratio of the third harmonic to the fundamental component ($I_3/I_1$) of the leakage current can provide valuable information about the occurrence of tracking and erosion in the polymeric material.

Based on results of the laboratory tests, the utilisation of the leakage current is a viable alternative, considering 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 more effective reference values.

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