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The Usage of Morphological filters in Process of Partial Discharge Activity Measurement

Abstract. *Partial discharge activity signal de-noising by morphological filters is presented. Morphological filters have the advantage of preserving original useful signal waveform and they can efficiently remove noise pulses from signal corrupted by noise and acquired during partial discharge measurement on electric power devices. We analyze the efficiency of morphological filtering for different noise type occurring in environment where partial discharge activity is measured.*

Keywords*: partial discharge, acoustic emission, morphological filter.*

Introduction

Electric energy supply reliability has high importance for electric energy supply continuity and quality. The operation of electric power devices without dropouts is the main aspect influencing electric energy supply reliability. For continual generation and distribution of electric power energy (by devices such as generators, power transformers device transformers), the insulation system in such device in an aspect which considerably determinates the lifetime of electric power device. For monitoring method, it is important to know the status of the insulation system of electric power device. For manufacturers as well as for their operators, take the advantage of lower maintenance costs and costs caused by servicing.

A non-destructive method of insulation system diagnostics is the partial discharge activity measurement and this is widely used nowadays.

Partial discharge activity in electric power device exploits monitoring by direct galvanic or indirect acoustic method.

Noise and its filtering methods

Measured signal that is measured during partial discharge activity monitoring comes from direct galvanic method or acoustic method. In addition, in real operation conditions there are many interfering noise signals in the environment. These noise signals can have different pattern and frequency range. For acoustic method, the noise is disturbing when it has the same frequency range as the useful signal originating from partial discharge activity. In the case of direct galvanic method, the electrical noise generated by environment is superimposed to useful partial discharge electric signal.

Usually, it is often very hard or even impossible to attenuate this interference. Narrow band sensors are used, however these deteriorate also the shape and characteristics of useful signal.

We have different possibilities of filtering and the filter type has to be selected carefully because it depends on effective signal parameters and on the characteristics of noise signal. Band filters is one possible choice often used. These filters are as analog filters (discrete electronic components) or they can have digital-software form, i.e. they are applied after sampling and quantifying the measured signal.

One of the methods is the usage of Wavelet transform as a filtering tool. The Wavelet transform is used together with thresholding technique. The disadvantage of these filters (Wavelet transform, band filters) is the deterioration of the shape for useful signal, disabling thus the extraction of partial discharge type markers from measured signal. E.g., the distortion of leading edge of partial discharge pulse is a typical case, which is caused by higher frequency removing from useful signal, which is called smoothing effect. The determination of pulse delay comparing to referential time is ruled out in this case. However, this is a very important parameter for acoustic measurement method when estimating a partial discharge source position in electric power device construction.

Morphological filters do not suffer from these disadvantages and they do not change the shape of original useful signal. However, they efficiently remove noise signals with pulse shape. The only point to consider is that noise pulses must have shorter duration than useful signal. The higher frequencies in useful signal spectrum are left untouched.

Noise sources interfering with partial discharge activity signals

During partial discharge activity measurement by direct galvanic method in real conditions the useful signal can be deteriorated by pulse shaped noise signals. The overview of the most common noise sources interfering with electric signals of partial discharge activity can be seen on Fig. 1.

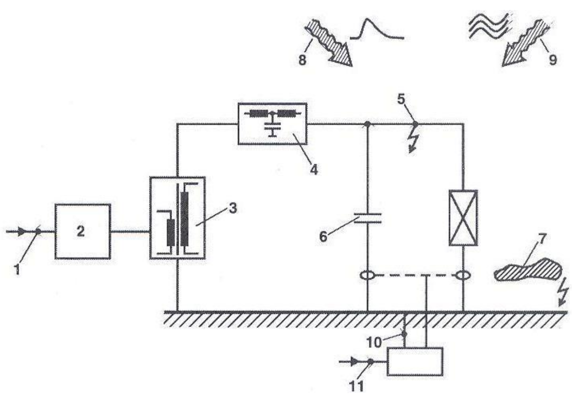

Fig. 1. The most common noise sources for direct galvanic measurement method

1- Measurement source circuit generating testing voltage
2- Regulation unit
3- High voltage source
4- Filter in high voltage part of the circuit
5- Wiring of the high voltage test circuit
6- Coupling capacitor
7- Near conducting objects without fixed potential
8- Pulse noise
9- Electro-magnetic interference from radio frequency transmitters

10- Noise currents in earthing system
11- Measurement device supply circuits

Noise signals are divided according to their parameters into these types:

- Pulse noise, in most cases caused by random pulse signals with very wide spectrum. They have very similar shape as the useful signal of partial discharge emission.
- Harmonic noise originating from power regulators, thyristor regulators etc.

Noise signals come from different source types:

- External noise sources caused processes that are independent from testing voltage in measurement circuit. These noise sources are identified by characteristic pulse shape. Typical noise sources of this category can be e.g. telecommunication transmitters, rotary machines, switching devices etc.
- Internal noise sources, which are dependent on testing voltage in measurement circuit. Typically, with higher testing voltage internal noise increases also. Main sources of internal noise can be e.g. partial discharges on physical parts of measurement circuit, un-sufficiently earthed parts of the circuit or near object without fixed potential.

