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Statistics based method for partial discharge identification in oil paper insulation systems

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ABSTRACT

An original partial discharge generated in oil insulation identification methodology based on simultaneously conducted measurements using electrical method, ultra high frequency method and acoustic emission method is presented in the paper. Three different partial discharge model sources as well as measuring instruments commonly applied for partial discharge detection in electrical power transformers are yielded within a laboratory research. Total of 45 scenarios, including proposed spark gap configurations, selected supply voltage levels and UHF frequencies are analyzed during measurements series. Furthermore, form among total of 93 descriptors assigned for every applied partial discharge model source configuration there are 24 proposed as potentially useful for partial discharge identification applications with their 95% confidence bounds. Attempt of discriminative descriptors selection for partial discharge source analysis in on-site transformer applications as well as a proposal of unique descriptors according to every selected spark gap configuration that could be potentially useful for partial discharge identification purposes are the main purpose of the presented paper. The proposed methodology verification on a real life transformer with particular consideration of the selected descriptors potential utility in the fields of partial discharge detection and identification in electrical power industry applications confirmed a proposed methodology usefulness.

1. Introduction

Partial discharge (PD) phenomenon has been commonly known as inseparable connected with every kind of high voltage apparatus exploitation, e.g. power lines, cables, generators and motors, switchgears, transformers. No matter what kind of electrical power device has been a PD afflicted, in a long term some serious insulation system faults may be caused by it. Nowadays PD diagnostics have been pointed as one of the electrical power fleet maintains and reliability management crucial item. Despite there have been numerous PD measuring methods commonly known and applied, their further improvement especially in the areas of measurement results interpretation as well as measurement procedures simplifying and above all apparatus under normal on-site operation conditions application has been still an essential issue [1–5]. A stochastic nature of a PD phenomenon has been the highest challenge for all of PD measurement methods so far. Most of the physical quantities values registered during a measurement tightly depend on the PD source nature as well as on environment conditions. Any modification of the environment or the PD generation conditions radically affect the final measurement results. There are various research papers where different environmental and physical factors influence on PD generation are investigated, e.g.: voltage level [1,6–9], oil type (mineral, vegetable, synthetic, silicone, etc.) [2,3,10], oil condition (contaminations, corrosive sulpfur, gasses etc.) [7,11–13], PD generating electrodes geometry and material [6,7,14–16], temperature [17,18], pressure [19,20] or even voltage harmonics [21]. Thereunder in order to provide an adequate measurement results interpretation an objective comparison of achieved data with representative database need to be supported [22–24]. In most cases an individual, relative measurement result is not an explicit and its interpretation may differ with reference to different apparatus or environment conditions. Various PD detection and analysis methods based on different physical phenomena accompanied by a PD generation have been presently known and applied for electrical power apparatus diagnostics [8,25–28]. The most commonly applied are inter alia: acoustic emission (AE) method based on a sound wave generation during a PD activity [15,29–32], spectrophotometry method based on a light emission [7,9,33], thermovision method, based on a heat emission [34], dissolved gas analysis (DGA) method [12,35,36], based

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on chemical reactions results, electrical method (EM), so-called a conventional method, based on a current pulse analysis [37–42], transient earth voltage (TEV) [39], based on an electromagnetic radiation in high frequency range, and ultra-high frequency (UHF) method [43–47], based on a radio frequency radiation. From among all of those techniques only an electrical method is a direct PD measurement method, which means it delivers exact information about testing phenomena, i.e. an apparent charge value. All other mentioned methods, so-called unconventional, are indirect measurement techniques, so measured physical quantities are proportional to the measuring phenomena properties. Thereunder all unconventional methods application supports PD intensity and apparent charge value survey estimation only [45,48–50]. However PD phenomena analysis and assessment in real-life high voltage apparatus insulation systems under normal on-site operation conditions are still one of those methods crucial aspects.

Another crucial aspect of PD analysis has been an identification of the PD source. It is commonly accepted that significant support for PD fault detection in real life apparatus may be achieved by proper PD source identification. There have been various methods and algorithms applied so far for PD identification purposes across last two decades. Usually one or at least two PD measuring methods are applied together for the research. Regarding an electrical method, PD identification is usually based on PRPD patterns and PD wave forms, also some advanced analyzing tools e.g. clustering methods, particle swarm based algorithms and fuzzy logic are commonly applied [39–41]. Similar algorithms and tools are applied according to UHF [53]. Regarding the AE method time runs are usually the source signals used for further analysis. Also advanced time-frequency and frequency domain signal processing tools are commonly applied e.g. wavelet analysis, STFT as well as neural networks or fuzzy logic based algorithms [15,31,54,60]. Combined measuring method are usually applied in configurations EM and UHF [38] or AE and EM [55]. It is worth mentioning that optical methods have been also at experimental stage according to PD source identification in oil insulation [9]. A common aspect of all mentioned methods and analytical tools is the highest computing power required for identification, which may be found difficult to apply in real life PD analyzing system for on-site purposes. It also has been characteristic that simultaneous application of not more than two different measuring methods is usually proposed. Another aspect of the mentioned state-of-art papers is that only a laboratory research and simulations are usually presented regarding a PD identification issue—generally no real life on-site verification of proposed algorithms and tools have been announced.

