Development of HFCT for partial discharge sensors

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Abstract. This paper presents partial discharge (PD) measurement techniques using a commercial sensor, High-Frequency Current Transformer (HFCT). An output signal from HFCT is read by a digital oscilloscope and compared with the reading of convensional that PD detector. When PD occurs, the signals detected using high impedance that has a long time of oscillations and cause the delay of next reading of PD signals. To avoid this issue, the time of oscillations must be reduced by installing a damper which is a resistor connected in parallel between the sensor and the oscilloscope. The result of the measurement shows that the damper has the same reading on peak values as read by the convensional PD detector.

1. Introduction
Many Partial discharges test (PD) in the laboratory has been conducted in industries as well as in educational institutions to monitor the aging of the insulation on electrical equipment. PD signals resulting in an electrical system are not a normal event. These events are easily observed and usually in the form of noise appear around the equipment. The presence of noise is easily heard, it is assumed that the aging of the insulation has taken place in the equipment of high voltage. However, the initial occurrence of noise could not be observed with the sound. Hence it needs a special tool to be able to observe. This observation can be done continuously or periodically and can be combined with another monitoring method to strengthen one phenomenon with other phenomena [1]–[4].

High-Frequency Current Transformer (HFCT) is a multipurpose sensor used to detect PD[5]–[7]. It consists of one primary turns and a few seconds turns with a ferromagnetic core. This sensor should be supported by a data acquisition tool to read the data. If PD data is read in one cycle of source wave, then the tool needs a sufficient sampling rate to read more than 90% of magnitude value[9].

The use of HFCT sensor as a phase-resolved PD detector will be determined by some factors such as the sensitivity in reading low magnitudes, response time of sensor to avoid interference in next
reading, also sufficient sampling rate and memory to detect PD in 20 msec. (one cycle of AC voltage with frequency 50 Hz). These factors need to be considered to understand how the HFCT can be implemented in phase-resolved partial discharge.

The paper proposed a partial discharge measurement technique using a commercial sensor HFCT. The output signal from HFCT is read for 20 msec. Which equal to one full waveform of source voltage with frequency 50 Hz. The use of input impedance of oscilloscope causes the longer time of oscillation after reading the signal. This can disturb reading for next PD.

2. Methodology

2.1. Experimental setup

![Figure 1. Experimental setup](image)

Figure 1 shows the experimental circuit that uses the HFCT sensor which its result compared to a result from the PD detector. The system is connected to a charge calibrator. The input of charge calibrator is fed by a pulse voltage that produced from a function generator. The variable magnitude of the pulse is controlled by a PC through a LAN.

One of the output port of the charge calibrator is connected to a coupling capacitor with a capacitance value of 1nF. The coupling capacitor has two ports. One port is connected to the PD detector as impedance for detecting PD and the other one which is the ground connected to the charge calibrator.

If a pulse voltage is produced by a function generator, a coupling capacitor will filter DC and pass the pulse voltage. The magnitude of the pulse current is read by the PD detector converted in the form of voltage and connected to the oscilloscope on channel 1 (CH1). The current also flows to the HFCT and also converted in the form of voltage during the induction process. It is read by the oscilloscope on channel 2 (CH2). The value of input impedance in the oscilloscope is set to 1 Mohm and 13 pF.

2.2. The equivalent circuit of HFCT and oscilloscope

Adjusting the performance of the sensor in PD measurement by, i.e., changing some turns is not possible. One of the possible ways is adding a resistor between the HFCT and the oscilloscope. Additional resistor changes the impedance value and also changes the form of signal. Since the sensor system is an RLC circuit which produces an oscillation, the resistor will affect number and time of oscillation.
3. Result and Discussion

Figure 3 is a sensor response towards the charge calibrator. The response is in the form of current and converted to a form of voltage in reading. In figure 3.a. Shows a standard PD sensor response. The sensor responds to the signal, and the signal is disappeared immediately in any second. It is called the damped signal[10].

