A Review: Partial Discharge Detection using UHF sensor on High Voltage Equipment

Roslizan N D¹, Rohani M N K H¹, Wooi C L¹, Isa M¹, Ismail B¹, Rosmi A S² and Mustafa W A³

¹High Voltage Transient and Insulation Health (HVTrans) Group, Centre of Excellence for Renewable Energy (CERE), School of Electrical System Engineering, Pauh Putra Campus, Univeristi Malaysia Perlis (UniMAP), 02600 Arau Perlis, Malaysia.
²High Voltage Transient and Insulation Health (HVTrans), Centre of Excellence for Renewable Energy (CERE), Department of Electronic Engineering Technology, Faculty of Engineering Technology, UniCTI Campus, Sungai Chuchuh, 02100 Padang Besar, Perlis, Malaysia.
³Department of Electrical Technology, Faculty of Engineering Technology, UniCITI Alam Campus, Sungai Chuchuh, Padang Besar, Universiti Malaysia Perlis (UniMAP), 02100 Padang Besar, Perlis, Malaysia.

Email: dayini@studentmail.unimap.edu.my

Abstract: Partial discharge (PD) is one of the most popular failure or breakdown that can happen at high voltage (HV) equipment. PD is the fault that causes the insulation breakdown occurred between two electrodes. It happened or occurred because of the improper insulation, ageing, environment effect and manufacturing defects. The loss of the power will affect consumer and system operation. One of the technique that can measure or detect the PD is by using ultra high frequency (UHF) method for HV equipment insulation condition monitoring and assessment. In this paper, the application of UHF method have been reviewed as the best method to detect PD in transformer, GIS and cable. The UHF method for every electrical equipment is described in order to detect the PD and the laboratory result shows that this method can be considered as suitable technique. Based on this review, the new design in UHF sensor is required in order to improve the sensitivity and bandwidth for PD detection in HV equipment. The valuable parameter such as size and PD frequency range can be used for early stage of designing new the UHF sensor.

Keywords: Partial discharge detection, High voltage equipment, Ultra High Frequency (UHF), Transformer, Gas Insulated Switchgear (GIS), Transmission Cable

1. Introduction

Partial discharge (PD) is includes study of materials, arcing characteristics, the sensor sensitivity, noise and data interpretation. Most of the engineers not have the time or available energy to seek such a course of study [1]. PD is the early stage of fault that occur in the HV equipment which can cause the insulation failure [2]. PD are small electrical sparks that happen within the insulation of medium and high voltage electrical properties. Each discrete partial discharge is the electrical breakdown of a cavity within the insulation. These discharges corrode insulation and in the end effect in insulation failure [1].

Nowadays, HV transmission was usually operated to transmit the high electrical energy. PD measurement was become a common procedure in off-line and on-line diagnosis testing of HV equipment system [1], [3]. In addition, the PD detection can be found in HV equipment such as switchgear, underground cable, transformer, generator and others [4]. The HV equipment have their own percentage of insulation failure as shown in Table 1. In real life, the PD phenomena also occurred inside the medium and insulation of the power apparatus. Based on the failure, this problem...
needs a solution on how to detect and measure the PD that happened.

| Table 1: Percentage of insulation failure of power apparatus [1]. |
|-----------------|-----------------|
| Equipment       | Percentage (%)  |
| Switchgear      | 95              |
| Underground Cable| 89              |
| Transformer     | 84              |
| Generator       | 49              |

This electrical insulation system is under the stress of the voltage and the PD deteriorates the insulation of a transformer and can cause its failure. It is important to perform partial discharge diagnostic measurements to detect discharges that begin to follow their early stages and locate their origin [5]. Based on the research that have being done, there are few difficulties to identify the fault and position of PD in power apparatus [1]. In order to defeat these obstacles, numerous techniques are used for diagnosis of PD in power apparatus. Each type of high voltage equipment has their method for the PD detection. Every method has advantage and disadvantage for the equipment to be applied.

2. Application of UHF Technique in High Voltage Equipment

The Ultra High Frequency (UHF) method is an effective technique for PD detection in electrical equipment especially in SF 6 Gas Insulated Switchgear (GIS) and transformer [6]–[8]. Lately, the application of UHF PD diagnosis in power transformer has gain popularity among researcher with more detail result [8], [9]. Location and detection PD in electrical equipment is important to avoid the damage and ensure the safety of environment.

