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A Review of an Investigation of Partial Discharge Sources and Locations along the High Voltage Transformer Winding

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Abstract - *Partial discharge (PD) is major fault in High Voltage Transformer winding. Partial discharge is nothing but dielectric breakdown in any point of transformers winding small part of solid or liquid insulating medium under the stress of high voltage. So, PD eventually degrades the insulating material and lead to break-down of insulation. These things reduce the efficiency and life span of transformer also maintenance of transformer is increase. The localization, diagnosis, monitoring and reduction of partial discharge are necessary for batter performance of transformer. There are several methods for detection of PD in transformer winding like, Emission Acoustic, Radio Frequency current transducer (RFCT) etc. Here, we develop new method to detect PD of transformer winding by using some HV transformer parameters like, dielectric strength of oil, current density of transformer winding and temperature. We implement coding & simulation with fuzzy logic controller/PD controller/PID controller to analyze the PD and on the basic of analysis result we try to reduce PD with this new approach project PD can be reduce, so the transformer efficiency will be increase and maintenance as well as life span will also be decreased.*

***Key Words*: Partial Discharge, High Voltage, Power Transformer, Fuzzy Logic Controller, PID Controller, PD Controller.**

1. INTRODUCTION

In this time more requirement of electricity demands we convert the line in a high voltage, extra high voltage and ultra-high voltage line. After that equipment are also required to sustain HV, EHV and UHV voltage. But in the transformer winding not sustain the HV that time partial discharge is produce. A PD is a one type of loss who produces in winding. If the winding insulation voids, cracks, and other imperfections lead to intermitted discharge in the insulation. In modern technology these are designated as 'Partial discharges' which in course of time reduce the strength of insulation leading to a total or partial failure or breakdown of the insulation. If the sites of partial discharge can be located inside equipment, like in a power cable or transformer, it gives valuable information to the insulation engineer about the region of greater stress and imperfection in the fabrication.

Based on this information, the design can be considerably improved.

Chemical methods are based on the analysis of dissolved gas generated inside the transformer due to PD activity. The integral characteristic of these regularly performed analyses allow indications on the long term behaviour of the PD activity and therefore on the insulation condition. For information on the actual PD occurrence acoustic and electric PD measurements are preferable. The focus of acoustic or ultrasonic measurements is bases on a PD location, whereas the electric measurements are orientated to a precise determination of the apparent charge, although investigations have shown, that sometimes a PD location is possible but complicated. A combination of both techniques with the aim to make an exact determination of the PD origins and the apparent charge are available.

Preliminary investigations have shown that online wideband electrical decoupled PD signals can in general be efficiently evaluated by various pattern recognition methods in order to determine the PD origin and its apparent charge. The functional principle of these methods is based on the evaluation of the characteristic distortion of a PD signal caused by its transmission from the origin through the winding to the decoupling point. Advanced post processing techniques are used to classify the signal in terms of type of deformation and origin using PD pattern. Furthermore a new method for the evaluation of electric measured partial discharges has been developed. This method uses the transfer functions of a transformer for a PD location and enables additional possibilities.[1]

1.1 What is Partial Discharge?

Usually partial discharge begins within cracks, or inclusions within a solid dielectric, interfaces within solid or liquid dielectrics, or in bubbles within liquid dielectrics. Partial discharge (PD) is a localized dielectric breakdown (DB) (which does not completely bridge the space between the two conductors) of a small portion of a solid or fluid electrical insulation (EI) system under high voltage (HV) stress. PD may occur in a transformer winding due to aging processes, operational over stressing or defects introduced during manufacture. An electrical discharge that only partially bridges the dielectric or insulating medium between two conductors. Earlier the testing of insulators and other equipment was based on the insulation resistance measurements, dissipation factor measurements and breakdown tests. It was observed that the dissipation factor (tan δ) was voltage dependent and hence became a criterion for the monitoring of the high voltage insulation. In further investigations it was found that weak points in an insulation like voids, cracks, and other imperfections lead to internal or intermittent discharges in the insulation. These imperfections being small were not revealed in capacitance measurements but were revealed as power loss components in contributing for an increase in the dissipation factor. In modern terminology these are designated as "partial discharges" which in course of time reduce the strength of insulation leading to a total or partial failure or breakdown of the insulation.

