Naturally Aged Polymeric Insulators: Washing and its Consequences

T. V. Ferreira, A. D. Germano, E. G. da Costa.
Federal University of Campina Grande.
Center of Electrical Engineering and Informatics.
Department of Electrical Engineering.
Campina Grande, Paraíba, Brazil.
tarso@dee.ufcg.edu.br

J. M. G. Angelini, F. E. Nallim.
Telecommunications Research and Development Center
Campinas, São Paulo, Brazil.
nallim@cpqd.com.br

P. Mendonça.
Pernambuco Electric Power Company
Recife, Pernambuco, Brazil
phillip@celpe.com.br

Abstract— **This paper analyzes the effect of natural saline pollution on polymer insulators that have been aged in the field, and the impact of washing on their performance. Leakage current measurement was the main method used, with infrared radiation detection employed as an auxiliary technique. The 69 kV insulators were in operation for eight years in Porto de Galinhas, in the overhead power lines of the Pernambuco's Electricity Company (CELPE).**

Keywords- Polymeric insulators, monitoring, diagnosis, infrared, ultraviolet, pollution, saline environment, natural aging.

I. INTRODUCTION

Ever since man was able to generate electricity in significant quantity (circa 1880), sufficiently robust insulators have been used for power transportation [1]. These devices have two main purposes: to provide electrical insulation and mechanical support for the structures. Thus, they are one of the most critical components of the system. Therefore, their electrical and mechanical integrity has a direct impact on the performance and reliability of the transmission system as a whole [2].

The first insulators were made of ceramic (glass or porcelain). However, over the last decades, polymeric equipment has been increasingly used in transmission, sub-transmission, and distribution power lines. Polymer insulators consist of a fiberglass reinforced plastic rod, encased in a polymeric sheath, usually made of EPDM or silicone, with a weathershed system [3]. The elements of a typical suspension insulator can be observed in Fig. 1.

This paper analyzes the effect of natural saline pollution on polymer insulators that have aged in the field and the impact of washing on their performance using infrared detection and leakage current measurement.

The presence of conductive or semiconductive layers (i.e. pollution) has a great impact on insulation performance [5]. Since it is hard to predict environmental efforts, insulators must be designed for acceptable flashover occurrence, even when under polluted conditions [6; 7]. Another option is to adopt alternative measures, such as periodic washing [8, 9].

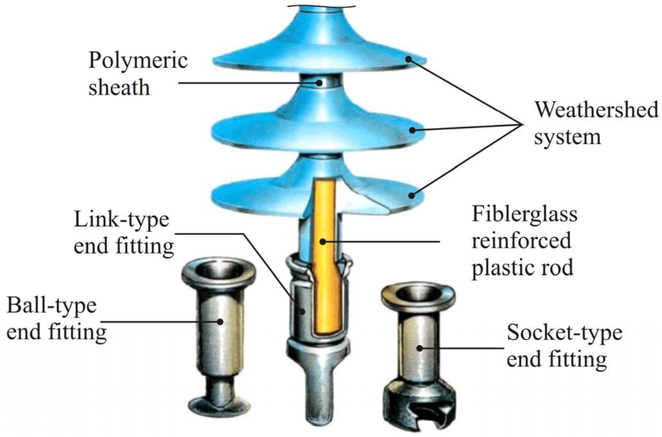


Figure 1. Polymer insulator elements [4].

Many methods have been used to detect defective in-service polymer insulators successfully, such as visual inspection, electric field measurement, corona detection, infrared thermography, hydrophobicity analysis and airborne noise detection [10, 11].

As for the methods used in this project, leakage current is widely accepted as one of the main parameters for evaluating equipment performance [12]. This method allows the exact operational status of insulators to be determined. High leakage current rates indicate contamination by pollution, loss of insulating capacity, carbonization, etc. An insulator in good condition normally presents a leakage current in the order of a few microamperes, under nominal operating voltage.

