# Partial Discharge Detection and Localization System

**M. Cap, P. Drexler, and P. Fiala**
Department of Theoretical and Experimental Electrical Engineering
Brno University of Technology, Technicka 3082/12, Brno 616 00, Czech Republic

**Abstract**— This article describes the partial discharges (PD) detection and localization system. Localization can be performed on the basis of measured UHF waveforms analysis during activity of the partial discharges. The time-shifts of the waveforms related to transient process occurrence in the signals are the main input parameters for localization methods. In order to estimate the position of the signal source in the 3D space a minimum of four antennas has to be used, since the time of the PD is unknown. Analysis of the PD starts with visual investigation of the signals present inside of the power oil transformer. PD signal level is in comparison to other signals inside the transformer very low. Therefore, signal line contains, except amplifiers, also controlled attenuators to reach required trigger conditions. Detailed investigation of all signals inside transformer is provided in memory mode in which system store defined number of signals for offline diagnosis a localization. Continual and memory mode of the system also contain discrimination method for non PD signals removing. Discrimination method is based on simultaneous detection of the signal inside and outside of the transformer with aim to acquire only signal which comes from inside of the transformer. Localization of the PD origin is based on TDOA and matrix algorithm. Resulting position are visualized as point in transformer 2D and 3D scheme.

## 1. INTRODUCTION

Partial discharges (PD) in the high voltage transformer could cause risk of the transformer damage. Detection of the discharge presence is possible by several methods based on sound, electromagnetic signal measurement or gas chromatography. This work is focused on measurement and evaluation of the UHF (Ultra High Frequencies) electromagnetic signal. Partial discharge is detected as a signal in range from hundreds of megahertz to units of gigahertz. Propagation delay of the signal from the place of the PD to the each detector can be used for spatial localization of the PD. Goal of this work to design software for detection, analysis and localization of the partial discharges.

## 2. MEASUREMENT SYSTEM AND LOCALIZATION METHODS

### 2.1. Diagnostic System

PD signal is detected by the special measuring system. Whole system contains 4 specially designed sensing heads (Figs. 1, 2), central unit (Fig. 3) and software for PD analysis and localization. Sensing heads are mounted in to the front wall of the transformer. Heads are connected by triaxial cables for simultaneous RF signal transmission and DC powering. Signal preprocessing part of each head includes conical antenna, controllable attenuators, amplifiers, high pass filter and RF limiter. Data are acquired by Agilent data acquisition system which uses a four-channel, 10 bit high speed cPCI digitizer. Signal is preprocessed by sensing heads and digitalized with 2GSa sampling frequency. Because of strong electromagnetic interference, diagnostic system is mounted in a shielded

Figure 1: Sensing head.

Figure 2: Sensing heads mounted on the transformer.

Figure 3: Assembly of the diagnostic system in shielded box.

box. This two stage box contains all required powering, data acquisition and communication parts, Fig. 3.

### 2.2. Localization Methods

#### *2.2.1. Time of Arrival*

Method of the partial discharge location is based on the time differences of signal arrival (TDOA). Signal arrival time is determined from energy accumulation curve EAC given by equation [1, 2]:

$$w_i = \frac{t_s}{Z_0}\sum_{k=0}^{i} u_k^2, \quad k = 1 \dots N \tag{1}$$

Selection of the signal arrival time could be done by two methods. Point could be marked as the time of signal arrival when energy accumulation curve or its first derivation reach threshold value. Method and threshold values for each channel are selected manually before localization algorithm starts. Precise detection of the signal arrival time is crucial point of signal spatial localization. Due to small dimensions of the transformer and short time of propagation cause small errors in arrival time detection big errors in spatial localization [3].

