A review: Partial discharge detection using acoustic sensor on high voltage transformer

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Abstract: Partial discharge (PD) is an electrical discharge which is one of the most critical breakdown factor that is affecting the electrical equipment. The loss of the power will affect consumers and system operation. High voltage (HV) transformer is one of the equipment’s subjected to phenomena PD. In this paper reviews an application of acoustic methods in transformer and piezoelectric sensors application on PD detection in HV transformer. Based on this review, the new design in acoustic sensor is required in order to improve the sensitivity and bandwidth for PD detection at HV transformer. The valuable parameter such as materials, size, and PD frequency range were discussed in this paper and can be used for early stage on designing new acoustic sensor. This detection method given some benefits on preventing the power electrical system from breakdown.

Keywords: Partial discharge (PD), high voltage transformer, piezoelectric, acoustic emission, PD detection.

1. Introduction

PD is an electrical discharge which is one of the most critical problem in electrical power equipment. Identify the localization and type of detection is very important for equipment performance. By definition, the PD is the conducting points with the instantaneous release of the energy that has been affecting the electrical equipment[1]–[4]. Statistics result shows 85% of power failures happen at medium and high voltage of power transformer [5], [6].

PD at high voltage transformer frequently occurs because of unscheduled maintenances, aging of equipment, breakdown of insulation, gas bubbles in insulation liquid or others[7]–[10]. In order to maintain constant performance of transformer, it is important to control, detect, and measure PD phenomena.

There are many detection methods that have been presented and at the end, it can be categorized as electrical, optical, chemical and acoustic detection[8], [9], [11]–[13]. Categorization of PD is based on the types of emission happens at power equipment. PD frequency and occurrence will increase by the time, leading to failure and can cause equipment damage by the absence of detection problems in transformers. For instance, electrical detection is focusing on capturing electrical impulses from PD, while optic detection is based on recording light as result of ionization, excitation and recombination during partial discharge[9], [14], [15]. Next, chemical follows changes in chemical structure of materials causes by PD like presents in[16], [17] and lastly, during PD differentiation occurrences, acoustic is recording mechanically and sense the acoustical signal produced [15], [18]. In [19]
presenting an experiment and mention, the acoustic signal is produced from the vaporization of the material around the hot steamer within the void and can cause an explosion which travels through the transformers tank in form of pressure field.

However, there are on point of observations and each one has some disadvantages like presented in[20]. For chemical, it is not suitable to apply online and on sight and for optical, it will be facing problem with transparency of equipment and electrical will not be immune to electromagnetic interference (EMI) compared to acoustic that is immune on EMI and it is possible to locate multiple sources and location of PD in power equipment such as oil-insulated transformers. It is used in big range as tool in reliability and the most applicable one in this method, which is very acceptable in terms of economic value to industry[2], [5], [21].

PD can also be categorized in three types which are internal discharge, surface discharge and corona discharge like mentioned in[22], [23]. Corona has highest intensity with high signal to noise ratio while surface and internal PD is less intense and their detection is effected by noise[23]–[25]. The phenomena of corona discharge generated in the high voltage electrical equipment outside surface will increase the insulation aging, surface filth or atmospheric humidity[4], [23], [26].

Classification of PD existence in power high voltage transformer is based on consideration, location, and some researches about the importance of an insulation system could occurs. However, in order to analyse the internal components of the equipment such as transformers to become fabricated, some techniques have been established in order to overcome the defect by other methods presenting in [27]–[30].

Application of acoustic methods in transformers
Nowadays, acoustic is one of an importance of detection to avoid damage to equipment. The aim of acoustic sensors is to sense and record the acoustic signal that have been successfully produced from PD and used to monitor PD in power transformers like presents in[22], [27], [31].

In order to identify sources, it is necessary to capture signal that produced by PD that can varies from 10 kHz to 300 kHz as mentioned in [32]–[35]. Acoustic method has a time past in PD detection. As regards on acoustic signal detection, comparative analysis has performed in focusing at impulse and corona PD in acoustic detection method and two differences piezoelectric structure have produced [7], [13], [15], [22]. Acoustic signal can be detected by setting the position sensor at the surface of the tank or inside the tank while the output will be analyse by normal data. Figure 1 shows the experiment on acoustic sensors on transformer. Figure 2 depicts the combination method of fibre optic and piezoelectric sensors. There are many sensors that have be used such as microphones, piezoelectric, fibre sensors, ultrasonic and etc. In some cases, combination of above is possible such as optical fibre sensor that acts as detector and used as the reference point for piezoelectric sensor to recognize the location detection[15], [22], [36], [37].

![Figure 1. Experiment on acoustic sensors on transformer](image-url)
Piezoelectric sensor applications

Piezoelectric sensor is one of the popular techniques of acoustic detection for PD which is converting vibration caused by acoustic signal into electrical signal like shown in [37]–[42]. There are several types of piezoelectric material that are widely used for example lead zirconatetitanate (PZT), zinc oxide (ZnO) and aluminium nitrate (AlN) which is mention in [36], [38], [43]. By different piezoelectric materials will affect the performance of the energy harvester due to the different of piezoelectric constant [43]. Piezoelectric also shows many benefits such as low electromagnetic including noise, low profile, high power density, and it performs a very high resistive load [34].

