Diagnosis of lightning arrester Using Fuzzy Logic and Wavelet Transform *

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Abstract. This paper presents an evaluation of thermal images from electrical substations belonging to the eletronorte/eletrobrás power plant, located in the Amazon region, Pará, Brazil. The solution presented in this paper is based on fuzzy logic and discrete wavelet transform. Wavelet transform decomposes thermal images, obtained by thermal imaging processes, into bands of different frequencies. The solution presented allowed for the detection of hot and not hot points, along the body of a lightning arrester, through noise discrimination according to scaling. The development of a fuzzy system solution was designed to predict average temperature differences using the thermal imaging data. By means of the proposed solution it was possible to prove that some variables observed during the capture process, of imprecise domains, can influence the generated diagnoses.

Keywords— logic fuzzy; wavelet transform; thermograms;

I. INTRODUCTION

Studies regarding the operating status of lightning arresters are of extreme importance to aid in the preventive scheduling and monitoring of these devices. Lightning arresters are used in order to protect a system against electrical power surges that can cause disruptions in the supply of electricity.

Thermal imaging is an inspection technique used in preventive maintenance operations of lightning arresters [1]. This technique is based on the heat energy emitted by the inspected equipment, presenting it as an image. The energy emitted by the body is captured with the help of a device called a thermal imager. This device captures a thermal image (thermogram) through infrared waves emitted by the lightning arrester [2][3][4].

In electrical substations, one of the key elements to be monitored with the use of thermal imaging is the emergence of Hot Points in physical contact with the structures that comprise the equipment and that can provide important information (thermal signature) of an incipient fault condition [1].

This paper proposes a solution using discrete wavelet transform in the evaluation of one hundred lightning arrester thermal images (50 with Hot Point features and 50 with Not Hot Point features) from thermal imaging techniques in electrical substations belonging to Eletronorte/Eletrobras, in the Amazon region, Pará, Brazil. The proposal aims to analyze the quality and image processing for artificial vision, from the observation of the temperature behavior along the body of lightning arresters, with the identification of Hot and Not Hot Point Point thermograms of the analyzed images. Combining thermovision and fuzzy systems, systemized and constructed by means of the tactic knowledge of Eletronorte specialists, was shown to be efficient in generating the operating condition diagnostics of lightning arresters in electrical substations. The results obtained by means of the proposed solutions were very close to the real results that are obtained in the operational environments.

Thermal imaging is a non-destructive inspection technique performed with the use of infrared systems for temperature measurement or observation of differences in the pattern of heat distribution [1]. When digitally processing the thermogram, other main variables can be obtained: maximum temperature, minimum temperature and temperature variation along the lightning arrester, as indicated by the selected red circular area shown in Figure 1.

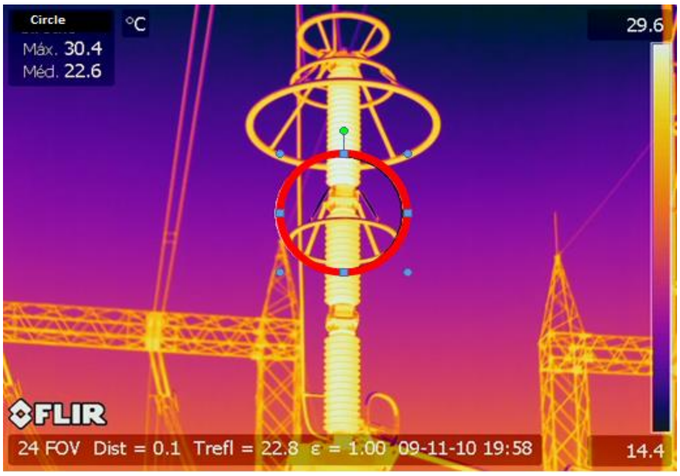

Fig 1. Thermal image of Lightning Arresters

The area is analyzed in order to generate a diagnosis of the inspected arrester. Other variables, such as air relative humidity, ambient temperature and distance are also acquired during the measurements by means of other devices, such as thermohygrometers and electronic measuring tapes [3][4].

Given the need for solutions that utilize new technological and computational approaches that produce better approximations in environments of uncertainty [5][6][7][8][9], this paper proposes the integration of thermal imaging and a Fuzzy System (FS) for predicting the influence of temperature in thermal images of lightning arresters.

II. Proposed Methodology

The thermal images from lightning arresters were captured in twelve electrical substations located in the Amazon region, Pará State, Brazil (Figure 2), using Flir equipment [10].

