PARTIAL DISCHARGE MEASUREMENT AS A DIAGNOSTIC TOOL FOR CURRENT TRANSFORMER

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ABSTRACT
Current Transformer (CT) is used for protection of major components and to provide reliable operation in power system. . Failure of a CT may cause incorrect current signals and lead to loss of supply. Therefore insulation diagnosis is of great importance for evaluation of CT. To ensure economic operation of high voltage current transformer reliable condition evaluation concepts are essential. It is important to know the degradation of insulation materials for the study of partial discharge behavior in CT. In this paper partial discharge phenomenon has been discussed along with different partial discharge detection methods. The application of partial discharge data for the diagnosis of insulation in high voltage current transformer is discussed.

KEYWORDS: *Partial Discharge (PD), Current Transformer (CT)*

I. INTRODUCTION

The Current Transformer forms an important part of the power system to observe load currents for protection and measurement purposes. The equipment requires insulation to isolate the high voltage windings from the low voltage windings. The insulation is used to withstand both for the steady state and transient state conditions which gradually deteriorate due to, electrical, mechanical, thermal and environmental stresses. Breakdown of a CT may cause incorrect current signals and lead to loss of supply. Therefore, it is important to detect early failures in CTs, so that they can be maintained or replaced, and the reliability of the power system is improved [1]. In the insulation system, PD occurs when the local electric field exceeds the threshold value and produces a partial breakdown of the surrounding medium. Consequently, PD activity can be indicative of some incipient weakness at an earlier stage, which occurs in voids or cavities within solid or liquid dielectric.

Existence of partial discharge (PD) indicates that there is a weak point in the insulation system. It is considered as one of the greatest threats to insulation in the electrical power industry. Partial discharges (PD) are small electrical sparks resulting from the electrical breakdown of a gas (for example air) contained within a void or in a highly non-uniform electric field. If the void is within a dielectric solid or liquid, the PD will degrade the dielectric material and may eventually cause the failure of the electrical insulation.

PD, in addition to causing electrical aging as discussed above. For example, voids within oil paper insulation may occur as a result of operation at high temperature, which causes 'gassing' in systems containing oil.

II. CURRENT TRANSFORMER STRUCTURE

Current transformers (CTs) are used to convert high level currents to a smaller reasonable level for use as input to protection relays and metering equipment. Within electrical systems, current transformers are essential to ensure the correct functioning and control of equipment and for providing operational data and information.

In live tank type of current transformers, the primary winding consists of aluminium sections accommodated in the top housing. The primary winding is rigid, concentric and distributed uniformly around the insulated secondary winding in order to have optimum mechanical endurance against short circuit forces. Fig.1 shows the basic structure of current transformer.

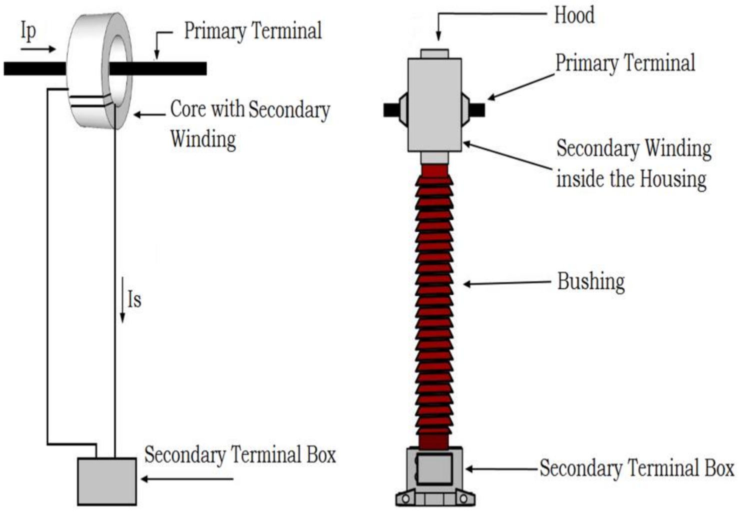

Figure 1. Current Transformer Structure

The cores and secondary windings (Fig. 2) are enclosed in a rigid aluminium shell which is fully insulated from the top housing. The secondary leads are taken to the base of the CT through an oil impregnated paper (OIP) insulated bushing.

