A new method to localize partial discharges on power cables using time reversal and TLM numerical method – A review

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Abstract

Insulation deterioration is often caused by partial discharge (PD) events. The adoption of on-line PD location methods is one of the most suitable methods to perform the power networks condition monitoring to improve their resilience and to guarantee electricity supply security. This paper reviews the results obtained in the design process of a new on-line PD location method based on the use of the electromagnetic time reversal (EMTR) theory and the Transmission Line Matrix (TLM) numerical method. Building on the work previously presented at the IWCS, where the method had been presented using two observation points, this paper shows further progress in this research and as a proof of its effectiveness, shows its ability in locating PDs using only one observation point. The procedure of the method is briefly described and its performance that overcomes the shortcomings of the traditional PD location methods are summarized. Finally, future related activities are described.

Keywords: Partial Discharge; faults; insulation degradation; location methods; power cable; power networks resilience; electromagnetic time reversal; transmission line matrix method; electricity security.

1. Introduction

Partial discharges (PD) are localized electrical discharge, starting in defects of the power cable insulation, that partially bridge the insulation between conductors [1]. The deterioration of the cable insulation in power networks is often caused by PD events that, for this reason, are considered the best warning indicators of insulation degradation [2]. Insulation failure in power cables of transmission and distribution networks range from faults to supply interruption and blackouts and so it can have severe social and economic consequences. Since, statistics indicate that more than 85% of equipment failures are related to insulation failure [3], then, the adoption of on-line PD location methods that can locate insulation degradation is an effective solution for condition monitoring of networks to improve their reliability and resilience.

The PD location problem in power networks is a topic widely investigated in the literature. Most on-line PD location methods are reflectometry or traveling wave-based techniques [**Error! Reference source not found.**-6], most of them multi-end measurement techniques (i.e. time of arrival, ToA, methods). They are based on the principle that a PD event produces electromagnetic waves that travel in either direction towards the cable ends. The incident wave, and the reflected waves from the other cable ends, are measured at different points on the line and the time of arrival of these pulses allows one to locate the PD source. But their practical implementation is difficult due to the complexity in the synchronization procedure, often realized using laborious global position systems. Moreover, their accuracy in locating PD is influenced by the distortion phenomenon that characterized the PD signals' propagation on power cables and by the presence of electromagnetic interference (EMI) on networks. Wavelet techniques [7-8] are adopted to overcome some of the shortcomings associated with reflectometry method, but these require a considerable amount of computational effort.

EMTR (Electromagnetic Time Reversal) [9] theory has been recently used in locating sources of electromagnetic disturbances in power systems and methods to locate lightning strikes, lightning-originated flashovers [10] and faults [11] have been developed, showing an improvement in the performance with respect to the classical location approaches. The authors have developed a new method for the on-line PD location based on the EMTR theory and on the use of the Transmission Line Matrix (TLM) numerical method to model the time reversal (TR) propagation of the PD signals [12-17].

This paper reviews the results obtained in the design process of this new PD location method. Building on the work previously presented at the IWCS [19], where the method had been presented using two observation points, this paper shows further development of the method. As a proof of its effectiveness, the paper shows its ability to locate PD sources in lines with both homogeneous and inhomogeneous cable sections using only one observation point. An analysis of the accuracy in the location of PD sources of the new proposed method with respect to the classical reflectometry methods is given, showing the improved performance given by the EMTR theory to localize PD sources and how the new method addresses and overcomes the big challenges affecting the classical PD location approaches. Finally, future activities related to the new EMTR-based PD location method are described.

2. EMTR-based PD Location Method

The EMTR-based PD location method is based on the invariance under time reversal (TR) of the telegrapher's equations in a non-dissipative medium [9]. For non-dissipative lines, shown in Figure 1, the telegrapher's equations in the TR domain, obtained by inverting the time *(t ⟶ –t)* and by changing the current sign, are given by:

$$\frac{\partial v(x,\ -t)}{\partial x} + L\frac{\partial(-i(x,-t))}{\partial(-t)} = 0 \qquad (1.1)$$

$$\frac{\partial(-i(x,\ -t))}{\partial x} + C\frac{\partial(v(x,-t))}{\partial(-t)} = 0 \qquad (1.2)$$

where L and C are, respectively, the per unit-length inductance and capacitance of the line, characterized by a propagation speed, u, and a characteristic impedance, Z_0, given by:

