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TELKOMNIKA, Vol.15, No.3, September 2017, pp. 977~983
ISSN: 1693-6930, accredited A by DIKTI, Decree No: 58/DIKTI/Kep/2013
DOI: 10.12928/TELKOMNIKA.v15i3.5149

The Correlation of Statistical Image and Partial Discharge Pulse Count of LDPE-NR Composite

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Abstract

High voltage insulation must be designed in such a way that it is very resistant to ageing including that from partial discharge (PD). Many studies were previously carried out on composites based on low density polyethylene (LDPE). However, the use of natural rubber (NR) and nanosilica (SiO_2) in the LDPE-NR based composites is relatively new. Furthermore, the PD resistant performance of the composites is yet to be extensively researched. This work aims to analyze the correlation between PD pulse count and its related image to interpreting the effect of PD signals. The results show there is a strong correlation between PD pulse count and the statistical image. The results indicate that the surface image statistical analysis can be used as a tool to justify the total of the PD pulse count on the surface for different samples of composite.

Keywords: *partial discharge, statistical correlation, low density polyethylene, natural rubber, surface image*

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1. Introduction

Different method of the PD analysis program is recently used by the expertise in PD field. For example, Monte Carlo method was used to evaluate the PD distribution to get the PD pulses phase and their related amplitude [1], the Genetic algorithm was used to rcognize the PD pattern in gas insulated switchgear (GIS) [2] and the statistical analysis of PD pattern was used to assess the insulation system in high voltage [3]. These methods contribute differently to enhance the PD analysis approach in order understand the PD phenomena.

The way to present the PD data is another important part of the PD analysis. The most common way to present the PD data is the graph of φ-q-N pattern that representing the phase angle of PD occurrence (φ), the PD apparent charge (q) and the pulses' number of PD (N) [4, 5]. This graph is called phase resolved PD (PRPD) pattern that is currently used by many researchers to evaluate the PD data. Using this graph, the phase angle of PD can be easily recognized as well as the apparent PD charge and number of PD pulses in every phase angle. Although the number of PD pulse count is one parameter of PD phase resolve analysis, but the detail analysis PD pulse count and its effect to the physical properties of insulation material was not discussed in depth.

The use of statistical analysis to analyze the PD data is very useful to quantify the partial discharge parameters to enhance the PD pattern [5-7]. An analysis of the kurtosis and the skewness confirmed that positive and negative polarity had counterclockwise and clockwise clustering distribution, respectively. Three PD parameters which are the pulse duration, pulse magnitude and pulse phase angle were also introduced for statistical evaluation of PD data [8]. The pulse duration is to correlate to the discharge mechanism with the condition of surface resistance. The pulse magnitude is to correlate the voltage stress in the discharging cavity as the indication of the formation of surface charges and surface conductivity. The pulse phase angle is to correlate the deterioration energy with the nature of physical changes in the discharge.

Insulation deterioration is a long-term process that occurs over a prolonged operational condition. So it is not uncommon that if the insulation system has a stable PD activity (even with a high PD level), insulation failure may not occur early. If a significant increase in PD activity within a certain period of time under the same test conditions is detected, it warranted

Received May 25, 2017; Revised August 18, 2017; Accepted August 30, 2017

investigation and is a warning sign of potential initiation of insulation failure. An increase of PD activity rather than an absolute PD magnitude can indicate severe probably insulation failure. A stable PD activity over time indicates that insulation deterioration has not progressed much. A significant increase in PD activity within a relatively short period of time (e.g. six months) indicates that the rate of insulation deterioration and the likelihood of machine failure has increased [9, 10].

An image histogram is the graphical representation of the intensity distribution of a digital image. It plots the number of pixels for each intensity value. The horizontal axis of the graph represents the tonal variations, while the vertical axis represents the number of pixels in that particular tone. The left side of the horizontal axis represents the black and dark areas, the middle represents medium grey and the right hand side represents light and pure white areas. The vertical axis represents the size of the area that is captured in each one of these zones. Thus, the histogram for a very dark image will have the majority of its data points on the left side and center of the graph. Conversely, the histogram for a very bright image with few dark areas and/or shadows will have most of its data points on the right side and center of the graph. Limited references which discussed the image due to the PD events can be found in [11]. The images were taken using the optical camera. The comparison between the surface image of neat LDPE and LDPE nanosilica composite due to PD event also was shown in [12], but without a deeper analysis.