a) **b)**

Figure 2. a) Core with secondary winding, b) Paper insulation on secondary winding

III. PARTIAL DISCHARGE PHENOMENON

According to IEC 60270, Partial Discharge is defined as: "localized electrical discharge, that only partially bridges the insulation between conductors and which may or may not occur adjacent to a conductor" [2].

The solid or liquid dielectric materials cannot be absolutely pure. They contain gases pockets or cavity or voids. The voids are generally filled with the material having lower dielectric strength such as air. When voltages are applied, due to the capacitive action, charges are induced in the voids. Due to an electric-field voltages are developed in the voids. When voltage reaches the breakdown strength of void-material, breakdown occurs.

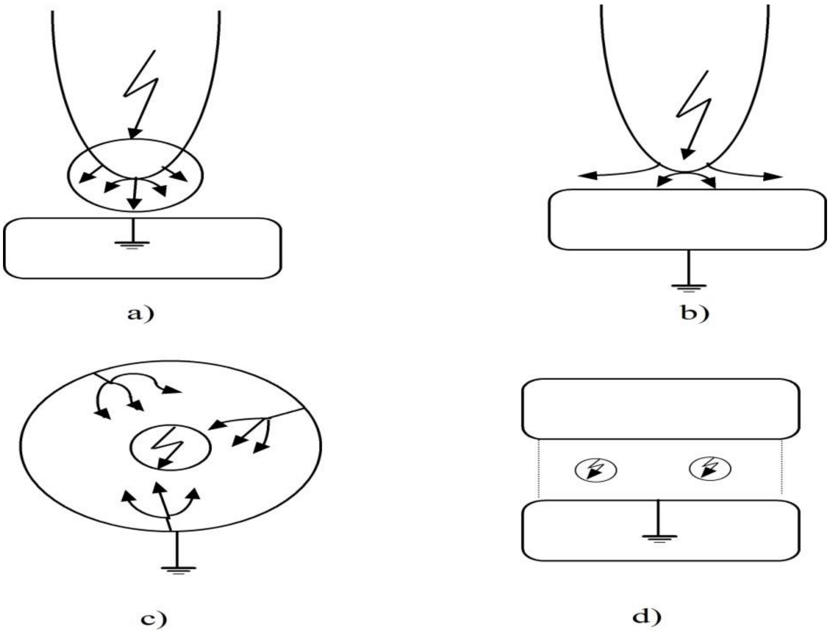

Figure 3. Various Types of Partial Discharge Occurring in the Insulator: a) Corona or Gas Discharge, b) Surface Discharge, c) Treeing Channel and d) Cavity Discharge

PD phenomenon can also be classified into the following types:

3.1. Corona Discharge

It takes place due to the non-uniformity of electric field on sharp edges of conductor subjected to high voltage. The insulation used for such type of discharge may be gas or air or liquid. This type of discharges appears for a long duration along the bare conductor. The Ozone formed due to the corona effect is responsible for the degradation of the insulation material.

3.2. Surface Discharge

It takes place on interfaces of dielectric materials such as gas/solid interface. This usually occurs in bushings, end of cable, any point on insulator surface, between electrodes (high voltage terminal & ground). The existence of such discharge depends on various factors such as:

i) Permittivity of the dielectric materials used
ii) Voltage distribution between the conductors
iii) Properties of the insulating materials

3.3. Treeing Channel

At the sharp edges of an insulating material, high intensity fields are produced, resulting in deterioration of the insulating material. This leads to a continuous partial discharge, also known as Treeing Channel.