In order to choose suitable piezoelectric sensor sensitivity, some parameters must consider in order to match bandwidth of acoustic signal. In publications [44], [45] were conduct an experiment on piezoelectric crystal and told that this sensors might be functioning at high temperatures without failure. Thus, the PZT-on-silicon electromechanical resonators is depending on the odd harmonic of the outline length-extensional methods to deliver a suitable result for voltage and current transformations with a single layer of piezoelectric [45].

The alternating current (AC) sensors like in [38] uses a permanent magnet attached to the free end of the piezoelectric cantilever beam which is combined with the magnetization direction associated with the mechanical submission direction of the cantilever beam as shown in Figure 3.

In [45] presents on experiment in order to prove the concept of test structure was fabricated from a silicon on insulator (SOI) wafer which has been mentioned that the dimension of wafer by 25 µm thick silicon device layer, 7 mm of width, 1.2 mm of anchor buried oxide layer and 500 µm thick layer of handle silicon. However, piezoelectric silicon that is sensing the component is small and generating the low output voltage, therefore this sensor technology might be mostly matched for battery operation system [45], [46].

Piezoelectric sensor usually installs at the walls of the transformers tank. Piezoelectric sensors are commonly used for acoustic detection but have some limitations due to oil-to-tank and tank-to-sensor interference that making elimination of noise hard [7], [32], [35]. PD acoustic wave bandwidth can reach 300 kHz with tendency to stay in range of 200 kHz to 300 kHz [22]. Moreover, other reasonable
condition that may impact the acknowledgment rate are concentrated. Publication[7], [31], [46] show the AE of piezoelectric to get signal for rating the differences considering about various PD areas, oil temperatures and having a limitation in the obvious pathway of the PD source and the AE sensor. In publication [36] shows the AE sensor is used at medium voltage and bandwidth range between 100 - 300 kHz and the resonance frequency at 150 kHz.

Additionally, in papers[40], [47] it have been presented an experiment by using piezoelectric material lead-zirconate-titanate (PZT). This experiment in [41] shows comparison between 2 µm, 4 µm, and 10 µm of the model measurement of fabricated PZT-on-silicon piezoelectric. However, for this experiment it was presented that high frequencies resonant with > 10 MHz for voltage and efficiency characteristic and also largely focuses on the RF-filtering applications applied on the modelling.

Lastly, in publication [43] presents that the design of MEMs piezoelectric energy harvester has been studied in order to understand the effect of piezoelectric material performance by using (ZnO), (PZT) and (AlN). As shown in Figure 4 [37], the piezoelectric energy harvester is made of ZnO between Al layers which serves as the top and bottom electrodes, respectively. The bottom of the layer is made of Silicon (Si) substrate as the supporting layer. The dimension is 150 µm length, 50 µm width with 1 µm thickness for each layer.

![Figure 4. Cantilever structure which contains of ZnO layer sandwiched between Al layers with bottom [37].](image)

In this experiment result also shows that ZnO piezoelectric energy harvester is the best candidate in generating maximum output power for the piezoelectric applications as shown in Table 1.

| Piezoelectric Material | Displacement (µm) | Resonance Frequency (MHz) | Electric Potential (V) |
|------------------------|-------------------|---------------------------|------------------------|
| ZnO                    | 5.85 x 10⁻⁹       | 0.17                      | 9.91                   |
| PZT                    | 1.08 x 10⁻¹⁰      | 0.15                      | 9.01                   |
| AlN                    | 8.66 x 10⁻¹¹      | 0.20                      | 9.62                   |

However, piezoelectric devices might be separated into several general classes such as sensors, actuators, generators, and transducers. Sensors and generator type always be used of the direct piezoelectric effect, which means it can convert the mechanical energy into electrical signal while effort of actuators is based on the reverse effect which is by transforming the electrical energy into mechanical energy show in publication[7], [46], [48]and transducers, both effects are utilized within the same device. In this publication are focusing on the specific applications and the related outcome.

2. Conclusion

Numerous detection methods on PD in high voltage (HV) like transformers have been covered in this review paper. The benefits and drawback of each detection methods likes electrical, optical, chemical and acoustic have been deliberate. Its shows that to monitor and control the high voltage equipment is very significant for consistency and to get effective process. The example of piezoelectric material also were discussed and studied on definitions and do some reviewed on other researchers’ projects. In other ways, the combination of methods proposed in several works can also design a respectable and appropriate result for on-site PD inspection such as acoustic technique and optical as planned. It is
general to develop ideal system for PD detection and will take time until each method comes to faultlessness and by following trend of power equipment and devices. There are several types of the piezoelectric materials, size, and PD frequency range also have been covered in this review. For example ZnO, PZT and AlN. From the observation, it shows that ZnO material is the best material because it is friendly to the environment. Lastly, PD also have challenges and one of the most significant challenges in PD detection is the standardization of the detected signal to reflect the kind of defecton. Even though there are frequent discussions on the techniques by the researchers but there is still no reliable standards to monitor this process.

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