Twin loop induction sensor for detection Partial discharge

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Abstract. Partial-discharge is a symptom of high voltage insulation aging, which is a small voltage pulse with high frequency and superposition with high voltage sources that have low frequencies. To find out the existence of this signal, it needs a reliable measurement technique to avoid misinterpretation. This paper presents a technique for measuring partial discharge with an induction method. The sensor used is circular twin loops. The first loop passes through a partial discharge signal, and the second induction receiver produces an induced voltage signal. Various sizes of loop diameters are designed with dimensions 3.2, 4.7, 8.9, and 11.4 cm to look for sensor sensitivity. The performance sensor is analyzed by reading the sensitivity test to the input given with 50-ohm oscilloscope impedance. From the measurement results, the higher the diameter of the sensor loop has good sensitivity.

1. Introduction

Partial discharge is a symptom of insulating aging. The energy produced by partial discharge is not too large, but it can burn the surface of insulation slowly. This combustion process can propagate like a tree; therefore, that at a particular time, then there is a short circuit between high voltage and ground. This incident makes electrical energy unusable accordingly that the activity of partial discharge requires periodic detection.

Partial discharge produces a momentary pulse of electric current that passes through an impedance that changes shape to a pulse voltage. The voltage caused by partial discharge has high frequency and low amplitude, which blends with the source voltage wave, which has high magnitude and low frequency. One measurement technique is known as the conventional method using a low voltage sensor. This sensor can detect the series with a coupling capacitor (CCa), which also functions to pass high-frequency waves (high pass filter) [1]–[4]. Digital techniques capable of changing analog signals to digital have been carried out. Therefore, the data storage is done digitally and using a sampling rate between 10 MS/s to 100 MS/s [3][5]–[8]. Digital observation can speed up analysis and be more reliable than physical analysis, and data can be stored and analyzed again without retaking measurements. The advancement of the digital technology era, the sampling rate reaches hundreds of MHz, which allows...
reading of the discharge signal as high frequency with induction pattern [9]–[16]. One of the advantages of this sensor is naturally protected when the measurement of insulation failure occurs.

In this study, a partial discharge sensor with an induction pattern was designed with simple and economical manufacturing. The sensor used is a twin loop separated from each other by an air gap, one side (one of the loops) functions as an input, and the other side functions as an output. The working principle of this sensor is the same as an air-core transformer with a coil ratio of one. The accuracy of the sensor readings must be following the capabilities of the digital equipment required. Accordingly, it needs to be examined. The electrical characteristics of the sensor to the digital reading with the 50-ohm oscilloscope input impedance and is expected to produce the same sensor capabilities as the tools used in the laboratory. Sensor materials are made from recycled goods, making it easy to present at a lower cost.

2. Methodology
In general, twin loop induction sensors work according to the laws of electromagnetic induction, where the instantaneous current through the primary conductor produces a momentary magnetic field in the form of flux. This flux field induces a secondary conductor in front of it. The induced secondary conductor produces an opposing flux marked by the potential difference between the conductor ends. This voltage is utilized as a result of the instantaneous current response to be detected. Where the voltage produced is proportional to the change in current produced over time. Mathematically, the resulting induced voltage can be expressed by [9], [13], [17]:

\[ E = M \frac{di_o}{dt} \] (1)

Where \( i_o \) is the seat current of the PD pulse that passes through the primary side, which changes with time function, and \( M \) is the mutual inductance between the secondary sensor loop with its primary part. Where \( M \) can be used according to the equation:

\[ M = \varepsilon_r \pi \left( \frac{d}{4} \right) \] (2)

Substitution \( M \) in equation 1 with equation 2, then equation 1 becomes to equation 3:

\[ E = \varepsilon_r \pi \left( \frac{d}{4} \right) \frac{di_o}{dt} \] (3)

The sensor output voltage that follows equation 3 can increase if the sensor diameter increases. Alphabet of \( d \) is the diameter of the circle, the name of the sensor. This study fully uses equation 3, which is to increase reading sensitivity.

The sensor used, as shown in Figure 1.a, two separate loops (loops) are formed following the shape of a PVC pipe circle. The first part is the primary loop whose edges are connected to the red connector as an input of the partial discharge signal, and to the black connector as a connector to ground. The second part is the secondary loop as an induction receiver generated by the primary loop, the end of the loop is connected to the BNC connector which can later be connected to the measuring instrument, in this study the measuring instrument used is a digital oscilloscope. This sensor can be said as a transformer with a core of air with a ratio of primary-secondary winding is 1: 1. Finally, the information above can easily be illustrated in Figure 1b.

In this study, there are 4 types of sensors that will be tested. The types of sensors are variations in the diameter of the circle. The diameter of the circumference used is 3.2, 4.8, 8.9, and 11.4 cm. The conductor miners used as coils are 0.5 mm. The explanation above can be seen in Figure 2.
Figure 1.a. The shape of the sensor used. b. Sensor equivalent circuit.

