Application of Ultra-Wideband Double Layer Printed Antenna for Partial Discharge Detection

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Abstract*- Partial discharge (PD) is a local electrification phenomenon that partially connects insulation between the conductors and occurs either on the surface of the conductor or inside the insulation (void). During the PD there are several phenomena that accompany the occurrence of PD, such as impulse currents, heat radiation, electromagnetic waves, mechanical waves and chemical processes. This phenomenon is detected and measured to know the existence of PD. One of the PD measurements is ultra high frequency (UHF) method, by measuring the waves generated by PD using antenna. One of antenna having good characteristics is UWB double layer printed antenna. In this paper the application of ultra-wideband double layer printed antenna for partial discharge detection is reported. The application of antenna on PD measurement, shows that the antenna is able to detect PD. The characteristics of PD: PDIV, PDEV, PD waveform are measured using this antenna. Ultra-wideband (UWB) double layer printed antenna is an antenna developed from a square microstrip antenna with symmetrical T-shaped tethering. The proposed antenna is implemented on Epoxy FR-4 substrate with permittivity of 4.3, thickness of 1.6mm, and 72.8mm x 60.0mm in size. The VNA testing of the antenna shows that the antenna bandwidth is from 50MHz to 2.30GHz. The measured results of PD wave are PDIV, PD waveform and PDEV.

Keywords-Partial discharge; UWB antenna; UHF.

I. Introduction

Partial Discharge (PD) is a local electrification phenomenon that partially connects insulation between conductors and occurs both on the surface of the conductor and inside the conductor (void). This discharge may occur in a conductor (conductor) in a short time, either at close range or at a great distance. PD can occur in solid insulating materials, liquid insulation materials and gas insulation materials. In general, PD can be caused by the local electrical stress concentration in isolation. There are three main things that can be the source of the occurrence of PD, which is Internal PD (the presence of a cavity between dielectrics or within a particular dielectric), Corona PD (occurs around the conductor) and Surface PD (occurs on the surface due to contamination). During the occurrence of PD, there are several phenomena that accompany the occurrence of PD, such as impulse currents, hot light radiation, electromagnetic waves, mechanical waves, and chemical processes.

This phenomenon is captured to know the existence of PD. The measurement and diagnosis of a non-electric PD is a measurement that does not measure electrical quantities. The concept of non-electric PD measurement is to use a number of sensor equipment and conversion devices from sensors into measurable quantities on measuring instruments such as spectrum analyzers, PD detecting, and oscilloscopes. PD causes electromagnetic waves in which this wave propagates from inside the source of the outgoing material PD. One method of PD measurement is the UHF method, the wave measurements induced by the partial discharge.

This study is an antenna investigation from the beginning of the design to the application of the antenna on the partial discharge measurement. The design of the previously researched reference antennas was re-experimented with PD measurement applications. Antenna design for the purposes of partial discharge measurements is numerous, such as antenna loops, bowtie antenna. However, the performance of the antenna still has its weaknesses in terms of antenna working frequency. The working frequency of the antenna is a parameter that must be considered because the partial discharge has a frequency that must be adjusted by the antenna to be designed. The antenna to be designed should match the antenna characteristics for the partial discharge measurement application. UHF band electromagnetic (EM) wave (300 MHz – 3 GHz) is characteristic PD emission at gas insulation substation (GIS). So far various types of antennas and sensors have been developed to detect PD [1-5]. However, the sensors bandwidth characteristics are still cut into various frequency ranges. This is not same at a certain frequency range.The antenna working frequency is expected to have the same range as the partial discharge frequency range or even more widely. Benefits obtained are, the antenna is able to perform partial discharge measurement applications on all types of isolation with just one antenna.