Potentiality of on-line detection and localization is the greatest important benefit of UHF method compared to conventional electrical method based on IEC 60270 [10]–[12]. Therefore, several types of UHF sensor and antenna have been studied and apply for PD measurement at GIS, transformer and power cable with their suitable UHF antenna. Publication [13] introducing the Hilbert fractal antenna as shown in Figure 1 (a) which has a great performance for PD detection at transformer. The Moore fractal antenna in Figure 1 (b) has been detail discussed in publication [14] for PD detection in GIS and for Figure 1 (c) the PD detection using HFCT and UHF sensors as mentioned in [15].

![Figure 1: UHF sensor for different design of an antenna. (a) Hilbert fractal (b) Moore fractal (c) UHF sensor [13]–[15]](image)

3. UHF PD detection in Transformer

Nowadays, the UHF technique is commonly used for upgrading and investigating the technology that controlled the method of partial discharge detection while a power transformer is in running condition [5], [16]. The UHF test method is less sensitive to outside interference in contrast with the electrical detection method at lower frequencies or acoustic method. Based on that, it gives advantage for on-site partial discharge monitoring or continuous on-line partial discharge observing of power transformers because PD signals are regularly weak [5]. The Ultra High Frequency (UHF) PD diagnosis technique is based on analyzing the electromagnetic waves formed from the PD location. The method has been established earliest for GIS in 1988 and later in 1997 for power transformers
The UHF sensor is one of the effective methods for PD detection which has the great sensitivity for PD signal since it is a fast electrical discharge that emits the electromagnetic emission with frequency band higher than 300 MHz (range 0.3 to 3 GHz) [13], [17]. This is because of the reasonably attenuated transmission of the emitted electromagnetic wave inside the transformer tank [17], [18]. In large power transformers, external electromagnetic disturbance such as noise from communication concentrated within UHF sensor normally has the highest signal to noise ratio (SNR) [19] and plus because of the shielding effect of a tank on internal PD pulse [17], [20], [21].

Currently, there were various of UHF antenna that have been applied to detect PD for on-line condition and experiment [22], [23]. Publications [24], [25] discussing the two-arm Archimedeans Planar which the design is from the gap-fed spiral to strip line –fed spiral that was tested in transformer for PD detection. Publications [20], [26] presenting the monopole antenna for PD electromagnetic propagation tested in transformer tank. The experiment has been conducted at the inside and outside of the transformer tank where the monopole antenna can captured the background noise and PD signal. Publications [27], [28] experimenting an inverted cone antenna to monitor the PD signal in oil immersed transformer. In [29], the author was discussing about three designs of Hilbert fractal antenna to capture PD in oil insulated system. The dimension of designed antenna is less than 20 cm where it is less than the diameter of drain valve. Based on the simulation and experiment that have been conducted, the result shows that the antenna with smaller size has the highest sensitivity for PD activities compared to bigger antennas. However, based on the performance of SNR, inception voltage and classification rate of signal, it can conclude that the Hilbert fractal antenna is perfect for capture PD from all over the transformer tank.

Publications [30], [31] were presenting the UHF Hilbert fractal antenna as the sensor to detect the different of PD type in an oil paper insulated system. Each type of PD signal was able been captured by 4th order Hilbert. The previous research [32] proposed the UHF stacked Hilbert antenna array for PD detection. The parameter design and the experiment result of the antenna shows wide bandwidth compare to Hilbert antenna with single patch. However, this UHF antenna array was designed in 3rd order antenna. In publication [33], the paper investigated about the iteration of the Hilbert fractal antenna in second, third and fourth order with different size for PD detection. From the result, it proves that the higher the order and smaller the size, higher the bandwidth and smaller the frequency resonance.

Publications [13], [17], [34] presenting the Hilbert fractal antenna as the most suitable UHF antenna for PD detection in transformer. The wide frequency pass band and small size of antenna which required for the design criteria of PD antenna is very difficult to fulfill all at once, where the frequency bandwidth of the antenna become large, the dimension of the antenna also should be increased [13], [35] However, the compact UHF PD antenna, Hilbert fractal antenna shows a good result in fulfilled the two criteria which are size and bandwidth. Hilbert fractal antenna was designed by refer the Hilbert fractal curve which the curve is a continuous curves by strict self-similarity [36]. There were several advantages of Hilbert fractal antenna over the other types of antenna such as easy to manufactured by etching or photolithography and it also easy be fed over 50 ohms coaxial cable in pass band [17], [20]. The length of Hilbert fractal curve should be longer if the order of the curve is increases. The Hilbert fractal antenna shows that it can be effective antenna to be applied for PD on-line monitoring for transformer.

