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A Comparative study on Partial Discharge Emulators

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***Abstract* — Partial Discharge (PD) detection plays a vital role in electrical power stations, it can help protecting the high voltage equipment, it can prevent explosion of these equipment and hence preventing a catastrophic failure. PD detection can be performed in two modes, i.e. frequency domain and time domain. The characteristics of PD signal varies due to size and type of equipment it arises from. Wireless emerging technologies such as Software Defined Radio (SDR) can be used for PD detection.**

In this paper two PD source were employed to generate PD signals, a floating-electrode PD emulator was used and PD signals were detected using SDR system, and, a floating-electrode PD emulator is replaced by a HVPD pC calibrator, while the detection system is kept the same. A comparison shows that afloating-electrode PD emulator generates stronger PD signals than HVPD pC calibrator. Furthermore, although a HVPD pC calibrator is commercial and more sophisticated and expensive than floating-electrode PD emulator, a floating-electrode PD emulator generates stronger signals and overall better results.

***Keywords* — Software Defined Radio, Partial Discharge.**

I. Introduction

The term partial discharge refers to insulation defects that partially bridge the electrodes that carry electrical currents. PD can be of various types including internal, external and surface discharge etc. [1-3]. PD initially is a slow activity and it gets stronger with time if not resolved properly. PD gets catastrophic when it leads to treeing in high voltage (HV) system. The process of treeing starts due to long term unresolved PD [4-7]. The high voltage systems could be of various types and applications including power transformers, cables, switch gears and generators. The discharge can take place at various positions as well within HV systems and it termed accordingly as well e.g. corona and surface discharges [8-9]. PD normally has the frequency band from 50 to 800 MHz with majority of the activity takes place at the lower frequencies. A PD pulse is a time dependent pulse with certain rise time that is very short. A typical PD pulse has the rise time of around 10 ns and pulse duration about 100 ns. The rise times and duration of PD pulses depend upon the type of materials used. For example, in air insulated substation (AIS), the pulse duration is small, whereas in gas insulated substations (GIS), the pulse duration will be large [10-13]. A typical PD pulse is shown in Figure 2 in section (IV).

The generation of PD pulse as mentioned above is based on the transverse electric field and Coulomb component [14-16]. The characteristics of partial discharge are based on key variables. Key variables include the type of the discharge source, i.e. HV transformer or any other material and location of the PD source within the HV system, e.g. surface or corona discharge. Also, the discharge has the key variable that is based on the type of sensor used for the detection system, due to the frequency range of the PD activity, it is imperative to use the detection sensors that operate within the entire bandwidth. Over the entire bandwidth, the PD activity may remain there but have different pulse characteristics depending upon the type of discharge [17-20].

II. PD Activity as Electromagnetic Waves Radiation

In HV systems, existence of PD is as a result of free electrons movement. Free movement of electrons creates electric field that cause electromagnetic (EM) radiation from the source that causing it.

A stationary charge will have electric field radially emitted. Charges that move possess both electric and magnetic fields. The distance between the radial displacement and the observer determines the strength of the magnetic field. When PD occur in HV systems, the electric field strength can be calculated as shown in equation (1) below:

$$E = \frac{Q}{4\pi\varepsilon R^2} \quad (1)$$

Where Q is the total moving charge in coulomb, R is the the distance in meters and ε is the free space permitivity with the value of 8.854×10^{-12}. The electric field quantity in equation (1) is a vector quantity having magnitude as well as the direction. The magnetic field strength can be calculated as shown in equation (2) below:

$$B = \frac{\mu Q c}{4\pi\varepsilon R^2} \quad (2)$$

Where C is the speed of light having the vlaue of $2.99 \times 10^8 m/s$.

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PD occurs when two different materials with two different characteristics in terms of their dielectric constant experience voltage. This causes higher electric field strength in within the region that has the smaller permittivity. If electric field is too high, it will cause an explosion resulting in catastrophic failure of the HV system and hence electrical breakdown. Figure 1 show a PD equivalent circuit [8-9].

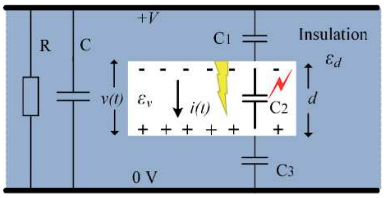

Fig.1. the PD equivalent circuit [11].

III. PD PULSE

Within HV systems and transformers, PD signals are produced and propagated inside the systems and reflected or refracted the medium as well as the components of the HV systems including transformers.