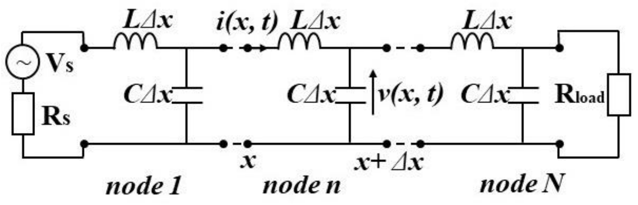


Figure 1. Loss-less transmission line.

$$u = \frac{1}{\sqrt{LC}} \quad ; \quad Z_0 = \sqrt{\frac{L}{C}} \qquad (2)$$

The Transmission Line Matrix (TLM) method has been used to solve equations (1) and to describe the TR propagation of the measured PD signal in a 1D lossless model of the line. The TLM method discretizes the transmission line, of length l, into a mesh of N segments, of length Δx. Each LC section of the line is represented by a transmission line of impedance Z_0, given by relation (2).

The basic steps of the EMTR PD location method are shown in Figure 2 [12-17]. They involve measuring the high frequency signal, $s(x,\ t)$, generated by the PD event, in an observation point (OP) of the line, time reversing the measured signal, and back-injecting the time-reversed signal into a model of the line.

The time reversibility of the telegrapher equations and the spatial correlation property of the EMTR theory allow the refocusing of the time reversed, back-propagated PD signal into its original source location.

The measured PD signal is time reversed as follows:

$$s(x,\ t) \rightarrow s_i(x, T - t) \qquad (3)$$

where T is the observation period, and it is back injected (from the same OP of the line where it was measured) into the 1D TLM model of the line. Then, several TR simulations are performed considering in each of them a guessed partial discharge locations (GPDL) in a node of the line. The GPDL node is characterized by a transversal capacitive impedance [4] representing the effect of the PD inside the cable insulator and the energy stored in it is evaluated as follows:

$$En = \frac{\frac{1}{2} C_{PD} \sum_{k=1}^{M} V_{GPDL}^{2}(k)}{\frac{1}{2} C_{PD} \sum_{k=1}^{M} V_{GPDL\_m}^{2}(k)} \qquad with \quad M = T/\Delta t \qquad (4)$$

where $V_{GPDL\_m}(k)$ is the maximum voltage of the GPDLs at the time step k, C_{PD} is the transversal capacitance of the GPDL, M the number of samples of the recorded signal and Δt the sampling time. The GPDL characterized by the maximum energy is the PD location because the time reversed PD pulses add up in phase at the real PD location during the backward propagation.

3. Simulated Performance of the EMTR PD Location method

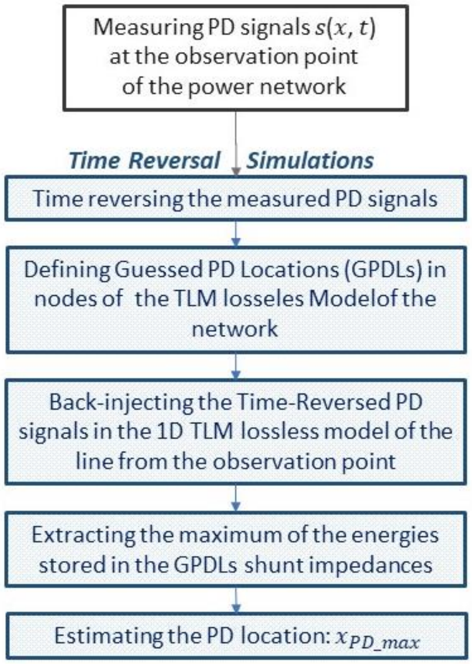


Figure 2. Schematic EMTR method to locate PDs [12-17].

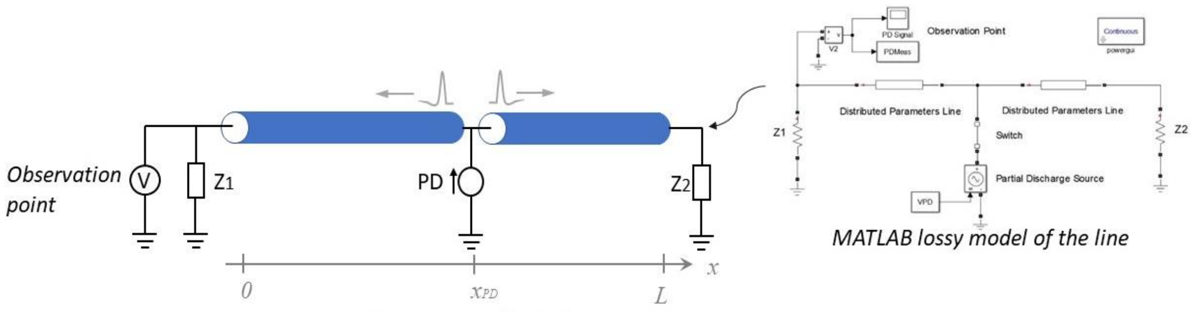
The method effectiveness has been proved by the authors both numerically [13-15] and experimentally [16] and both in homogeneous and inhomogeneous power lines. Here, for the purpose of illustration, some simulation results are given to show the method's behavior and its effectiveness in localizing PDs. To this aim, the measurement of PD signals in real lines, that is the first step of the EMTR location procedure reported in Figure 2, is here substituted by a simulation in the direct time (DT) domain as follows.