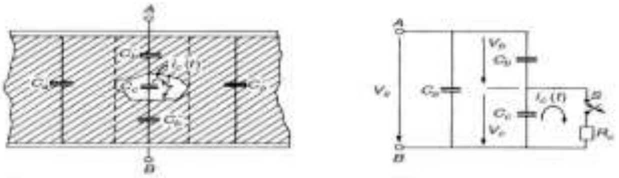

Fig 1. Scheme of an insulation system and Equivelant Circuit

An electrical discharge that only partially bridges the dielectric or insulating medium between two conductors. Examples are: internal discharges, surface discharges and corona discharges. Internal discharges are discharges in cavities or voids which lie inside the volume of the dielectric or at the edges of conducting inclusions in a solid or liquid insulating media. Surface discharges are discharges from the conductor into a gas or a liquid medium and form on the surface of the solid insulation not covered by the conductor. Corona is a discharge in a gas or a liquid insulation around the conductors that are away or remote from the solid insulation.

Partial discharge measurement mathematical equation,

$$q = C_b \Delta Vs$$

1.2 Types of Partial Discharge

Partial Discharge phenomenon is divided into two types:

1) External Partial Discharge: External Partial discharge is the process which takes place outside of the power equipment. Such type of discharges occurs in overhead lines, on armature etc.

2) Internal Partial Discharge: The PD which is occurring inside of a system. PD measurement system gives the information about the properties of insulating material uses in high power equipment.

Type of Typical Partial Discharge:

- *Corona Discharge:* PD around a conductor in free space is called corona discharge. Corona discharge takes place due to non-uniform field on sharp edges of the conductor subjected to high voltage. The insulation provided is air or gas or liquid.

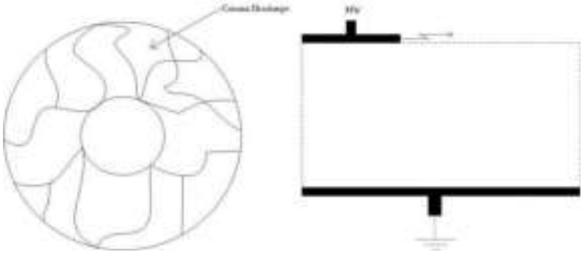

Fig 2.Corona Discharge and Surface Discharge

- *Surface Discharge:* Surface discharge takes place on interfaces of dielectric material such as gas/solid interface as gets over stressed times the stress on the solid material.

- *Cavity Discharge:* The cavities are generally formed in solid or liquid insulating materials. The cavity is generally filled with gas or air. When the gas in the cavity is over stressed such discharges are taking place[2].

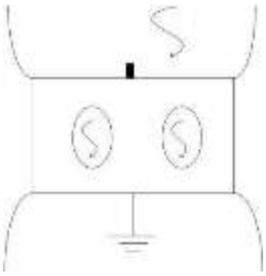

Fig 4.Cavity Discharge

2. METHODS OF PARTIAL DISCHARGE DETECTION

2.1 Conventional Electrical PD Measurements

According to IEC 60270, the preferred setup to measure apparent PD charges is shown in Fig 5.

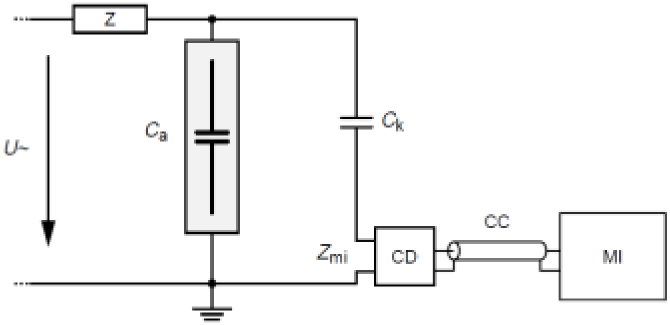

Fig. 5Diagram of Conventional PD Measurement

- The C_k capacitance acts as a coupling capacitor to decouple high frequency PD pulses both from a source inside the transformer tank and from outside the tank (external sources).

- For bushings without a capacitive tap, an external coupling capacitance is connected in parallel with the bushing.

- The PD measurement system is connected to the sensors via co-axial cables.

