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Localization of Partial Discharge in a Transformer Winding Using Ladder Network – A Review

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***Abstract*- The Detection of the location of partial discharge in the windings of power transformers has always been considered a challenging task because of the convoluted structure of the winding. There are several methods proposed for the localization of partial discharge in the transformer winding. In this paper, we have concluded a detailed study on detecting the partial discharge using a ladder network to compute the response of a partial discharge in a winding of a transformer. The algorithm for two separate winding sections that are along and across the winding is computed. A response is calculated at the winding neutral terminal.**

***Keywords*- partial discharge, formatting, lumped parameter, ladder network, frequency response, correlation.**

I. INTRODUCTION

The condition for power system utilities has changed to a great extent from the last few decades. Similarly, the demand for a reliable supply of energy has also increased in the same period considerably requiring minimum fault operation of power systems. Insulation breakdown is considered to be the most important cause of the failure of any machinery in power systems.

Since repair time is not very less and even backup units are not always accessible, it is important to assess the condition of each and every unit in the network. An international survey of CIGRE [1] on large power transformers has shown that the failure rate is 1-2% per year. This failure rate is not very high but on a large transformer, it can still cause large disbursement for the utility. Partial discharge (PD) is thereby contemplated as the utmost cause of the insulation breakdown.

PD is a highly confined electrical discharge under high voltage stress, due to the presence of incipient faults such as cracks, voids, and some other imperfections in the insulation [2]. The early detection of partial discharge before evolving it into a full discharge can prevent the degradation of the insulation and thus avert the requirement of repair or replacement of transformer. Monitoring of PD can be done by localizing its source. According to the physical phenomena associated with PD, several methods have been developed to study and detect partial discharge.

The physical phenomena accompanied by the PD are:

- Generation of mechanical vibrations that produce the acoustic waves in the ultrasonic range.
- Electromagnetic waves are emitted in ultra-high-frequency UHF).
- Emission of ozone and nitrogen oxide due to the chemical reaction.
- Emission of heat and light energy.

Research on PD in transformer windings was initiated dated back in the 1970s [3] where conventional methods namely electrical methods were used. Electrical methods use digital filtering, capacitive component localization, and travelling wave. Likewise, electrical methods, lately some nonelectrical methods were also discovered which optical, chemical, acoustic methods are.

In [4] we can see the comprehensive comparison between the different methods of detection and measurement of PD.

There are several models by which proper insulation can be designed. Some of these models are:

- RLC lumped network model which incorporates disc to disc modelling for several kilohertz of frequency.
- Multi-conductor transmission line (MTL) model which uses the turn-to-turn model for a few megahertz of frequency range [5] [6]
- A hybrid model for the frequency range of 10 KHz to a few MHz [7].

Studies show the statistics for the failures in transformers and the parts involved in the failures [8] [9].

The table represents the percentage fault distribution for Power Transformer failures.

From the table, we can clearly identify that winding and core are majorly involved in the failure of a power transformer. Hence early detection of the faults in both these components of the transformer is very important.

Table 1. Percentage fault distribution for power transformer failures.

	%	%
Defective Component	CIGRE Survey	CEA Survey
Bushings	29	29
Tap-Changer	15	15
Insulation	12	16
Winding	31	16
Core	2	10
Leads	11	6

II. PARTIAL DISCHARGES

Partial discharge is defined as a localized electrical discharge that partially bridges the insulation between the conductors i.e. the insulation between the conductors is partially punctured. According to the standard textbooks, Partial discharge (PD) is the name given to electrical discharge involving only a portion of a dielectric between two electrodes and which does not bridge the gap [10].

Partial discharges can take place at voids either inside the insulation or on the surface of the insulation. With the exponential rise in world population, the need for electric power is also increasing for our daily requirements and also in industries, health services, and several other areas. So, continuous supply of power has become a challenging task,

Apart from increasing the generation unit, the transmission of such huge power is also an onerous job. Therefore, for significant transmission of power, the power devices must be well functioning and should be efficient.

A transformer is a must-have in all power systems for stepping up and down of AC voltages without altering their frequency. Winding in Transformer is one of the important parts and its protection is a necessity. Fault in windings can mainly occur due to insulation failure which can be predominantly caused by Partial discharges. Thus early detection of PD is of utmost importance for the appropriate working of the Transformer and its long life span.

Partial Discharge can be classified into the following categories:

1. External Discharges:
It is the phenomena that occurs external to the equipment i.e. in the transmission lines.

2. Internal Discharges: It is the phenomena that occur within the insulation i.e. in voids, treeing, etc. Apart from Transformers, PD also occurs in Generators, Cables, and Transmission lines. Detection of these types of discharges is a cumbersome process and requires greater experience and knowledge.

