ELECTROMAGNETIC TIME REVERSAL APPLIED TO ONLINE PARTIAL DISCHARGE LOCATION IN POWER CABLES: INFLUENCE OF INTERFERING REFLECTIONS FROM THE CABLE CIRCUIT

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Abstract

In online single-sided partial discharge (PD) location settings, PD reflection patterns are affected by all components present in the cable circuit. This paper describes the performance of electromagnetic time reversal (EMTR) when interfering reflections contribute to the transient waveforms emitted by the PD. The analysed situation refers to a ring main unit (RMU) in the medium voltage (MV) grid where PD recordings are disturbed by signals reflected from the other cables connected to the RMU, potentially affecting the PD location accuracy. We show that the accuracy of EMTR-based location methods is unaffected by such effects.

1 Introduction

Online partial discharge (PD) location in cable insulation in power grids improves the grid reliability and avoids faults [1]. In medium voltage (MV) grids, PD measurement units are installed inside a ring main unit (RMU) as shown in Fig.1 [2]. An RMU has typically 1 to 5 connected MV cables and an MV/low voltage (LV) distribution transformer. One cable section between two RMUs or more consecutive cables, with RMUs in between, are monitored [2]. The effectiveness is affected by the noise in the grid and PD signal distortion during propagation that make it difficult to identify the proper PD signal peaks to locate the PD source [1]. One challenge in single-sided PD locating, monitoring a cable in an RMU, arises from PD pulses reflected from the cables connected to the same RMU. The RMU distribution transformer and the cable connecting the transformer to the busbar act as a complex impedance often characterised by a reflection coefficient that allows transmission from the other RMU connected cables. The PD return signals affect the measured PD signal, making it difficult to locate the source with traditional methods like signal threshold discrimination.
In previous work [3, 4], the authors have shown that EMTR overcomes PD localisation issues due to noise and signal distortion. In this paper, the effect of the PD return signals is analysed and how an EMTR-based method addresses it is described.

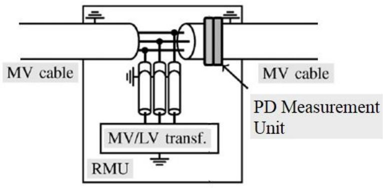

Figure 1: RMU with the PD measurement unit [1].

2 EMTR method and system under study

The EMTR method [3] uses a Transmission Line Matrix (TLM) model of the line to perform the time reversed (TR) simulations. The involved steps are: (i) measure the PD-emitted transient signal, (ii) time reverse the measured PD signal, (iii) inject the TR signal into the TLM model of the cable network, (iv) perform TR simulations for different guessed PD locations (GPDLs) along the line, and, (v) locate the PD based on the maximum energy concentration at GPDLs.
The system in Fig. 2 is used to simulate the PD waveforms. The cable under test (L_2) is monitored at the observation point (OP). A cable (L_1) is connected to the OP. Both cables are open ended. The cable model described in [4] is used for the simulation. A PD is simulated at an arbitrary location on L_2. The PD signal propagates along L_2 and reaches the OP. Part of the signal reflects back (if the characteristic impedances of the cables are different) and part of it continues along L_1. The PD sensor at OP measures the direct and reflected PD signals from L_2 but also the return signals from L_1. In this first simplified analysis, the RMU at the OP is not modelled, and only the interfering effect of the PD reflected signals is considered.

3. Results and discussion

The EMTR method is used to locate PDs in the system of Fig. 2. The impedances same Z_1 and Z_2 of lines L_1 and L_2 are equal to 10 Ω.

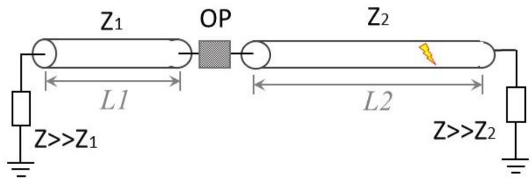

Figure 2: System under study.

A PD is simulated 1500 m from the OP in L_2. The length of L2 is 2 km. At the OP, the sensor measures a PD signal disturbed by the PD return signals from L_1. Fig. 3 shows the PD signal when the line L_1 is, respectively, 400 m and 1200 m long. In Fig. 3, the PD signal measurements in the two cases are quite different due to the return signals, even though the PD originates from the same location. Classical single-sided Time Domain Reflectometry methods require prior identification of the origin of the peaks, which can be hard if severe overlapping occurs.

The TR method is applied using the disturbed PD signal collected at the OP. Each TR simulation is performed on both the L_2 and the L_1 lines. So, GPDLs explore the whole cable system connected to the OP.

