The effect of the core material of the Rogowski coil sensor on the sensitivity of the magnitude of partial discharge

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Abstract. The Rogowski Coil sensor is one of the sensors used to detect aging insulation, which is marked by the occurrence of Partial Discharge. Aging is damaged, which fails power tools when operated. If the insulation is aging and even causing damage, the distribution of electrical energy will be disrupted. This research presents two types of Rogowski Coil sensor core materials to detect Partial Discharge with the same number of turns. The number of turns is 5. The first sensor is a sensor with a ferromagnetic core and the second sensor is a sensor with a non ferromagnetic core. The test of the sensor is carried out by using a magnitude test using a charge calibrator as an imitation of Partial Discharge. The magnitude of the Partial Discharge read by the sensor uses a digital oscilloscope with an impedance of 50 Ohm. Measurement results compared to commercial sensors. The measurement results read by the oscilloscope found that the type of sensor core influences the magnitude value of Partial Discharge. The magnitude of the Partial Discharge sensor with a ferromagnetic core is greater than that of a sensor with a non ferromagnetic core. However, both results are much smaller than the commercial sensor even though the digital oscilloscope can read them.

1. Introduction

Partial discharge (PD) is a local or dielectric discharge that experiences high local voltage caused by an inhomogeneous electric field. The cause of the occurrence of an electric field that is not homogeneous is due to the presence of bubbles or air cavities in the dielectric. If PD occurs continuously and is left for a long time, it will result in a decrease in the quality of the isolation, and the formation of electric tree growth (treeing), so that the complete failure of isolation will occur [1–4].

PD has a high frequency so that before the occurrence of complete failure in isolation, detection and identification can be done to find the cause of PD. PD detection can be done using 4 methods, namely, electrical methods, optical methods, acoustical methods, and chemical methods. The method used to detect PD in this study is electrical methods with a frequency range of 3-30 MHz [5],[6]. PD detection and identification are generally conventional, where this method requires a large enough space because the sensor has a large size and is relatively uneconomical, therefore in this study PD
detection and identification was carried out by induction and economical [7],[8]. To test the sensor and compare the results from Hafely to the PD signal using an oscilloscope, which functions as the sensor’s output, as a control for the amount of charge that is the input of the charge calibrator, a function generator used. The Labview program controls this measurement by connecting to a local area network (LAN) with a HUB, and the results of storage are in the form of digital data. In this study, the induction sensor used is the Rogowski Coil sensor. This Rogowski Coil sensor consists of a different toroid core, namely ferromagnetic and unferromagnetic with a number of turns. The resulting characteristic results are compared with commercial sensors.

2. Methodology
Rogowski Coil (RC) sensors generally work based on Faraday's Law or what is often called the Law of Electromagnetic Induction, where the instantaneous current through the primary winding will produce an immediate magnetic field in the form of flux. This flux field induces a secondary winding. The induced secondary winding will produce an opposing flux, which is indicated by the occurrence of a potential difference between the ends of the windings. This voltage is used as a result of the instantaneous current response to be detected. The resulting voltage is proportional to the change in the resulting current over time. The resulting induced voltage can be calculated by:

\[ E = M \frac{d}{dt} i_p \]  

(1)

\( i_p \) is the instantaneous current of the PD pulse passing through the primary side, which changes with the time function, and \( M \) is the mutual inductance between the secondary side of the loop sensor and the primary side. The \( M \) can calculate with:

\[ M = \mu \frac{bW}{2\pi} \ln \frac{b}{a} \]  

(2)

The value of \( M \) depends on the type of material (\( \mu \)). In this research using ferromagnetic and non ferromagnetic materials, the non ferromagnetic used in this research is a solid polymer. The same sensor size is shown in figure 1, where \( a \) is the inside diameter of the sensor, \( b \) is the outside diameter of the sensor, and \( W \) is the height of the sensor [9]. At the same time, the sensor names are shown in table 1. All researchers agree that the equivalent circuit of the Rogowski Coil sensor is the same [9–11], the equivalent circuit can be seen in figure 2. The view of the Rogowski Coil sensor that has been made can be seen in figure 3.
Number of coil turns (N)

\[ a = 1.2 \text{ cm} \]
\[ b = 2.5 \text{ cm} \]
\[ W = 2.5 \text{ cm} \]

**Figure 1.** Sensor dimension

\[ \begin{align*}
V_{in} &= M \frac{di_0}{dt} \\
C &= R_{os} \quad V_{out}
\end{align*} \]

**Figure 2.** Equivalent circuit of RC sensor with oscilloscope

**Table 1.** Sensor conditions

| No | Name of sensor | Toroid of sensor              | Number of turns |
|----|----------------|-------------------------------|----------------|
| 1  | F              | Ferromagnetic                 | 5              |
| 2  | UF             | Non ferromagnetic             | 5              |
Figure 3. RC sensors with the number of turns of 5 and outside diameter of 2.5 cm (a) in ferromagnetic (b) in non ferromagnetic

Figure 4 is testing circuit for RC sensor. Rogowski Coil sensor testing is carried out using a function generator at 50 Ohm impedance. In addition to using a function generator, this measurement also uses a charge calibrator, oscilloscope, coupling capacitor, PD detector, and Haefely sensor (commercial sensor) as a comparison. In this circuit the function generator functions as a source and regulator of the load which is the input for the charge calibrator.