A simulation in the DT domain is performed in a lossy model of the power line under study with a PD event that occurs at a point, x_{PD}, of the line. The generated PD high frequency pulses are recorded at one observation point (OP) located at the left end of the line. Figure 3 shows a schematic of the system under study.

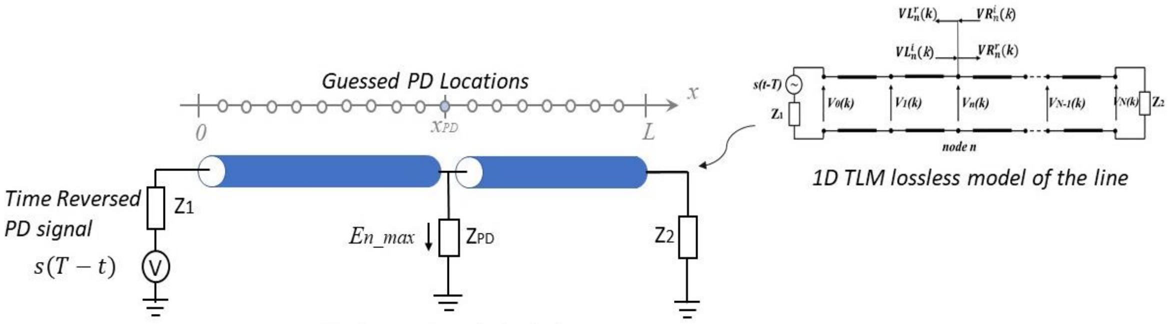
The DT simulation is performed using a lossy model of the line developed in Simscape, a MATLAB toolbox. The model uses the Bergeron's traveling wave method adopted by the Electromagnetic Transient Program (EMTP) [18]. The distributed parameter blocks, shown in Figure 3, realize a mono-phase distributed parameter line with lumped losses. The Bergeron model approximates losses by considering the conductance G=0 and adding series lumped resistance into a lossless distributed LC parameter model of a transmission line with a characteristic impedance Z_0 and phase velocity u given by relations (2). The losses are concentrated at the two line ends and in the middle of the line as follows: R/4 at both ends and R/2 at the middle, with R the series resistance of the line. The Bergeron model of a line, even with concentrated losses, does not represent the frequency dependence of R and L parameters, given by the skin effect, so it doesn't reproduce the travelling-wave dispersion and distortion.

The power line under study is connected at its ends to the impedances, Z_1 and Z_2 representing two power transformers. Then, the value of Z_1 and Z_2 is defined equal to 100kΩ that is the evaluated value of the input characteristic impedance of power transformers at the high frequency [15].

The impulsive signal generated by the PD event is represented by a double exponential signal with a rise time of 2 ns and a pulse length of 10 ns [15]. Since the PD event occurs inside the insulation between



(a) Direct Time simulation



(b) Time Reversal simulations

Figure 3 Schemes and MATLAB lossy model of the line for the DT simulation (a) and scheme and 1D TLM lossless model of the line for the TR simulations.

the inner conductor and the external shield, ground connected, in the model, the PD pulse is applied between the conductor and the ground. The generated signal, *s(x,t)*, is recorded at the OP, using an ideal voltage sensor. This signal is time-reversed and back-injected in the 1D TLM lossless model of the line to perform the TR simulations and localize the PD source, as explained in Section 2 and following the steps showed in Figure 2.

The analyzed line is 2 km long and it is formed by a 33 kV MV single-phase coaxial cable with copper conductors and Cross-Linked Polyethylene (XLPE) insulator [19]. The cable characteristics are reported in Table 1 of Figure 4 (a).