#### *2.2.2. TDOA*

Due to given antenna arrangement shown in Fig. 2 the localization results lies on circle which plane is perpendicular to the straight line join of antennas. Therefore, solution can be found only in 2D space as an intersection of the circle with relevant part of tested transformer. The initial equation system defines source position towards three antennas

$$x^2 + y^2 = v^2 t_0^2, \tag{2}$$

$$x^2 + (y - y_2)^2 = v^2 (t_0 + t_{12})^2, \tag{3}$$

$$x^2 + (y - y_3)^2 = v^2 (t_0 + t_{13})^2, \tag{4}$$

Solution of Equations (2)–(3) leads to definition solution for $t_0$, $x$, $y$ as

$$t_0 = \frac{v^2 \left(y_2 t_{13}^2 - y_3 t_{12}^2\right) + y_3 y_2^2 - y_2 y_3^2}{2v^2 (y_3 t_{12} - y_2 t_{13})}, \tag{5}$$

$$y = \frac{y_2}{2} - \frac{v^2 \left(y_2 t_{13}^2 - y_3 t_{12}^2\right) + \left(y_3 y_2^2 - y_2 y_3^2\right)}{2y_2 (y_3 t_{12} - y_2 t_{13})} t_{12} - \frac{v^2 t_{12}^2}{2y_2}, \tag{6}$$

$$x = \sqrt{v^2 \left(\frac{v^2 \left(y_2 t_{13}^2 - y_3 t_{12}^2\right) + y_3 y_2^2 - y_2 y_3^2}{2v^2 (y_3 t_{12} - y_2 t_{13})}\right)^2 - \left(\frac{y_2}{2} - \frac{v^2 \left(y_2 t_{13}^2 - y_3 t_{12}^2\right) + \left(y_3 y_2^2 - y_2 y_3^2\right)}{2y_2 (y_3 t_{12} - y_2 t_{13})} t_{12} - \frac{v^2 t_{12}^2}{2y_2}\right)^2}. \tag{7}$$

Results of PD localization are calculated as a mean value from three partial solution obtained from different combination of channels.

#### *2.2.3. Matrix Method*

Due to high sensitivity of TDOA to precision of the signal arrival time determination is useful to use results accumulation. This method use matrix of propagation times from defined points in transformer to all sensing heads. Calculated time differences of signal propagation are compared to matrix values and points which are in tolerance interval are with defined neighborhood marked as a potential source of the signal. Each detected point increase value in $50 \times 50 \times 50$ cm cube around signal potential origin. Space surrounding the signal origin will increase its value after each detected signal. Localization results are defined as a points with value higher than 50% of maximal value.

## 3. PARTIAL DISCHARGE DIAGNOSTIC AND LOCALIZATION SOFTWARE

PD localization software application is designed as a multithread application. Basic function concept of this application is to split measurement and visualization into separate threads in order to achieve maximal possible computer performance for both application parts.

### 3.1. Acquisition Settings and Attenuators Control

#### *3.1.1. Settings*

Basic acqusition setting is shown in Fig. 5. These parameter are setted up with regard to signal parameters. Possibillity of changing of acqusition parameters is crucial especially in case of first examination of signals in continual aqusition mode.

#### *3.1.2. Attenuators*

Controable attenuators regulate transmition path output power. Attenuator attenuation depend on controll voltage which is set by usb controlled hardware in range 3–40 dB, see Fig. 4.

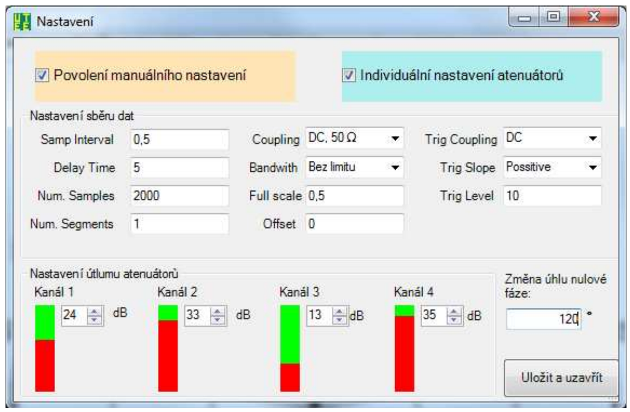



Figure 4: Settings.