The distribution of colours in an image processing technique is represented by a colour histogram that cover all possible the image's colour space. For digital images, a colour histogram represents the number of pixels that have colours in each of a fixed list of colour ranges. If the set of possible colour values is sufficiently small, each of those colours may be placed on a range by itself; then the histogram is merely the count of pixels that have each possible colour. The image histogram may also be represented and displayed as a smooth function defined over the colour space that approximates the pixel counts. Like other kinds of histograms, the colour histogram is a statistic that can be viewed as an approximation of an underlying continuous distribution of colours values.

An image histogram is a graphical representation of the number of pixels in an image, whose X-axis represents the tonal scale (black at the left and white at the right), and Y-axis represents the number of pixels in an image in a particular area of the tonal scale. If there are more pixels, the peak at the certain intensity level is higher. A colour histogram of an image also represents the distribution of the composition of colours in the image. It shows different types of colours appeared and the number of pixels in each type of the colours appeared. The relation between a colour histogram and a luminance histogram is that a colour histogram can be also expressed as “Three-Colour Histograms," each of which shows the brightness distribution of each individual RGB colour channel

In observing the surface defect, the image quality plays an important role. So it is important to maintain the image in a high quality before it is processed to get a good an image histogram. The term of image quality, technically refer to image attributes like image resolution, contrast, brightness, noise and contrast-to-noise ratio (CNR). This image quality attributes change during the editing, converting and uploading process. To maintain the image quality, the traditional method by using the error summation method can be used. But in recent development the different method like the histogram-based image quality index was used to maintain the image quality [13]. Other method to maintain the image quality is by using the Bayesian image estimation to improve the CNR [14]. In order to improve the contrast, it can be done by enhancing the image histogram wrapping [15].

2. Research Method

There are three steps shoud be done to achieve the purpose of this research; samples preparation, PD Testing and picturing the sample surface before and after the PD test. Two different polymers, namely organic polymers (NR) and inorganic polymers (LDPE), with different compositions are mixed during sample preparation. To check the effect of PD, PD measurement is done. Before and after the PD test, the sample surface image was taken using an electronic microscope with 20x optical zoom.

2.1. Sample Preparation

The compositions of the prepared samples are tabulated in Table 1. The LDPE/NR blends were made up of NR with different compositions, ranging 0 wt% - 10 wt%, 20 wt% and 30 wt%. The temperature for both roll mills was set at 150°C during the blending process. The three categories of samples were prepared by first melting the LDPE, and then a small amount of NR or nanosilica was gradually added until the NR dispersed well. The same process was repeated for categories B and C. The next process is to prepare the sample as required by CIGRE Method to obtain the required thickness using the molding machine. The same temperature was also set at the molding machine. In order to get a good melt of sample, the sample was heated between 5-8 minutes before pressure was applied to the mould. The sample was then cooled down using the water cooling machine for at least 8 minutes or until the room temperature was achieved.

Table 1. Samples prepared for three different categories

Sample Name	Silica (gram)	LDPE (gram)	NR (gram)
A1	-	100	-
A2	-	90	10
A3	-	80	20
A4	-	70	30

2.2. Experimental Setup

A 50 Hz AC voltage source with a peak value of 6.5 kV rms was applied to the test electrode while the plane electrode was earthed. Two (2) different protection units were installed to protect the sample and measuring unit from over current and over voltage. The high voltage resistor was installed in series with the sample to limit the returning high current in case of a breakdown. Additional protection system was achieved by the sphere gap, which functions as a high voltage limiter. It is noted that by using the CIGRE Method II, and with the given experimental conditions, the PD activities only occur in the void area. Figure 1 shows the laboratory set-up for the PD test system. Figure 1(a) is the schematic diagram and Figure 1(b) is the picture of the real PD measurement set-up. It consists of an AC high voltage supply and its measuring system, a test cell constructed according to the CIGRE Method II (CM-II) [4], and a data acquisition system (made up of a Picoscope 5203 device and a PC).