To also show the method's effectiveness in lines with inhomogeneous cable sections, a line 2 km long, formed by two sections, respectively l_1 =1200 m and, l_2 =800 m long, is considered with the characteristics shown in table 2 of Figure 3 (d). The second cable section is the same as the first section but with EPR insulation between the inner and outer conductors of the coaxial cable. Then, two cable sections have a different shunt capacitance per unit length and a different characteristic impedance and propagation speed, as Table 2 shows.

For both the considered lines, Figures 4 and 5 show the simulation results of the localization procedure based on EMTR, with four different PD source positions along the lines. In more detail, for the homogeneous line the localization results when the PD source is located at 250, m and 1360 m from the observation point are shown, while for the inhomogeneous line the results when the PD source is in the first section of the line at 500 m and when the PD source is in the second section of the line at 1650 m from the OP are reported. As the figure shows, the method is able to localize the PD source both in homogeneous and inhomogeneous power lines, using only one OP, with an error, evaluated with respect to the line length, always lower than 0.2%. In the case shown in Figure 4.(c) the relative error is, in fact, of 0.1%, and in Figures 5.(b) and (c) is, respectively of 0.05% and 0.2%. In Figures 4.(a) and 5.(b) the PD signals measured at the OP for both the homogeneous and inhomogeneous lines are reported, when respectively the PD source is at 250 and at 1750 m from the OP. The time reversed signals, used to perform the TR simulations, are also shown. Due to the concentrated losses of the adopted model for DT simulations, an attenuation on the PD signal's amplitude can be observed. Moreover, Figure 5.(b) shows the PD signal reflections due to the discontinuity of the line. In the following sections, the accuracy of the EMTR method is analyzed and how its performance overcomes the shortcomings of the classical PD location methods is discussed.

4. Accuracy Analysis of the EMTR Method and Comparison with Classical Approaches

This section discusses how the proposed EMTR method addresses and solves most of the phenomena affecting the accuracy and effectiveness of the classical PD location methods.

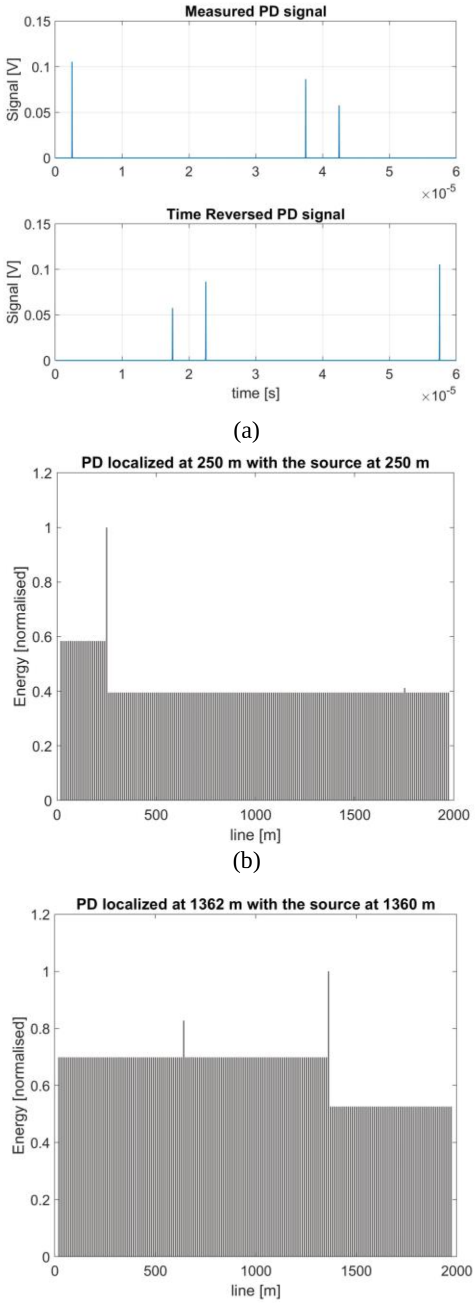
The accuracy and effectiveness of the classical reflectometry-based approach adopted to localize PD on power networks are affected by the following phenomena:

- Distortion of PD signal during propagation along the line due to the variation with frequency of the cable characteristics and to the line inhomogeneities caused by the presence of joints and different cable sections.
- Distortion of the PD signal by to the sensor used to measure PD signals at the observation points.
- Presence of electromagnetic interference (EMI) on power lines that often completely overshadow PD signals.

Each of these phenomena is also introduced and explained in the following subsections.

