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DWT-based method for partial discharge pattern recognition

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Abstract.

The new proposed method of pattern recognition is based on the application of Multi-resolution Signal Decomposition (MSD) technique of wavelet transform. This technique has shown interesting properties in capturing the embedded horizontal, vertical and diagonal variations within an image obtained from the PD pattern in a separable form. This feature has been exploited to identify in the PD pattern's MSD, relative at various family of PD sources, some detail images typical of a single discharge phenomenon. The classification of a generic PD phenomenon is feasible through a comparison between its detail images and the detail images typical of a single discharge phenomenon. Tests have been performed on specimens having single defects. The obtained results prove that the proposed improved classification methods is quite efficient and accurate.

Keywords: Discrete wavelet transform, partial discharge, multi-resolution signal decomposition.

1. Introduction

It is well known that Partial Discharges (PD) sources in insulating systems can be of different types and they can present different discharge mechanisms. The related different shape on PD pattern (i.e. its distribution versus phase position and pulse amplitude) is determined by physical and geometric parameters of the discharging site. The parameters controlling the patterns appearance are the shape of the gas inclusion, the availability of the initial electron, as well as the surface conductivity and other physical properties of the inclusions boundaries. Geometry and location of defect inside the insulation system modifies the electric strength distribution also influencing the discharge inception voltage value[1] . Since each defect has its own characteristic discharge parameters, different discharge sources will result in different patterns. Thus PD pattern recognition can be effectively used to discriminate among different types of PD activities that occur in the insulating systems of electrical apparatus. Detected discharges are often displayed as three dimensional patterns where PD height vs. phase and number of discharge are reported. From this representation, it is possible to extract different parameters that characterize single PD's phenomenon. By mean of a set of parameters (statistics, fractals, etc) different pattern recognition algorithms and neural networks techniques were implemented showing good results on classifying the PD source[2] . In the last years the application of Discrete Wavelet Transform (DWT) allowed to implement new algorithms both for PD denoising and recognition techniques[3] . In this paper a new method, able to perform PD pattern recognition of singles defect specimens, is presented to identify cavity, surface and corona discharges. The MSD technique of wavelet transform is applied to 3D patterns in order to extract horizontal, vertical and diagonal details are extracted for more then ten levels of decomposition. By comparing a set of pattern of the same discharge family (cavity, surface and corona) in different specimens or conditions (vs. different temperature) some details (best for horizontal and vertical type) at the same decomposition level show similar characteristics. Then, by comparing only a few number of details shape at the same decomposition level is possible to recognize a specific PD source.

2. Acquisition system and PD Pattern representation

The specimens representing the different defect models are inserted into a specific high voltage test circuit, and partial discharges are generated in the material. The test circuit output signals (partial discharge and sync ones) are sent, by an optical coupler system, to the D^2SI acquisition system[4] , whose scheme is reported in Fig. 1.

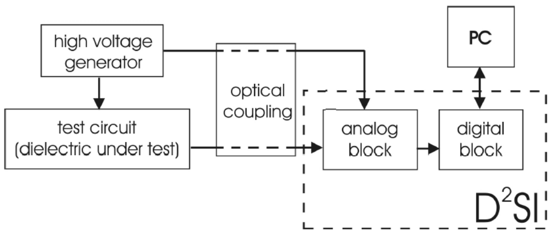

Fig. 1. Complete D^2SI acquisition system architecture.

The partial discharge signal is amplified and integrated to obtain a waveform whose peak value is proportional to the $q(t)$ charge produced in the sample; this value is then acquired by the A/D converter together with the sync signal, necessary to obtain the partial discharge phase reference. Due to the stochastic nature of discharges its necessary to implement a digital buffer to make the microcontroller data elaboration process independent of the variable rate data arrive from the analog block. Buffered data can be sent to an external PC, via the USB port, and/or be processed by the microcontroller itself and displayed on the system internal LCD. The use of an external PC let to perform more complex elaborations (Weibull analysis[2] , Skewness e Kurtosis parameter calculation, etc.) on the complete set of acquired data. Furthermore, 3D visualization of test results, shows the occurrence phase of every single discharge and the number of discharges of a certain amplitude and occurrence phase in a pre-established acquisition time.