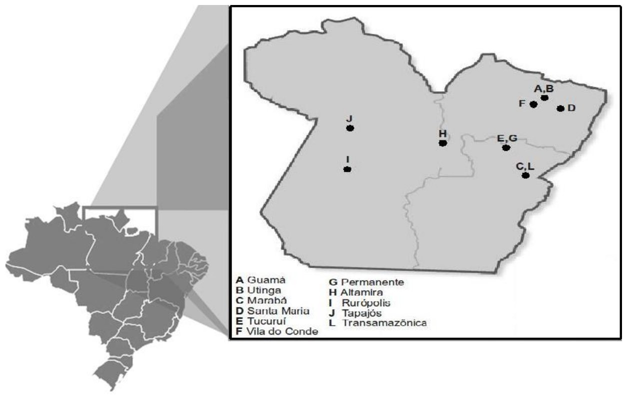

Fig. 2. Electrical Substations Located In The Amazon Region

The state of Pará is approximately 1247 km2, with very diverse climatic variations. This area, located in the Amazon region, presents unique environmental characteristics that may influence phenomena observed in this environment, such as the case of monitoring lightning arresters in electrical substations [11][12]. This process can be influenced by environmental variables, such as temperature rates, relative humidity and insolation index, which are high in this region in comparison to other Brazilian regions.

The thermal imaging method used for arrester diagnosis at Eletronorte was developed from the monitoring of lightning arresters and validated by the criterion of current leakage, electrical tests in arresters taken from the field and visual inspection. The thermographic measurements consist in measuring the surface temperature over the body of the arrester (porcelain or polymeric), with emphasis on temperature values. The current leakage method consists in measuring the current flowing through the arrester while being powered by the nominal neutral-to-ground tension of the system. The current leakage measurement is performed using a plier-type milliamperometer with a resolution of 100 μA.

This method considers the measured value (MV) and the average temperature difference (Δθ), which is the difference between the maximum temperature and average temperature of the body of the arrester, obtained during the analysis of the thermal images. It considers that the MV follows a normal distribution with mean μ and variance σ2.

III. Fuzzy System Applied Process Capture Thermograms Lightning Arrester

Therefore, with the proposed solution, combining thermovision [13][3] with fuzzy systems (FS) [14], it was observed that some variables, of imprecise domains (Table 1) during the thermal image capture, can influence the diagnosis on the arresters performed under operating conditions in electrical substations. The results were very close to the actual results of the operational environments.

TABLE I – Description of Variable Input and Output of Fuzzy System

Linguistic Variable Inputs	**Representation**
Maximum Temperature	Represents the maximum surface temperature for porcelain-rays measured in the thermogram
Average Temperature	Average temperature of the porcelain surface-rays to measure the thermogram.
Without Solar	Without Solar level registered at the time of capturing the thermogram.
Breeze	Occurrence of wipers during the capture process thermogram.
Linguistic Variables Output	**Representation**
Influence Temperature	Calculating the level of influence in the average temperature difference (a thermogram).

IV. Fuzzy Results

From the experience of the experts on the subject, it was observed that, when the distance of the inclination angle at which the thermal imaging is performed varies, the temperature difference may vary. It was also shown that the temperature difference varies when the lightning arrester receives solar radiation or the influence of breezes.

In this work we analyzed the presence of Without Solar and breeze during the capture process thermograms lightning arrester. For the simulated situation, the system found the fuzzy value 0.88, this value shows a high degree of influence on the generation of diagnostics. It was proven that two variables (Without Solar = 1 = High; Breeze = 1 = High) strongly influenced the results used to generate diagnostic lightning arrester. Table II shows the diagnosis and confirms the result.

TABLE II – DIAGNOSIS OF LIGHTNING ARRESTER

Fuzzy System	**Level of influence in temperature**	**Diagnosis of lightning arrester**
If Without Solar = 1 e Breeze = 1	then Influence Temperature = 0,88	Condition lightning arrester:
HIGH	**HIGH**	**SUSPECT / DEFECTIVE**

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Therefore, with the proposed solution, combining thermovision [2][3] with fuzzy systems (FS) [14], it was observed that some variables, of imprecise domains, such as time, position, distance and breeze during the thermal image capture, can influence the diagnosis on the arresters performed under operating conditions in electrical substations. The results were very close to the actual results of the operational environments.

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V. RESULTS WAVELET TRANSFORM

Figure 3 shows the result of the multi-resolution decomposition obtained through wavelet analysis in the filtering of a lightning arrester thermal image. To this end, we used the mathematics suite Matlab and its associated toolbox Wavelet 3.0 from the Mathwork company. In this case we used the multi-resolution decomposition for 4 (four levels) from the wavelet family Db4 [15] [16] [17].

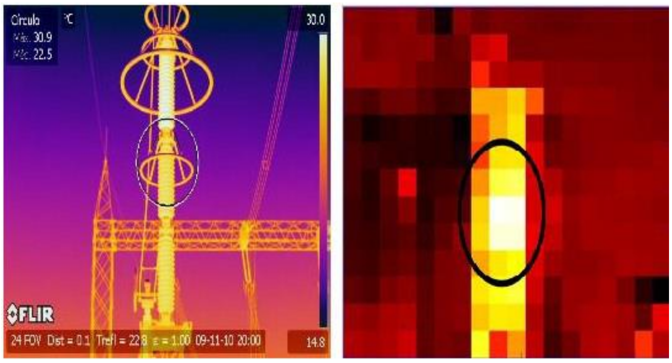

Fig. 3. Original image (left), image processed using wavelet db4, approach to level 4 (right) (source: laboratory enee Eletronorte).