Table 1. Parameters of the homogeneous line

Parameter	Value	Unit
R	$0.099 \cdot 10^{-3}$	Ω/m
L	$3.8515 \cdot 10^{-7}$	H/m
C	$0.259 \cdot 10^{-9}$	F/m
u	$1.001 \cdot 10^{+8}$	m/s
Z_0	38.57	Ω



(a)

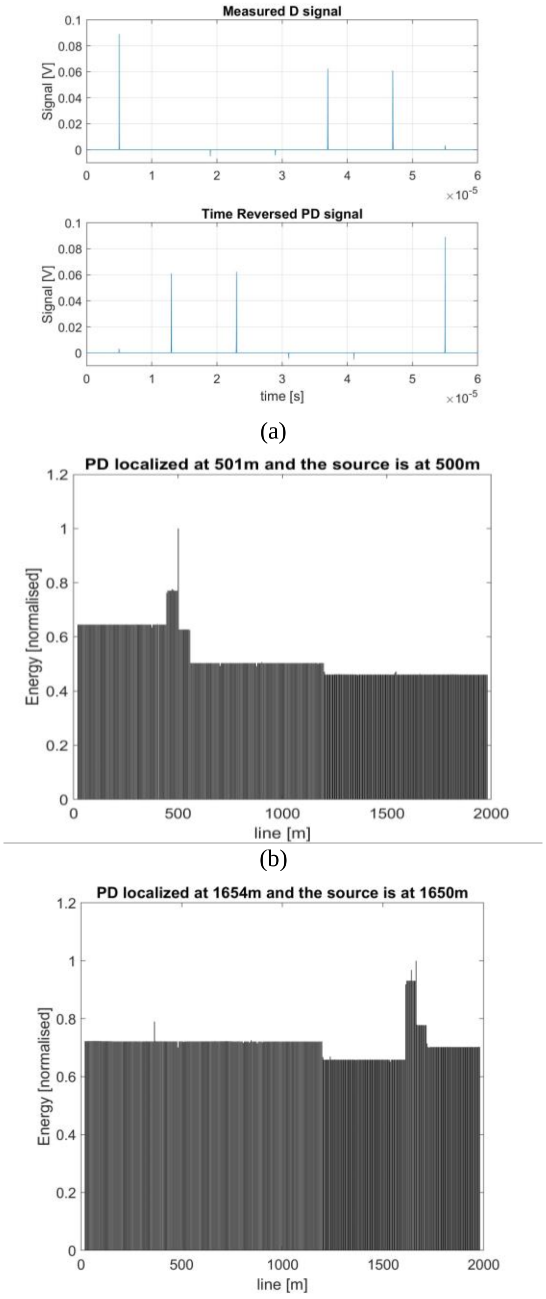
(b)

(c)

Figure 4. Recorded and TR PD signals with PD at 250 m (a), energy at the GPDLs with PD source at 250 m (b) and at 1360 m (c), in the homogeneous line.

Table 2. Parameters of the inhomogeneous line

Parameter	Value	Unit
R	$0.099 \cdot 10^{-3}$	Ω/m
L	$3.8535 \cdot 10^{-7}$	H/m
C_1, C_2	$0.259 \cdot 10^{-9}$ $0.309 \cdot 10^{-9}$	F/m
u_1, u_2	$1.001 \cdot 10^{+8}$ $0.9166 \cdot 10^{+8}$	m/s
Z_{01}, Z_{02}	38.57, 35.30	Ω



(a)

(b)

(c)

Figure 5. Recorded and TR PD signals with PD at 1650 m (a), energy at the GPDLs with PD source at 500 m (b) and at 1650 m (c) in the inhomogeneous line.

4.1 PD signal distortion and line inhomogeneities

PD signals during their propagation along the line are subjected to the phenomena of dispersion and attenuation that produce distortion of the PD with respect to the PD signal at the source.

This is due above all to the nonlinear dependence with frequency of the complex characteristic impedance, Z, and the propagation function, γ, of the line given by:

$$Z = \sqrt{(R + j\omega L)/(G + j\omega C)} \qquad (5)$$

$$\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)} \qquad (6)$$

where $(R + j\omega L)$ and $(G + j\omega C)$ are the distributed complex impedance and admittance of the line, $\omega = 2\pi f$ is the angular frequency and f the frequency, α and β the attenuation and the phase function.

The attenuation function, α, produces a reduction of the amplitude of the travelling signal, while the phase function, β, is related to the phase velocity of the signal, u, by the relation:

$$u = \frac{\omega}{\beta} = \frac{2\pi}{\beta} f \qquad (7)$$

Because in real power lines, β is not directly proportional to the frequency, the velocity u is not linear with the frequency causing the PD pulse dispersion. These two phenomena produce a separation of the frequency components of the PD signals and a different attenuation of the frequency components with the frequency. In particular, the higher frequency components are attenuated more quickly than the lower ones and the higher frequency components propagate more quickly than lower ones, causing the distortion of the PD signals [13].