#### *3.1.3. Trigger*

Detection of the partial discharge is provided on all digitizer channels. Detected signal energy depends on the place of origin of the PD. If the PD will occur on the left or right side of the transformer winding the energy of detected signal will be biggest on the first or fourth channel. Therefore, trigger input is configured as a multichannel trigger so the trigger input is used all four input channels.

### 3.2. Application Modes

#### *3.2.1. Continual and Memory Mode*

Diagnostic of partial discharge could be split into the two modes. Firs mode works in loop in order to acquire and visualize data continuously. This mode is to a certain extent similar to the basic function of the traditional oscilloscope. Second mode could be described as "acquire and wait". In this case program will acquire 300 of data packets and stops acquisition. Both modes use two types of acquired signal visualization, phase chart and time graphs of all four channels which shows position of the acquired data to the zero supply voltage point, Fig. 5. Chart uses two values, first is angle 0°–360° calculated as the position of data to the time of the supply voltage zero time, Fig. 6. Actual angle need to be additionally corrected with power and transformer angle difference. Second parameter is mean value calculated from maximal voltage values in all channels [4, 5].

#### *3.2.2. Calibration Mode*

Determination of the system hardware and software correct functionality is provided by detection of signal injected into the third sensing head space. Calibration could be done with or without synchronization of the signal source and digitizer trigger. In case of synchronous trigger is the signal source and digitizer triggered at the same time. Therefore, only injected signal is measured [6, 7].

#### *3.2.3. Interference Signal Discrimination*

Detection of presence of the partial discharge is because of strong interference relatively difficult. Huge amount of signals is getting into transformer thru high and low voltage bushing. Moreover, interference signals are in its principle of creation similar to the partial discharges. Difference between the interference signal and partial discharges is in propagation distance. Resulting interference signal have longer duration time and narrower bandwidth [8]. One of the key part of this work is to detect partial discharges and suppress number of detections of the interference signals.

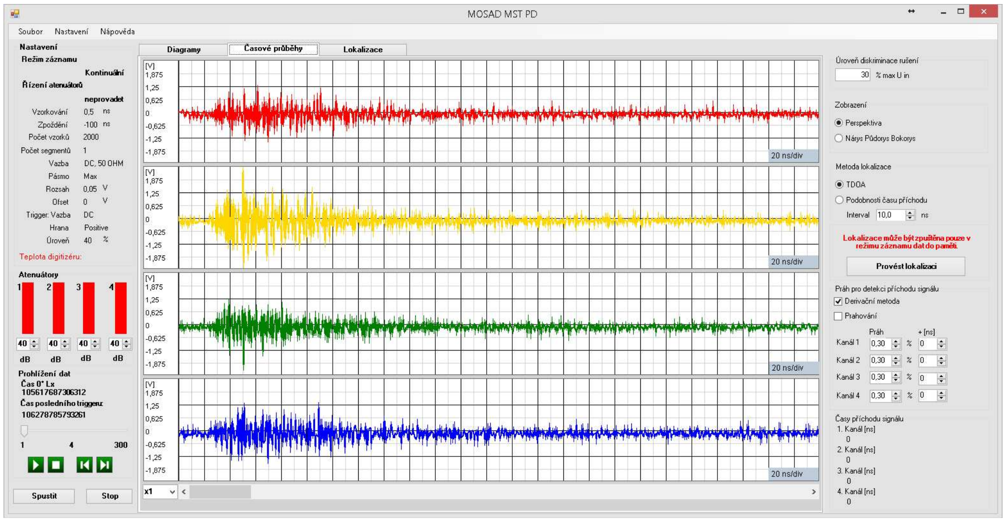



Figure 5: Visualization of the signal in time domain.