3.4 Cavity Discharge

This type of discharge usually occurs in solid or liquid insulating materials. The cavity present is generally filled with gas or air. When the gas in the cavity is over stressed, Cavity Discharge takes place [3], [4].

IV. REASONS FOR PD IN CURRENT TRANSFORMERS

Partial Discharges actually includes a number of possible defects of the electrical insulation system of the CT. It is observed that in few cases the presence of partial discharges could be due to external pollution or improper handling.

The instrument transformers when manufactured in factory, due to its manufacturing process and workmanship, some voids are present. These voids over a period of time start increasing in size due to overvoltage in system or ageing. When a voltage is applied to the object the gaseous particles start getting ionizing. At a particular stage the void size increases causing the apparent charge (pC) value to increase and finally cause failure of the instrument transformer. The failure or increase in PD value can also be due to moisture or contamination of the external surface of the equipment which may cause tracking with respect to earth.

V. NECESSITY OF PARTIAL DISCHARGE DETECTION IN CURRENT TRANSFORMER

A current transformer is very important equipment of any power system for metering and protection. Failure of this equipment will cause

i) Short circuit fault in the system
ii) Damage to other surrounding equipment / switchgear
iii) Cause Non-availability of the system

Failure of CT may lead to an energy explosion and result in phase to ground fault that will hinder the operation of a substation. Therefore insulation diagnosis is of great importance for evaluation of CT. Fig. 4 shows few insulation failure cases in current transformer.

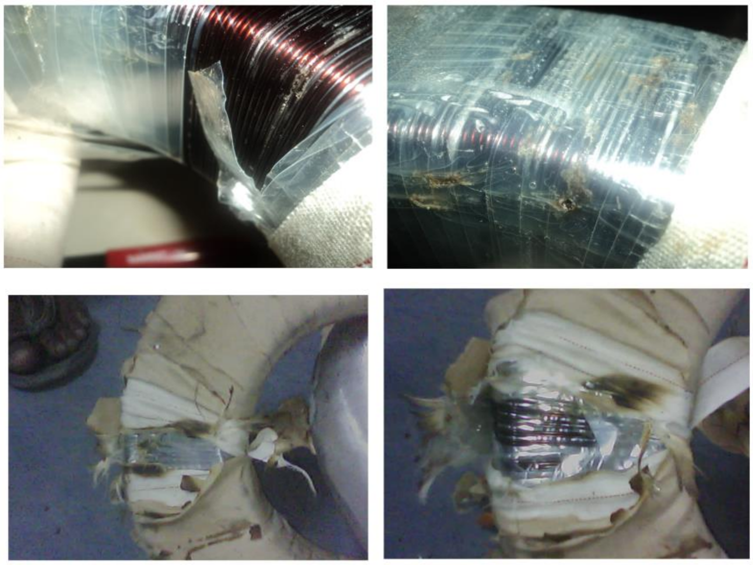

Figure 4. Insulation Failure in Current Transformer

Standard IEC60044-1 recommends partial discharges test as a routine test for CTs. This means that each unit coming out of production shall be PD tested in order to be compliant to such standard [5], [6].

PD impulses are characterized by their charges (apparent charge), their polarities and their phase positions. With this data and the repetition rate (number of pulses within a timeframe), general information about the insulation condition can be given. This is because the occurrence of PD is in most cases a sign of an insulation failure.

VI. DIFFERENT PD MEASURING METHODS FOR CURRENT TRANSFORMER

6.1 Conventional /Electrical Measurement

When a partial discharge pulse occurs, there is a very fast flow of electrons from one side of the gas filled void to the other side. Since the electrons are moving close to the speed of light extremely fast across a small distance, the pulse has a very short duration, typically a few microseconds. The electrons carry a charge, thus each individual discharge creates a current pulse (i = dq/dt). The PD current in the void creates a disturbance and results in pulse current and voltage that flows away from the PD site. This impulse is basically detected through a recharge process from a coupling capacitance [7], [8].