In real lines, this behaviour is caused above all by the skin effect that is a nonuniform distribution of the current density inside the conductors due to the time-varying magnetic flux.

In Figure 6 the distortion of a PD signal during its propagation along a line is shown [13]. The figure shows the PD signal at the beginning of the line and the same PD signal after 200 m of propagation, obtained in simulation using a theoretical validated model of a line developed by the authors in [13] that is able to reproduce the skin effect. As Figure 6 shows the signal is attenuated and its shape is modified causing a reduction of its bandwidth [16].

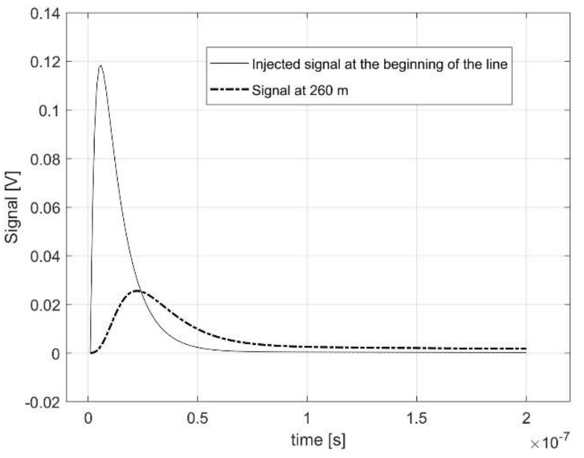


Figure 6. PD signal distortion during its propagation along the line [13].

Furthermore, the PD signal is distorted by the presence of joints, terminations [16] and cable sections with different impedances and propagation constants [13,14], before reaching the observation point, to be recorded there.

The travelling PD pulses will be reflected and attenuated at all changes of the characteristic impedance along the line.

These phenomena affect the accuracy of the on-line location method; and when the attenuation and distortion is too heavy, a multi-measurement PD location method is required with synchronized PD signal measurements in two or more observation points of the line. Multi-end measurements methods are difficult to implement because of difficulties in the synchronization procedure, and the loss of the GPS signal coming from the on-line GPS measurement stations, recently also affected by intentional electromagnetic interference (IEMI) due to the line cyber-attacks.

The proposed EMTR method is able to localize PD source with a relative error with respect to the line length of about 0.14% in real MV power lines up to 2 km long using only one observation point [12] and with a relative error that is always ≤1.5% in inhomogeneous lines [13,14].

4.2 Sensors for PD signal measurement

The on-line detection of PD signals is performed using a sensor, such as high frequency current transformers (HFCT) sensors, Rogowski coils, ultrasonic and acoustic sensors, coupled to the cable and connected to a processing system, e.g. digital oscilloscope or spectrum analyser. The measurement device produces a further distortion of the PD signal due to the limited bandwidth of the sensor, allowing the detection of only a portion of the frequency content of the PD signals. For example, HFCTs, the most used sensors, are characterized by passbands from a few hundred kHz to a few MHz [12]. Then, considering a 100kHz-20MHz HFCT, its behavior can be simulated using a passband filter. Realizing it in MATLAB using a FIR digital filter [16], its effect on a PD signal, that can be represented with a double exponential equation as follows:

$$s_{PD}(t) = A_0\left(-e^{-\frac{t}{\tau_1}} + e^{-\frac{t}{\tau_2}}\right) \qquad (8)$$

with A_0=0.1, τ_1 = 2 ns, τ_2=10 ns, is reported in Figure 7.

This further distortion on the measured PD signal affects the accuracy of the TDR-based methods.

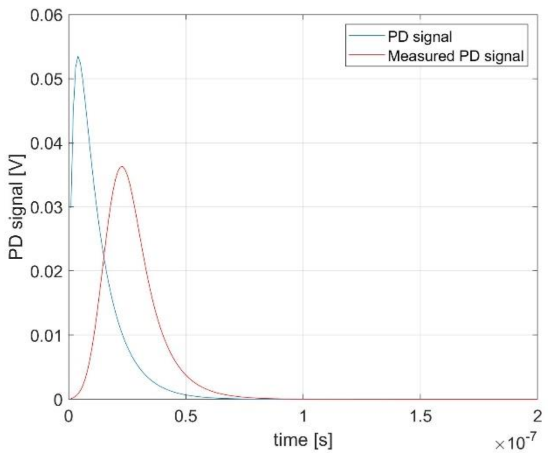


Figure 7 PD signal at the input of the HFCT sensor (blue) and PD signal at the output of the sensor (red) [17].

