10 Segment Spiral Antenna to Measure Partial Discharge on High Voltage Equipment

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Abstract. Electricity basically has become the main requirement for human beings on earth. Thus electrical reliability is the most important things so that electricity flow to consumers is not interrupted. The most electricity vital is substation, there are some disturbances that commonly occur in high voltage equipment in substation such as disruption due to old tool, interference due to human error, and natural disruption resulting in equipment damage. To minimize these disturbances we need a tool that can detect interference, namely sensors. One of disturbances in substations is Partial discharge. To find out a partial discharge in voltage equipment there are several ways such as measuring using a RC sensor detector and using an antenna. This study discusses partial discharge sensor that will detect the level of partial discharge that exists in high voltage equipment such as transformers, cables, GIS (Gas insulated switchgear) and others. Spiral antenna is the main topic in this research by making spiral antenna with 10 segments. The steps in making this antenna are firstly carried out design and simulation using CST 2018 software then implementing antenna on FR4 epoxy PCB. The antenna is tested for its characteristics based on several parameters such as VSWR, RL, and Bandwidth. This test is carried out using a VNA measurement tool. The test results show that this 10 segment spiral antenna produces a VSWR value of less than 2, an RL value of less than -15, and bandwidth included in signal frequency by partial discharge is around 300MHz - 3GHz.

Keywords: partial discharge, GIS (Gas Insulated Switchgear), antenna spiral, high voltage equipment

1. Introduction

To date electricity is a very important part to support daily activities. The electricity supply service must be reliable in delivering electricity to consumers. In order to maintain it, quality of electricity must be as stable as possible. Industrial class consumers want reliable electricity supply. Because if their system has a blackout, it can be detrimental to industry its self. This makes monitoring and
protection process for electrical system are the most important aspect to keep system running normally. Substation is most important thing in delivering electricity from electricity centers to electricity load with various classes of consumers. At substation, there are various kinds of high voltage equipment that supports electricity distribution to consumer load. High voltage equipment is Transformer, GIS (Gas insulated switchgear) and others. The high voltage equipment can suddenly experience interference, therefore it is necessary to make a regular basis diagnosis on high voltage equipment [2].

Damage that occurs in this equipment is usually caused by several kinds such as: set-up errors, interference with insulation, and incorrect voltage or power settings used. Most of it is in insulation that leading to partial discharge [1]. To check the condition of high voltage equipment and diagnose existing damage, UHF method is often used to measure partial discharges because of its sensitivity in capturing electromagnetic waves and its resistance to interference from surrounding noise [4]. Partial discharge has a frequency range from 300 MHz - 3 GHz. So that the UHF sensor must have a same frequency range as partial discharge frequency range [3].

In this research, a spiral antenna with fr4 epoxy PCB material will be made. Before antenna is implemented, it is designed and simulated using CST studio suite 2018 software, then best antenna is selected to used in measuring partial discharge. Spiral antenna that has been made is expected to be a better antenna than have been made in previous studies.

2. Literature Review

Here are some previous studies using 10 segment spiral antennas that will be compared within this research:

a. Bow-tie antenna (by Asep Andi Suryandi 2015) has been designed bow-antenna antenna with the following antenna test specifications VSWR = 1.29, RL = -23.21 dB and has a bandwidth around 390 MHz.

b. Bow-tie antenna (by Joko Muslim 2013) The bow-tie antenna made in this study has a small bandwidth around 200 MHz at a return loss of -10 dB.

c. Bow-tie antennas (by Hanalde Andre 2013) Antennas are designed and simulated using Ansoft HFSS 14 software. From antenna bandwidth simulation results obtained are not too different from previous studies of 282 MHz and 202 MHz. The minimum return loss obtained from this simulation is small enough to modified antenna which is -40.27 dB.

3. Research Method

![Figure 1. Method](image.png)
3.1 Literature Study
3.1.1 Partial Discharge
Partial discharge is a partial electrical discharge event in isolation that does not fully connect between two conductors, where this discharge can occur either near or not near the conductor, and occurs due to a non-homogeneous field [1]. This partial discharge does not connect two electrodes / conductors which are isolated by insulation (solid, liquid, or gas)[2]. However if partial discharge occurs continuously, it will cause insulation damage and gradually decrease quality or dielectric strength of the insulation. This case causes an insulation failure or breakdown voltage (Breakdown Voltage) [3].