PD pulse shape depends upon the source where the pulses are generated. For various types of sources, there will be varying PD pulse shapes. The pulse duration can vary from 10ns to 100ns depending upon the source of PD. As mentioned above that a PD pulse is modeled by using the Gaussian function, and the equation below defines the pulse [21]:

$$i(t) = I_{MAX} e^{-\frac{t^2}{2\sigma^2}} \quad (3)$$

Where $i(t)$ is the current that is function of time.

I_{MAX} is the peak current magnitude

σ is the proportional to the width of the pulse and it is chosen to fit with the shape of the pulse.

It can be seen that when time is 0, the current will be maximum.

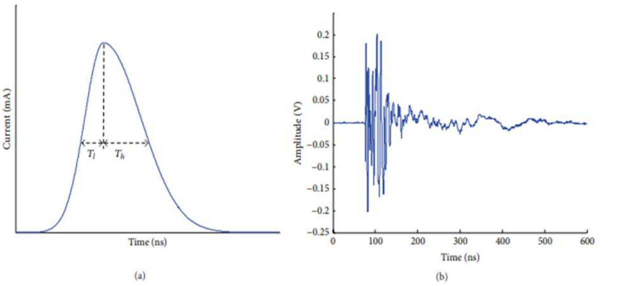

Fig. 2. (a) Tpyical PD current pulse and (b) Tpycical signal arriseing from radiated PD energy [8].

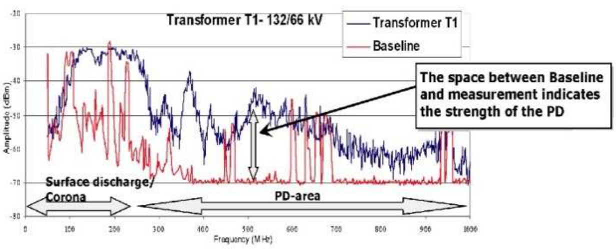

Fig. 3. A typical PD frequency spectrum: lower trace is a reference in the absence of PD [8].

To get the spectrum of the above equation the Fourier transform is used [6].

$$F\{ I(t) \} = \int_{-\infty}^{\infty} I_{MAX} e^{-\frac{t^2}{2\sigma^2}} e^{-j\omega t^2} dt = I(\omega) \quad (4)$$

The Fourier transformation of the above equation will generate the spectrum that is also a Gaussian pulse.

$$I(\omega) = I_{MAX}\sigma\sqrt{2\pi}\, e^{\frac{-\omega^2\sigma^2}{2}} \quad (5)$$

For the Gaussian pulse, the time required to reach from 10% to 90 % of the pulse is called the rise time, and it can be calculated by using the equation 6 given below [21]:

$$T = \frac{3.2}{\sigma}\, erf^{-1} \quad (6)$$

IV. SYSTEM OVERVIEW AND RESULTS

As mentioned earlier the PD pulse current duration is short and can vary from 10 ns to 100 ns and its measurable energy spectrum occupies frequency range of VHF and UHF. Fig 1. (a) Typical PD current pulse and (b) Typical signal arriseing from radiated PD energy [21].

So PD activity is the generation of radio waves. These radio waves are electromagnetic signals in nature and are radiated by these PD current pulses. PD signals are captured using a measuring unit connected to sensors. The recording of PD signals can be conducted in either the time domain or in the frequency domain [21].

In the time domain PD signals are recorded with the use of an oscilliscope. The shape of PD signal in the time domain consists of the magnitude versus time over the entire band.

In the frequency domain PD signals are recorded using spectrum analyzer (SA). The PD spectrum consists of magnitude versus frequency [23].

V. PD DETECTION

A high voltage power system including power transformers is critical in electricity generations and distributions. Their reliability depends on the insulations conditions used within them. It is essential to detect symptoms that lead to catastrophic failures to avoid disruptions and economic losses. The biggest drawback associated with PD presence is that it long term persistence may result in failure in the insulation systems of the equipment such as power transformers. A long term PD may lead to deterioration of the equipment and can lead to an ultimate breakdown of the insulation system of the transformer. The heat generation due to PD activity can initiate chemical reactions that can also lead to accelerating the ageing of the insulation systems of power transformers [23].

Two major techniques are quite common in PD detection, these include:

1. Electromagnetic detection
2. Acoustic detection

The above two techniques do not conform to IEC 60270. Both techniques mainly detect the signal rather than quantity of charge. For this reason, several conventional and non-conventional methods are used for PD detection and are quite common. Conventional methods include measurement of charges and measurement of pico coulombs (pC). Non-conventional methods include the use detection of EM transients, detection of compounds and detection of signals from 10KHz to 10MHz [22-25].