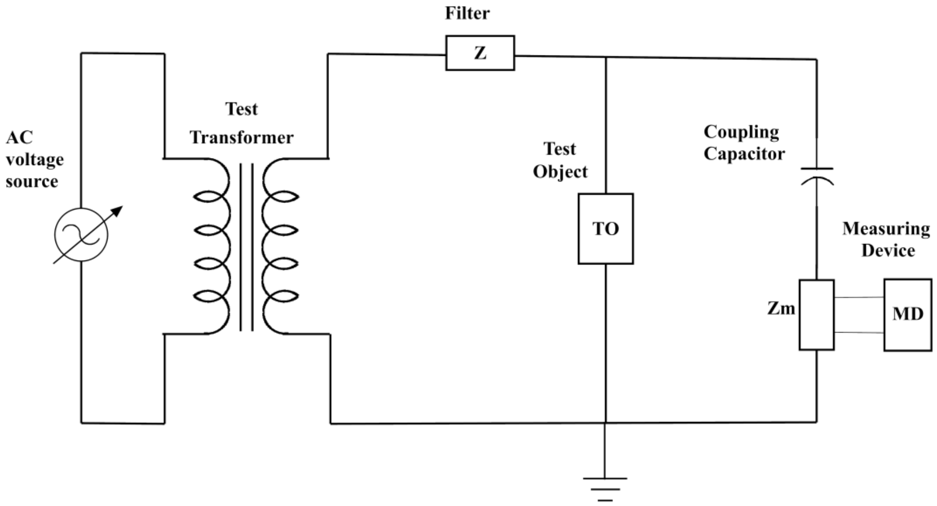

Figure 5. Conventional PD Measurement

A conventional PD measurement according to Standards 60270 is shown in figure 5 [2]. This is off-line PD test in which, a coupling capacitor is connected across the test object which converts the input currents to low output voltage. The output of this coupling capacitor is fed to the PD measuring instrument which gives the PD value in Pico Coulomb and also indicates the discharges on the sinusoidal waveform. The conventional PD measurement method is the only one that can be calibrated.

6.2 Electrical measurement with high frequencies

6.2.1 UHF Measurement of Partial Discharges

In the last years the ultra-high frequency (UHF) method was established as usual PD measuring procedure. The ultra-high frequency PD detection is based on the detection of the high frequency signals generated in the event of discharges. PD impulses of very short duration, produces electromagnetic waves, whose spectrum reaches up to the GHz range. The UHF PD measuring method is very high sensitive to measure PD under insulation test by frequencies up to the ultra high range (300 MHz to 1.5 GHz). It can predict the complete information concerning the PD activity [10]. Capacitive sensors, as like antennas/Probes have been developed, which can detect transient waves.

Partial discharges under oil are very fast electrical processes and radiate electromagnetic waves with frequencies up to the ultrahigh range. Electromagnetic waves are detectable with UHF probes. Although the UHF-method is an electrical measurement, it cannot be calibrated. For a practical application, an UHF system needs to be compared to a conventional system [11].

6.2.2 RF Detection

In this method wide bandwidth coils are designed to detect the radiating frequency (RF) from Partial Discharge. The copper coils wind uniformly around the test object from the top to bottom. Using this structure, the localization issue for UHF and Acoustic methods may be solved. Also due to uniform distribution of coils, it can pick up the PD signal effectively.

