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Assessment of Partial Discharges Evolution in Bushing by Infrared Analysis †

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Abstract: The quality of power systems is related to their capability to predict failures, avoid stoppages, and increase the lifetime of their components. Therefore, science has been developing monitoring systems to identify failures in induction motors, transformers, and transmission lines. In this context, one of the most crucial components of the electrical systems is the insulation devices such as bushings, which are constantly subjected to dust, thermal stresses, moisture, etc. These conditions promote insulation deterioration, leading to the occurrence of partial discharges. Partial discharges are localized dielectric breakdown that emits ultra-violet radiation, heat, electromagnet, and acoustics waves. The most traditional techniques to identify these flaws on bushings are based on the current, ultra high frequency, and acoustic emission analysis. However, thermal analysis stands out as a noise-resistant technique to monitor several components in the power systems. Although the thermal method is applied to detect different types of faults, such as bad contacts, overloads, etc, this technique has not been previously applied to perform partial discharge detection and evaluate its evolution on bushings. Based on this issue, this article proposes two new indexes to characterize the discharge evolution based on the infrared thermal analysis: the area ratio coefficient and the Red, Green, and Blue (RGB) ratio coefficient. Seven discharge levels were induced in a contaminated bushing, and an infrared thermal camera captured 20 images per condition, totalizing 140 images. New coefficients were used to perform the identification of discharge evolution. Results indicated that values of the new indexes increase with the partial discharge activity. Thus, the new imaging processing approach can be a promising contribution to literature, improving the reliability and maintenance planning for power transmission systems.

Keywords: partial discharges; bushing; insulation systems; infrared sensors; monitoring systems

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1. Introduction

Insulation devices play a key role in electrical power systems and their failures can impair the quality of electrical energy supply. For this reason, the industry has been growing attention to developing systems whose objective is diagnosing incipient failures in these components aiming to guarantee efficiency in the energy supply with planned maintenance [1–3].

However, insulation devices such as bushings can suffer unexpected failures originated by heat, moisture, dielectric contamination by dust, thermal and electrical stresses, etc. [1,4]. These critical issues can lead the insulation system to Partial Discharge (PD) activity, which is defined as electric pulses that emit UV radiation, current, heat, acoustic and electromagnetic waves, causing a progressive deterioration of dielectrics [5,6]. Therefore, several methodologies have been proposed to extract features of PD activity such as acoustic emission [7], current analysis [8], capacitive divider [3], UHF measurement [9], etc. However, as PD imposes a progressive deterioration to the insulation system, it is crucial to assess its evolution to enhance control, safety, and maintenance planning.

One of the most traditional techniques applied to monitor failures in electrical machines and insulation systems is the thermal analysis, which can assess flaws such as bad contacts and overload by using an infrared camera [10–13]. The basis of this technology is to detect the infrared wavelengths emitted by objects which are subjected to a temperature above the absolute zero (−273 °C) [14]. Although it has proven to be a promising tool to perform fault detection, the assessment of partial discharges in insulation systems has not been previously performed using this technique.

Based on this issue, this article proposed a new approach to perform the identification of PD severity evolution in bushings by applying infrared thermal analysis and image processing. In this sense, two new indexes were developed to characterize the PD levels: The Area Ratio Coefficient (ARC) and the RGB Ratio Coefficient (RGBRC).Therefore, these two statistical parameters are the contribution of the work for literature since the assessment of PD evolution can be an improvement for maintenance planning infrared-based.

This paper is organized as follows: Section 2 presents the new indexes applied to characterize the PD evolution by infrared analysis. The experimental setup is described in Section 3, and then, in Section 4, the results are presented and discussed. Section 5 reports the conclusions of this article.

2. Infrared Thermal Analysis Applied to PD

All objects below the absolute zero (−273 °C) radiate infrared wavelengths, which consists of a kind of electromagnetic wave, out of human eyes perception that relates to the field of the temperature of the object. In this scenario, infrared thermal cameras have set of sensors which can measure the infrared rays emitted by the surface of objects. This device can acquires infrared radiation from an object and digitize the radiation pattern into an image or video. After that, a hot spot caused by nonconformity can be identified [14,15].

Once several types of flaws can change the heat emission pattern, the infrared analysis is a promising tool to assess nonconformity in electrical machines and insulation systems [14]. Due to the advantages of being non-destructive sensors, thermal cameras have been widely used in the industry, electric power systems, etc. [15].

