International Journal of Scientific Research & Engineering Trends
Volume 6, Issue 2, Mar-Apr-2020, ISSN (Online): 2395-566X

A Review Article of Partial Discharge Analysis of HV Transformer

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***Abstract* – Electrical networks of power transmission practically deals in the bulk transfer of electrical energy, from generating stations situated many kilometers away from the main consumption centers or the cities. For this reason the long distance transmission cables are of utmost necessity for effective power transfer, which in-evidently results in huge losses across the system. The Reliable electrical network is one that transports the energy with minimal power losses, losses partial discharge effect represent one of causes that hinder reaching this performance in HV lines are either permanent mode or in the transient mode.**

In this Works we present the phenomenon of partial discharge and its behavior in different climatic and atmospheric conditions such as rain, humidity, the dust, the sand, dry weather of the one part and over-voltages induced by strokes lightning. We deal in this paper, the influence of the partial discharge under these different conditions on the power losses in the power lines and the proposal of a new model of three-phase line with transient partial discharge.

***Keywords* – PD, HV rotating machine, MATLAB Simulink.**

I. INTRODUCTION

Partial discharges are small electrical sparks that occur within the electric insulation of switchgear, cables, transformers, and windings in large motors and generators. Partial Discharge Analysis is a proactive diagnostic approach that uses partial discharge (PD) measurements to evaluate the integrity of this equipment. Each discrete PD is a result of the electrical breakdown of an air pocket within the insulation. PD measurements can be taken continuously or intermittently and detected on-line or off-line. PD results are used to reliably predict which electrical equipment is in need of maintenance.

Just as every material has a characteristic tensile strength, each material also has an electrical breakdown (dielectric) strength that represents the electrical intensity necessary for current to flow and an electrical discharge to take place. Common insulating materials such as epoxy, polyester, and polyethylene have very high dielectric strengths. Conversely, air has a relatively low dielectric strength. Electrical breakdown in air causes an extremely brief (lasting only fractions of a nanosecond) electric current to flow through the air pocket.

The measurement of partial discharge is, in fact, the measurement of these breakdown currents. Electric equipment can suffer from a variety of manufacturing defects or operating problems that impair its mechanical reliability. The electrical insulation of motors and generators is susceptible to:

1. Thermal stresses
2. Chemical attack
3. Abrasion due to excessive coil movement
4. In all cases, these stresses will weaken the bonding properties of the epoxy or polyester resins that coat and insulate the windings. As a result, an air pocket develops in the windings.

PARTIAL discharges (PDs), sometimes also known as corona, are small electrical sparks that occur in deteriorated or poorly made stator-winding insulation systems in motors and generators rated 3.3 kV and above. Over the past 15 years, online PD monitoring has become the most widely applied method to determine the condition of the electrical insulation in such machines [l]-[3]. PD testing detects most (but not all) of the common manufacturing and deterioration problems in form-wound stator windings, including the following:

1. Poor impregnation with epoxy;
2. Poorly made semi conductive coatings;
3. Insufficient spacing between coils in the end winding area;
4. Loose coils in the slot;
5. Overheating (long-term thermal deterioration);
6. Winding contamination by moisture, oil, dirt, etc.;
7. load cycling problems; 8) poor electrical connections (although this is not strictly an insulation problem)

II. PROJECT MOTIVATION

Partial discharge measurement system
A partial discharge measurement system basically consists of:

1. a cable or other object being tested
2. a coupling capacitor of low inductance design
3. a high-voltage supply with low background noise
4. high-voltage connections
5. a high voltage filter to reduce background noise from the power supply
6. a partial discharge detector
7. PC software for analysis
8. A partial discharge detection system for in-service, energized electric power equipment:
9. a cable, transformer, or any MV/HV power equipment
10. Ultra High Frequency Sensor (UHF) Detection Bandwidth 300 MHz-1.5Ghz
11. High Frequency Current Transformer (HFCT) Bandwidth 500 kHz-50 MHz
12. Ultrasonic microphone with center frequency 40 kHz
13. Acoustic Contact Sensor with detection bandwidth 20 kHz - 300 kHz
14. TEV sensor or coupling capacitor 3 MHz-100 MHz
15. Phase-resolved analysis system to compare pulse timing to AC frequency.