In the classical TDR-based methods, to obtain a good location resolution, the PD measuring systems must be characterized by a detection sensor with bandwidth of several MHz [1].

The new EMTR-based method has shown to be able to localize PD source with errors <0.15% using the currently adopted HFCTs with bandwidth of 100 kHz to 20 MHz [12].

4.3 EMI on power networks

The presence of electromagnetic interference (EMI) on power networks is one of the big challenges in on-line PD location. Power networks are indeed subject to several electromagnetic disturbances that can be classified into [12]:

1. narrow band noise, that arises from communications systems such as AM/FM radio signals.
2. wide band noise that is pulse-type and that comes from power electronics, due to the increasing use of inverters and VSD/VFD motors on medium voltage networks, lightning and switching operations.
3. Gaussian white noise produced by measuring instruments and high voltage equipment.

Because PD signals are pulses with a low amplitude, a fast rise time, a duration of a few hundred nanoseconds, in the network harsh noisy environment, they are often completely overshadowed by EMI. Figure 8 shows, a typical PD signal that can be measured on-line at an OP of the network. The signal is buried in white noise with a SNR (signal to noise ratio) equal to -5dB. The signal in Figure 8 has been built using the model of a lossy line developed by the authors in [13] that is able to reproduce the PD signal distortion due to propagation and then by adding the white and narrowband noises to the signal using toolboxes of MATLAB. The presence of EMI heavily affects the accuracy and often can annul the effectiveness of the on-line PD location methods.

To address this shortcoming, the wavelet transform (WT) techniques are currently applied to de-noise the PD signals in most on-line detection and location methods. But even if the WT techniques are powerful signal processing tools that can be implemented in both time and frequency domains, they also require a considerable amount of computational effort and experienced operators. The proposed new EMTR method has shown [12] to be able to localise PD source also in an electromagnetically noisy environment on power line with error always <0.5% with SNR down to -7dB and with a computational time of only 3 minutes.

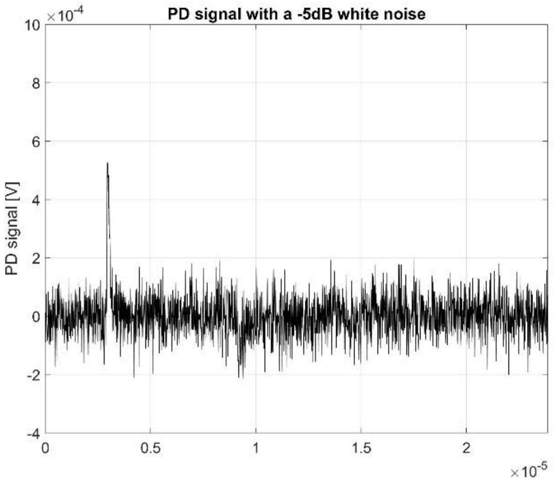


Figure 8 Simulated PD signal with on-line noises in power networks, in time and frequency domain.

5. Conclusions and Future Works

The paper describes the effectiveness of a new method to localize on-line PD in power networks and analyze its improved performance with respect to the classical PD location approaches, The New method based on the EMTR theory and on the use of the TLM numerical method to describe the time reversal propagation of the Pd signals is introduced and explained. Its effectiveness is shown in simulation for both homogeneous and inhomogeneous power lines. The accuracy of the EMTR-based method is analyzed and its ability to overcome the shortcomings of the classical approaches related to the PD signal distortion due to the frequency dependent variation of the line characteristics, to the presence of joints and inhomogeneous cable sections in the power lines and the bandwidth of the adopted measurement sensors is discussed. The ability of the new method to address and solve the great challenge of the EMI presence that affects the effectiveness of the classical approaches, is also presented. The accuracy of the EMTR method also with the presence of joints in power lines is under analysis with good results. Future planned works are the analysis of the performance of the method in a more complex/branched power network. Studies to further increase its accuracy improving the procedure to estimate the lines parameters to be used in the 1D TLM model for the TR simulations are also planned.

6. Acknowledgments

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7. References

[1] EN 60270 - High-voltage test techniques - Partial discharge measurements (IEC 60270:2000) – 2001.

[2] F. Auzanneau,Wire Troubleshooting and diagnosis: Review and perspectives, Progress In Electr. Res.h B, Vol. 49, 2013.