Fig. 4 shows the results from the EMTR method (normalized energy at each GPDL) in the cases of Fig. 3. Fig. 5 shows the PD signal and the location result

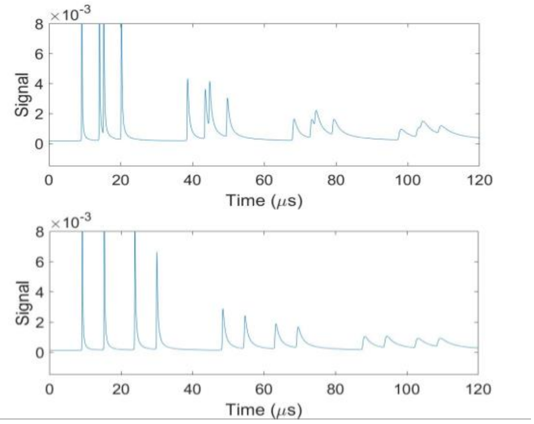

Fig. 3 PD signal at the OP when L_1=400 m (upper) and L_1=1200 m (lower).

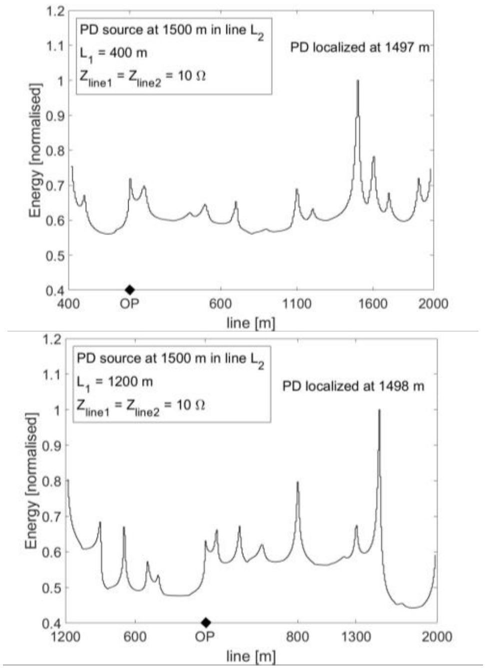

Fig. 4 PD source at 1500 m, Z_1=Z_2 and L_1=400 m (upper) and L_1=1200 m (lower).

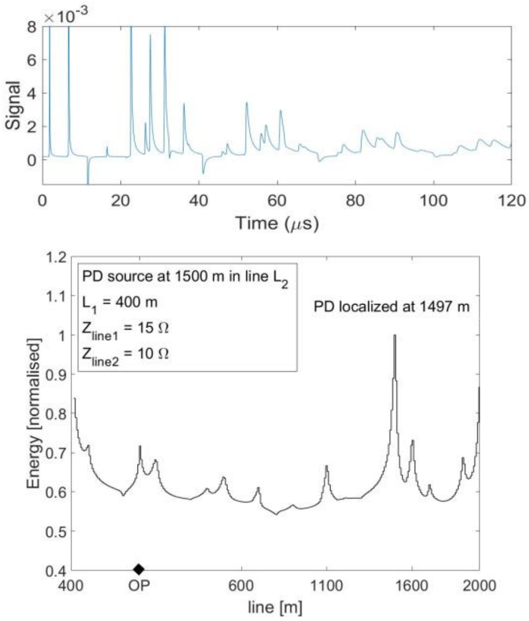

Fig. 5 PD signal (upper) and PD source at 1500 m, L_1=400 m and $Z_1 \neq Z_2$ (lower).

when L_1=400 m and Z_1=15 Ω. The results show that the method can locate PDs despite the presence of interfering reflections.

4. Conclusion and future activities

The paper shows that EMTR is promising in locating PDs in the presence of interfering PD reflected signals coming from discontinuities along the cable circuit. It shows also that the monitoring point can be located at an arbitrary point along the line and not necessarily at the line termination. In our future work, we are planning to include the RMU into the cable network model to also consider the signal distortion by the RMU impedance.

References

[1] F. Auzanneau, "Wire Troubleshooting and diagnosis: Review and perspectives", *Progress in Electromagnetics Research B*, Vol. 49, 2013.

[2] P. Wagenaars, P. A. A. F. Wouters, P. C. J. M. van der Wielen, E. F. Steennis, "Influence of ring main units and substations on online partial-discharge detection and location in medium-voltage networks," *IEEE Trans. Power Delivery*, vol. 26, no. 2, Apr. 2011.

[3] 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 L-EMCPA,* Vol.3, n.1, March2021

[4] A. Ragusa, P. A. A. F. Wouters, H. Sasse, A. Duffy, "The Effect of the Ring Mains Units for On-line Partial Discharge Location with Time Reversal in Medium Voltage Networks", *IEEE Access*, 22 March 2022.