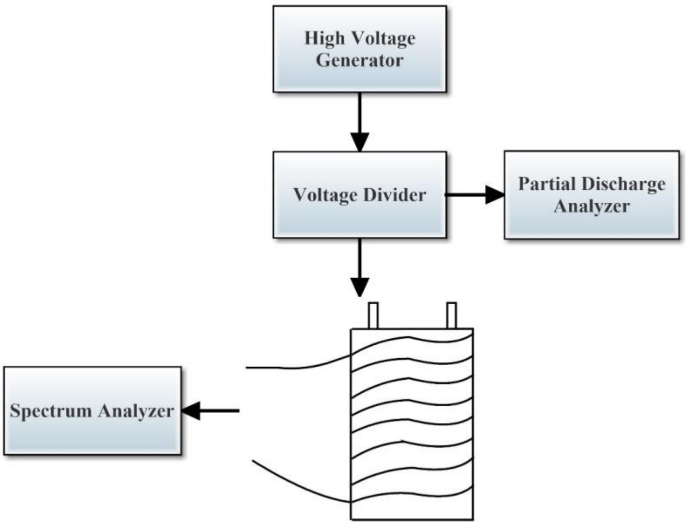

Figure 6. RF PD Detection.

As Shown in fig.6 windings are uniformly distributed on the CT. To evaluate the performance, output voltage of High-Voltage Generator is adjusted to excite the partial discharge in the test object. The voltage divider senses the partial discharge from the CT return to the test system, and the radiation of PD signal pick up by the coils around the CT [12].

6.2.3 Time Domain Detection

In this study, Two RF coils are used to detect and locate the radiating frequency (RF) from partial discharge. Two RF coils installed at two surfaces of the current transformer are used to pick up the partial discharge. From the amplitude and the occurrence of the PD signal on the time scale, we can locate where the partial discharge occurs [13].

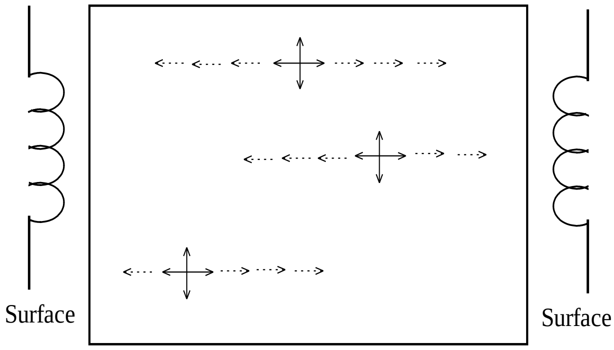

Figure 7. One dimension radiation path of the partial discharge in the current transformer.

The partial discharge may occur at any location in the current transformer, depend on the allocation of the weak points and the electric field intensity. Two RF loop coils are attached to the opposite surfaces to detect the radiation signal from the current transformer. If the partial discharges occur at the centre of the CT, as shown in the upper parts of Fig. 7, the radiation spread out to every direction. But, only those partial discharges whose powers are large enough can reach both surfaces of the CT and pick up by two RF loop coils. The others are too weak and disappear at some locations. In the other case, as shown in the lower parts of Figure 7, the partial discharges occur near one surface. Unless the powers of the partial discharges are very large, they cannot reach the far end. Therefore, from the appearance of the peaks of the partial discharge on the scope, we can locate the position of the partial discharge.

6.3 Chemical measurement

The detection of PD with chemical methods is based on the analysis of the by-products that are caused by discharge impulses themselves. Chemical detection is predominantly used in applications with liquid or gaseous insulating materials, which is the case for transformers, machines, GIS and GIL. As CT is also oil filled equipment, Dissolved Gas Analysis (DGA) of CT was also started from last few years on case to case basis. DGA is a very important tool, for identifying the manufacturing process defects or aging effect of CT at the very initial stage.

DGA has been developed extensively to detect fault generated gases. DGA is the simplest and cheapest technique available for testing, and is used extensively as the primary indicator of malfunctions leading to overheating, arcing and PD. The DGA is performed in following three steps:

i) Extraction of all the gases in the oil sample.
ii) Measurement of the quantity of each gas in the extracted gas.
iii) Calculation of the concentration of each gas in the oil.

Fault gases typically generated include acetylene, methane, hydrogen, carbon dioxide and ethylene plus (to a lesser extent) ethane, oxygen, nitrogen and carbon monoxide [14].

6.4 Acoustic Measurement

Acoustic detection of partial discharges is based on the detection of the mechanical energy wave which propagates from the discharge site through the insulation [15]. This wave can be detected by a variety of transducer techniques and the data analyzed.