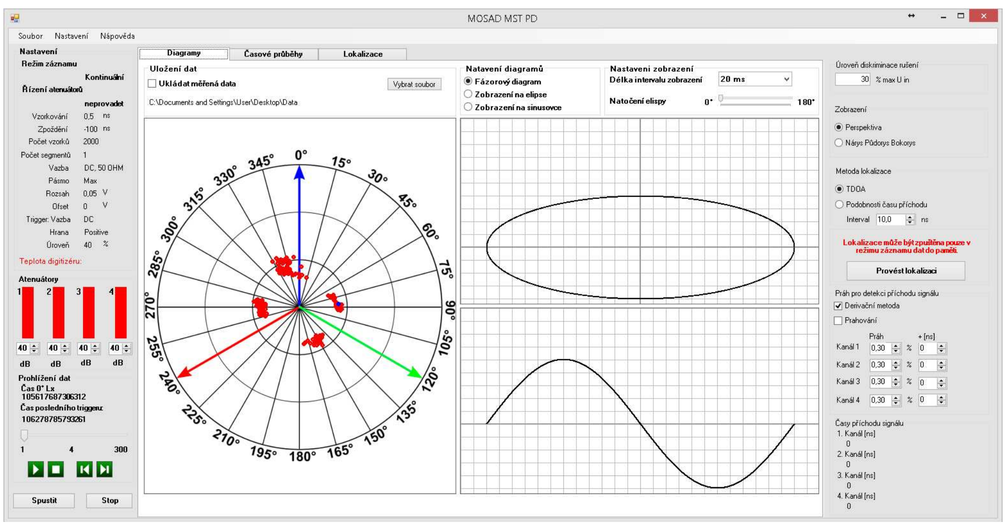


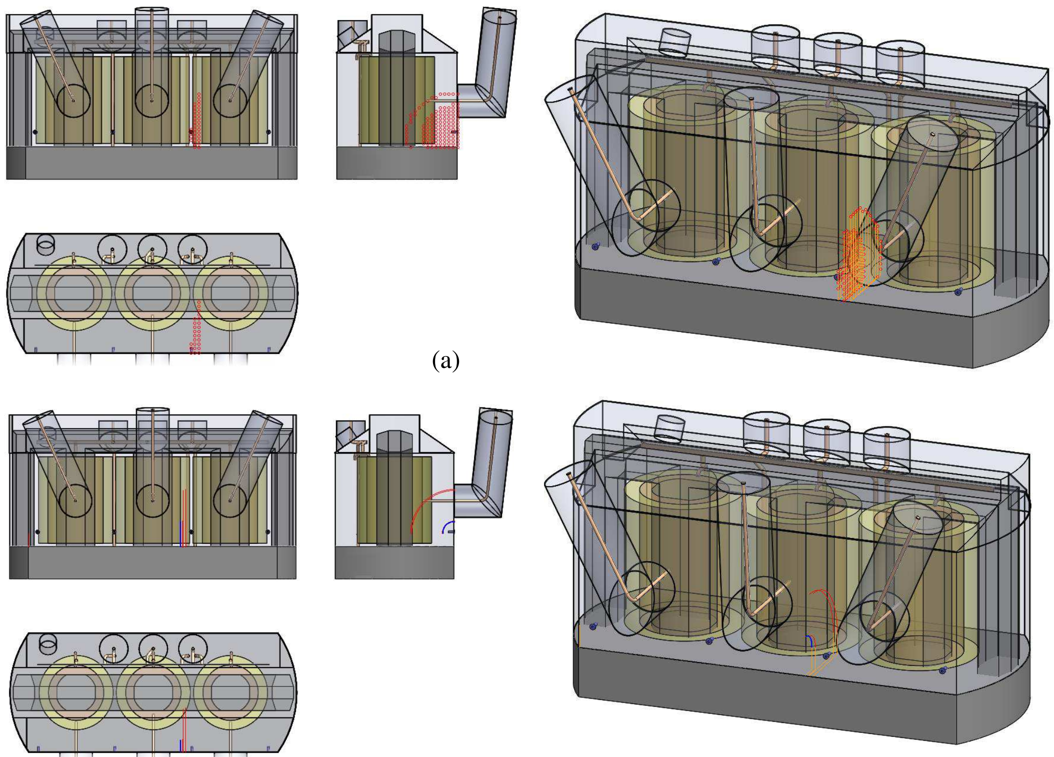

Figure 6: Main window with phase chart.