This research method uses a reference from the antenna form that has been studied with characteristics suitable for partial discharge measurement applications. The antenna as a sensor acts to receive EM waves. A good sensor should operate at the frequency generated by the PD which located on UHF band (300 MHz – 3 GHz). In this study the one of the antenna is UWB double layer printed antenna. The antenna reference is simulated in antenna design and simulation (ADSS) to obtain parameter results such as return loss and VSWR. The ADSS results are compared with the previously researched reference results. From the obtained frequency results are appropriate, the next step of the antenna is fabricated and tested to obtain data from the form of measurement based on vector network analyzer (VNA). The results of the VNA test compared to the simulated antenna reference results, the VNA test results should not be too much different or maybe the result can be just the same. The next test is antenna testing for partial discharge measurement. The working frequency of antennas in the partial discharge range makes the antenna capable of measuring the partial discharge.

II. Design Of Antenna

A. *Reference Antennas*

The Antenna is one of the sensors used in PD measurement using UHF method. In this study the one of the antenna is UWB double layer printed antenna [6]. Figure 1 shows the antenna design, dimensions of the antenna, either on the patch, subtrate, or groundplane. UWB double layer printed antenna proposal is then implemented on epoxy FR-4 substrate with a permittivity of 4.3 with a thickness of 1.6mm, and of 72.8mm x 60.0mm in size.

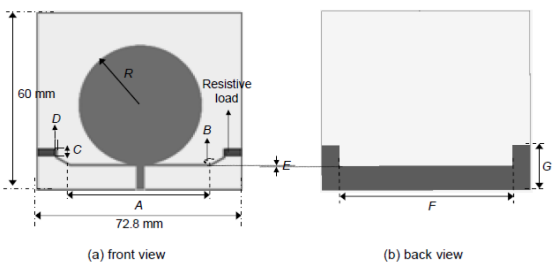

Figure 1. Antenna design.

The reference antenna shape has a wide band yield of 50MHz-5GHz that is capable of being implemented to detect PD signals. The frequency of the PD signal is in the 300MHz-3GHz range. This indicates that the antenna bandwidth is still suitable for PD measurements. Figure 2 shows the result of VSWR measurement of the antenna.

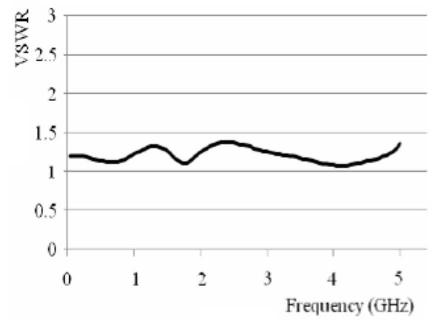

Figure 2. VSWR of proposed reference antenna with optimum dimension.

B. *Simulation of Reference Antennas*

The design is simulated again in using ADSS. Software is used to test each form of the antenna so that working frequency range of the antenna obtained. This simulation shows the result of antenna parameter the return loss and VSWR show the working frequency range of an antenna. The result of return loss measurement and VSWR is based on simulation software.

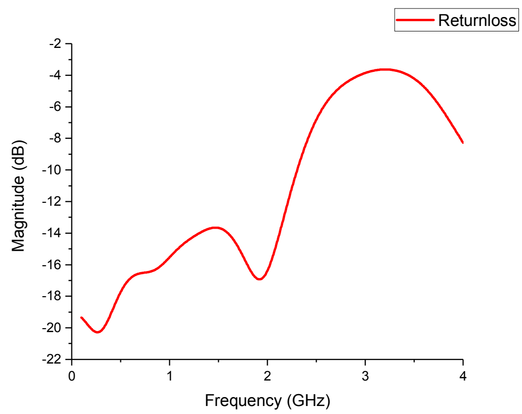

Figure 3. The simulation result of antenna return loss.

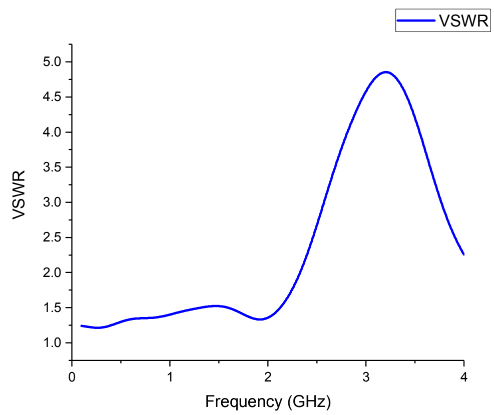

Figure 4. The simulation result of antenna VSWR.