[3] S. Refaat, M. Sham – "A Review of Partial Discharge Detection, Diagnosis Techniques in High Voltage Power Cables" - IEEE Int. Conf. on Comp. Pow. Elect. and Power Eng., 2018.

[4] M. S. Mashikian, R. Bansal, R. B. Northrop – "Location and Characterization of Partial Discharge sites in Shielded Power cables" - IEEE Trans. on Pow. Del., Vol. 5, No.2, April 1990.

[5] Y. Zhou, Y. Qin, P. Chappell – "Cost-Effective On-Line Partial Discharge Measurements for Cables" - IEEE Electrical Insulation Mag, Vol. 22, No. 2 Mar-Apr 2006. Pgs.31-38.

[6] F. P. Mohamed, W. H. Siew, J. J. Soraghan, S. M. Strachan - "Partial Discharge Location in Power Cables using a Double Ended Method Based on Time Triggering with GPS"- IEEE Trans. on Dielec. and Elect. Insul., Vol. 20, No. 6; Dec. 2013.

[7] H. Zhang, T.R. Blackburn, B.T. Phung, D. Sen - "A Novel Wavelet Transform Technique for On-line Partial Discharge Measurements Part 1: WT De-noising Algorithm"- IEEE Trans. on Dielect. and Elect. Insulation, Vol. 14, No. 1; February 2007.

[8] J. Zhon, X.Bi, Q. Shu, , M. Chen, D. Zhou, D. Zhang, "Partial Discharge Signal Denoising Based on Singular Value Decomposition and Empirical Wavelet Transform" IEEE Trans. on Instr. and Meas., Vol. 69, No. 11, Nov. 2020.

[9] F. Rachidi, M. Rubinstein, M. Paolone, "Electromagnetic Time Reversal – Application to Electromagnetic Compatibility and Power System" - John Wiley & Sons Ltd, 2017; pp. 95-97.

[10] G. Lugrin, N. Mora Parra, F. Rachidi, Fellow, Marcos Rubinstein, G. Diendorfer, "On the Location of Lightning Discharges Using Time Reversal of Electromagnetic Fields", IEEE Trans. on EMC, Vol. 56, No. 1, 2014.

[11] S.Y. He, Y.Z. Xie, Z.Wang, F.Rachidi, B.Y. Liu, Q Li, X. Kong - "Norm Criteria in the Electromagnetic Time Reversal Technique for Fault Location in Transmission Lines"- IEEE Trans. on EMC, Vol. 60, No. 5, Oct. 2018.

[12] A. Ragusa, H. Sasse, A. Duffy, M. Rubinstein – "Application to Real Power Networks of a Method to Locate Partial Discharges Based on Electromagnetic Time Reversal", accepted by to IEEE Trans. on Power Delivery in July 2021.

[13] A. Ragusa, H. Sasse, A. Duffy, "On-Line Partial Discharge Localization in Power Cables Based on Electromagnetic Time Reversal Theory - Numerical Validation", accepted by IEEE Trans. on Power Delivery in July. 2021.

[14] A. Ragusa, H. Sasse, A. Duffy, "Electromagnetic Time Reversal to Locate Partial Discharges in Power Networks with Inhomogeneous cables using the Transmission Line Matrix Method"- CIGRE Science and Engineering Journal, June 2021

[15] A. Ragusa, H. Sasse, A. Duffy, F. Rachidi, M. Rubinstein, Electromagnetic Time Reversal Method to Locate Partial Discharges in Power Networks using 1D TLM modelling, IEEE Letters on EMC Practice and Appl., Vol. 3, No 1, March 2021.

[16] A. Ragusa, H. Sasse, A. Duffy – "Time Reversal for Partial Discharge Localization on Power Lines with Different Termination Impedances" – The 2021 Asia-Pacific Inter. Symp. on EMC (APEMC) Bali, Indonesia, 27-30 Sept. 2021.

[17] A. Ragusa, H. Sasse, A. Duffy, "Electromagnetic Time Reversal to Locate Partial Discharges", 2021 MCAA Annual Conference, 5 – 7 March 2021.

[18] Dommel, H., "Digital Computer Solution of Electromagnetic Transients in Single and Multiple Networks," IEEE Trans. on Power Apparatus and Systems, Vol. PAS-88, No. 4, April 1969.

[19] https://www.elandcables.com/media/1460439/wpd-19-33-36-kv-single-core-unarmoured-copper-conductor.pdf, last access on the 30th of July 2021.

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