Thermography was also employed as an auxiliary method. Commercial equipments for infrared radiation detection have been successfully employed to inspect several components of the electric systems. These equipments expands the limits of human sight to visualize the infrared radiation from the heat emitted by the insulator. Insulator heating is not caused by corona deterioration, but rather by the presence of leakage current. Overheating of the inner rod is usually caused by defects in the rod itself, while the surface normally heats up

This paper received financial support from Eletrobrás to buy instruments and equipment, according to agreement ECV- 082/2005, and from CNPq for the researchers' scholarships.

due to damages sustained by the sheds or sheaf as well as to dry-band arcing.

UV radiation detection was also used as an auxiliary method. By overlaying the UV image to that of a normal camera, the corona source can be accurately pinpointed, even during the day [13]. It was, thus, possible to detect small electric discharges – a characteristic of aged polymeric insulators, particularly in the vicinity of the end fittings. Corona discharges were also detected.

II. Material and Methods

A. Material

The insulators submitted to the tests described in this paper had been in operation for approximately eight years. The six samples had been in use in the CELPE System, more specifically in a 69 kV, 02N7/IPO-PTG power transmission line that feeds the Porto de Galinhas-PTG substation, near the PE-009 highway.

All the samples were 69 kV insulators, with 23 sheds of alternate diameters, weighting about 6.6 lbs each. Photos of the samples, showing details of their state of conservation, can be observed in Fig. 2.

B. Methods

The purpose of the tests was to determine to what extent washing affected superficial leakage current in insulators. Several samples were washed from distance (with a water jet), and one them was washed with a synthetic sponge and water. All the tests were run in the High Voltage Laboratory of the Federal University of Campina Grande, in August 2009. Leakage current was measured specifically under different conditions:

- **Dry Leakage Current Test (DLCT):** The samples were tested at room humidity (75%). UV and infrared inspections were carried out when necessary.
- **Wet Leakage Current Test (WLCT):** The samples were sprayed with a clean mist of water, until their surface was covered with water. UV and infrared inspections were also carried out when necessary.
- **Post-Wash Wet Leakage Current Test (PWLCT#):** Two samples were washed with a jet of water (PWLCT1) and one with a synthetic sponge (PWLCT2). Leakage current was then measured again. UV and infrared inspections were also carried out when necessary.

The schematic arrangement for these measurements is shown in Fig. 3. DayCor II and FLIR P85 cameras were used for UV and infrared detection, respectively.

Figure 2. Photos of tested samples.

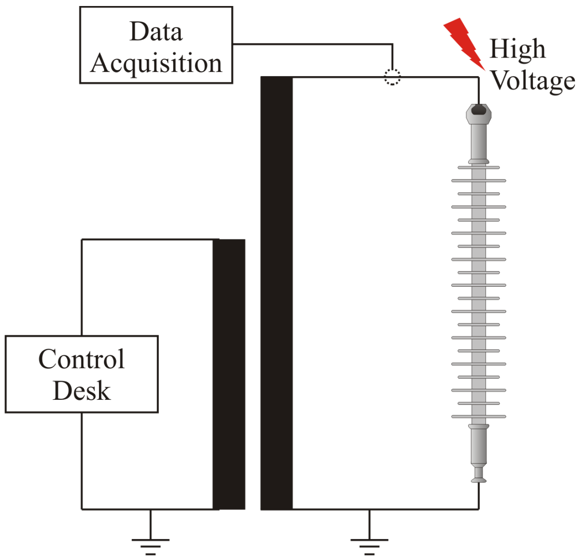


Figure 3. Assembly diagram for measuring leakage current.

III. Results

A visual inspection revealed that all the samples presented small cracks in their polymer sheath, loss of hydrophobicity, and oxidation in the end fitting, especially in the live fitting. The sheds were covered with a white powder. This white powder is possibly a mixture of alumina, a component of the polymer sheath, with the environmental pollution of the region where the insulator was installed.

A. Leakage current

The leakage current of all six samples were measured under dry and wet conditions, as explained in Section II. The results are exhibited in Table I.

TABLE I. WET AND DRY INSULATOR LEAKAGE CURRENT.