To carry out PD pattern classification, specimens with different types of defects were tested to produce PD signals. In particular, three family of PD phenomena, named internal, surface and corona discharge, have been taking into account. The internal discharges have been generated in spherical void specimens with diameter ranging from about 1.3 mm to about 2 mm, but with constant inter-ele trodic resin thickness equal to 3.5mm. For this specimens both 20°C and 80°C tests have been taken in to account. The surface discharges have been generated on two wire twisted samples, with different diameters (0.367 - 0.989 mm) and on CIGRE' II test cell. Finally, the corona discharges have been

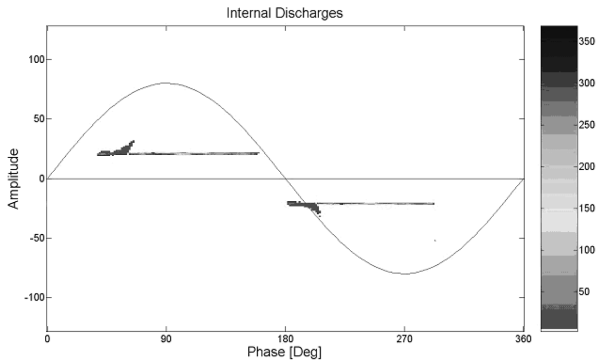

Fig. 2. Typical PD pattern for internal discharges. The reported amplitude is referred to the electric charge separated in the sample. The colour-bar represent the discharge's number.

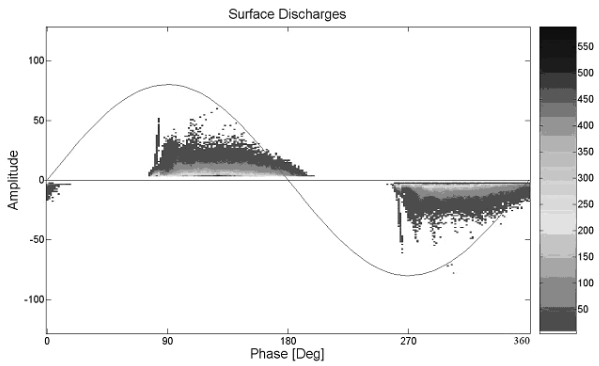

Fig. 3. Typical PD pattern for surface discharges.

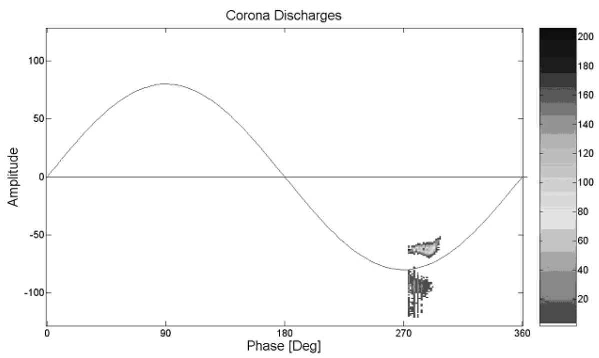

Fig. 4. Typical PD pattern for internal corona discharges.

produced by using a needle-plane electrode arrangement with 10 mm air gap. The typical 3D PD pattern for each type of defect is shown in Fig.2 - Fig.4, and not less of 20 PDP acquisitions for each type of defect have been performed.