For example, in [11] a prediction of transformer fault in cooling system using combining advanced thermal model and thermography. Shanker et al. (2017) proposed a transformer breather thermal image decomposition for fault diagnosis [16]. Wang et al. (2020) applied thermal images to assess an insulator condition under extreme operation conditions [17]. Besides the applicability of thermal images in the power system, infrared thermography can also used to monitor aerospace components according to [18].

Several methodologies combine infrared with imaging processing techniques to improve the effectiveness of the monitoring systems. Zhao et al. (2016) [15] applied a Support Vector Machine (SVM) to detect the insulator strings in infrared images. The objective is to perform temperature analysis with complex background. An insulator fault detection method based on spatial features of aerial images was proposed by [19] to identify flaws in ceramics. The recognition accuracy of thermal spots was improved by [20] by Hough Transform. The major contributions in infrared analysis are focused on the improvement of the accuracy in complex backgrounds and perform detection of hot spots caused by bad contacts. However, PD activity is an important indicative of the condition of the insulation system, and, therefore, the incipient assessment of this issue by thermal images can be a promising contribution to avoid unexpected stoppages of the electrical power systems.

By analyzing thermal images of insulators, this article proposed two indexes to perform the identification of PD evolution: the area ratio coefficient and the RGB ratio coefficient.

The ARC index is defined as:

$$\mathrm{ARC} = \frac{A_{hs}}{A_T}, \tag{1}$$

where A_{hs} is the area of hot spots and A_T is the total area of the insulator. The hot spots were defined as the spots with a temperature different from the ambient temperature.

The RGBRC index is defined as:

$$\text{RGBRC} = \frac{P_{ro}}{P_T}, \tag{2}$$

where P_{ro} is the number of pixels orange or red in the image, and P_T is the total number of pixels in the whole image. The number of pixels orange or red represents 30% of the highest temperatures of the thermal camera scale.

3. Materials and Methods

In real-life scenarios, insulation systems are constantly contaminated with dust, which can promote PD activity. Therefore, a transformer's bushing was contaminated with powdered graphite to emulate this condition. Additionally, a high voltage AC source (0–40 kV) was connected to the extremities of the component to induce partial discharges. One of the most relevant steps for the improvement of maintenance planning is the PD evolution assessment. Due to material deterioration, the electrical charges produced by the failure increase. Based on this behavior, the PD evolution was carried out by increasing the voltage level for the same contamination pattern. The PD started at 13 kV, and, after that, the voltage was increased by a step of 2 kV up to 23 kV, totaling six different flaw levels. For each level, 20 images were taken using a thermal camera (FLIR, −20 °C to +400 °C, 19.200 (120 × 160) pixels). Additionally, 20 more images were taken when the insulator was without PD activity (0 kV) to assess the effectiveness of thermal analysis for PD evolution. Figure 1 shows the experimental setup.

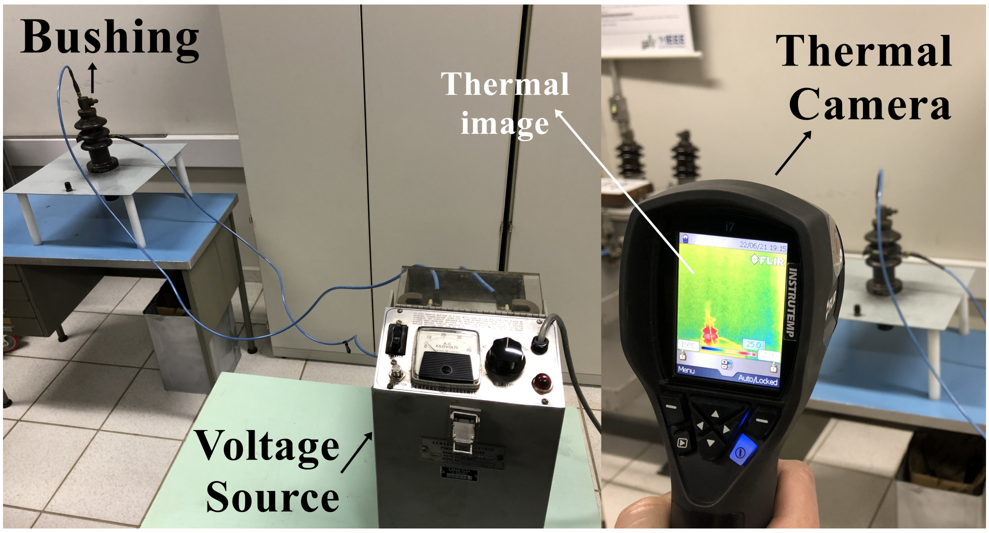


Figure 1. Experimental Setup.