Method	Sample	RT (°C)	RH	Applied Voltage (kV_{RMS})	Leakage Current (μA_{RMS})
DLCT	A1	23.9	75	44	20.55
	A2	24.0	76	44	20.72
	A3	24.0	76	44	19.96
	A4	24.1	76	44	21.90
	A5	24.0	76	44	20.68
	A6	24.0	76	44	21.27
WLCT	A1	25.3	-	44	3233.61
	A2	24.8	-	44	2800.20
	A3	24.8	-	44	3441.60
	A4	24.8	-	44	4017.42
	A5	25.1	-	44	3984.63
	A6	24.8	-	44	2915.98
PWLCT1	A1	24.0	-	44	2206.97
PWLCT2	A2	24.1	-	44	768.65
PWLCT1	A3	24.0	-	44	1545.08

Table I shows that in dry tests, the leakage current never left the microamperes range (with an average of 20.85 μA_{RMS}), despite superficial saline pollution. With the application of a water mist and the resulting increase of superficial moisture, the currents reached the milliamperes range (averaging 3.4 mA_{RMS}). This increase in leakage current by two orders of magnitude was not unexpected, and can even be greater in field situations, where several degrading agents act simultaneously. The laboratory environment reproduced the effects of applied voltage, pollution and elevated moisture, but not the summed actions of other agents such as solar radiation, eolic incidence, etc.

After being washed with a water jet, samples A1 and A3 reduced their leakage currents by 31% and 55%, respectively. The sample A2, washed with a synthetic sponge, presented a reduction of 72% in leakage current, as well as a recovery of hydrophobicity.

Fig. 4 shows the waveform of leakage currents measured during the tests of samples A1, A2 and A3. Observe that corona discharges were intensified after the wash, in spite of leakage current reduction (right column).

B. Infrared detection

All samples were inspected with a thermovisor during WLCT tests. The resulting images are shown in Fig. 5. For easier inspection, thermographies were performed horizontally. Insulators are shown with live end to the left and grounded end to the right.

Unequal layers of pollution on the insulators added to different regions of polymer sheath damage produced various thermal profiles.