III. LITERATURE REVIEW

V. S. Deolankar, W. Z. Gandhare "Partial Discharge Analysis in High Voltage Current Transformers" (2017) In High Voltage (HV) electrical power systems, variety of materials (solid, liquid and gaseous) is used for insulation purpose to protect the incipient failure in Current Transformers. Most of insulating materials are not perfect in all respect and contains always some impurities. The presence of air bubble is one of such impurities in insulating materials and highly undesirable for such type of insulation which causes a local weak zone inside the insulator. Due to the high voltage stress the weak zone inside the insulator causes the partial discharge (PD) and finally the insulation properties of such materials is enormously degrades its quality. In this work, the simulation of PD activity due to presence of a small cylindrical void inside the solid insulation material of high voltage power equipment is analyzed with the MATLAB Simulink platform.

P. Fiala,T. Jirku,P. Drexler,and P. Dohnal "Detection of Partial Discharge inside of HV Transformer, Modeling, Sensors and Measurement" (2010) The aim of this paper is to present the particulars of result research in the HFmeasurement method and modeling of starting process partial discharge inside of high voltagetransformer. The numerical analysis of the electromagnetic wave attenuation helped to set up conditions to decrease it and get of information for sensors conception preparing and detection apparatuses construction and measurement methods.
Jun Jiang , Mingxin Zhao , Chaohai Zhang , Min Chen , Haojun Liu and Ricardo Albarracín "Partial Discharge Analysis in High-Frequency Transformer Based on High-Frequency Current Transducer" (2018) High-frequency transformers are the core components of power electronic transformers (PET), whose insulation is deeply threatened by high voltage (HV) and high frequency (HF). The partial discharge (PD) test is an effective method to assess an electrical insulation system. A PD measurement platform applying different frequencies was set up in this manuscript. PD signals were acquired with a high-frequency current transducer (HFCT). For improving the signal-to-noise (SNR) ratio of PD pulses, empirical mode decomposition (EMD) was used to increase the SNR by 4 dB. PD characteristic parameters such as partial discharge inception voltage (PDIV) and PD phase, number, and magnitude were all analyzed as frequency dependent. High frequency led to high PDIV and a smaller discharge phase region. PD number and magnitude were first up and then down as the frequency increased. As a result, a suitable frequency for evaluating the insulation of high-frequency transformers is proposed at 8 kHz according to this work.

h tatizawa , g f burani "analysis and location of partial discharges in power transformers by means of electrical methods" Considering the number of failures in high voltage power transformers caused by problems in bushing and winding insulation, it is important to study means for diagnosing incipient failures, to avoid long unavailability periods and its consequences. The aim of this work is to study detection and measurement procedures, concerning the evaluation of position of partial discharge inside the transformer, in order to evaluate the degree of danger for the equipment. The methodology is based on a noninvasive measurement of partial discharges from the transformer bushing. The position of the partial discharge source is estimated considering the transformer winding model, and the measurement and proper evaluation of the response to the partial discharge pulses. By means of a proper modeling, measurement and interpretation, the localization of the problem can be performed.

Olga I. Karandaeva , Ivan A. Yakimov , Alexandra A. Filimonova , Ekaterina A. Gartlib , and Igor M. Yachikov "Stating Diagnosis of Current State of Electric Furnace Transformer on the Basis of Analysis of Partial Discharges" (2019)

The article is dedicated to research of the technical state of a furnace transformer. The study was conducted on the basis of statistical processing of continuously measured parameters of partial discharges (PD).

The authors characterize the causes of PD occurrence and their impact on the insulation condition. The article provides information on the on-line monitoring system applied at high-voltage transformers of superpowered arc steel-melting furnaces and ladle furnaces at metallurgical plants. The system implements (among other methods) the method of diagnosing the insulation state by means of mathematical processing of PD parameters. Continuously measured values are apparent charge and the parameter called partial discharge intensity (PDI) characterizing the power and intensity of PD. The authors studied the parameter trends and conducted the statistical processing of the measurements results. In addition, the authors give the rationale for the application of the parameter "reciprocal stochastic connection force" between the PD amplitude and PDI as a generalized criterion of the insulation state and failure localization. The article compares trends of power and PD amplitude at various transformer technical states (before and after unscheduled repair). The authors confirm the possibility to diagnose emerging defects by comparing the correlation factors of these dependences. An example of defect occurrence and its location is provided. As a result, the authors manage to prove the efficiency of the proposed method of analysis of the high-voltage transformer state. This research has produced an integrated approach that enables on-the-go technical diagnosis, fault localization, and accident prevention. The key product of this research is a transformer diagnosis method based on processing the data of online PD monitoring. To that end, the proposed method uses statistical toolkits available for a PC. The areas for further prospective research are outlined. The authors also give recommendations on a more extensive application of the developed method.