3.1.2 Elektromagnetik
In a discharge case, free electron charge that is initially stationary will be accelerated and slowed down based on external energy. The process of acceleration and deceleration produces varying electromagnetic fields that radiate out from location of partial discharges that change within time [5].

3.1.3 Antenna
Electromagnetic waves are one of energy produced by partial discharges that occur in high voltage equipment. So that measurements can use UHF (Ultra high frequency) antennas as partial discharge detection sensors. The simplest form of UHF (Ultra high frequency) sensor is length of wire [6].

3.2 Spiral Antenna Design
These two parameters have a significant influence on antenna performance results, influence of r1 and r2 is on measurement results of VSWR, RL and bandwidth. So it is necessary to calculate r1 and r2 in accordance with partial discharge working frequency that around 300 MHz - 3000 MHz. To find values of r1 and r2 can be done using equation 1.[4]

\[
f_{lw} = \frac{f}{2\pi r_2} 
\]

(1)

Keterangan:

\( f_{lw} \) : antenna Low frequency limit.

\( C \) : length of light propagation

\( r_2 \) : outer diameter of spiral antenna

After calculating, a 10 segment spiral antenna design is performed using CST 2018 software. The design results are shown in figure below.

![Figure 2](image_url)

**Figure 2.** (a) PCB spiral antenna path; (b) BNC connector.

r1 : antena inner radius                  t   : Copper PCB thickness
r2 : antena outer radius                h   : substrate (PCB layer thickness)
S  : distance between PCB lines         Connector: BNC connector (female)
3.3 Making a spiral antenna
Spiral antennas are used to obtain partial discharge signals based on detection of electromagnetic waves generated from needle-plate electrode system. The inner diameter of spiral antenna is 1 cm and outer diameter of 13.8 cm. Figure 3 shows a picture of a spiral antenna.

![Figure 3. 10 Segment Spiral Antennas](image)

4. Result

![Figure 4. (a) RL curve of 10 segment spiral antenna](image)

![Figure 4. (b) VSWR graph of 10 segment spiral antenna](image)

| Table 1 Bandwidth and Return Loss Antenna Spiral 10 Segments |
|-------------------------------------------------------------|
| Resonansi (MHz) | Bandwidth (MHz) | Frekuensi Optimum (MHz) | Return Loss (dB) |
|-----------------|-----------------|-------------------------|------------------|
| 540 - 459       | 19              | 451                     | -13.286          |
| 512 - 521       | 9               | 517                     | -20.684          |
| 621 - 632       | 11              | 627                     | -27.053          |
| 675 - 683       | 8               | 687                     | -20.245          |
| 742 - 751       | 9               | 748                     | -18.861          |
| 801 - 814       | 13              | 809                     | -35.035          |
| 861 - 874       | 13              | 869                     | -16.152          |
| 948 - 962       | 14              | 954                     | -21.244          |
| 1043 - 1060     | 17              | 1055                    | -21.046          |
| 1162 - 1194     | 32              | 1179                    | -27.633          |
| 1252 - 1275     | 23              | 1262                    | -21.692          |
| 1272 - 1296     | 24              | 1282                    | -17.261          |
From results of bandwidth measurement, the return loss that has a value of less than –10dB states that power loss from reading signal is <90%. Measurement data bandwidth on antenna shown in Table 1. The measurement results of VSWR in antenna VSWR shows that more than 1, whereas a good VSWR value is worth less than 2. The way RL with VSWR match on an antenna has VSWR less of 2.

5. Conclusion
From the test results it can be drawn to several conclusions:

a. The 10 segment spiral antenna test results of the return loss curve characteristics of less than -15 in bandwidth are in accordance with characteristics of a partial discharge frequency that is 300 MHz - 3 GHz.

b. The results of VSWR characteristic test on 10 segment spiral antenna also show a value of less than 2 and in partial discharge frequency bandwidth means that it meets the requirements of an antenna.

c. The 10 segment spiral antenna production results can be tested to measure partial discharge on high voltage equipment, this is indicated by testing characteristics result of 10 segment spiral antenna on several parameters such as bandwidth width, return loss value and vswr value. Some of these parameters meet the requirements to be an antenna as a measurement of partial discharge based on electromagnetic waves generated by partial discharge.

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