After that, the thermal images were transferred to a computer. The image processing analysis was performed according to the Area Ratio Coefficient (ARC) and RGB Ratio Coefficient (RGBRC) indexes. Furthermore, the maximum temperature of the insulator was analyzed.

4. Results and Discussion

Figure 2 presents the thermal images taken for all PD levels. It can be noted that the thermal analysis is suitable to perform PD evolution detection since the temperature increases with the PD activity. By Figure 2a, when the failure is not present at the component, the average temperature was 22 °C. After the PDs started, it can be observed hot spots promoted by failure heat emission. However, the visual analysis was not enough to perform a quantitative estimation of PD evolution. Furthermore, in some figures, the effects of the faults in the thermography are too subtle (e.g., Figure 2b) and may not be detected without the development of a specific index. On the other hand, in Figure 2e–g, it is hard to define which one represents the highest PD level, reiterating the creation of new imaging processing approaches. A basic analysis of the maximum temperature value is not sufficient to assess the PD evolution since the maximum temperature spot of the image remains at 25 °C for PDs higher than 17 kV, as shown in Figure 3.

Therefore, based on these issues, the feature extraction of PD evolution was achieved by the novel indexes ARC and RGBRC, according to Figure 4. By analyzing the results, it can be noted that ARC and RGBRC indexes increase with the PD evolution. The strong correlation between the voltage levels and the indexes allows a linear regression. Then, the regression equations presented in Figure 4a,b can be applied to estimate the PD level based on the thermal images.

The ARC increased from 0 to 80%, which means that the intensity of the PD activity can change the thermal pattern in the whole insulator. Furthermore, the relation between the high-temperature pixels and the total number of pixels can be a promising tool to detect the failure evolution once the red and orange patterns increased as presented in Figure 4.