With conventional PD measurement (IEC 60270), the apparent charge is measured in pC which is the integrated current pulse, caused by a PD, which flows through the test circuit. The conventional method allows a precise calibration but requires a sufficiently high signal-to-noise ratio (SNR) in the measurement circuit to easily resolve the PD signal in question. The standardized method of IEC 60270 has been practiced since the 1960s and is well regarded. PD pulse amplitude, PD pulse trend and phase-resolved PD (PRPD) patterns are well known to correlate with the extent of insulation damage. Reference PRPD patterns are widely available for different discharge defects and for different high voltage components, which is another significant advantage of conventional measurement. For factory transformer PD acceptance testing, IEC 60270 imposes lower and upper limits on the measurement frequency. The primary goal is to have uniformity in the transformer PD testing process across different laboratories so that results can be compared against a pass / fail criterion (e.g. 500pC). Factory testing is performed inside Faraday-cage styled shielded laboratories with PD-free connections and terminations. This isn't practicable for PD measurements on in-service transformers, which are exposed to a variety of 'noise' sources outside the tank. Examples of such 'noise' sources would be inadequate corona shielding of line terminals, bad or loose connections, PD from other interconnected HV systems, or arcing from the transmission line. Several established procedures are available to suppress these interferences to make on-site noise free PD measurements. The unique advantage of conventional PD measurements is that the charge content in a PD pulse can be related to a known reference. Phase-resolved PD patterns are widely available for different discharge defects and for different HV components. Therefore, it is widely used during factory and on-site transformer PD Testing[3][4].

2.2 Ultra High Frequency PD Measurements

The principle of ultra-high-frequency (UHF) PD measurement is illustrated in Fig. 2. The electromagnetic emission from a PD source is measured using an UHF antenna which is inserted into the transformer tank through an oil-sampling valve. The metal surface of the transformer tank acts as a natural Faraday-cage to filter out electrical interferences from outside the tank. High Voltage bushings' C1 capacitance acts as a low-pass filter to reduce electrical interferences from outside the tank. These advantages make it suitable for measurements in noisy environments, e.g. on-site / online measurements and monitoring.

UHF measurement is based on the common assumption that PD takes the form of fast rise-time electrical impulses which radiate electromagnetic (EM) waves with frequencies up to the ultra-high frequency range (UHF: 300 MHz to 3000 MHz). Investigations by the author show that high frequency current flowing through the metallic parts of the transformer (e.g. winding), transforms the metal surface to an emitter of EM waves, therefore they are the source of the EM emission and not the PD source itself. In general, the radiation behaviour of UHF PD sources is more complex and only partially understood. Oil (drain) valve UHF PD probes are designed for use inside straight-opening oil-filling valves of at least 1.5" in diameter. This design has several restrictions. The design requires by default, straight opening oil valves, which are not common. The method of use requires the UHF probe head to stick-out horizontally from the inside wall of the tank by at least 2 inches or ~5cm. Because of the probe head's close proximity to the windings under voltage, its location requires careful selection to avoid compromising the safety of the transformer. In some transformer designs, oil-flow guiding tubes are present behind the valve openings (inside tank), which limits the depth to which the probe heads can be inserted. The depth of the probe head and antenna design has a significant effect on the PD measurement sensitivity.

Hatch cover type UHF probes are designed for use inside dielectric windows custom fitted directly onto the transformer tank wall or onto the hatch cover plates. This requires a circular slot cut in the hatch cover plate to insert the dielectric-window. The UHF probe sits inside the slotted window. This procedure requires an outage on the transformer and oil drainage up to a level below the hatch cover plate. This installation procedure is not suitable for transformers operating in service due to practical constraints in implementing this on site and the risk of exposing the internal parts of the transformer to the atmospheric air. Flange-type UHF sensors are designed to fit snugly around the lower shed of the high voltage bushings. Due to its use outside the transformer, they are vulnerable to external electrical interferences[3][5].

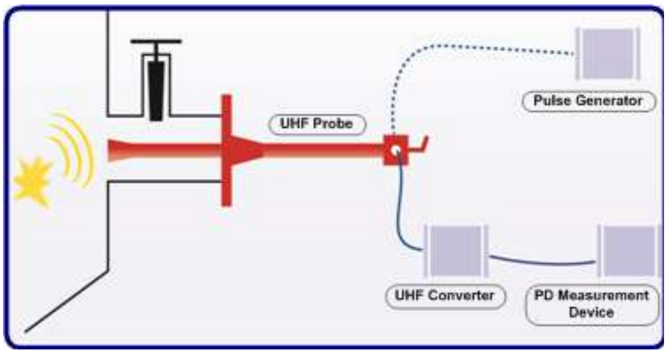

Fig. 6 Diagram of Ultra High Frequency PD Measurements

2.3 Ultrasonic (Acoustic) PD Measurements

The main purpose of permanently installed online acoustic monitoring systems is to provide an early indication of an incipient fault to a remote location which can then be followed by more extensive field tests. Common industry practice is to perform these measurements in response to abnormal gas-in-oil test results or sounds that may indicate partial discharges.