2.1 Partial Discharge in voids: The presence of voids lead to the stronger electric field in void which may exceed maximum field strength in some parts and leads to partial discharge activities in those vicinities. When partial discharge occurs, it starts from one end of the cavity surface, bridging through the gas-filled cavity, and reaches the other end of the cavity surface [11].

2.2 Surface Discharge: Surface discharge is termed as dielectric barrier discharge when one or both the conductors are covered with the insulator, which can be either gas, liquid or vacuum [12].

2.3 Corona Discharges: Corona is a discharge caused by the ionization of air that surrounds the conductor due to the exposure of high voltage which exceeds that of the conductor's critical value [13].

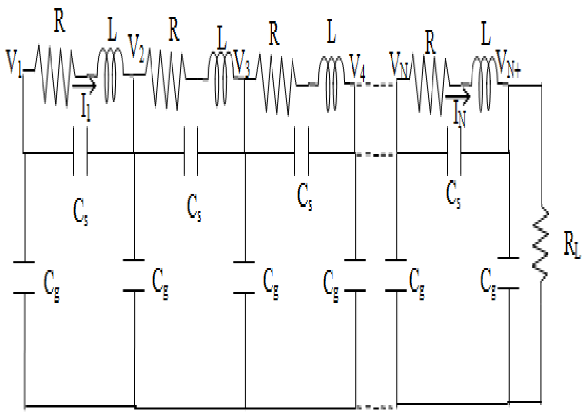

Fig 1. Lumped Parameter Network of a Transformer Winding.

3. Methods for Detecting Partial Discharges are:

3.1 Electrical Methods: These methods involve the measurement of the amplitude, phase, pulse rate, pulse height, etc. Earlier, with the traditional methods, the partial discharge is measured by studying the signals displayed on the oscilloscope [14].

3.2 Chemical Methods: The chemical measurement techniques for detecting PD in the high voltage transformer are based on the collection and some chemical measurements of oil and gas samples released during the PD process. Two chemical measurement techniques are used at the present moment. They are the high-performance liquid chromatography method (HPLC) and the dissolved gas analysis method (DGA) [15][16].

3.3 Acoustic Methods: Acoustic method involves the placement of the sensors at a different location in the transformer and therefore it is a bit costly method. The PD detection test by the acoustic method allows for online monitoring by studying the attenuation in amplitude and phase delay [17].

4. Lumped Parameter Model:
In order to detect PD, we usually consider a continuous disc or interleaved windings. In 1915 Abetti has first time used the lumped parameter model to analyze the Partial discharge and named the model as Abetti coil. A lumped parameter model is designed from the frequency response at the terminal with consists of winding capacitance Cs (inter disc capacitance), shunt capacitance Cg (stray or earth capacitance), self-inductance L, Mutual inductance Mij, Resistance R, and terminal resistance RL across which the response is measured.

N sections are contemplated in the ladder network and since we have considered a uniform transformer winding so each section is made identical to the other. This is the structure of the transformer winding that has been used by several researchers for detecting partial discharges using a ladder network. The ladder network of N sections is shown in Fig.1.

III. LITERATURE REVIEW

There have been a lot of studies undertaken in the past years on partial discharge or more precisely at the end of the last century when High Voltage Technology came into existence in the generation and transmission of electric power. Partial Discharge was considered to be hazardous and thereby study was initiated in this context. It can cause a severe deterioration in the insulation and progressive deterioration can even cause a complete breakdown of the insulation. Several electrical and acoustic methods have been evolved and discussed in past studies.

K. Ragavan and L. Satish: This method discusses the construction of a physically realizable driving point impedance function with the help of the frequency response of the winding of the transformer. The frequency response data consists of phase and magnitude. The lumped parameter model is selected because along with providing the impulse behavior, it also includes the length of the winding. Hence physical winding can be easily visualized. This has proved the advantage of lumped parameter networks over other models. [18].

Mithun Mondal and G.B. Kumbhar: In their paper has explained PD briefly along with its causes and effects? They have also discussed various methods used for the detection of partial discharge in a power transformer. It also deals with several models that can be used for designing the windings of power transformers. It provides great help for the researchers working on this area as it contains the overview of the PD from the detection to the methods of controlling it [4].

Hettiwatte, S.N.Wang, Z.D, Crossley, P.A., Darwin, A., Edwards, and G.: Partial discharge pulses in 6.6kV continuous winding transformer is investigated. To achieve this, a calibrator is used to inject PD pulses into the windings and a wideband current transformer (CT) is used to measure current signals at the line and neutral endpoints. The authors conclude that the position of a trough (zeros) in the frequency spectra of the measured time-domain signal change depending on the location of the PD injection and the crests (poles) of the spectra are not affected by the position of the injection [19].