Figure 3 and 4 show the simulation results using ADSS. The working frequency range (VSWR <2 and return loss <-10dB) of the antenna is 50MHz-2.30GHz. The frequency results are already able to detect the PD signal since the PD signal frequency range still exists in the antenna's frequency range. The comparison of simulation results using ADSS differs from the antenna reference simulation result, the reference antenna is capable of working frequency 50MHz-5GHz, while the antenna simulation using ADSS is only 50MHz-2.30GHz. This is because of that there are several unknown dimensions in the reference. However, the result can still be in working frequency which is feasible to be used for partial discharge measurement.

C. Fabrication of Reference Antennas

Fabrication is process where the antennas that have been simulated on the software begin to be made the original form. Antenna material made from PCB makes antenna easy to fabricate. Other components also have a connector sma as a connector to an oscilloscope, and resistor 82 ohm as resistor loading on the antenna. The following is the shape of the result of the fabrication of antenna in figure 5.

Figure 5. Front view of the antenna.

III. TEST OF ANTENNA USING A VECTOR NETWORK ANALYZER (VNA)

The antenna is tested using VNA. The test check the working frequency range of the fabricated antenna. It is then compared with the simulation result. simulation results of antenna working frequency of 50MHz-2.30GHz. The VNA result should be the same or close to the result of the antenna simulation in the software. Figure 6 shows a series of antenna testing using VNA.

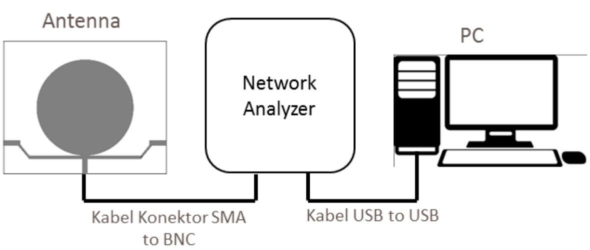

Figure 6. Antenna Testing circuit using VNA.

VNA test results show return loss and VSWR approaching simulation results. Figure 7 and Figure 8 show the return loss and VSWR obtained from VNA testing.

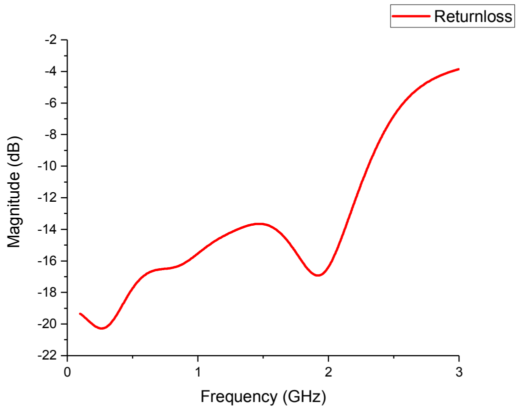

Figure 7. The return loss of antenna using VNA.

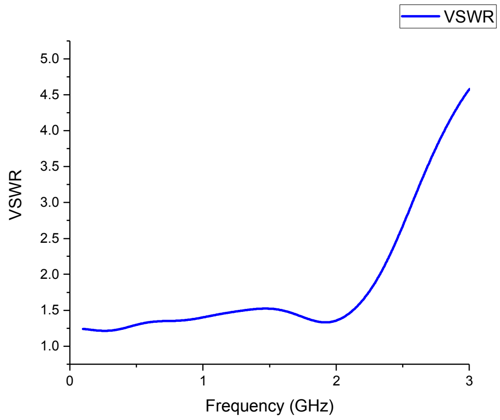

Figure 8. VSWR of the antenna using VNA.

The test results indicate the working frequency range of antenna that has been in fabrication reach 50MHZ-2.34GHz. This indicates that the results of the simulation using the software show results that are not much different from when the antenna has been fabricated and tested using VNA.