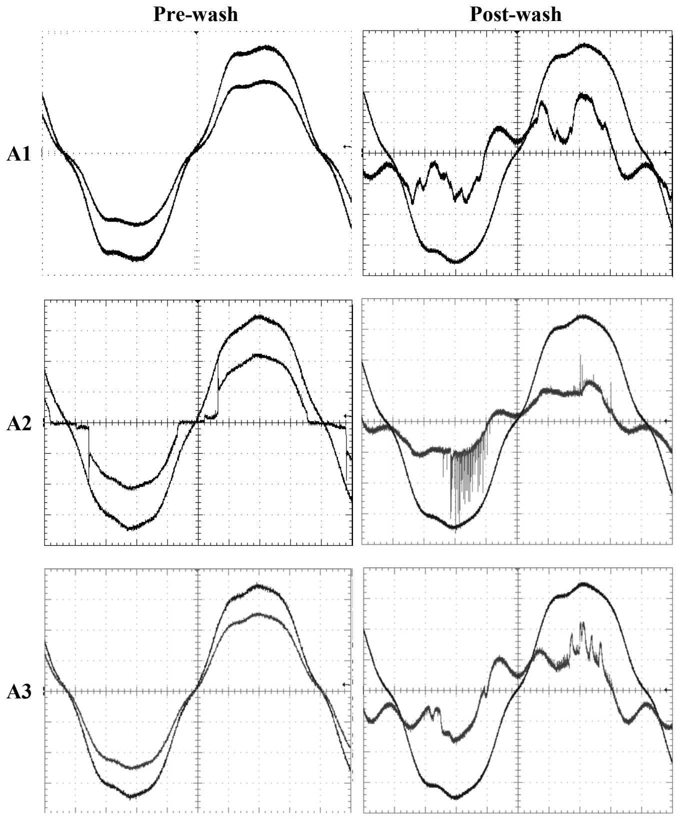


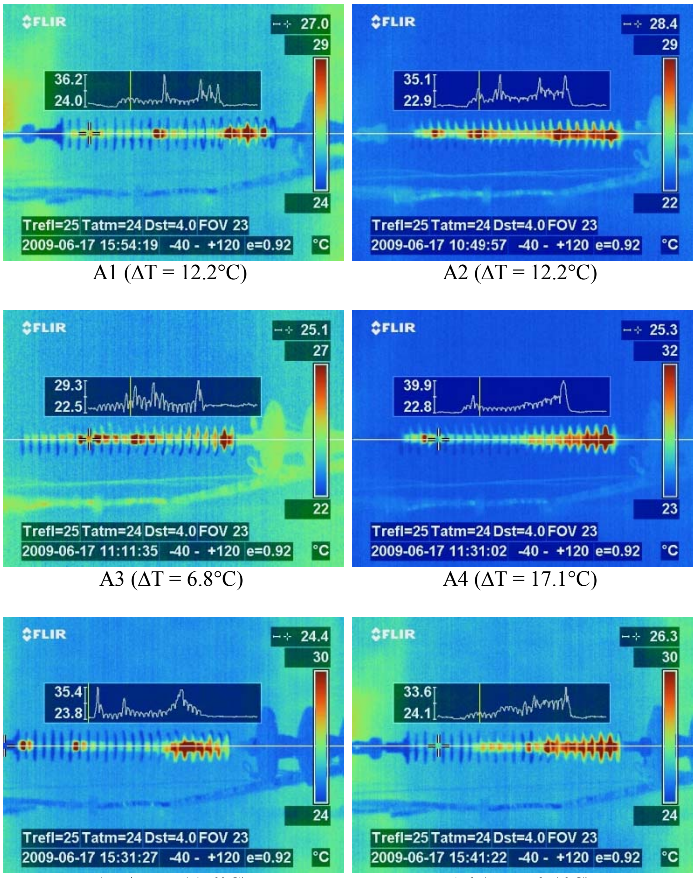
Figure 4. Leakage current waveforms of samples A1, A2 and A3, respectively, with pre-and post-wash superficial moisture. Waveforms with the highest maximum values represent voltage signals.

After applying high voltage, the hottest areas presented intense surface discharge activity, with dry-band formation. After a long period of operation under the action of several degrading factors, the insulator's polymer sheath no longer exhibited acceptable hydrophobicity, causing dry-band arcing.

The regions on the vicinity of the live metallic end fittings had less surface discharge activity. The greater environmental contamination of these areas induces increased surface conductivity and parasite currents, preventing arc formation. These currents, however, cause intense heating, which can also accelerate polymer degradation.

C. UV Detection

Samples presented practically no corona activity or surface discharges during dry tests (DLCT). Samples A1, A2, A4, A5 and A6 presented occasional corona spots near the live end fitting, which is perfectly normal for equipments in this condition, without equalizing electrodes. Sample A3 had no discharges. For illustrative purposes, Fig. 6(a) shows sample A1 during UV inspection. Since the images of the other samples are practically the same, they are not shown.



A1 (ΔT = 12.2°C) A2 (ΔT = 12.2°C)

A3 (ΔT = 6.8°C) A4 (ΔT = 17.1°C)

A5 (ΔT = 11.6°C) A6 (ΔT = 9.1°C)

Figure 5. Thermographic profiles of six samples, with natural pollution and elevated superficial moisture (ΔT is the sample's greatest temperature difference).

Most samples presented little or no discharge activity near the live ending. However, because there was a crack in its polymer sheath in this exact region, sample A5 presented a certain amount of discharge activity. This crack is shown in Fig. 6(b). Each sample presented specific corona points, according to the number of flaws in their polymer sheaths

Dry-band formation near grounded endings was detected in all samples in tests with superficial moisture and pollution (WLCT), as shown in Fig. 7. This induced the formation of electric arcs visible to the naked eye, with consequent localized heating, as revealed by infrared inspections.