When PD impulses occur, they also produce mechanical effects (waves) besides the electrical ones. Actually, the arc is responsible for some sort of shock wave that propagates through the surrounding insulation. As shown in fig. 8, a suitable sensor is placed on the outside of the equipment and detects the acoustic wave caused by a discharge inside. When more sensors are in operation, location of a failure inside the equipment might be possible. Acoustic detection is used widely in plant diagnostics, particularly in transformers and gas insulated substations (GIS). Acoustic PD measurements cannot be calibrated, so it is not possible to determine the apparent charge. Nevertheless, for PD localization, acoustic methods are well suited. Especially in combination with electrical/conventional measurement, the efficiency and accurateness is increased.

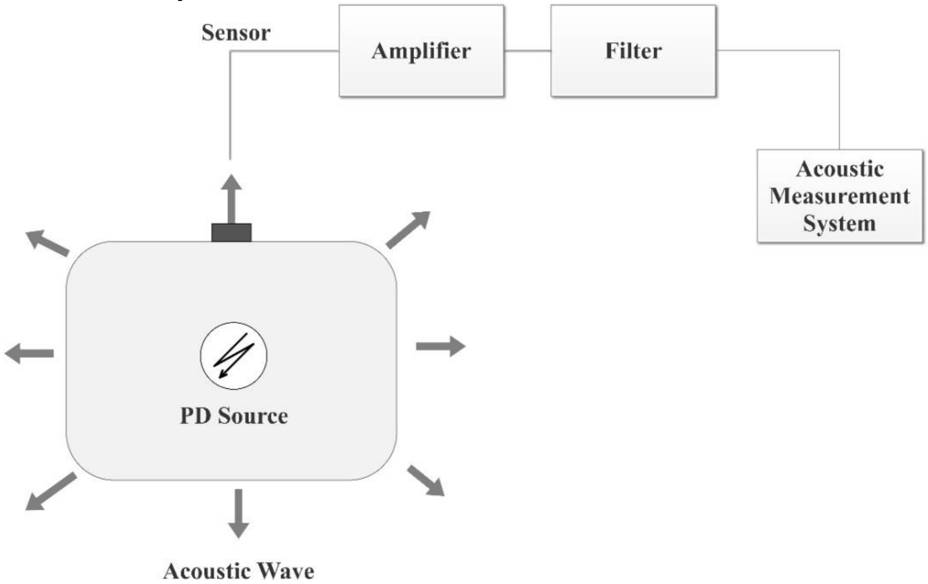

Figure 8: Acoustic PD detection

6.5 Optical Measurement

The optical partial discharge detection is based on the detection of the light produced as a result of various ionization, excitation and recombination processes during the discharge. However all electrical discharges emit radiation but the optical spectrum of different types of discharges is not the same. Different factors like the temperature, pressure etc. plays - apart from the chemical components (gaseous, liquid or solid) of the isolation system - an important role for the amount and wavelength of the emitted light. So the light spectrum emitted by an individual partial discharge depends on the surrounding medium and the discharge intensity. Thereby the optical spectrum reaches from the ultraviolet over the visible into the infrared range [16]. The optical measurement is a very sensitive method in comparison to the conventional electrical or acoustic techniques especially by on-site measurements.

VII. CONCLUSION

This paper discusses partial discharge phenomenon, its classification, necessity of partial discharge detection in current transformer and different PD detection methods.

The PD detection techniques can be used to diagnose the condition of the electrical insulation. Although it is difficult to conclude about life-span of equipment based on PD measurement, but based on knowledge about the intensity of PD impulses, it is possible to draw conclusion whether equipment needs to be maintained immediately or not.

However, knowledge of the insulating material of the current transformer is very important for diagnosis.

The use of new techniques like acoustic or optical detection is possible an early recognition and localization of PD activity, but only conventional PD measurement method is standardized because of its quantitative measurement.

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