IV. EXPERIMENTAL SETUP FOR PARTIAL DISCHARGE DETECTION

The antennas designed in this experiment calculate the benefits of efficiency, and the effectiveness of partial discharge detection so that an antenna can only receive waves from the front only by making a copper-like cube that resembles a bird cage. In Figure 9 shows the partial discharge experiment, the electrodes of plates with 5mm acrylic insulation media are obtained at breaks of 9.12 volts in multimeters or 36.48 kV. PD experiments performed using voltages smaller than (80% x 36.48 kV), or about 29.18 kV and on a 7.30-volt multimeter, this is the maximum limit value for injection into the system. Figure 10 shows a series of PD tests using antenna. While in figure 11 shows the location of each component on the test in the laboratory.

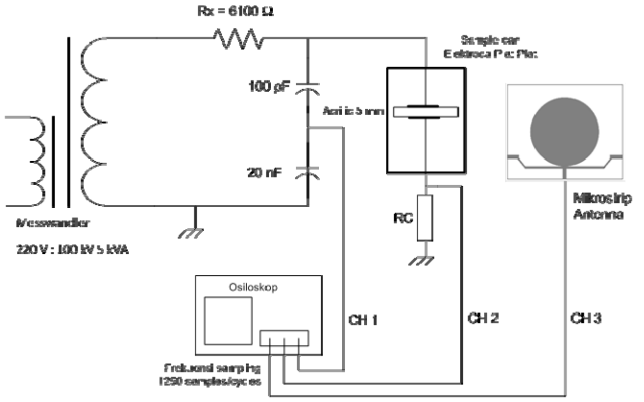

Figure 9. The PD test circuit using antenna sensors

The oscilloscope as a partial discharge wave measurement tool to see PD signal waves. In the oscilloscope, there are three channel probes used. Channel 1 (CH1) is used for the channel from the step-up transformer source. Channel 2 (CH2) is used for detecting impedance sensor measurement. Channel 3 (CH3) is used for antenna sensor measurements.

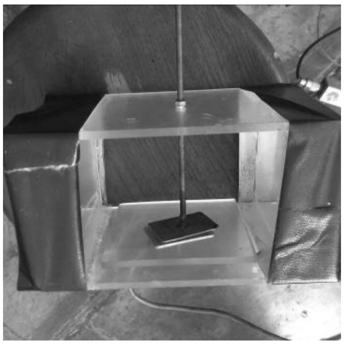

Figure 10. Source of PD

Figure 11. PD testing in laboratory.

V. Measurement Result And Discussion

A. Background noise measurement results of PD (Background ON and Background OFF)

Accurate experimental results are obtained primarily related to the partial discharge waveform, first observed in the background noise test circuit with the oscilloscope. The first measurement is the background noise in the position of the AC high-voltage source from the step-up transformer at the OFF position, the AC voltage source signal (red color graph), the signal captured by the antenna sensor (blue graph) and the signal captured by the RC detector colored blue) as follows in figure 12.

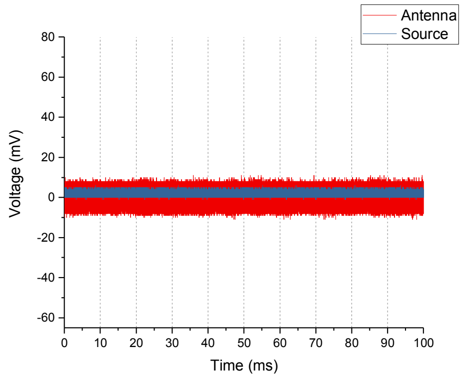

Figure 12. Background noise OFF.

Figure 12 shows the background noise signal when the voltage regulator has not been turned on. This is necessary to know the amount of noise signal coming from the external system. Before the test voltage source turned on it was already seen there is noise that is read on the oscilloscope. The oscilloscope-readable noise is derived from the environment around the experimental execution, in the form of the electric engine sound or interference from electromagnetic waves of equipment in the laboratory. Further observed when the source voltage is switched on to the test circuit.