3. MSD-based wavelet transform

Multi-resolution signal decomposition (MSD) using Wavelet Representation is an effective tool in time-frequency signal processing technique. The analysis provide to divide

the frequency band of the signal into different levels with different degree of details. Furthermore, the two-dimensional wavelet transform, normally applied to image processing, has been proposed for its ability to separate the 3D image's characteristics present in determined bands of frequency related to fixed spatial orientations.
The image is seen like a finite energy function $f(x, y) \in \mathbf{L}^2(\mathbf{R}^2)$, where $\mathbf{L}^2(\mathbf{R}^2)$ is the vector space of measurable, square-integrable and two-dimensional functions. A multiresolution *approximation* (V_{2^j}) $j \in Z$ of a signal $f(x, y) \in \mathbf{L}^2(\mathbf{R}^2)$ at the resolution 2^j is equal to the orthogonal projection of $f(x, y)$ on the vector space V_{2^j}. The difference of information between the approximation of a function $f(x, y)$ at the resolutions 2^{j+1} and 2^j is called the *detail* (O_{2^j}) signal at the resolution 2^j. This detail is equal to the orthogonal projection of the signal $f(x, y) \in \mathbf{L}^2(\mathbf{R}^2)$ on the orthogonal complement of V_{2^j} on $V_{2^{j+1}}$. The two-dimensional analysis can be computed with a separable extension of the one-dimensional decomposition algorithm by mean of one-dimensional convolutions of the rows and columns of the image $A^d_{2^{j+1}}f$ with the impulsive response of the one dimensional quadrature mirror filters $\tilde{G}$ and $\tilde{H}$. In particular, at each step, the image $A^d_{2^{j+1}}f$ are decomposed into $A^d_{2^j}f$, $D^1_{2^j}f$, $D^2_{2^j}f$, $D^3_{2^j}f$ that represents the approximation and the details of the image at the approximation j respectively. This algorithm, described in work of Mallat[5] , is illustrated by a block diagram in Fig. 1.

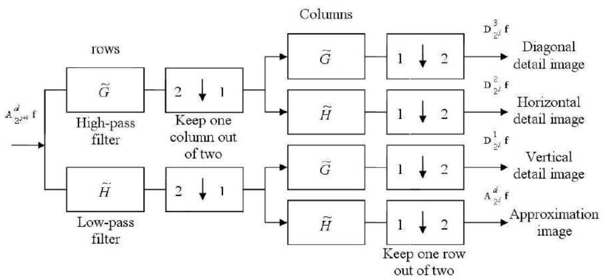

Fig. 1. Decomposition of an image $A^d_{2^{j+1}}f$ into $A^d_{2^j}f$, $D^1_{2^j}f$, $D^2_{2^j}f$, $D^3_{2^j}f$.

4. Classification procedure and results

The MSD-based wavelet procedure was applied to 3D PD patterns by means of biortogonal 3.7 mother wavelet. This wavelet was selected for its properties of phase linearity end for the shape of impulsive response of $\tilde{G}$ and $\tilde{H}$ filters. In order to determine the significant images, a ten levels decomposition has been adopted. As a consequence of this process it is possible to evidence that:

- the approximation images are not very significant because are an approximate version of original image without high frequency signals ($\tilde{H}\tilde{H}$ filters);
- the diagonal detail images are similar for the three types of discharge families, therefore they do not seem to be useful to the classification process;
- the horizontal and vertical detail images seem to be useful for the classification process. In fact, they have turned out different shape based on the type of source of the selected PD.

For thoroughness the decomposition process has been extended beyond level 10, obtaining that from level 11 the vertical and horizontal detail images supply of useless and redundant information for the classification process. From the previous considerations the vertical and horizontal detail images seem to be the most significant ones. In particular, by carrying out an high number of decomposition processes it has been noticed that for the internal discharges, the horizontal detail image at level 10 (H10), has always the same shape i.e. concavity (Fig. 1). In the same way, for the surface discharges, the horizontal detail image at level 10 (H10), has always the same shape i.e. concavity, but different from that related to internal discharges (Fig. 2). For the third discharge family, the horizontal detail image H10 appears much similar to H10 detail of the internal discharges (Fig. 3). As a consequence, it is obtained that the H10 detail allows to distinguish between surface discharges and the discharges associated with the other two families.