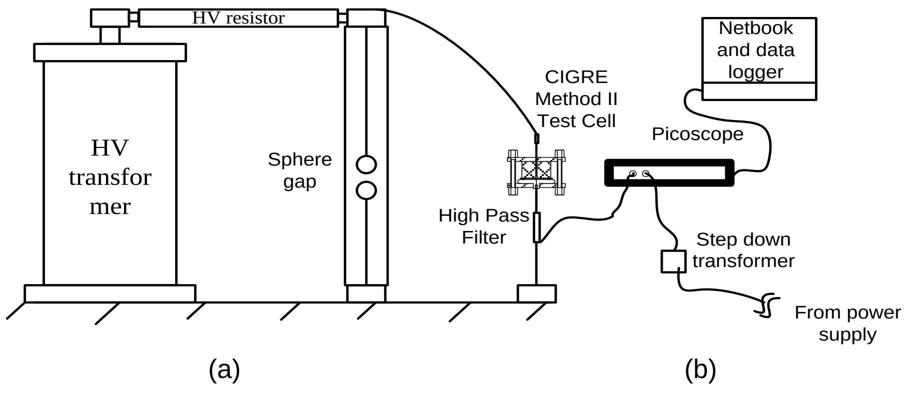

Figure 1. Test set-up for the partial discharge test, the photo of the experimental set-up

3. Results and Analysis

3.1. PD Pulse Count Characteristics of LDPE-NR Composites

Two different analyses were carried out on LDPE-NR samples, PD count and surface image analysis. PD count analysis was done for all samples and image analysis was done for sample A1 and A3.

3.1.1 Cumulative PD Pulse Count

Figure 2 shows the cumulative positive and negative PD pulse counts obtained from different LDPE-NR compositions over a 60 minute stress duration. It can be seen that the negative PD pulse count is higher than the positive PD pulse count except for sample A1. The increment of the measured PD pulse count for every ten minutes is somewhat linear indicating a constant PD pulse count for the given time interval except for sample A3. The total PD pulse count after six consecutive cycles (60 minutes) of high voltage stress was about 2000 for all samples in category A except for sample A3, which was 8000. Thus the PD count for A3 is four times higher than those for samples A1, A2, and A4. A high PD pulse count indicates a high deterioration level of sample surface due to the electrical stress.

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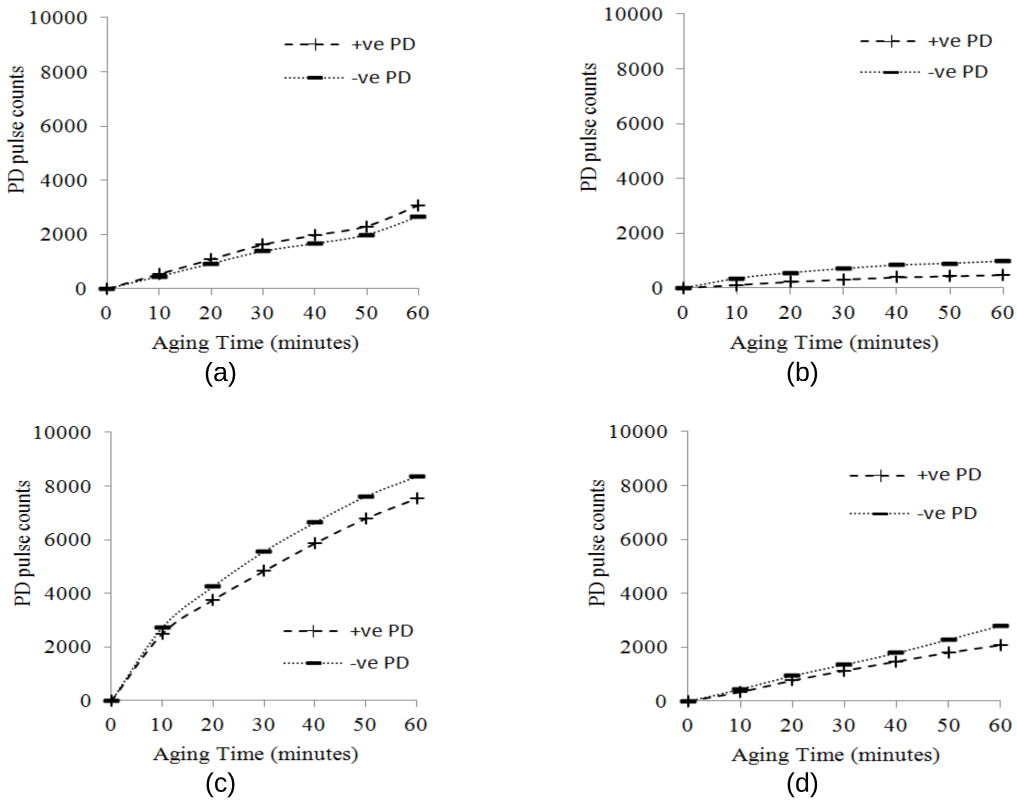