Using high voltage filters internal noise can be filtered out. In case of corona partial discharges, sharp peaks and edges can be removed from measurement circuit and its environment.

Overview of noise types

A random noise process with equal power in the whole spectrum is called white noise. This type of noise can be achieved only theoretically because indefinitely high power is needed to generate such noise. We can consider noise with limited flat spectrum as white noise in first approximation.

Noise with the pulse shape waveform consists of one or more short randomly generated pulses. Typically, they have different amplitude, duration and other signal characteristics depending on noise source. In addition, their shape is changed by transmission channel through which pulses travel from source to the sensor.

The dot noise can be found e.g. in systems using radar wave technology, in image processing systems etc. It is called also „salt and pepper“ noise due to white or black dots in image. The term image stands for real two-dimensional image or a one-dimensional signal considered as one-dimensional image with superimposed pulse noise creating thus dots in original partial discharge waveform. Conventional filters can remove such noise, but they also deteriorate the original image. Morphological filtering can overcome this.

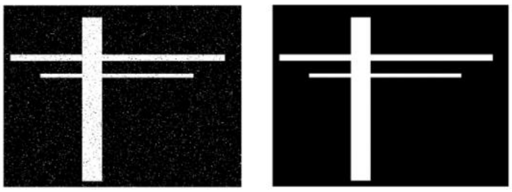

Fig. 2. 2D binary image with dot noise (left) and morphologically filtered result (right)

Morphological filters

Mathematical morphology uses the theory of sets, integral geometry and topology. Morphological operators used for filtering an n-dimensional image are local non-linear operators using masks or so called structuring elements.

By a set of dots, images of any dimension can be modelled. Euclidean space and a system of its subsets is a natural definition domain for planar shape description. For binary image, the dot set consists of a set of integer number pairs and in the case of greyscale image these become triplets.

If we write:

(1) X={(0,2),(1,1),(1,2),(1,3),(2,0),(2,1),(3,1),(4,1)}

as a set of whole number integers, they describe black and white image depicted on fig. 3.

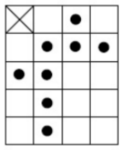

Fig. 3. Black and white image specified by a set of number pairs

A morphological transform of dot set A is defined as an interaction with other smaller set of dots B, which is called a structuring element. This set is used to go through the A set and locally transforms the A set according to predefined rules. For n-dimensional A set we need n-dimensional B set called structuring element.

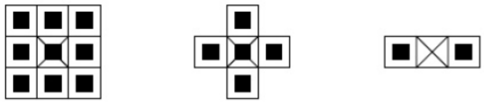

Fig. 4. Examples of planar two-dimensional structuring elements

According to rules used during filtering process by a structuring element, we can differentiate between various morphological filters:

The dilation searches for maximum value of dots in X set within the area of the structuring element B. This maximum value is then assigned to the referential coordinates of X set.

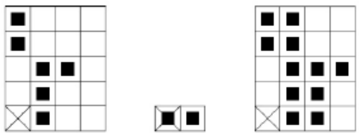

Fig. 5. Examples of planar two-dimensional structuring elements

Dilation can be used to fill small gaps in original signal and it serves as a basic operation for more complex morphological operators.

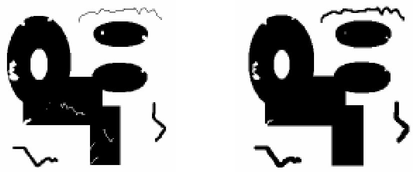

Fig. 6. An example of dilation operator by 3x3 structuring element

Erosion is an operator dual to the dilation, enlarging small gaps in the original signal.

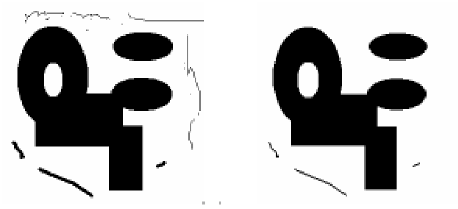

Fig. 7. An example of erosion operator by 3x3 structuring element

Dilation and erosion are inverse operations and by combining them in determined order we get the operators of opening and closing, which result in simplified but much less sharp signal - image.
The definition of opening morphological operator:

$$X \circ B = (X \oplus B) \oplus B \tag{2}$$

Fig. 8. An example of opening operator by 3x3 structuring element

The definition of closing operator:

$$X \circ B = (X \oplus B) - B \tag{3}$$

Fig. 9. An example of closing operator by 3x3 structuring element

These operators still have the disadvantage of corrupting the useful original signal, though removing efficiently short pulse noise signals.
Therefore, more complex morphological filters such as opening-closing, closing-opening, opening-closing by reconstruction and closing-opening by reconstruction are used for noise filtering which in addition reconstruct the original shape of useful signal.
The pulse noise signal with duration shorter than the structuring element is filtered out from the useful signal of partial discharge emission.