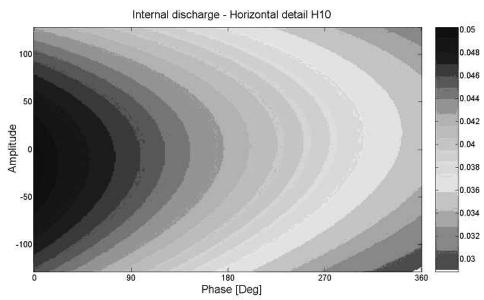

Fig. 1. Horizontal detail image at level 10 of internal discharges.

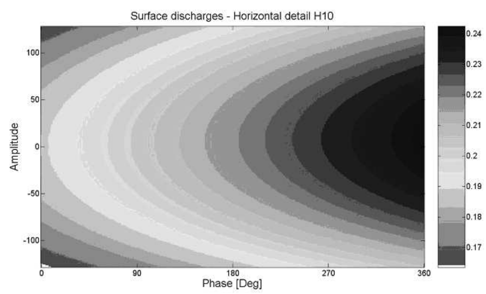

Fig. 2. Horizontal detail image at level 10 of surface discharges.

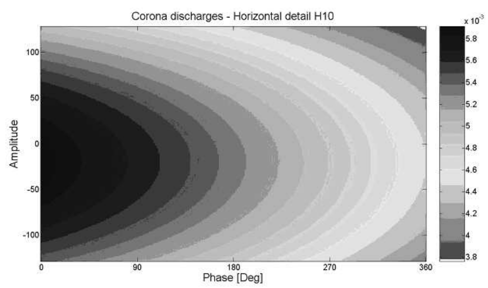

Fig. 3. Horizontal detail image at level 10 of corona discharges.

In order to distinguish the remaining discharge phenomena the vertical detail image V8 at level 8 (Fig.4) of MSD process of internal discharges shows similar characteristics for all tests performed.

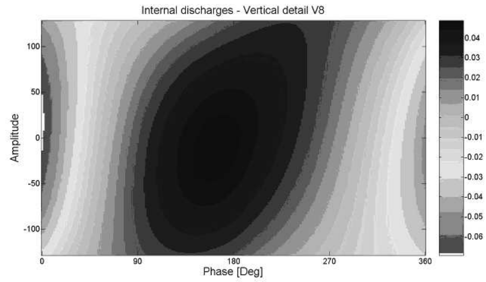

Fig. 4. Vertical detail image at level 8 of internal discharges.

At the same time, the vertical detail image V8 of corona discharges shows a completely different shape with regard to internal discharge, as reported in Fig.5. The obtained results show as the decomposition process is able to extract vertical and horizontal details characteristic of a single discharge phenomena. This involves that the V8 and H10 images that represent respectively $\tilde{G}\tilde{H}$ and $\tilde{H}\tilde{G}$ filtering's process, can be seen like the characteristic frequencies referred to the signal corresponding to original image.

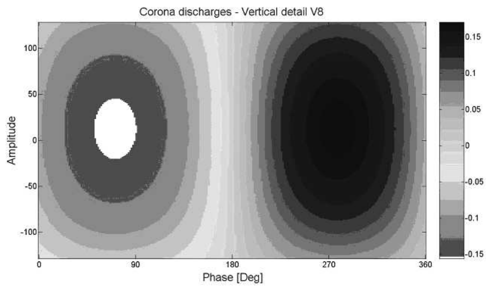

Fig. 5. Vertical detail image at level 8 of corona discharges.

Conclusions

The new proposed method of pattern recognition, based on the application of Multiresolution Signal Decomposition (MSD) technique of wavelet transform, has shown interesting properties to recognize the different discharge phenomena. By the comparison among details V8 and H10 related to different defect, it is possible to carry out the classification of the three discharge's phenomena. In particular, the differences in the horizontal and vertical details of the different discharge phenomena, are combinable to different frequency band characteristic of the single discharge's phenomena.

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