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Research Article

A Complete Analysis for Detection and Localization of Partial Discharges in XLPE Cables, Power Transformers and Generators

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Abstract

The failures of the power system are caused by insulation damages of HV apparatus including transformers, HV cables and generators. They are expensive. In the beginning, insulation failures occur in limited insulation regions, called partial discharge (PD). When PDs are not detected online, they will spread along the insulation and bridge the whole insulation, eventually resulting in total breakdown. Thus, the HV apparatus fails. This research introduces different sensors such as HFCT and coupling capacitors required to detect the PD of different HV devices including power transformers, HV cables, switchgears, motors and generators. The properties of PD signals occurring in the HV apparatus are determined by experimental results related to PD signals detected from these HV apparatus. Then, an approach uses the correlation between signals energy is suggested to determine the location of PD occurred in the HV devices. The suitability of the proposed approach is satisfied by simulating the PD signals in the EMTP-RV software and processing the detected signals by MATLAB software. It is concluded from the experimental outcomes that the suggested sensors can accurately detect the PD signals that occur in the XLPE cables and transformers. The outcomes show that the suggested method based on the correlation between signals energy can accurately determine the location of PD source in HV devices.

Keywords: Partial Discharge, Power Transformer, XLPE Cable, Correlation, EMTP-RV Software.

Highlights

- Performing a complete study on various sensors used for partial discharge detection in the power transformers, high voltage cables and generators.
- Localization of partial discharges occurred in the power transformers, high voltage cables and generators through detecting of similarity and correlation of PD signals.
- Investigating the effectiveness of localization of PDs in the high voltage apparatus by simulation performed by MATLAB and EMTP-RV software.

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1. Introduction

In recent years, the reliability of the power system results in continuous service with minimal electric power outages is an important aspect of the power system. Experience has shown that most of the recorded failures occurred in the power system are caused by the insulation damage of the high voltage apparatus including power transformers, high voltage XLPE cables, motors and generators, switchgears and so on. These devices are the most expensive apparatus in the power system and so, the failure of them will impose great costs on the power system. The partial discharges are high frequency signals that occur in the limited area of the insulation of high voltage equipment arising from the reduction of insulation strength of that area. If the partial discharge signals are not detected in initial stages, they will spread along the insulation and bridge the entire of insulation resulting in the total breakdown on the insulation. Thus, the condition monitoring of the partial discharge signals that occur in the high voltage apparatus of the power system is important to prevent the insulation damage of this equipment. Due to the importance of the partial discharge detection of the power system equipment, many researches have been performed to study these high frequency signals that occur in the high voltage apparatus including power transformers, XLPE cables, switchgears, motors and generators. In [1], a method is proposed to localize single and multiple partial discharge sources using of signal processing and machine learning based techniques including the mathematical morphology aided feature extraction, and sparse representation classification. In [2], a physical model is proposed for high voltage transformers considering the effect of the windings and the cores on the acoustic wave propagation. In [3], the partial discharge inception voltage and the location of the partial discharge source are determined using of Paschen’s theory. In [4], the localization techniques of the partial discharge at cable ends in the off-line single-sided partial discharge cable measurements are studied.

2. Innovation and contributions

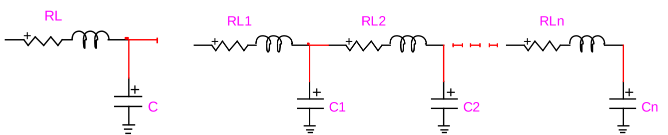
In this paper, a comprehensive study is performed on the partial discharge detection and localization in the high voltage equipment of the power system. Among the innovations of this paper, the following can be stated:
Different sensors used for detection of PD signals in the high voltage apparatus are introduced. The characteristics of the PD signals that occurred in the XLPE cables and transformers based on the experimental tests in the time and frequency domains are presented. A new technique based on the correlation between two signals is introduced for the localization of PD signals in the high voltage apparatus. The effectiveness of the proposed method is examined using the EMTP-RV software.

3. Materials and Methods

In this section, the partial discharge that occurred in the high voltage apparatus of the power system including high voltage XLPE cables and the transformers is detected, and using the frequency analysis, the characteristics of these high frequency currents are determined. A 20kv variable AC voltage source is applied on the conductor of a 11kv XLPE cable. The shield of the cable is connected to the ground and using the high frequency current transformer placed around the ground wire, the partial discharge occurred in the understudied cable is detected. A 20kv variable AC voltage source is applied to the high voltage side of a 20kv/400v old transformer. A copper strip as a capacitive sensor is placed around the high voltage bushing of the transformer and using of a wire, this copper strip is connected to the ground. A high frequency current transformer is place around the ground wire to detect the partial discharge pulses occurred in the transformer and present the waveform of the partial discharge on the oscilloscope screen. In this paper, a novel method based on the current signals measurement using of the calculation the energy correlation is proposed to localize the partial discharge source. For this purpose, the partial discharge pulse is applied to the high voltage equipment. The characteristic of the partial discharge pulses for different high voltage apparatus is different and is dependent on the different mechanisms resulting in the discharge, insulation materials, impurities inside the insulation, and the magnitude and frequency of the applied voltage. The main characteristics of the partial discharge signals include the pulse width, magnitude, frequency spectrum, rising time and damping time. Based on the characteristic of the partial discharge associated with the understudied equipment, the corresponding partial discharge pulses are simulated. Due to the movement of the partial discharge signals in the insulation, the pulses are changed and attenuated (the magnitude and the pulse width of the signal may be changed). The proposed algorithm can determine the location of the partial discharge source based on the signal deformation due to the movement in the insulation. A database composed of the partial discharge signals that occurred in different locations of the insulation must be available. In this method, the distance between the detector to the location of the partial discharge source is changed and in each state the waveform of the partial discharge signal is determined. To localize the partial discharge source, the detected partial discharge by the suitable sensors is compared with the partial discharge signals occurred in different locations. The location of the partial discharge source is determined based on the signal from the database that most closely resembles the detected partial discharge signal.