V. Jeyabalan and S. Usa: In their paper studies partial discharge in a 22KV interleaved winding with the help of various statistical techniques. They have mentioned three techniques Regression Analysis, Least Slope and Phase Angle Difference Method, and Statistical Correlation Method which collectively can be used to determine the PD. For a generation of real-time PD signals, a standard PD calibrator can be used. To validate these techniques experimental analysis is performed on the windings which have further proved it to be suitable for PD detection [20].

K. Ragavan and L. Satish: In their paper have synthesized an equivalent circuit which is the reference circuit by measuring its open circuit and short circuit natural frequencies. Next, changes were introduced at different locations in the model winding, and its natural frequencies were measured. Corresponding to every new set of measured natural frequencies, a new circuit was synthesized (with topology remaining unchanged). A comparison of these circuits with the reference circuit revealed that mapping could be established between changes introduced in the model winding and those predicted by the synthesized circuits.

Luo Yini Zhou Lixing: In their paper used ATP Draw and MATLAB to simulate two PD sources and determine the PD source with the help of sectional winding Transfer Function theory using Hopfield Neural Network. But this method has high accuracy only when two PD sources are acting, In case there are more PD's than an artificial neural network can be used to increase the efficacy [21].

S. M. Hassan Hosseini, Mehdi Vakilian, and Gevork B: Have compared various models for the detection of Partial Discharges. They have basically compared the Multi transmission line model and the ladder network for very fast transients in their study. The two network models have proved to best in the respective frequency ranges. MTL network was found to be suitable for 1MHz to 5 MHz whereas ladder network was found to satisfactory in the frequency range of 10KHz to 1MHz .

Ueno Takahiro, Aoi Tsuneo, Oya Makoto, and Muto D: Have explained the importance of high voltages in hybrid vehicles and electric vehicles and thus the increasing voltage is an effective challenge against these vehicles. With the involvement of high voltages, the role of insulation is also vital. They have explained the Partial Discharges in the motor windings. The detection of PD is accompanied by determining the Partial Discharge inception voltage.

The PD inception voltage is determined for different models of the windings and thereafter compared.

A. Mazhab Jafaforri, A. Akbari: Have described an algorithm for determining the partial discharge in Multiconductor transmission line model using section winding transfer functions. In the case of the MTL model also first the winding parameters are determined using different formulations and methods which require transformer design data. The designed algorithm can be generalized for a large range of windings [23].

Mohammad S. Naderi, M. Vakilian, T.R. Blackburn, B.T. Phung, and Hio Nam O, Mehdi S. Naderi, and R. Ghaemmaghami: In their paper described a hybrid model for the propagation and detection of Partial discharge in the Abetti winding. The hybrid model uses both the ladder network model and the Multi-conductor transmission line model. The modeling of the winding is based on a ladder network and the current and voltage response are calculated considering the MTL model. In this way, the hybrid model can be used for a wider frequency range with efficacy. Further, they have applied the frequency analysis and with the help of the DPI response of the winding.

Azevedo, C. H. B., Marques, A. P. And Ribeiro, C. J.: Their has given a predictive technique which consists of establishing a diagnosis and analyzing tendencies based on test results and on the analysis of phenomena that occur during the operation of a device. When the diagnosis is final and conclusive, if an abnormality has been detected, the necessary measures should be taken to correct it.

To this end, preventive or corrective maintenance can be scheduled for the equipment in question. The detection of partial discharges by the acoustic method offers the advantage of allowing one to pinpoint the region where partial discharge activity occurs. Moreover, as in DGA, this method can also be used without requiring the shutdown of the transformer to be tested [24].

M. S. Abd Rahman, P. L. Lewin and P. Rapisarda: The fundamental technique used for detection of Partial Discharge is the wavelet multi-resolution process for computing the energies at different range of frequencies and the output produced by the principal component can be used for detecting the location of Partial discharges.

This process is further improved by using 3D filters for detecting the location. The internal data obtained is based on frequency detection and sensors [25].

IV. CONCLUSION

These methods and formulations can be successfully used to compute the partial discharge response of the winding of the transformer for an adequate frequency range. A ladder network is designed to represent the structure of the winding. The winding parameters are calculated by any of the formulas or algorithms in order to construct the lumped parameter network.

A DPI response is plotted for the network, through which crest and trough frequencies are extracted. These frequencies represent the poles and zeros. A rectangular pulse signal depicting the PD signal of a pulse width of few micro seconds is applied to the ladder network and the current response is calculated through a resistor at the neutral end. It is observed that the location of poles is the same but the location of zeros is changed by the application of the PD.

Thus with the help of the frequency spectra, we can deduce the location of PD i.e. the disc at which it has occurred.

V. FUTURE SCOPE

The future scope of partial discharge lies in the understanding of the propagation of the partial discharge signal. These methods have proved to be substantially accepted and even cost-effective methods that can be used for further analyzing the nature of the PD signal.

This method can further be incorporated with an artificial neural network in the case of a large number of signals.

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