Ardila-Rey, J.A.; Martínez-Tarifa, J.M.; Robles, G.; Rojas-Moreno, M; Albarracín, R. "A Partial Discharges Acquisition and Statistical Analysis Software"(2012) Partial Discharges (PDs) are responsible for unexpected failures in power system equipment, so their measurement is a fundamental tool for electrical equipment maintenance. In order to characterize PDs activity, some statistical magnitudes are necessary. For this purpose, PDs acquisition and processing is an important tool for critical decisions related to power systems. In this paper, the main difficulties and challenges facing PDs detection, acquisition and processing are presented. Results will be compared to a commercial PDs detection system.

Greg C. Stone , Vicki Warren, "Objective Methods to Interpret Partial-Discharge Data on Rotating-Machine Stator Windings" (2006) —Partial-discharge (PD) measurements have long been used to assess the condition of the electrical insulation in motors and generators rated 3.3 kV and above. There are many ways to measure PDs during normal service of the motor or generator. Unfortunately most of the measurement methods mix stator PD with electrical-interference signals from poor electrical connections, power tool operation, corona from transmission lines, etc. The result can be false indications of stator-winding problems, reducing confidence in PD measurements. Another issue with online PD testing is interpretation, i.e., identifying which machines are in good condition and which machines need maintenance. In the past decade, a database of over 60000 test results has been assembled. In hundreds of machines, the condition of the insulation determined by a visual inspection has been compared to the PD levels. The result is a table that provides an objective means of determining the statorinsulation condition relative to other similar machines. An analysis of the results also shows that there are significant differences in PD activity between manufacturers. This paper gives a review of the methods that can reduce the risk of false indications, thus making the measurement less subjective.

Yuanlin Luo , Zhaohui Li and Hong Wang "A Review of Online Partial Discharge Measurement of Large Generators" (2017) Online partial discharge (PD) measurements have long been used as an effective means to assess the condition of the stator windings of large generators. An increase in the use of PD online measurement systems during the last decade is evident. Improvements in the detection capabilities are partly the reason for the increased popularity. Another reason has been the development of digital signal processing techniques. In addition, rapid progress is being made in automated single PD source classification. However, there are still some factors hindering wider application of the system, such as the complex PD mechanism and PD pulse propagation in stator windings, the presence of detrimental noise and disturbances on-site, and multiple PD sources occurring simultaneously. To avoid repetition of past work and to provide an overview for fresh researchers in this area, this paper presents a comprehensive survey of the state-of-the-art knowledge on PD mechanism, PD pulse propagation in stator windings, PD signal detection methods and signal processing techniques. Areas for further research are also presented.

A. Cavallini , G. C. Montanari1 , D. Fabiani , L. Testa "Advanced technique for partial discharge detection and analysis in power cables" Polymeric cables are the most common choice for transmission and

distribution in populated areas, as well as for the connection of components (transformers, GIS, etc.) in new power stations, replacing paper-oil cables. Indeed, they do possess superior characteristics with respect to oil-filled cables. As an example, they do require lower maintenance, they are lighter (easier to deploy) and, in case of breakdown, they are not flammable and do not cause polluting leaks. The drawback of polymeric cables is their scarce ability to withstand partial discharge activity over long periods of time. Therefore, partial discharge measurements performed soon after cable laying (generally during the 1-hour AC withstand test) or on aged cables are getting a key tool to ensure reliable performance of transmission lines. This paper introduces a novel technique for partial discharge detection, processing and diagnosis. The technique is based on the use of the information borne by the partial discharge pulse waveforms. It enables noise rejection and dealing with contribution of different sources separately and, therefore, allows accurate diagnosis to be carried out. The Measurement results enable, moreover, localization of partial discharge sources to be performed. Some practical examples of on-field partial discharge measurements and partial discharge source localization, performed applying the here presented technique, are reported and commented.
Carlos Takeshi Kudo Yasojima, Matheus Seribeli Furmigare , Fernando de Souza Brasil , Terezinha Ferreira de Oliveira, and Antonio Morais da Silveira "Partial Discharge Analysis and Inspection Alert Generation in High Power Transformers: A Case Study of an Autotransformer Bank at Eletrobrás-ELETRONORTE Vila do Conde Station" This paper presents an exploratory study using statistical and IA techniques in the partial discharge database located in Vila do Conde substation, Barcarena, Pará state, Brazil, ELETRONORTE property. Through ambiental and system variables analysis, it was possible to identify that the 230kV reactive power and period of day have a strong relation to partial discharge measures. With the obtained knowlegde and specialists knowlegde, a initial fuzzy system is proposed for partial discharge classification in diferents operational situations of alert, contributing to the operational status diagnosis of power transformers and amplifying the knowledge about the theme.

