ELECTROMAGNETIC TIME REVERSAL
FOR PARTIAL DISCHARGE LOCALISATION IN DC SYSTEMS

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Abstract

The paper analyses the possibility of using electromagnetic time reversal (EMTR) with transmission-line matrix (TLM) numerical method to locate partial discharges (PD) in DC power systems, introducing the open challenges with PDs in DC systems.

1 Introduction

In cables, partial discharges (PDs) are electrical discharges occurring inside the defects of the insulation and, after a period of activity, they can cause insulation breakdown. Therefore, on-line PD localisation allows the avoidance of faults on the power grid, with resulting possible supply interruption, and it is a desired feature in the protection schemes of modern networks to enhance electricity security [1]. DC power transmission and distribution is increasingly used due to lower transmission losses than for AC systems, driven by the rising use of renewable energy sources (RES) from climate change concerns. While a large body of works exist on PD phenomena, detection, monitoring and localisation in AC networks, the research related to PD in DC systems is still limited [2].

This paper discusses the possibility of using the electromagnetic time reversal (EMTR) theory, with transmission-line matrix (TLM) method [3], for the localisation of PDs in DC systems. The open challenges on PDs in DC systems are introduced and the EMTR-based localisation method for AC PD is described, highlighting its ability to overcome the shortcomings of the classical localisation approaches based on Time Domain Reflectometry (TDR). Finally, reasons are given why EMTR is promising for application in DC systems.

2 PDs in DC systems and open challenges

PD has been widely investigated in AC but unlike the AC case, the mechanism of PD initiation in DC systems is different, and the related research is at the initial stage. The following challenges and lack of knowledge still exist:

a) PD physics: in DC the field distribution is mainly determined by the insulator conductivity and not by the permittivity like in AC. Insulator conductivity is strongly and non-linearly dependent on temperature, affecting the space charge and so the electric field distribution inside the defect. So, the frequent temperature variations due to the load changes in DC systems make the prediction of DC PD behaviour extremely complex. A definition of PD inception voltage under DC doesn't exist with the highest electric stress depending on time and cable load. [2].

b) PD models: still under development. The well-known three capacitors equivalent circuit in AC must be modified to be used in DC adding the non-linear behaviour of the conductivity, that cannot be simply represented by a resistor in parallel to the capacitors [2].

c) PD sources classification and characterisation: pulse shape parameters are used in AC to discriminate different PD sources, but in DC the strong temperature dependence of cable parameters causes significant PD pulse deformation making source identification and, also, localisation significant challenges. Moreover, Phase Resolved Partial Discharge (PRPD) patterns for the visual representation of PD activity in an AC cycle, can't be used in DC because of the absence of synchronisation with an AC voltage [2]. Some results in characterising the PD pulse shape, in DC compared with AC, have been proposed for corona discharge [4] and in voids of DC cable [5] but the analysis is at an early stage.

c) PD signal de-noising: the electromagnetic environment of DC networks is still not defined and complicated by ripples, pulses, and electromagnetic interference (EMI) from converters, used to change the DC levels and to connect loads and RES to the grid. Separation of noise from PD pulses is technically challenging because the DC PD activity analysis is still at an early stage [2].

d) Standardisation: it is also at an early stage. The Cigrè WG D1.63-"Partial discharge detection under DC voltage stress" states that standards for DC PD measurements are non-existent and the Cigrè TB852 [6] still contains many gaps and weak points [7]. A 4th edition of the IEC 60270 standard is under development, but it primarily considers AC PD measurement, in terms of apparent charge, and considers that specific problems of this technique can arise for DC.

Considering the state-of-art of knowledge on DC PDs, a methodology for their localisation is still at the beginning. It appears to be more difficult in DC than in AC for the following reasons: 1. the absence of periodic voltage reversal, producing different charging process and field distribution inside the defect under DC, makes the PD source classifications more complex, 2. the difficulty in discriminating PD signal from noise, 3. the PD signal distortion due to the strong temperature dependence of the cable characteristics. Within this context, initially, it is necessary to verify if the large bibliography on AC PD is suitable for DC systems. Most of the AC PD location methods are built on the TDR technique based on the measurement, at an observation point (OP), of the direct and reflected PD-generated pulses travelling on the line from the source. Evaluating the delay between the direct pulse reaching OP and the pulse reflected from the other line end allows the PD to be localised. Measurements in multiple OPs are used to decrease the accuracy loss caused by distortion of the PD pulses during propagation along the line, due to inhomogeneous line sections, the presence of joints and ring main units. Computationally intensive wavelet transform techniques, have been adopted to mitigate EMI**.** So, the classical AC approaches' effectiveness is affected by the PD signal distortion and noise, requiring PD signal de-noising, and the use of multi-end measurement methods which require precise time recording to synchronise the multiple measurements. The additional impacts of DC system behaviour on PD propagation means that the use of the classical TDR methods for PD localisation in DC systems will be challenging and new approaches are desirable. Recently, an AC PD localisation method based on the use of EMTR and TLM method has been designed [8-9] that solves the AC methods' shortcomings.

3 Time Reversal for PDs localisation

The localisation method uses the EMTR theory and a lossless TLM model of the grid [8-9]. To build the TLM model only the knowledge of the line characteristic impedance and propagation speed are needed. The method's steps are: (i) measure the PD signal, (ii) time reverse the measured signal, (iii) inject the time reversed (TR) signal into the TLM model, (iv) perform TR simulations for different guessed PD locations (GPDLs) in the line, (v) identifying the GPDL with the maximum energy which localises the source. Results so far on the EMTR method's effectiveness show a significantly improved performance compared to the classical approaches, demonstrating robustness against the EMI presence and effectiveness in complex networks with: several line sections inhomogeneities, the presence of interfering signals, coming from the cable circuit, and a heavy distortion of the PD signal. For example, Fig.1 and Fig. 2 show the EMTR localisation results in the presence of, respectively, noise [8] and a heavily distorted PD signal in a system with other interfering signals [9]. For these reasons, EMTR localisation technique shows promise for use in DC systems.

4. Conclusion

Some challenges on PDs localisation in DC systems are presented and the results in AC systems of the EMTR-based localisation are described. At present, EMTR looks promising for use in DC, then further work is worthwhile.

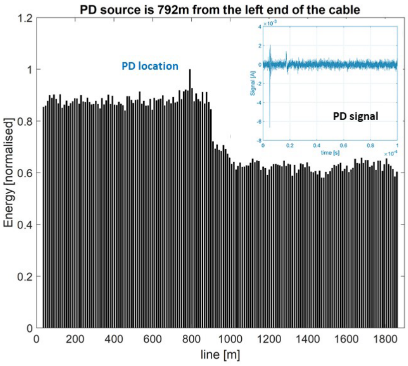

Fig. 1 EMTR PD localisation with noise [8].

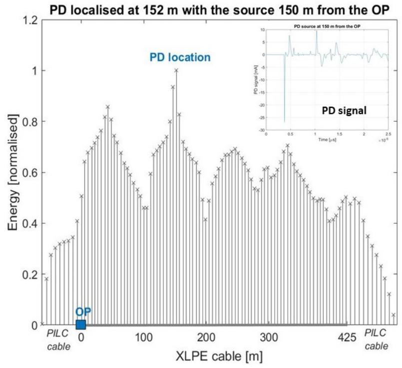

Fig. 2 EMTR PD localisation with interfering signals [9].

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