Figure 2 *Cumulative positive and negative PD pulse counts for different LDPE-NR compositions* over 60 minutes stress duration; (a) sample A1, (b) sample A2, (c) sample A3, and (d) sample A4

3.1.2. Total PD Pulse Count

Figure 3 shows the total PD pulse counts both for positive and negative after 60 minutes electric stress for LDPE-NR composites. The total negative PD pulse counts for all samples are higher than that for the positive PD, except for sample A1. The higher total count for the negative PD indicates that the LDPE-NR is more susceptible to surface at defects compared to pure LDPE. A good insulation material should have an equal PD pulse count for both positive and negative when subjected to a symmetrical voltage stress.

Figure 4 shows that the total PD pulse counts for different LDPE-NR dielectric samples (A1, A2 and A4) are below 6000, except sample A3, which is almost 16,000. The total PD pulse count of sample A1 is slightly higher than that for sample A4, but the total PD pulse count for sample A2 is much lower than those for samples A1, A3 and A4. A higher weight percentage (wt%) of NR is expected to increase the PD resistance. It was found that the PD pulse count for sample A3 is greater than those for samples A2 and A1. This happens because of many factors, including the possible existence of voids during sample preparation which then leads to a lower

PD resistance than that for the base or reference insulation material. Even though sample A4 has a higher PD resistance than sample A3, the value is only slightly better than that for sample A1.

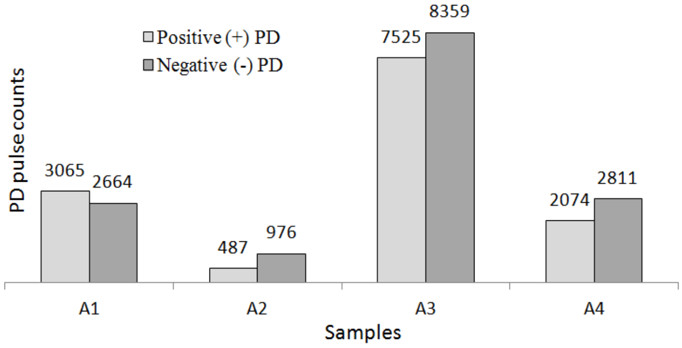


Figure 3. Positive and negative PD pulse counts of different LDPE-NR compositions over 60 minutes stress duration; (a) sample A1, (b) sample A2, (c) sample A3, and (d) sample A4

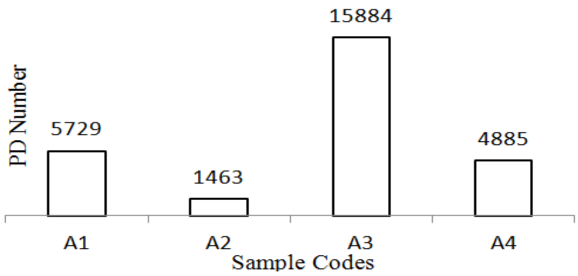


Figure 4. Total PD pulse counts of different LDPE-NR composition over 60 minutes stress duration; (a) sample A1, (b) sample A2, (c) sample A3, and (d) sample A4

The above analysis of PD pulse count shows that sample A2 is the best and sample A3 is the worst. The addition of NR to LDPE with smaller than 10 wt% of NR seems to improve the PD resistance of the LDEP-NR composite.