Applying morphological filters on partial discharge activity signals

From our experiments, we have recorded a large set of partial discharge activity signals, during both experiments by direct galvanic method and indirect acoustic method. For both cases, signals were recorded and archived for later analysis. As they were influenced by different types of noise signals, we tried to apply morphological filtering to reduce noise interference.
Below waveforms of recorded partial discharge activity signals can be seen in time domain. We applied morphological filtering implemented in Scilab environment.

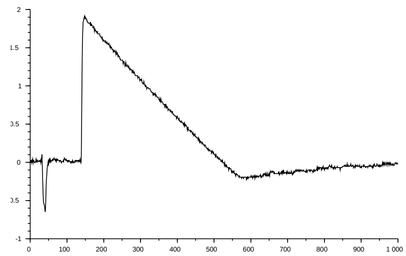

Fig. 10. Partial discharge pulse waveform with superimposed pulse noise

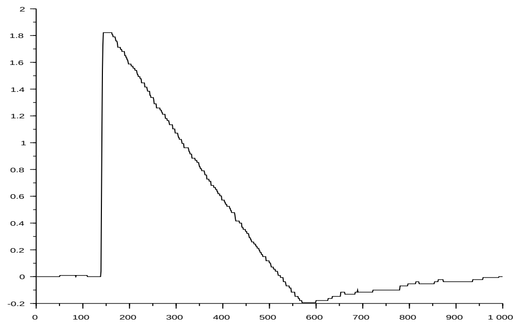

Fig. 11. Partial discharge pulse waveform with superimposed pulse noise after morphological filtering with structuring element of size 5

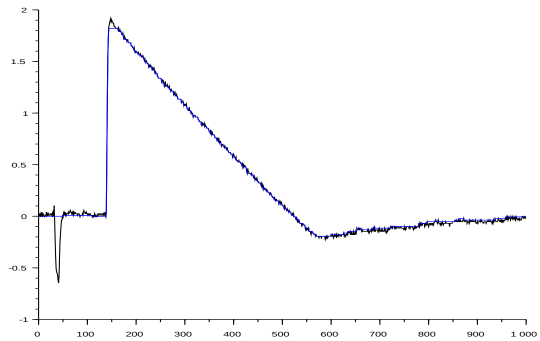

Fig. 12. Partial discharge pulse waveform with superimposed pulse noise and filtered signal after morphological filtering with structuring element of size 5

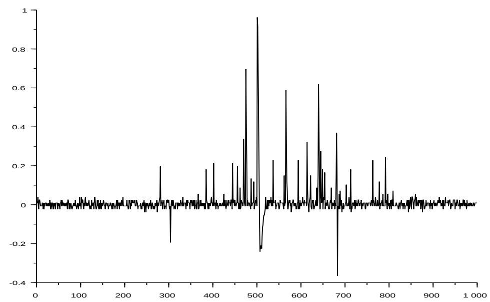

Fig. 13 Partial discharge pulse waveform with superimposed pulse noise – partial discharge in stator coil

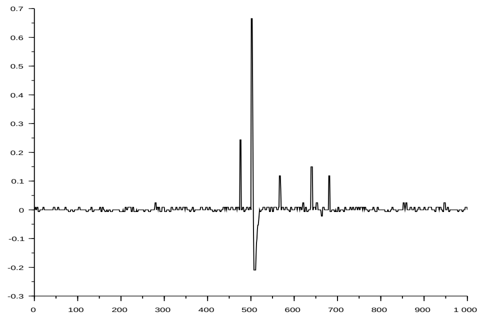

Fig. 14 Partial discharge pulse waveform with superimposed pulse noise – partial discharge in stator coil, after morphological filtering – structuring element with size of 5 samples

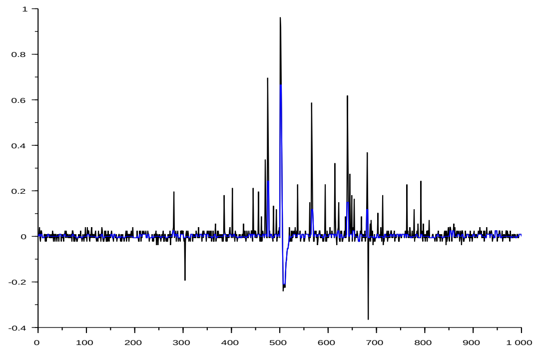

Fig. 15 Partial discharge pulse waveform with superimposed pulse noise – partial discharge in stator coil and the signal after morphological filtering – structuring element with size of 5 samples

Conclusion

As demonstrated on figures above, morphological filtering can remove efficiently pulse shaped noise peaks from partial discharge activity signals, no matter if they come from direct galvanic or indirect acoustic method. At the same time, these filters leave the original useful signal untouched (they literally reconstruct the original signal). By choosing appropriate size of structuring element, we can adjust the width of noise pulses to remove from useful signal.

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