The Daubechies wavelet family in each of the decomposition sequences generated approximations and details, which correspond respectively to low and high frequencies. In this analysis, we withdrew only small scales from the image and only the large scales remained, which is similar to the methodology adopted by Mundim [18].

The performed decomposition (Figure 3) allows the differentiation of edges and textures and the discrimination from noise with increasing scales. As the level of the transformed increased noise appeared less. This identification was possible from the increased scale of the image, which means that the image was rendered at a higher resolution than the original image (Figure 3). This increased resolution allowed the observation of details, since in lower resolutions we could only observe an general overview of the image.

From the performed decomposition using multi-resolution analysis a visual expression of the operation state of the lightning arrester was generated, with the identification of Hot Point areas. From the hot identification it was found that the core image, selected area, had basically a uniform pixel distribution, taking into account the uniformity of the pixel colors.

In order to prevent the generation of false diagnostics, a study was developed in order to assist the solution used by the laboratory, from the simulation of possible characteristics of certain faults detected in lightning arresters, such as sealing loss, degradation of the varistors, external pollution and the presence of internal moisture. These simulations allowed the identification of targets in thermal images of lightning arresters such as Hot and Not Hot Points. These points are noted for being a temperature above or below room temperature.

The proposed solution has been developed with the data that makes up the database of this lab. Evaluations were conducted using the Wavelet transform, one hundred lightning arrester thermal images (50 with Hot Point features and 50 with Not Hot Point features) plus the information necessary for analyses of the temperature profile in the lightning arrester bodies. The dataset underwent a preprocessing process to obtain the format used by the wavelet transform, available in the Matlab statistical package [19][20].

A multiresolution analysis was used [21][22]. The procedure used to interpret the images was similar to that applied in image processing [23][24][25][26]. The representation of the object during the image processing consisted in storing the border and the interior of the segmented objects. This information related to the border and interior pixels of the object were stored in arrays.

During recognition, each segmented object received a label, while the interpretation associated meaning to a set of segmented objects. Each pixel was referred to by a number from 0 to 255, which may represent RGB or gray tones. In this sense, we generated a normalization that allowed interpreting the entry training/testing data and output data that were used to generate a new image representation with the indications of Hot Point and Not Hot Point.

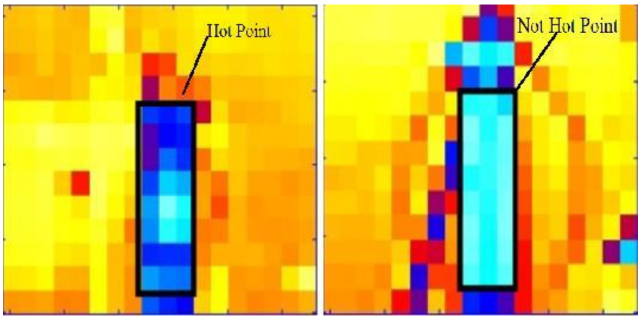

Fig. 4a and 4b: Identification of Hot and Not Hot Points using DWT Db1.

From the Not Hot Point identification we verified that the core image, selected area (Figure 4b), basically showed a non-uniform pixel distribution.

VI. CONCLUSÕES

This study proved that some of the variables observed during the thermal imaging process of lightning arresters, of imprecise domains, such as time, position, distance and breeze, can influence the diagnostics conducted by thermograms. The proposed solution, combining thermovision and fuzzy systems, systemized and constructed by means of the tactic knowledge of Eletronorte specialists, was shown to be efficient in generating the operating condition diagnostics of lightning arresters in electrical substations. The results obtained by means of the proposed solutions were very close to the real results that are obtained in the operational environments.

With the results obtained by the proposed solutions we observed that the comprehension of the thermal image capture process of lightning arresters is still a delicate process, possible, but complex, due to the imprecision present during field measurements, mainly in the form of environmental characteristics. The temperature measurement conducted by thermal imaging is efficient, but requires the use of a criterious methodology, since there is the possibility of false diagnostics. The fuzzy system on the other hand, is, besides an amply, and successfully used in different areas, can also be used in the construction of solutions to support decision making in uncertain areas, such as the one presented in this study.

With the obtained results, we observed that the understanding of temperature behavior in the body of lightning arresters, in view of the complexity involved, is still a delicate process, however, very possible. The use of the wavelet transform allowed for the correlation of temperature variation throughout the body of a lightning arrester with color variations across the pixel array of the image.

The filtering obtained in this study showed a stable means from the original image and a reduction of the variance when using a multi-resolution analysis, which is demonstrably common when conducting methods of this nature. The multi-resolution analysis was better at preserving the variability of the original data set (original image).

With the used method we were able to analyze stationary and non-stationary processes, contrasting with other techniques, such as the Fourier analysis. The wavelet transform allowed a location in both the time domain, with its translations, and the frequency domain, with its dilation and expansion.

We have verified that the Wavelet Transform, besides being an already successfully widely used technique in applications of different areas of knowledge, can also be used in the process of monitoring the operating status of lightning arresters and can contribute in improving the effectiveness of this process. Thus, the proposed method has helped to improve thermal images quality for the human visual interpretation of thermograms.

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