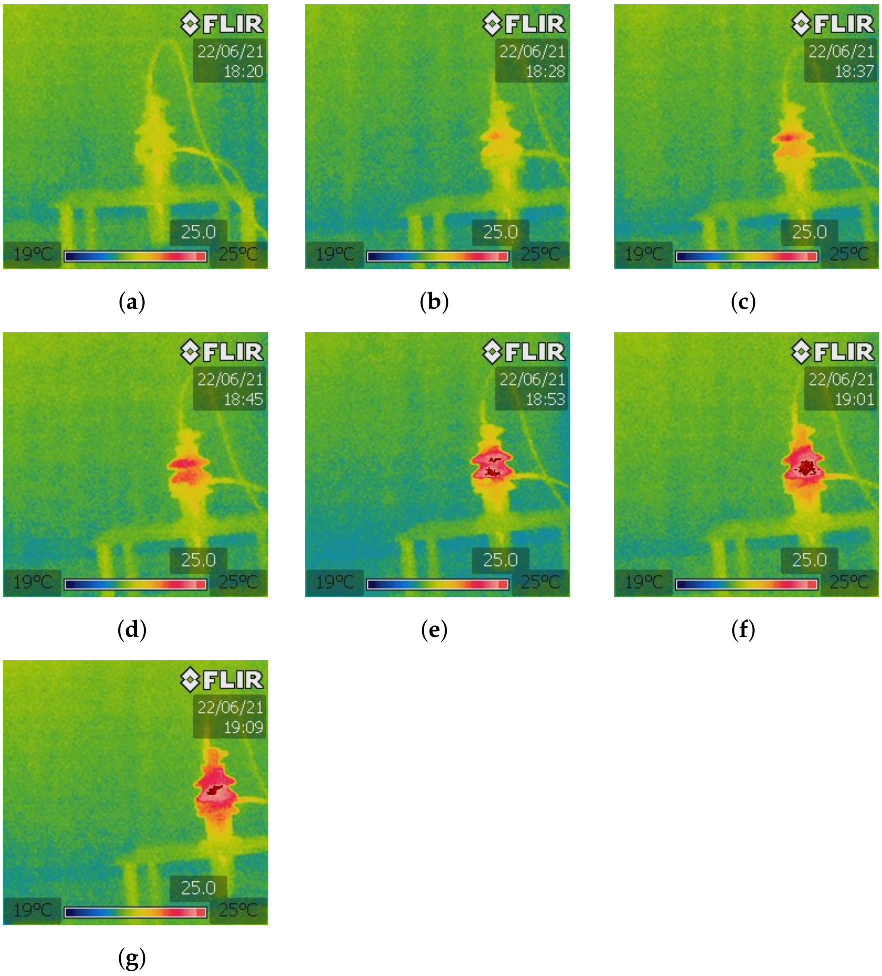


Figure 2. Thermal imaging of bushings subjected to (**a**) no discharge; and discharge levels generated by: (**b**) 13 kV; (**c**) 15 kV; (**d**) 17 kV; (**e**) 19 kV; (**f**) 21 kV; (**g**) 23 kV.

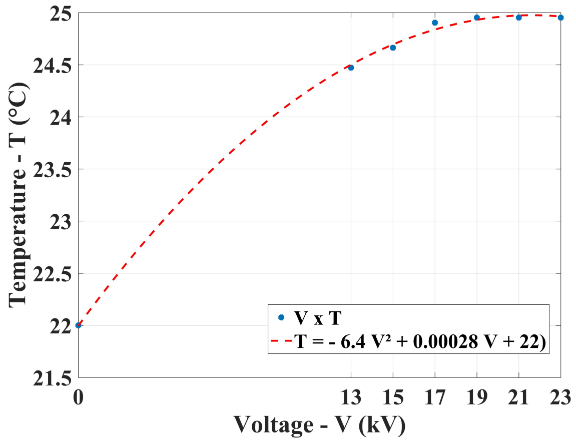
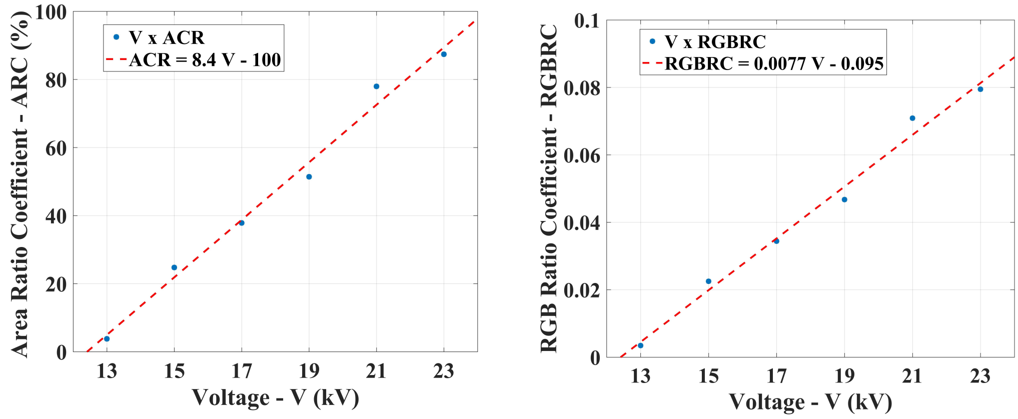


Figure 3. Maximum Temperature per PD level.



(**a**) (**b**)

Figure 4. (**a**) ARC per PD level. (**b**) RGBRC per PD level.

5. Conclusions

The bushings are crucial components of the power systems. Therefore, industry and science seek to develop monitoring systems aiming to enhance the maintenance plans and avoid failures. Partial discharges are characterized by incipient flaws that can lead the insulation system to total failures. Therefore, their earlier diagnosis can avoid financial loss and stoppages in the electrical system. Furthermore, the assessment of PD evolution can be an improvement for maintenance planning.

In this context, this work proposed the creation of two new indexes to monitor the evolution of PDs in bushings. After the experiments which imposed several PD levels to an insulator, the results pointed to a strong correlation between the ARC and RGBRC indexes values and the voltage levels applied to the bushing. For both cases, the indexes increased with the failure intensity. Although this work used simple tools as infrared cameras, the results proved that the indexes provided robust and reliable estimations for PD evolution, adding a new feature for thermal analysis.

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Abbreviations

The following abbreviations are used in this manuscript:

PD	Partial Discharge
UHF	Ultra High Frequency
RGB	Red, Green, and Blue
ARC	Area Ratio Coefficient
RGBRC	RGB Ratio Coefficient
SVM	Support Vector Machine

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