Arc formation was significantly reduced in samples washed with water jets (A1 and A3), as seen in Fig. 8. However, sample A3 still presented a certain amount of arcing. All three samples presented dry-band formation.

Figure 6. (a) UV discharge patterns detected during DLCT; (b) Cracks in sample A5's polymer sheath.

A1

A2

A3

A4

A5

A6

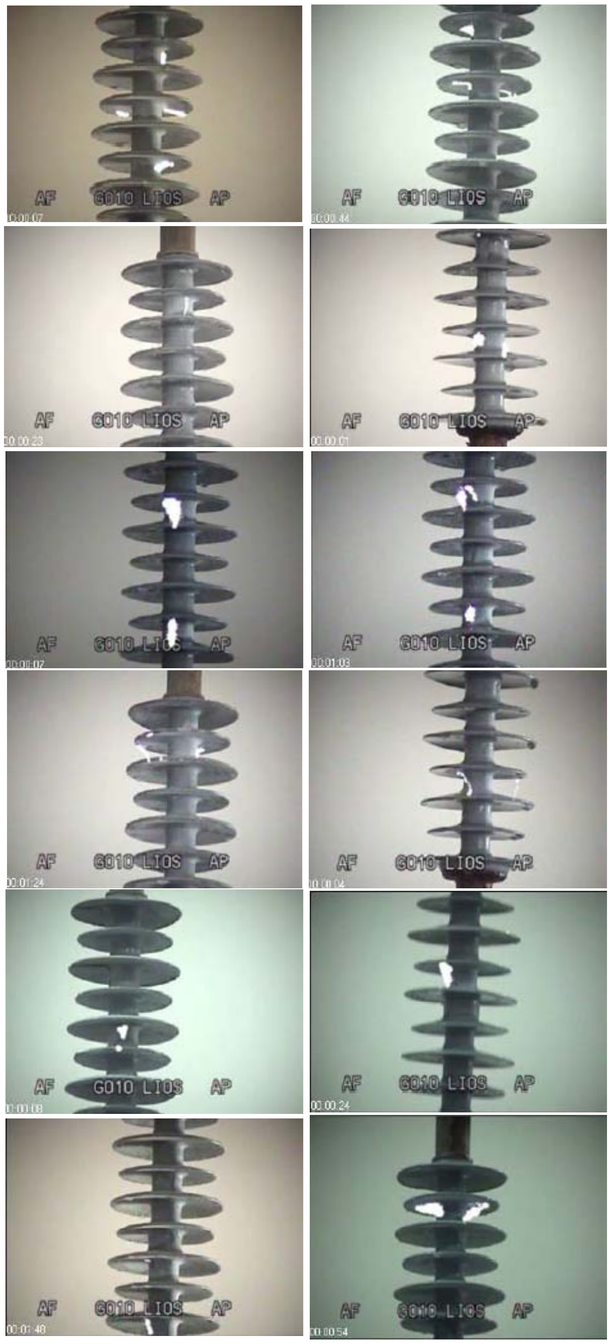


Figure 7. UV discharge patterns detected during WLCT.

A1

A2

A3

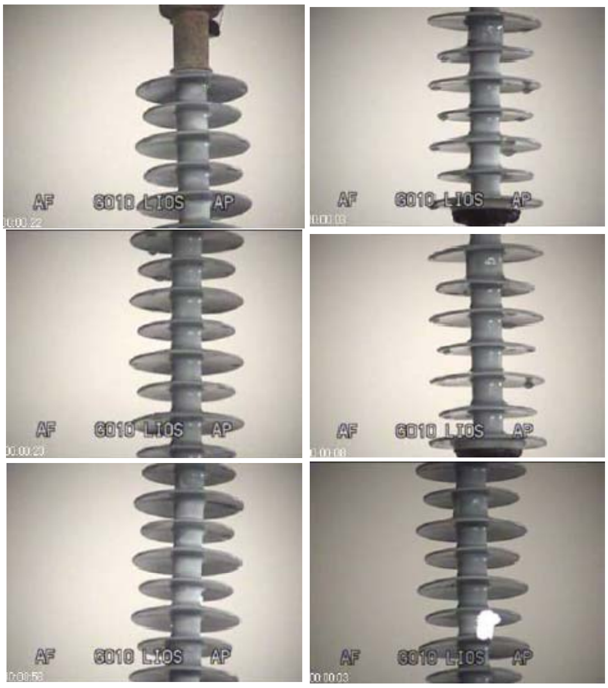


Figure 8. UV discharge patterns detected during PWLCT#.