Active PD sources in oil-filled transformers produce acoustic emission signals that propagate away from the source in all directions. The acoustic signals travel through the intervening material to eventually arrive at the transformer tank wall. The distance travelled is dependent on the time that it takes for an acoustic signal to complete this journey as shown below. **Distance travelled = acoustic wave speed x time**

Consequently, sensors placed at different locations on the tank wall, i.e. at different distances from the source, will experience different signal arrival times. The signal arrival times are then used to determine the position of the PD source inside the tank. There are two general categories of acoustic location systems: all-acoustic systems and acoustic systems with an electrical PD trigger.

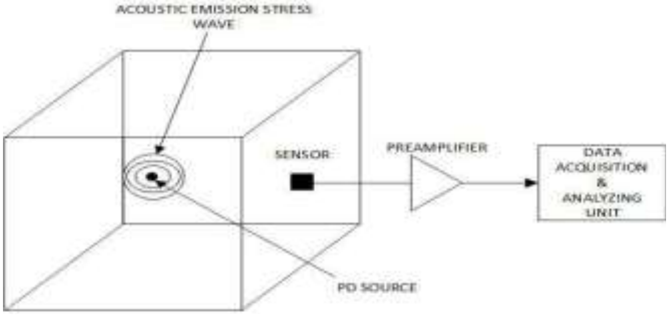

Fig. 7Diagram of Ultrasonic PD Measurement

The first category, the all-acoustic system, consists of one or more ultrasonic transducers that are sensitive to the acoustic emissions generated by a PD event. The detection and coarse location of one or more sources can be accomplished by moving one sensor around the transformer. A more precise location of a PD source may be determined by the relative arrival times of the acoustic signals at each of the sensors. No voltage or current readings are required on the transformer. This makes the all-acoustic system a suitable tool for source location on operating transformers in the field. The second category, the acoustic system with an electrical PD trigger, pairs the array of acoustic sensors described above with a current or voltage measurement device that detects the PD signal electrically. Since the electric signal is detected instantaneously, the arrival time of the electric signal can be used as time zero for the PD event. The difference in arrival times of the electric signal and an acoustic signal is the propagation time between the PD source and that sensor location. Thus PD location in this type of system is based on the absolute arrival time at each sensor, as opposed to the all-acoustic system described above which uses the difference in arrival time between sensors.

Signal sensitivity is unique to each acoustic monitoring system. The general experience has been that the following PD sources can be generally identified: PD sources outside the winding, arcing or tracking of the bushing surface in oil, PD inside the tap-changer and very high intensity discharges within windings. Discharges within windings, inside HV bushings and acoustic signals produced by gas bubbles are usually difficult to detect. Weather (rain, snow, sleet, hail, lightning strikes) and mechanical disturbances created within or outside the tank (core magnetostriction, pumped liquid noise, loose shielding connections inside the tank wall, loose name plates, fan noise, etc.) also interfere with the measurement. Apart from these factors, how the sensor is placed on the tank, shielding used inside the tank wall and insulating barriers between the sensor and fault source have a significant effect on the measurement sensitivity[2][3][6].

3. PD MEASUREMENT TECHNIQUES COMPARISION

Key Difference	**Conventional**	**UHF**	**Acoustic**
Immunity from electrical noises	Low	High	High
Immunity from mechanical noises	High	High	Low
Availability of reference PRPD patterns for different PD defects & HV components.	Yes	No	No
Sensitivity	High	High	Low
Used during factory transformer acceptance testing	Yes	No	No
PD calibration as per IEEE & IEC standards	Yes	No	No
Geometric Location of PD Sources	No	No	Yes
Identification of defect type using phase-resolved PD patterns	Yes	No	No

Table 1: Comparison of PD Measurement Techniques

4. PARTIAL DISCHARGE ANALYSIS METHODS

4.1 Fuzzy Logic

Fuzzy logic is widely used in machine control. The term "fuzzy" refers to the fact that the logic involved can deal with concepts that cannot be expressed as the "true" or "false" but rather as "partially true". Although alternative approaches such as genetic algorithms and neural networks can perform just as well as fuzzy logic in many cases, fuzzy logic has the advantage that the solution to the problem can be cast in terms that human operators can understand, so that their experience can be used in the design of the controller. This makes it easier to mechanize tasks that are already successfully performed by humans. A fuzzy control system is a control system based on fuzzy logic a mathematical system that analyzes analog input values in terms of logical variables that take on continuous values between 0 and 1, in contrast to classical or digital logic, which operates on discrete values of either 1 or 0 (true or false, respectively)[7].