4. UHF PD detection in GIS

The current pulse created by PD might have a very quick rising advantage and stimulates the electromagnetic wave in UHF range (0.3 - 3 GHz), therefore UHF analysis method can be applied for online recognition PD in GIS [13], [37]. Publications [13] and [28] summarizing that Moore fractal antenna is suitable for online PD detection in GIS with two types of sensor which are internal and external. These publications compare the Moore with Hilbert fractal antenna in various aspect such as
dimension, multiband, characteristic, performance analysis, radiation and VSWR. The analysis from the experiment shows the Moore fractal antenna has a good performance for PD detection in GIS.

Both radiation and VSWR of Moore fractal antenna proved that it has greater amplitude and sharper initial edge. Also has more exact and faster response for PD signal detection. Besides, it also shown that it has better response and greater recognition sensitivity. Other than that, the findings in publications [7], [37], [38] highlighting the typical of PD sources for detection in GIS. There were several types of typical defect in GIS which have been tested, such as floating metal, protrusion, void in spacer and therefore, the experiment results show that the floating metal model has more appropriate sensitivity verification than others model. The UHF method has been used to prove that the highest sensitivity and linearity of PD detection system is able to be verified accurately.

The publications [9], [39]–[41] investigating the sensitivity of two UHF sensors which has a disc-type and loop-type measuring electrode for PD detection in GIS. The disc-type electrode can detect the PD with wide frequency up to 8 GHz and while the loop-type electrode proved that it has more sensitivity on conductor. These both disc-type and loop-type measuring electrodes are able to detect the various type of defect that exist in GIS. In [42], the author provides the information about the bowtie antenna. The bowtie antenna was modified followed the UHF range signal and result from the simulation and laboratory experiment satisfy that UHF sensor meet requirement for PD detection in GIS. In [43] and [44], the paper introduce the dipole antenna model for PD detection. The author investigating the effect of length and width of sensor on the characteristic of PD. The result from the comparison of dipole and T antenna shows that dipole antenna has better performance where it has 12% higher detection of sensitivity.

5. UHF PD detection in Cable

PD is known as the early failure or breakdown due to the high voltage in an equipment. PD need to be detected earlier so that a proper maintenance can be conducted. However, for PD detection in power cable, the power equipment need not to be turned off in order to proceed the detection procedure.

Publication [15] prove that the combination of high frequency current transformer (HFCT) and UHF methods is effective in power cables condition diagnosis. The combination of method in have been done due to the complexity of on-site cable network interconnection, interference in field environment and wide band frequency in order to measure the PD in cable.

Other publication such as [8] stated that for PD detection on power cable, the standard of UHF analysis on the plug in cable termination can be applied. The inductive sensor and capacitive sensor detect the passing electromagnetic field produced by PD. However, the experiment result shows that PD test are not capable because of SNR where measurement frequency is less than 500 kHz and by the increasing the frequency, the PD signal can be detected in power cable. Therefore, the UHF method is the right technique that can be applied for PD detection in power cable for example in termination and joints.

In [2], [45] authors discussed about the algorithm location of PD in underground cable. After all the tests that has been conducted by using UHF sensor for PD detection in cable whether in experiment or online condition, this paper shows that the data can be analysed by using the technique of trimmed mean data filter to get the accurate PD location in cable which include excessive noises. The observation of PD signal especially on HV equipment which popular at transformer, GIS and power cable by using an online monitoring system is quite common nowadays, because it is very important to detect PD in early stage [46], [47]. An early prevention is very important in order to avoid any explosion or damage of the equipment [48]. Thus, the UHF technique is proposed to overcome the problem in PD detection.
6. Conclusion

In order to monitor and diagnose the insulation status of transformer, GIS and cable, the UHF method can be applied for PD detection in these high voltage equipment. Several types of UHF sensors have been discussed in this review where each type of electrical equipment have their UHF sensor in order to monitor the PD activities. The Hilbert fractal antenna have been reviewed as a suitable antenna for PD detection in transformer which have advantage in aspect of bandwidth, size and sensitivity. Besides, the antenna for GIS also been studied which the VSWR and radiation pattern shows good results. The advantage and disadvantage of the type of sensor also been discussed. Furthermore, the combination of UHF method has been reviewed to cover the disadvantage of the method. By the analysis of the laboratory experiment, it is presented that UHF method have a very high sensitivity and can be considered as a suitable technique for PD detection and measurement.

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