Figure 2. Sensor loop with diameter (a) 3.2 cm (b) 4.8cm (c) 8.9cm (d) 11.4cm
The linearity test sensor sensitivity is done by increasing the input provided and reading the output in the form of an increase as well. As shown in Figure 3. The function generator (FG) as the source voltage and charge regulator for the input calibrator, where the product of the charge calibrator capacitance (C) with the input voltage from the source FG (V) is the simulation charge magnitude of the motions partial discharge. The formula can be written as follows.

The order of testing is as follows. First, the charge value is set through the generator function in the form of a pulse voltage and inputted to the Charge calibrator (Haefly Type 9218 signal calibrator), the charge value can be calculated using formula 3. One of the output calibrator (CC) outputs is connected to the upper CCa connector (Haefely Couling Capacitor Type 9230). The lower part of the CCa connector is connected with a commercial sensor (CS) made by Haefly with the name of the PD detector Type 9231. The CS ground side is connected to one of the Twin loop induction sensor (TLIS) inputs, and the other side is charged to the unconnected CC, which this circuit forms a closed circuit.

Momentary voltage (high frequency) that enters the circuit will be responded by CS, where the output is connected to channel 1 oscilloscope. Likewise, TLIS responds according to formula 1, whose output is connected to channel 2 oscilloscopes. Optimal results in reading the signal used a sampling rate of 200 Mega Sampling per second (MS/s). All equipment used can be controlled automatically or manually using the Labview program, and measurement results can also be stored with digital data.

3. Result and Discussion

In Figure 4 illustrates the results of commercial sensor (CS) measurements arranged in series with the TLIS sensor. The amount of charge injected to the circuit is 705 pC. From the measurement results, there is no change in the magnitude of the CS sensor even though the diameter of the TLIS sensor changes. The CS sensor waveform has the property of critical response because this wave does not oscillate; the results show a peak value, which means it has a clear polarity. TLIS sensor measurement results are marked with rectangles with dotted lines. The maximum TLIS sensor readings on the sensor diameter are 11.4 cm; the TLIS magnitude reading is 36% smaller than the CS sensor. TLIS response is earlier than CS sensor. However, TLIS pulse width is shorter compared to CS sensor. The oscillating waveform allows the magnitude value to be represented by the peak or valley value.

Figure 5 illustrates the characteristics of the linearity of commercial sensors and TLIS sensors. This graph draws an input function in the form of a charge value that is given to the sensor and produces an output response in the form of a voltage. The sensor response can convert to a charge form, but the shape of the readings or the accuracy of the measuring instrument (oscilloscope) is not visible. The results illustrate that the Commercial sensor satisfies the input given, so does the TLIS sensor has excellent linearity in taking PD values, namely at the peak or valley. The commercial sensitivity of the sensor to the reading of the given input is better than that
of the TLIS sensor, but measurements are carried out using a digital oscilloscope that has high sensitivity so that this problem can resolve.

Figure 4. Respond to commercial sensors and TLIS sensors

Figure 5. Linearity test of CS sensor and TLIS sensor

Figure 6 illustrates the combination of two different types of graph functions. The graph of the first type of function is a function, which is the response of the TLSI sensor output to the circle diameter owned by the sensor. The first function is marked by a small circle with the direction of the function in the form of an arrow, which is numbered 1, where the direction is to the magnitude of PD. A simple way to compare the magnitude of the peak and valley values visually (in graphical form), must be placed at the same value, the valley value has a value that is opposite to the peak value, then the value of the valley that is negative is positive so that it is easily seen that the magnitude Peak ratio is greater than the absolute magnitude Valley. The second function is indicated by a small circle with the direction of the function in the form of an arrow, which is numbered 2, where the direction
is to the percentage error magnitude function. The PD magnitude value is determined at the valley value on an oscillating PD wave. The error value is calculated by dividing the difference in magnitude peak and valley and divided by the magnitude peak multiplied by 100%. From the graph, it can be said that even though the sensor diameter is magnified, an error occurs of approximately 10%. Following formula 3, it is the result of a substitution of formulas 1 and 2, to see the effect of the sensor diameter. The results show that there is conformity with the measurement results where the sensor response increases with increasing sensor diameter for both polarities.

Figure 7 shows the calculated sampling rate values at the peaks and valleys of a PD wave [5]. There is no change in the value of the sampling rate even though the diameter of the sensor is enlarged in the selection of the peak or valley to determine the magnitude of the PD. However, there is a comparison between the peak and valley sampling rates. From the figure, it can conclude that the detection of magnitude PD using the valley wave value has a lower sampling rate compared to the determination using the peak wave value.

![Figure 6](image6.png)

**Figure 6.** Magnitude PD is a function of the sensor diameter and the percentage of errors in the reading of magnitude in the magnitude valley.

![Figure 7](image7.png)

**Figure 7.** The sampling rate for magnitude and valley detection
4. Conclusion
TLIS sensors have magnitude sensitivity properties if the sensor diameter is enlarged, while the digitizing process is more efficient using valley waves because it has a low sampling rate.

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