Assuming that the origin of the interference signal is outside of the transformer itself we can use external sensing head for detection of the interference presence outside of the transformer. In case of interference we can say that signal will be present inside and outside of the transformer. In case of partial discharge the signal will be present only inside of the transformer. Discrimination criteria is the amplitude on the third channel which is used for external antenna. If the signal in third channel exceed defined threshold (defined as % from other channels signal maximum) is signal marked as an interference and deleted. Interference discrimination is available for continual and memory mode.

### 3.3. Partial Discharge Location

Partial discharge location uses TDOA and matrix method. Localization is because of large amount of processed data in online mode available only in memory mode. Use of four antennas allows us to locate position of partial discharge in three dimensions. Unfortunately, transformers in nuclear power plant Dukovany has all antenna plug-in points placed on the front side in line (see Fig. 2). Hence, results of the localization lies on the circle with center on sensing head line and with diameter calculated from localization algorithm.

Signal origin is from TDOA and matrix algorithm visualized in perspective and front, side and top view of the transformer. In case of TDOA is signal visualized as a circle, for matrix method are used points with 10 cm distance. Localization of the signal source mounted in third sensing head space is shown in Fig. 7.



(a)

(b)

Figure 7: Injected signal localization results of (a) Matrix and (b) TDOA algorithm.

## 4. CONCLUSION

Basics of the partial discharge detection is analysis of the signal shape and its time position in supply voltage waveform. For correct localization is necessary to process large amount of signals. Setting of the variable attenuators and trigger conditions allows with interference signal discrimination reduction the amount of interference signals. If mentioned settings reduce number of detected interference signal then the special localization of the signal origin will give us more accurate results. Other factor affecting accuracy of the spatial localization are signal to noise ratio and signal shape itself. In case of low SNR and long propagation length will be difficult to correctly detect the signal arrival time and calculate position of the signal origin.

## ACKNOWLEDGMENT

The research described in the paper was financially by project of the BUT science fund, No. FEKT-S-14-2545/2014, and a project from the Education for Competitiveness Operative Programme, No. CZ.1.07.2.3.00.20.0175 (Electro-researcher).

## REFERENCES

1. Fiala, P., T. Jirku, P. Drexler, and P. Dohnal, "Detection of partial discharge inside of HV transformer, modeling, sensors and measurement," *PIERS Proceedings*, 1013–1016, Cambridge, USA, July 5–8, 2010.
2. Myška, R. and P. Drexler, "Simulation and verification of methods for partial discharge source localization," *PIERS Proceedings*, 704–708, Kuala Lumpur, Malaysia, March 27–30, 2012.
3. Dalarsson, M. and M. Norgren, "First-order perturbation approach to elliptic winding deformations," *Proceedings of International Symposium on Electromagnetic Theory*, 13–16, Hiroshima, Japan, 2013.
4. Dalarsson, M., A. Motevasselian, and M. Norgren, "Using multiple modes to reconstruct conductor locations in a cylindrical model of a power transformer winding," *International Journal of Applied Electromagnetics and Mechanics*, Vol. 41, No. 3, 279–291, 2013.
5. Fiala, P., "Pulse-powered virtual cathode oscillator," *IEEE Trans. Dielectr. Electr. Insul.*, Vol. 18, No. 4, 1046–1053, 2011.

6. Szabo, Z., J. Sedlacek, and M. Hadinec, "Optimization method of EMI power filters and its measurement," *PIERS Proceedings*, 1085–1088, Hangzhou, China, March 24–28, 2008.
7. Marcon, P., P. Fiala, M. Steinbauer, and M. Cap, "Special high voltage function generator," *PIERS Proceedings*, 1000–1003, Suzhou, China, September 12–16, 2011.
8. Szabo, Z. and P. Fiala, "Characterisation and testing shielding fabrics," *PIERS Proceedings*, 1273–1276, Moscow, Russia, August 18–21, 2009.