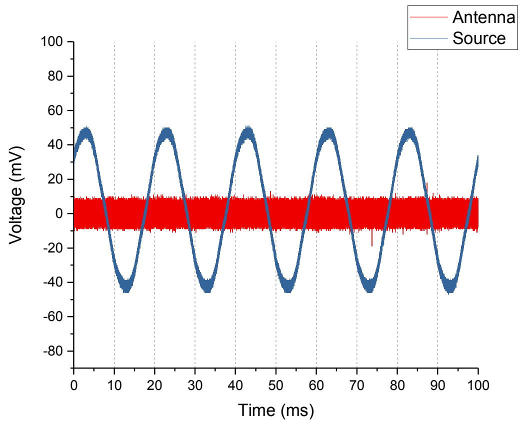

Figure 13. Background noise ON

Figure 13 shows the signal data of the AC voltage source (blue graph), the signal captured by the antenna sensor (red graph), the background noise signal is known when the voltage regulator is turned on. This is necessary to know the amount of noise signal generated by the internal system. The background noise (BGN) measurement is performed before starting the experiment to distinguish between the noise signal and the partial discharge signal to be measured. Once the voltage source is turned on, there is little change in the more noise emerging. Observation background noise becomes a parameter in the observation of the wave that appears in the next oscilloscope. The purpose to avoid taking data partial discharge wave that was only limited to noise.

B. PDIV measurement results

Observation of the partial discharge inception voltage (PDIV), the source voltage is increased gradually and observations are made on the channel oscilloscope 3. Figure 14 shows the signal data of the AC voltage source (blue graph), the signal captured by the antenna sensor (red graph). When the voltage reaches 18 kV (readings of a 4.5 volt multimeter) appears a negative PDIV signal. This occurs because, at half the negative cycle, the partial discharge is generated by electrons derived from field emissions arising from the surface of the electrode. If further observation turns out this also happens in some other negative wave cycle. This signal exceeds the value of background noise on the negative cycle so it can be ascertained that this is a partial discharge wave signal.

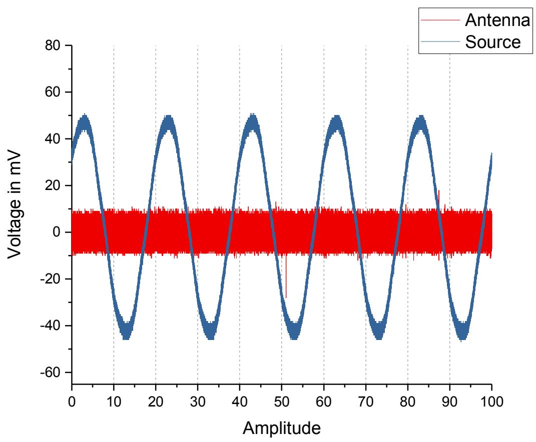

Figure 14. PDIV waveform

Figure 14 shows a negative PDIV signal. This PD signal is the first PD signal to appear on the negative side. The first partial discharge signal that emerges is a negative PD signal. If further observation turns out this also happens in some other negative wave cycle. This signal exceeds the value of background noise on the negative cycle so it can be ascertained that this is a partial discharge wave.

C. PD Waveform Results (Rise Time and Fall Time)

Figure 15 shows that the shape of the partial discharge signal and waveform appearing is not too disturbed by noise in the test circuit. In general, we can observe the basic form of partial discharge signal in the experiment.