Petr Drexler, Martin Čáp, [...], and Lubomír Kočiš "A Sensor System for Detecting and Localizing Partial Discharges in Power Transformers with Improved Immunity to Interferences" The paper reports on the solution, principles, and application results related to a system for diagnosing main transformers in power plants via the radiofrequency method. The subject of the diagnostics is the occurrence of partial discharge activity in transformers. The technical solution of the system is characterized in the introductory section of the article. There then follows a description of the operating principle and the implemented novel advanced methods for signal detection and source localization. The results obtained from practical application of the system within the diagnostics of high-power transformers are presented as well. Because ambient electromagnetic disturbance was recognized as a major issue during the system development, novel detection methods were proposed, implemented, and verified. The principal approach utilizes an external radiofrequency sensor to detect outer impulse disturbance and to eliminate disturbance-triggered acquisitions, and it also ensures direct real-time visualization of the desired impulse signals. The ability of weak signal detection was verified via artificial impulse signal injection into the transformer. The developed detection methods were completed with localization techniques for signal source estimation. The desired impulse signal was detected and localized during full operation of the main transformer, despite the presence of strong electromagnetic interference.

IV. CONCLUSION

Partial discharge is the main problem in high voltage power equipment system. Therefore, detection and measurement of partial discharge is necessary to keep the equipment's in healthy condition during their operation. In this work an epoxy resin is taken as a solid insulation material and MATLAB Simulink based model has been introduced to observe the partial discharge activity inside the solid insulation. It is found that with the increase in applied voltage to the void present inside the insulation, partial discharge increases. This study is employed to find out the maximum partial discharge, the number of partial discharge values, the frequency content of partial discharge pulse and other partial discharge parameters. Based on the SIMULINK model partial discharge characteristics are plotted. Partial discharges are a major source of insulation failure in high voltage power system which needs to be monitored continuously to avoid the incipient failure in the power system network. To understand the PD activity inside the solid insulation a MATLAB based simulink model has been developed in this work. The PD activity inside the solid insulation is highly depends on the entire geometry of the void presence inside the solid insulation model (epoxide resin sample). In addition, PD is increases with the increase of applied voltage inside the solid insulation. In this study an efforts have been made to investigate the maximum PD magnitude, number of PDs and number of other PD related parameters like PD distribution, frequency content of obtained PD pulse by using phase resolve partial discharge (PRPD) measurement technique.

Based on the developed SIMULINK model and calulated parameters used for epoxide resin sample, the characteristic of PDs has been studied. This study will ensure the power engineers to predict the quality of the insulation used for high voltage power equipment. The present work is to be extended for further study in different high voltage power equipment such as current transformer (CT), potential transformer (PT), switch gear and circuit breaker. In this dissertation we present wavelet transform approach for analysis of void formation in insulator by observing the PD voltage across insulator by detector circuit. Using wavelet transform we easily analyzed the frequency and time information of signal and also analysis of small void formation in insulator also possible due to wavelet decomposition techniques.

V. FUTURE SCOPE

The criteria and guidelines to support the optimal selection of a mother wavelet for analysis of signals recorded during impulse testing are a new attempt. This homework is an outcome of the following difficulty faced with the existing literature. In spite of the wavelet transforms potential for numerous possible applications, there is no literature till date that provides the guidelines and explanations supporting the optimal choice of a mother wavelet for signal analysis. However, each of the mother wavelet has specific characteristics with maximum likelihood estimation functions and maximum correlations with certain features of a signal. In spite of the fact that many wavelet families have near similar characteristics, the choice of any wavelet filter is important in identifying the characteristics of signals.

Since the inner product measures the similarity between the signal and wavelet basis function, the simplest method to choose a wavelet is to observe the signals time-frequency behaviour. This chapter, presents such an attempt with signals recorded during the impulse analysis of transformers for specific signals such as the impulse voltage, neutral current, capacitive transferred current and partial discharge.
Detection of PD activity in cable insulation by different detection method so that safe and reliable operation of HV cable can be achieved.

- Development of highly sensitive and multi resonant antenna to detect EM radiations emitted by PD signal.
- Detection of PD activity inside the transformer oil tank by placing antenna inside the oil tank.

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.

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