The upper part of the coupling capacitor is served to one of the charge calibrator inputs, the coupling capacitor functions as a voltage divider and is also a sensor of low frequencies, which means that this sensor only accepts high frequencies and does not receive low frequencies. Whereas the lower part of the coupling capacitor is served with a proper PD detector and as output from the sensor is actually served to Chanel 2 on the oscilloscope. Then the ground part of the sensor Haefely serves to one of the RC sensor inputs and the other side to the charge calibrator that is not yet connected. The ability to read this sensor can be seen by connecting the output from the RC sensor to Chanel 3 on the oscilloscope, after completion, the measurement results can be saved.

The amount of charge can be calculated by:

\[ Q = C \cdot V \]  

where \( Q \) is the amount of charge in pC, \( C \) is the capacitance in F, and \( V \) is the voltage in V. The upper part of the coupling capacitor is connected to one of the charge calibrators inputs, the capacitor value used is 141 pF, while the lower part of the coupling capacitor is connected to the sensor Haefely. The output of the sensor must be connected to the channel 2 oscilloscope. Then the ground part of the sensor must be connected to one of the Rogowski Coil sensor inputs and the other side is connected to a charge calibrator that is not yet connected. The ability to read this sensor can be seen by connecting the output from the Rogowski Coil sensor to the channel 3 oscilloscope. All these measuring activities are controlled by the LabVIEW program by connecting a local area network (LAN) and all storage in digital data.
3. Result and Discussion

Figure 5 is the measurement results of Haefely (commercial) sensor waves and RC sensors with ferromagnetic and non ferromagnetic cores with a total of 5 turns. This wave is a function of time. The left Y-axis is the magnitude reading for the Haefely sensor while the right side is for the two RC sensors. RC sensor waveforms and commercial sensors are very different. Commercial sensors are shaped like an impulse wave which is not oscillating or not underdamped with a duration of 0.5 microsecond. While the RC sensors both oscillate (underdamped) with a duration of about 0.15 microseconds. Consequently, RC sensor waves dissipate faster than Commercial sensors. This is also caused by the small oscilloscope impedance value which makes the number of oscillations small.

![Figure 5](image)

**Figure 5.** The response of RC sensors in ferromagnetic and non ferromagnetic with 5 turns

Figure 6 is a measurement of the peak value for each sensor. The Haefely sensor has the greatest significance of about 0.71 volts. RC with ferromagnetic cores is greater than non ferromagnetic cores. In accordance with the formula, magnetic ferromagnetic will increase the value of $M$, which also increases the induced voltage according to formula 4. Where the magnitude of the RC sensor with a ferromagnetic core is 0.109 Volt and a non ferromagnetic core is 0.013 Volt. With the sophistication of digitization technology, small values can be read perfectly (millivolt scale).
Figure 6. The response of Haefely, ferromagnetic and non ferromagnetic sensors

From figure 5, wave normalization is carried out for commercial sensors, RC ferromagnetic, and non ferromagnetic cores so that the results in figure 7. This normalization has a peak magnitude value of 1 Volt.

The measurement results from figure 5 are normalized for each wave, in order to see the effect of the ferromagnetic and non ferromagnetic cores on the response time. Accordingly that the results in figure 6 are obtained and, as a reference, are waves from commercial sensors. The normalize data purpose to make a sensor response that produces the same waveform even though the amplitude changes [12]. The two RC sensors respond earlier than commercial sensors. However, the peak width of 90% of commercial peak sensors is wider than that of RC sensors. The effect of the core Ferromagnetic peak 90% positive polarity is wider than unferomagnetic, but in contrast to the negative polarity, unferromagnetic is wider [13].

Figure 7. Normalized wave response in ferromagnetic and non ferromagnetic for 5 turns

4. Conclusions
The analysis described above, it can be concluded that the PD magnitude value of the wave response with a ferromagnetic core is greater than that of an non ferromagnetic core. However, even though the non ferromagnetic value is small with the sophistication of digital technology, the value is still legible.
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