IV. CONCLUSIONS

This paper analyzed the effect of natural saline pollution on polymer insulators that were aged in the field, and how washing affects their performance. Despite being aged in the field, the samples presented acceptable leakage current rates when dry tested. Under high moisture conditions, leakage current increased by two orders of magnitude.

Leakage current decreased significantly in environmentally contaminated insulators after being washed. Water jet washing reduces leakage current by an average of 40%, and synthetic sponge washing by as much as 72%.

The main cause of increased leakage current proved to be the superficial layer of saline pollution, meaning that the samples maintained good electrical integrity. It is concluded that, despite their long-time operation, the samples had preserved a good electric condition with no significant leakage current rates.

The cracks in the polymer sheath, however, are a risk factor. It is impossible to foresee how long it will be before water ingresses between the rod and sheath, and how much time it will take for this to cause insulator failure. One thing is certain: this infiltration will increase leakage current even more.

Thermo-visible and UV radiation inspection results were coherent among themselves regarding the state of the insulators. Saline pollution induces increased heat of the area near live endings, due to surface discharges. Arc formation was observed using the thermovisor and UV detector.

V. REFERENCES

W. L. Vosloo, R. E. Macey, C. de Tourreil, "The Practical Guide to High Voltage Insulators". South Africa: Crown Publications cc, 2006. 220 p.

S. Bisnath, A. C. Britten, D. H. Cretchley, D. Muftic, T. Pillay, R. Vajeth, "The Planning, Design & Construction of Overhead Power Lines". South Africa: Crown Publications cc, 2005. 772p.

S. Bisnath, A. C. Britten, E. Marshall, T. Pillay, J. Reynders, "The Fundamentals and Practice of Overhead Line Maintenance". South Africa: Crown Publications cc, 2006. 258p.

Rodurflex. "The history of RODURFLEX® – Quite a long story covering more than 3 decades". Available on the internet at: http://www.lappinsulator.com/downloadcenter/catalogs.asp. File downloaded in December 2005.

J. P. Reynders, "Guide to the choice of outdoor insulators for AC systems under polluted conditions". Proceedings of National Energy Council Seminar. Pretoria: 1992.

D. A. Swift, "Polluted AC insulators: An overview based on personal research". Seminar on the performance of high voltage AC insulators in polluted environments. South Africa: Department of Mineral and Energy Affairs. February, 1992.

CIGRÉ, "The measurement of site pollution severity and its application o insulator dimensioning for AC systems". WG 33-04. Electra n.54. 1979

H. J. Geldenhuys, "The effect of lightning on distribution lines". Seminar – The Lightning protection of distribution lines. SAIEE and CSIR. Pretoria: August 1989.

W. L. Vosloo, F. F. Bologna, "Practical maintenance guideline for polluted outdoor high voltage insulators". Eskom Report No. TRR/E/99/EL089. September 1999.

IEC 60815. "Guide for the selection of insulators in respect of polluted conditions". 1986.

F. F. Bologna, N. Mahatho, D. A. Hoch, "Infrared and ultraviolet imaging techniques applied to the inspection of outdoor transmission voltage insulators". Proceedings of the IEEE Africon Conference. George: October 2002.

R. G. Houlgate, "Natural testing of composite insulators at Dungeness insulator testing station". Non-ceramic outdoor insulation international workshop. Paris: April 1993.

M. Lindner, "Third UV Inspection User's Group Meeting". Orlando, Florida, USA. February 11-13, 2004.