In the presented paper there has been proposed an alternative statistics based PD identification method that uses measurement results achieved by simultaneously performed electrical, UHF and acoustic methods. Application of the three measuring methods significantly increased noise and disturbance immunity (since every method is based on a different physical phenomenon) also precision of the identification process has been gained. Furthermore some low computer power demanding algorithms have been proposed, based on commonly available tools, that may be potentially easily applied for the future on-site PD analyzing system. Finally further real-life on-site applications of the proposed methodology have been considered on the grounds of the on-site verification performed on electrical power transformer under normal operation conditions.

2. PD generation background

Generally a breakdown process of pure, ideal liquid dielectrics is quite similar to those for gasses [51,56,57]. However real liquids are usually contaminated by solids, other liquids and dissolved gasses which significantly influence a breakdown process. An initial state of a breakdown process is a PD generation. There are few main contemporary theories of PD generation in liquid dielectrics based on: e.g. gaseous inclusion, liquid globules, solid particles, electro convection, cavity. No matter what mechanism a PD is generated by, it is always accompanied by numerous physical phenomena which are related with different forms of energy such as e.g. chemical reactions (hydrogen and other hydrocarbon gases generation), local heat emission, acoustic wave emission, electromagnetic wave emission, light emission and local pressure adjustments. Referred to the applied three measuring methods (electrical, UHF and acoustic emission) acoustic wave emission and electromagnetic wave radiation is to be explained a little more-in-depth. From the acoustic point of view a PD phenomenon may be read as a micro explosion within a dielectric. According to liquid dielectrics a mechanical energy is represented by acoustic wave—a kinetic energy is associated with particles oscillation motion while a pressure adjustments are connected with potential energy. An energy is radiated into the springy resilient environment, which is e.g. an oil in case of transformers. When reaching a boundary of different environments an acoustic wave is partially reflected, absorbed and attenuated. Generally PD phenomenon leads on an ultrasound (20 kHz–1.5 MHz) wave radiation. Although an AE generated by a single PD source is represented by a discrete signal. In insulation systems there usually multi PD sources appear. As a result a summed sequence of single pulses is received by a measuring sensor, which in fact is read as a continuous emission signal. For example a signal read by joint sensor placed on the outer wall of a transformer tank is fed by AE signals run in oil as well as in steel tank [7,15,31].

Slightly different problems are associated with electromagnetic radiation. It is commonly known that PD pulse rise time is usually in the range of approx. few ns. Such short pulses are accompanied by electromagnetic wave radiation. Some part of the emitted radiation travels within the galvanic parts connected with a PD source (in both directions: to the supply source as well as to the ground), while the other is emitted into the surrounding environment. The propagation mechanisms of electromagnetic signals in galvanic parts and in oil inside the transformer are significantly different and it also results in different attenuations of the signals. Signals measured in galvanic parts using electrical method, are influenced by the inductivity of every turn and all stray capacities which works as a low pass filter, thus a measured upper frequency limit is typically limited to approx. tens of MHz. The propagation of the electromagnetic signals inside of the tank is a radiated emission in the entire volume of the transformer, in oil and pressboard. So as a result an original PD emitted electromagnetic wave may by attenuated and reflected by metallic parts and a measured frequency band is usually from hundreds of MHz to few GHz (UHF range) [5,52,53].

3. Measurement setup and research methodology

3.1. Measurement setup

There have been two stages of the research: laboratory one and on-site one. Simultaneous registration and analysis of signals emitted by a PD source immersed in mineral transformer insulation oil using EM, UHF and AE methods have been the research subject. Following spark gap configurations for PD source simulation have been selected for the laboratory measurements: point to point (PP), multi-point to plate (MPP) and surface type (SRF). Such PD model sources choice has allowed simulations of different forms of PD generation in oil insulation. In general point of view some aspects related with insulation faults of electrical power transformers may also be found in such PD model sources selection [12,54,55], e.g. point to point—a PD generated by a single insulation