VI. PD DETECTION WHEN THE SOURCE IS PD EMULATOR

Fifgure 4 shows the sysetm set-up used to detect the PD signal. The PD source is PD emulator that is placed in wooden box for health and safetey reasons. PD source is used to generate the PD signal, detection unit that include USRP N200 with a dipole antenna that connected to a laptop to record the captured data to be processed offline, further explanation on how SDR is employed for PD detection can be found in [4][13]. Figure 5 shows a schematic illustration of a floating-electrode PD and (b) a floating-electrode PD emulator, more information can be found in[4][25]. Figure 6 shows the obtained results when the floating-electrode PD emulator was used as a PD source.

Fig.4. The experimental set up: A floating-electrode PD emulator is used as a PD source [16].

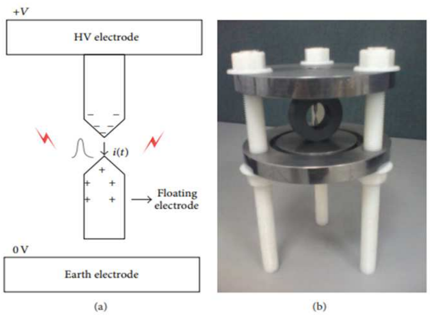

Fig. 5. (a) Schematic illustration of floating-electrode PD and (b) floating-electrode PD emulator [10].

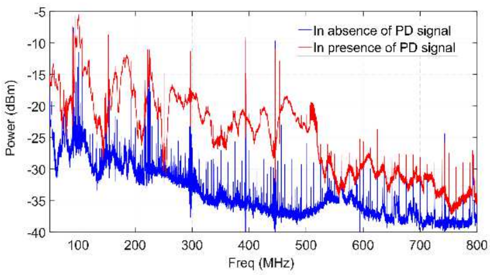

Fig. 6. Measured spectrum of PD signal that is generated by a floating-electrode PD emulator [16].

VII. PD Detection When the Source is PD Calibrator

Figure 7 shows the system set-up used to detect the PD signal.

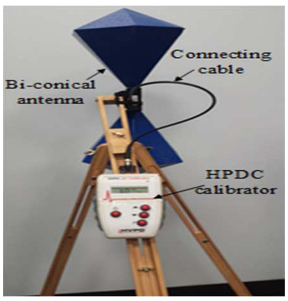

Fig.7.HVPD pC Calibrator is connected to a Biconical antenna is used as a PD source.

The PD source used here is HVPD pC calibrator. It consists of a HVPD pC calibrator as an artifial PD source to generate the PD signal, the detection system is the same for a floating-electrode PD emulator. Figure 8 shows the PD calibrator. Figure 9 shows the results obtained when the HVPD pC calibrator is employed.

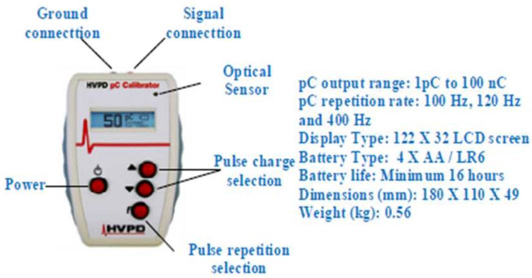

Fig. 8. HVPD pC calibrator

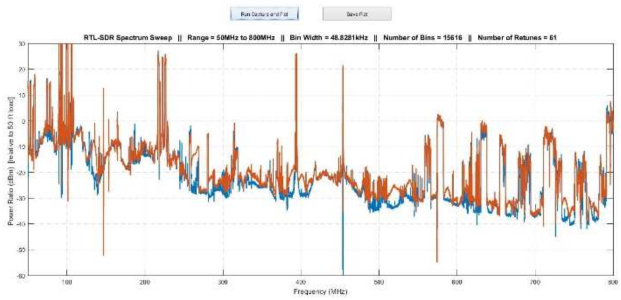

Fig.9. Measured spectrum of PD signal that is generated by a HVPD pC calibrator.

VIII. Discussion

As mentioned in the figure 3, the space between baseline, i.e noise background (Blue curve) and the measurment (the Red curve) indicates the strength of PD signals. Comparing both results , it is very clear that PD signals obtained from a floating-electrode PD emulator are stronger and have higher power. A floating-electrode PD emulator present a much higher effective radiated power ERP than HVPD pC calibrator, in this case by approximately 15-25 dB. this is due to the fact that PD puleses generated by HVPD pC calibrator are hard to measure it in frequency domain, however it is possible to be measured in time domain. The principle of these modern calibrators is described in [25].

IX. Conclusion

Two PD sources were employed to generate PD signals, a floating PD emulator and HVPD pC calibrator, PD signals are captured using SDR system in a Lab, a comparison between the two PD sources is made. The comparison indicates that PD signals generated by a floating PD emulator was stronger. The PD detection system is previously validated using spectrum analyzer.

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