4. Results and Discussion

In this part, the EMTP-RV software is used to simulate the proposed technique for the localization of PD signals in the high voltage XLPE cables. Due to the high frequency content of the partial discharge waves, the lumped model cannot be used for modeling the high voltage apparatus of the power system. Thus, a distributed model composed of the numerous lumped circuits as presented in Fig. 1 is suggested for this purpose. For different apparatus, the value of the R, L and C are different. To increase the accuracy of the model, each lumped circuit can model shorter length (or fewer turns) of the apparatus.



(a) (b)

Figure 1. The model of high voltage apparatus for PD signals propagation (a) the model of a short length of the equipment, (b) the total model

In this part, an XLPE cable is modeled in the EMTP-RV software as presented in Fig. 14 with 50 lumped parts. A PD pulse is applied to this cable at different locations and the received signals at the end of the cable are determined. These total waveforms received at the end of the cable associated to the application of the PD signal at different locations are presented in Fig. 2.

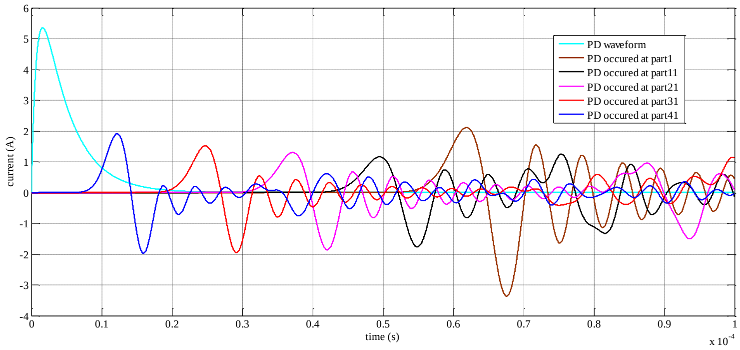


Figure 2. The received signals

The correlations between the signals recorded in the database and the signals detected in the second stage are determined and presented in table 1. It is concluded from the results that the proposed technique can localize the PD source with good accuracy.

5. Conclusion

In this paper, the detection and localization of partial discharge signals that occurred in the high voltage apparatus of the power system are studied. Due to the importance of the online partial discharge monitoring of the high voltage equipment of the power system, different sensors including inductive coupling sensors such as high frequency current transformer and Rogowski coil, capacitive coupling sensors, directional coupling sensors, galvanic coupling sensors, Hall Effect sensors, resistance temperature detectors and the semiconductor layer of the cable are introduced. The frequency characteristics of the partial discharge signals that occurred in the XLPE cables and the transformers are determined based on the frequency analysis of the partial discharge signals recorded in the high voltage laboratory. In these experimental studies, a 11kv XLPE cable and a 20kv/400v transformer are taken into consideration and using of the variable 20kv AC voltage source, the partial discharge is occurred in these apparatus and detected using of the proposed sensors. To determine the location of the partial discharge source in the high voltage equipment, this paper proposes the calculation of the similarity between the detected partial discharge signal and the recorded signals in the database based on the correlation criterion of the energy of the signals. To investigate the effectiveness of the proposed method, three case studies associated to the localization of the partial discharge signals occurred in the XLPE cable, the transformer and the generator are simulated using of the EMTP-RV and ATP-Draw softwares. To determine the correlation criteria between different signals, the MATLAB software is utilized. It is deduced from the experimental results that the proposed sensors can accurately detect the partial discharge occurred in the XLPE cables and transformers. It is also concluded from the simulation results that the proposed technique based on the correlation between the energy of the signals can accurately determine the location of the partial discharge source in the high voltage apparatus.

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Appendix

Table 1. The correlation between the signals

The part of PD applied	1	11	21	31	41
The correlation with the signal detected at the end	0.1295	0.2521	0.7475	0.6793	0.0004
The correlation with the signal detected at part 10	0.1334	0.4748	1	0.6872	0.4171

Table 2. The correlation between signals

	I1	I2	I3	I4	I5	I6
I26	0.1185	0.1168	0.1132	0.1075	0.0991	0.0874
I35	0.1500	0.1513	0.1539	0.1576	0.1623	0.1679
	I7	I8	I9	I10	I11	I12
I26	0.0717	0.0513	0.0254	0.0068	0.0457	0.0916
I35	0.1741	0.1806	0.1870	0.1929	0.1978	0.2015
	I13	I14	I15	I16	I17	I18
I26	0.1448	0.2051	0.2720	0.3451	0.4234	0.5056
I35	0.2035	0.2036	0.2016	0.1972	0.1903	0.1804
	I19	I20	I21	I22	I23	I24
I26	0.5902	0.6749	0.7571	0.8334	0.9001	0.9529
I35	0.1671	0.1499	0.1279	0.1000	0.0650	0.0214
	I25	I26	I27	I28	I29	I30
I26	0.9876	**1**	0.9866	0.9451	0.8748	0.7772
I35	0.0326	0.0988	0.1785	0.2729	0.3817	0.5031
	I31	I32	I33	I34	I35	I36
I26	0.6563	0.5186	0.3727	0.2291	0.0988	0.0071
I35	0.6324	0.7617	0.8784	0.9653	**1**	0.9563
	I37	I38	I39			
I26	0.0779	0.1062	0.0961			
I35	0.8111	0.5684	0.2934			

Declaration of Competing Interest: Authors do not have conflict of interest. The content of the paper is approved by the authors.

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