Online Partial Discharge Detection and Localization of Medium-voltage Overhead Distribution Networks

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Summary

Medium-voltage (MV) overhead distribution networks play a vital role in ensuring reliable power supply and minimizing disruptions and inconveniences to consumers; however, insulation faults in these networks can result in power outages, compromising stability, and causing significant economic and social impacts. The solution to this problem is to conduct condition-based maintenance of the networks. Partial discharge (PD), a phenomenon able to reveal or cause incipient failure of electrical apparatus, is a fundamental indicator in condition-based maintenance. Traditionally, technicians patrol along MV overhead lines to identify PDs by vision- and ultrasonic-based methods. However, this technique is insensitive to the PDs inside the electrical equipment and is laborious and time-consuming for sizeable distribution networks. To overcome these limitations, the traveling wave-based PD diagnosis technique has been explored recently, and it has been proven to detect PD more efficiently and allow monitoring of all apparatuses in the networks online. However, uncertain PD signal propagation distortions, electromagnetic noise interferences, synchronization problems in PD localization, etc., significantly reduce the accuracy and reliability of the technique, impeding its further application for distribution networks. The issues in the traveling wave-based PD diagnosis technique motivated our current study, which offers the following contributions:

PD propagation characteristics in MV three-phase overhead distribution networks are thoroughly investigated. Firstly, PD propagation in MV three-phase overhead distribution networks is modeled based on multiple-conductor theory, along with considering the effect of the alongside towers. The formulas for calculating the

frequency-dependent transmission line parameters are derived from the physical parameters of the overhead line. The developed models and formulas allow us to simulate PD signals at any location within an overhead distribution network. Simulations and measurements validate the feasibility and accuracy of the developed models and formulas. Furthermore, PD propagation simulation experiments are conducted in PSCAD to quantitatively evaluate the effects of network parameters and structures on PD signal features. The results reveal several crucial PD propagation characteristics in MV three-phase overhead distribution networks.

A fully automatic tool for extracting PD signals from noises is developed. The proposed solution addresses the challenges of field noise filtering and hardware selection. On one side, field noise has unavoidable detrimental effects on monitoring, thus demanding a clever and robust solution. On the other hand, the implementation of limited resource hardware is a crucial requirement for a practical design, allowing to reduce production costs. This work describes an adaptive and efficient PD de-noising algorithm based on the improved spectral decomposition of the noisy PD signal. PD pulses are accurately extracted from the noisy signal by cleverly selecting the dominant components via a low-rank singular value decomposition of the time-frequency spectrogram of the signal, thus reducing the size of the involved matrices and the computational complexity. The performance of the proposed de-noising algorithm is first demonstrated on a synthetic PD signal and compared with state-of-the-art alternative techniques implemented on three embedded systems commonly used for PD monitoring. Finally, the proposed approach's strength and effectiveness are further validated on experimental data, demonstrating its better de-noising performance in improving the sensitivity and accuracy of on-site PD measurement.

An improved double-sided (or multiple-sided) PD detection and localization method is developed. Firstly, a specialized high-frequency current transformer with a notch is designed for detecting PD signals online, and a digital compensation algorithm is developed to enhance its performance. Then, an innovative PD localization technique is proposed utilizing an improved double-sided traveling-wave method. This method boasts two key advantages: precise synchronization of double-sided testing units through the combined use of Global Positioning Systems and a pulse-based interaction process, as well as the integration of a windowed phase difference method that robustly estimates time-of-arrival differences even in environments with low signal-to-noise ratios. Moreover, an algorithm for estimating the PD source location based on statistical mapping of multiple location results is proposed to reduce the uncertainty caused by noise. Further, building upon the double-sided localization method, a multiple-sided location algorithm is formulated to identify the source of PD in radial networks. The effectiveness and reliability of the algorithm are verified through Monte Carlo simulations.

Two system prototypes with different PD diagnosis functions are developed based on the proposed methods and techniques. The first is an online PD monitoring system, including a set of compact PD monitors that can achieve low-cost, flexible, and real-time PD monitoring. The in-house design of the PD monitor is presented, including non-invasive sensing, a field energy harvesting function, a low-power working operation, and reliable networking and diagnosis. The other is a portable PD detection and location system, which outputs more detailed information on PDs, i.e., the PD apparent quantity, the PD source location, and the PD-affected apparatuses. The issues of non-invasive pulse injection, safe signal transmission, and clock precise improvement are addressed in this system. The strengths of the two systems are validated via multiple typical application cases. Furthermore, a cost-efficient PD diagnosis strategy for MV overhead distribution networks is developed via the joint application of the two systems.