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Electromagnetic sensing for predictive diagnostics of electrical insulation defects in MV power lines

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ABSTRACT

Insulation degradation is one of the most frequent causes of the failure of electrical components. Partial discharge (PD) has been proven to be a reliable indicator whose early diagnostic can avoid the complete breakdown of the affected component. This paper proposes an online system for PD diagnostic system in a distribution network. A comprehensive diagnostic system is presented by developing a cascaded organization of the detection, location and quantization features. Rogowski coil (induction sensor) is employed for non-intrusive electromagnetic measurement of PD signals. Experimental evaluation is made for over-head covered conductor (CC) lines and medium voltage cables. A scheme is proposed for integration of the developed diagnostic system into the cable network. The explored diagnostic features are equally applicable for cable and CC line based regions of the electricity network. The favorable operating features of the Rogowski coil sensor and simplicity of the applied scheme make it easily adoptable for developing an efficient condition diagnostic system for the distribution networks.

1. Introduction

Environmental and operational stresses cause various types of failure to a power distribution network and hence affect its reliability. The EU studies from 2008 [1] indicate that total economic loss due to power supply outages and bad power quality can be up to 0.15 trillion Euros annually for the EU countries. Network failures can be divided into two categories; unpredictable and predictable failures. Unpredictable failures caused by a natural phenomenon, human intervention or a random operational disorder, are difficult to avoid, as they provide no indication beforehand [2]. However, modern grid of today is improving its resilience by reducing the outage duration. Predictable failures normally have certain traces by which ongoing failure mechanism can be detected with the help suitable monitoring system. Insulation degradation is one the most common causes of failures in critical power components, transformers, switchgears and power lines (cables and over-head covered conductors) [3,4].

Insulation degradation can be caused due to various types of stress such as, aging, environmental, mechanical and operational stresses. PD is a clear indication and then an added cause of insulation deterioration which occurs at weak insulation spots. There are different phenomena which appear during discharges such as, electromagnetic radiation, sound or noise, thermal radiation, gas pressure, chemical formation, and electromagnetic impulses. These phenomena give rise to respective indicators for the detection of the discharge activity. The measurement methodology of PD is based on the type of the energy exchange which takes place during discharges.

Electromagnetic radiation can be in the form of electromagnetic radio frequency waves and optical signals. The

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energy released is caused due to ionization, excitation and recombination processes during discharge. Radiometric techniques have been implemented using ultra high frequency (UHF) receivers (antennas) having bandwidth in few GHz range [5,6]. The ultra violet radiation emitted during PD can be detected by optical sensors such as photographic recorders, photo-multipliers or image intensifiers [7,8]. During discharges the released energy heats the adjacent insulation material which results in a small and rapid explosion producing sound or noise (acoustic) waves. The amplitude of these waves is proportional to the energy released during discharges. Piezoelectric effect based transducers or other acoustic transducers in combination with amplifiers are the most common methods to perform acoustic measurements in power equipment [9,10]. The temperature of the surface of defective site is increased and can be measured by using thermal sensors, however these techniques have not been frequently used for PD measurements [11]. Chemical stresses have a significant contribution in degradation of the dielectric materials and at the same time the discharge process causes chemical changes in the vicinity of the damaged spot [12]. Due to chemical reaction of activated oxygen with the insulation, the internal gas pressure decreases as the discharge occurs. Similarly appearance of by-products such as wax in mass-impregnated cables can be determined to monitor PD [11]. Dissolved gas analysis (DGA) is one of the most commonly used chemical methods for PD diagnostics [13]. Similarly, an important class of PD sensors measures the electromagnetic impulses. Due to rapid movement of the charges during discharge event, voltage and current transient appears in the form of electromagnetic waves. These transients can be measured by resistive, capacitive or inductive methods [14,15]. According to IEC standard 60270, electrical sensors for PD sensing are normally referred as conventional methods whereas non-electrical sensors (mentioned above) are non-conventional methods [16].

In order to get reliable information of the PD faults, it is important to select a suitable type of sensor for measurements. Selection of a PD sensor should be based on the type or structure of the under investigation network component. The generators, transformers, switchgear, and power lines are the most critical components of an electrical power network. These power components can be divided into two groups: Group 1: Closed size components, such as power transformers, generators, motors, and switchgear, which have a definite size and are positioned at a specific place. Group 2: Open size components, such as cables and CC lines, which are distributed along a wider region (few hundred meters up to kilometers).

In this work, PD investigations are focused on 20 kV distribution power lines (overhead covered conductor and cables) as the affected components. The electromagnetic signals are considered for evaluation of PD defects. Considering the suitability of the measurement features of the sensors [17], Electromagnetic induction sensor is selected to capture the propagating PD signals.

Efficient PD diagnostic depends on the performance of the measuring sensor, techniques of measurement and frequency of inspection. This asks for economical sensors, implemented with the techniques providing useful data which contains a clear recognition pattern for correct assessment, and can be easily integrated in the power network on more or less continuous basis. This paper provides a comprehensive approach for developing an online system for insulation condition diagnostics in a distribution network. A high frequency Rogowski coil [18] induction sensor has been employed as PD sensor. A simple measuring technique is implemented for assessment and the location of the PD defects. Based on experimental investigation, a scheme is proposed to integrate the diagnostic system into the network. The contributions of this work can be adopted to enhance the capability of such kind of proactive, diagnostic system.

2. Partial discharges in solid insulation

The ability of the high-voltage insulation material to keep the charges apart at the opposite electrodes depends on its dielectric properties which determine the electrical breakdown strength of that material [19]. During operation, the voltage applied across a component exerts an electric force at its insulation. At normal operation, the electric force is uniformly distributed across its healthy insulation and is less than its rated breakdown strength. However when this material has some defects, voids, gaps or cracks, electrical breakdown strength of this portion of the material decreases. In this case, charges would be able to penetrate through the material, even at normal operating voltages. Such localized charge transfer events are called partial discharges.

PD most often begin within the inclusions in a solid dielectric or at conductor–dielectric interfaces. Initially the discharges are localized and only partially bridge the gaps between the electrodes which are under a certain operational voltage stress. Once the process is triggered, the insulating materials start to deteriorate progressively and eventually lead to a complete electrical breakdown. During each PD event, high frequency electromagnetic pulses of small amplitude are produced which propagate way from the discharge location and can be detected by using high frequency sensors. In this section, PD phenomenon is investigated experimentally and important features of PD signals are explored for PD diagnostics.

2.1. Experimental setup

Test arrangements were made in the laboratory (see Fig. 1(a)) to study the PD signals produced from a test object. Test object (shown in Fig. 1(b)) used in this experiment consists of a plate–plate electrodes assembly inside a cubical solid epoxy resins insulation material. The distance between electrodes is 0.5 cm and there are few air-filled voids within the insulation, between the electrodes. A voltage of 50 Hz is applied across the test object, from a 230 V ac voltage supply to a high voltage (HV) 230 V/100 kV power transformer with variable secondary turns of HV transformer in order to vary the output voltage between 0 and 100 kV. Capacitor C_1 and C_2 makes a voltage divider to measure the applied voltage. PD signals with