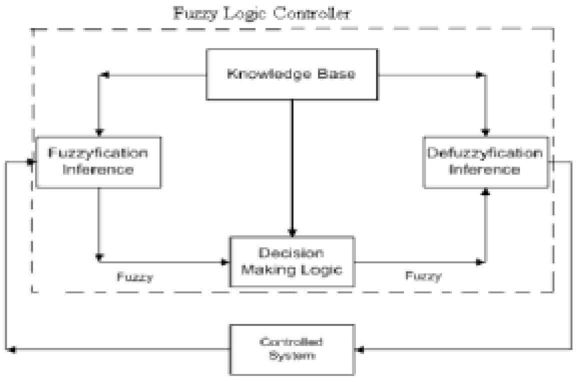

Fig. 8 Diagram of Fuzzy Logic Controller

4.2 Proportional Integral Derivative

A proportional integral derivative controller (PID controller. or three-term controller) is a control loop mechanism employing feedback that is widely used in industrial control system and a variety of other applications requiring continuously modulated control. A PID controller continuously calculates an error value {\display style e(t)}e(t) as the difference between a desired set point (SP) and a measured process variable (PV) and applies a correction based on proportional, integral, and derivative terms (denoted P, I, and D respectively), hence the name. In practical terms it automatically applies accurate and responsive correction to a control function. An everyday example is the cruise control on a car, where ascending a hill would lower speed if only constant engine power is applied. The controller's PID algorithm restores the measured speed to the desired speed with minimal delay and overshoot by increasing the power output of the engine. The first theoretical analysis and practical application was in the field of automatic steering systems for ships, developed from the early 1920s onwards. It was then used for automatic process control in the manufacturing industry, where it was widely implemented in pneumatic, and then electronic, controllers. Today there is universal use of the PID concept in applications requiring accurate and optimized automatic control[8].

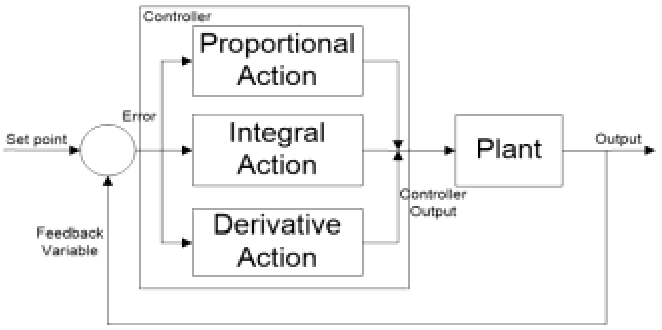

Fig. 9 Block diagram of PID Controller

4.3 Proportional Derivative

Proportional-Derivative control is useful for fast response controllers that do not need a steady-state error of 0. Proportional controllers are fast. Derivative controllers are fast. The two together is very fast. Below is a review. Proportional-Derivative or PD control combines proportional control and derivative control in parallel[9].

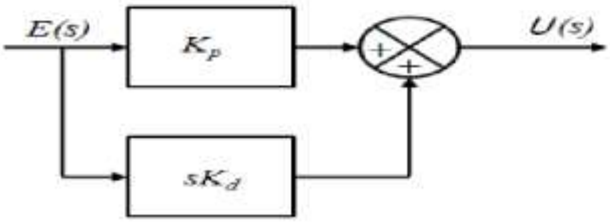

Fig. 10 Block diagram of PD Controller

5. CONCLUSION

A method has been proposed and detailed for locating partial discharge activities inside a transformer winding. Primarily, the proposed method is based on the analysis of dielectric strength of oil, current density of both HV & LV winding and temperate of insulating oil measured at accessible points of particular winding. This has led to the development of an autonomous PD locating tool that uses a program based mathematical operations of the full analysis. The performance of both approaches have been evaluated using a model winding under laboratory conditions and results indicate that the proposed approach is feasible and with further development may provide an autonomous tool capable of determining the location of a PD source within a transformer winding without the need for human intervention compared to the existing methods using different techniques such as Fuzzy Logic/PID controller/PD controller based method.

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