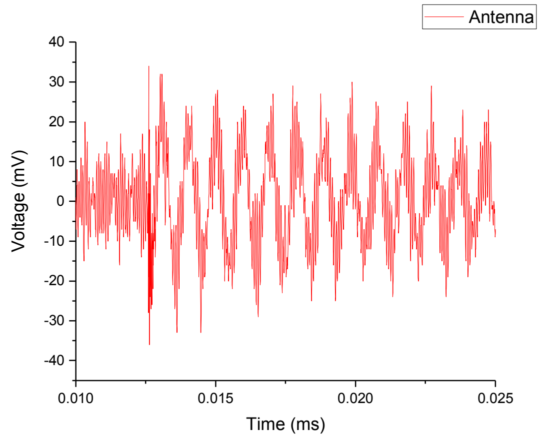

Figure 15. PD waveform measured by antenna at 5.9 kV

Partial discharge waveform can be split into the two-time rise and time fall. Generally, the rise time for partial discharge waves is from 10% to 90% of the peak. While the time fall ranging from 100% to 90%. In addition to being divided into time rise and time fall, the partial discharge waveform can also be divided into two currents due to the flow of electrons and currents due to ion movement. The electrons flow quickly and only in a short time. While the ion currents move slowly and in a relatively long time. This explains the shape of a partial discharge signal that has a sharp rise at the beginning and drops gently after it reaches its peak.

D. Partial Discharge Extinction Voltage (PDEV) Results

The voltage source during the occurrence of PD and the voltage source is lowered gradually, it will get the voltage value when the PD will disappear gradually in the positive PD and followed by the negative PD. However, in experiments with plate electrode to plate with acrylic, it cannot be distinguished PDEV negative and PDEV positive because it occurs at a narrow voltage or occurs at about the same time at the source voltage of 19.6 kV for PDEV antenna. Figure 16 shows the PDEV results on the antenna.

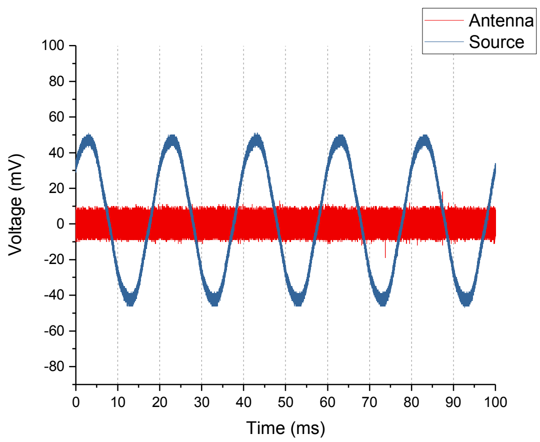

Figure 16. PDEV waveform

VI. Analysis and Discussion

The ultra-wideband double layer printed antenna has been tested. Test antenna such as simulation on software ADSS, measurement with VNA and measurement partial discharge detection.

The first, the antenna has been tested on software ADSS for get data of return loss and VSWR. The results of return loss and VSWR antenna have a good frequency for detecting partial discharge 50MHz-2.30MHz. this results indicated antenna can used measurement for partial discharge detection.

The second, after simulation in ADSS, next step is fabrication of antenna and then testing antenna with VNA. The result VNA for antenna have range frequency in 50MHz-2.34GHz. it mean, result of measurement in simulation and VNA not much different value.

And the last experimental, the antenna used to measurement partial discharge. We know the antenna has frequency in 50MHz-2.30GHz. Frequency of partial discharge detection is 300MHz-3GHz. The PD detection range is in the antenna frequency range. Therefore the antenna can be used to detect partial discharge. The result of partial discharge, such as backgrond noise, PDIV, PDEV and PD waveform result is successful to detection with the antenna. The background noise signal is known when the voltage regulator is turned on. This is necessary to know the amount of noise signal generated by the internal system. The background noise (BGN) measurement is performed before starting the experiment to distinguish between the noise signal and the partial discharge signal to be measured. Once the voltage source is turned on, there is little change in the more noise emerging.

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From the measurement results partial discharge can be stated that the ultra-wideband double layer printed antenna can be included in the classification of one type of partial discharge detection.

VII. Conclusion

The results of several experimental tests that have been done, both on antenna design and antenna testing on the partial discharge measurements in the laboratory, have good results, both in terms of antenna parameters to partial discharge measurements. following the conclusions of the experiments that have been done:

1. The antenna design made has different results on antenna parameters both return loss and VSWR, this is because there are several dimensions of the reference antenna unknown size
2. Antenna designs are made capable of performing partial discharge measurements since the range of antenna receives is in the partial discharge frequency range.
3. The ultra wide band double layer antenna can perform partial discharge detectin and measurements: PDIV, PD waveform and PDEV.

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