3.2. Surface Image analysis of LDPE-NR Composites

Figure 5 shows the image of sample A1 and A3 before and after the high voltage stress had been applied for 60 minutes. The differences in the surface conditions before and after the test were clearly identified. Several randomly located dark spots with variable sizes are seen in the after stress image. The dark spots are created area due to the carbonization phenomenon as a result of PD activities. It is noted that the dark spots are only vviable using a magnifying camera. Using the wavelet analysis approach, the surface roughness of the two images could be distinguished easily.

Table 2 shows the histogram of LDPE-NR composites (samples A1 and A3). As can be seen, the shape of the histogram changes from before stress to after stress. Sample A3 shows a larger change than sample A1. The peak value is reduced below 120,000 pixels and intensity with a low pixel appears. As can be seen that addition of NR to LDPE changes the shape of the histogram to become slimmer. The change of histogram shape indicates the change in the corresponding statistical parameters. The change of histogram shape indicates that the colour of LDPE-NR surface changed during the high voltage stress due to PD activities. It is understood that during a PD incident, the defective surface will be created as a result of the carbonization process. Carbonization occurs because the PD generates heat and can burn and damage the surface of the insulator. The damaged surface area can be identified by the dark color associated with the defective area.

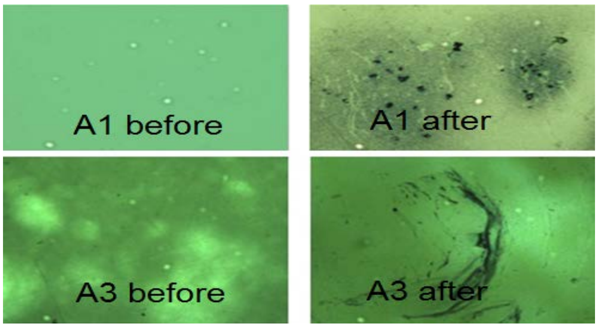
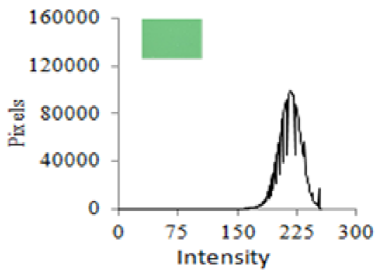
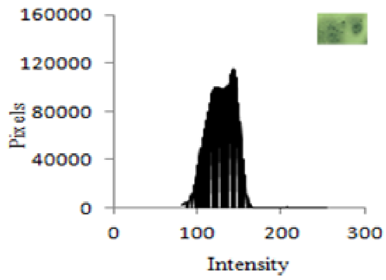
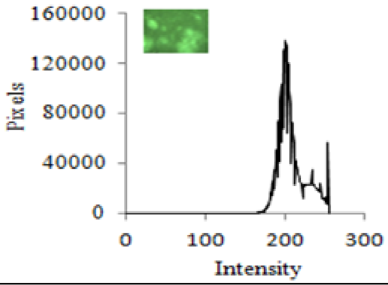
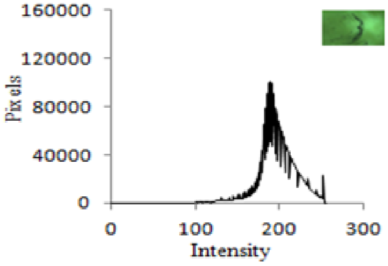


Figure 5. The surface images of LDPE-NR composite sample A1 (100:0) before and after 60 minutes high voltage stress

Table 2. LDPE-NR composites intensity histogram of sample A1 and sample A3 before and after 60 minutes high voltage stress

Sample	Histogram	
	Before	After
A1		
A2		

4. Conclusion

Research has shown a strong correlation between the PD pulse count with the extent of damage on the surface of the sample surface LDPE-NR. The results indicate that the surface image statistical analysis can be used as a tool to justify the total of the PD pulse count on the surface for different samples.

Acknowledgements

The authors would like thank Universitas Andalas, Padang, Indonesia (Contract Number 012/UN.16.09.D/PL/2016 and Universiti Teknologi Malaysia, Johor Bahru, Malaysia for supporting this research with the good quality equipment. We also like to thank Engineering Faculty of Universitas Andalas for supporting the publication process of this paper.

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