A response read in HFCT sensor (figure 3.b.) is in the form of oscillated voltage where its amplitude during oscillation decrease to settled in time. After induction voltage happens due to an instant pulse voltage in primary turns, an initial voltage will be produced in the sensor output. If the charges are positive, then the initial value of oscillating voltage response will be positive. The same process happens in the equivalent circuit in figure 2.a. On the HFCT sensor, induction happened equally to the value of mutual induction multiplied by currents flowing through the sensor. During the process occurring, charges storing happens in the capacitor Ci. After the process finished, the oscillation process is used in the equivalent circuit in figure 3.b with some assumptions applied, i.e., Vcoil eliminated due to only happens once for each PD signal produced by the PD calibrator. The value of Rc very small compared to Ri can be neglected.

In the next step, equivalent circuit [10] is used as in figure 2.b. After the induction process happens, the capacitor will be charged (Ci). While Ci will be discharged, the charges will be moved and stored in Inductor. The charges are transferring happen in the resistor. Therefore every time charges

![Equivalent Circuit Diagram](image-url)
transferred from Inductor to Capacitor or conversely which is in the form of the voltage signal, the amplitude decreases due to energy absorption by the resistor. The process continues to oscillate until all of the charges replaced.

![Figure 3. a. A sensor response in Standard Partial Discharge. b. A sensor response in HFCT](image)

**Figure 3.** a. A sensor response in Standard Partial Discharge. b. A sensor response in HFCT
Figure 4. The effect of two waveform intervals towards reading in the oscilloscope. **a.** Reading in the PD detector. **b.** Reading in the HFCT sensor when the second waveform is bigger than the first one. **c.** The second waveform is the same as the first one read in the HFCT sensor. **d.** The first waveform is bigger than the second one read in the HFCT sensor.

Figure 5. The effect of decreasing value of Rx towards waveform. **a.** \( Rx = 1 \) Mohm. **b.** \( Rx = 33 \) kohm. **c.** 10 kohm. **d.** 800 ohm.
The sensors are used to detect two waves with close time adjacent as shown in figure 4. In figure 4.a shows a standard detector response. If the charge calibrator produces two same input waves, the response in reading will be the same.

Figure 4 shows that the first waveform has a thinner line than the second one. There are three basic possibilities why this happened. The first possibility, the second waveform becomes bigger than the first one as shown in figure 4.b. The second, the first waveform is the same as the second one as in figure 4.c. The last, the second waveform is smaller than the first one as in figure 4.d. The results confirm that the amplitude of the first waveform affects the amplitude of the second waveform. In the other word, the oscillation affects the value of amplitude in the next reading.

The measurement results in figure 3.b show that an underdamped response of parallel RLC circuit. It is resulted after charging due to an induction process creating an oscillated input wave in the oscilloscope. The impedance of the Oscilloscope usually has a high resistance value that makes less discharging and number of oscillations. In the figure shows that it have more than 30 times of oscillation to reach steady state. It means time for oscillation is longer than expected.

Some oscillation should be reduced to get short oscillation time. Therefore, the circuit in figure 2.b needs to be modified to get a critically damped response that has a shorter oscillation time. This can be achieved by changing one of the parameters in the circuit [10]. The simplest way to modify the circuit is by changing the value of resistance by installing a resistor in parallel connection between the sensor terminals and the oscilloscope as seen in figure 2.c.

Figure 5 shows that the effect of Rx towards an input voltage of the sensor read in the oscilloscope. At R = 1 Mohm, it doesn’t affect much but the time of oscillation decrease half of the initial value which is from 0.0005 sec to 0.00025 sec as shown in figure 5.a. Rx decreased to 33 kohm (fig. 5.b.), some oscillation becomes 8 times and time of oscillation is 0.00008 sec.

Furthermore, with Rx = 10 kohm (fig. 5.c.), some oscillation is 2 times and time of oscillation is 0.00002 sec. Oscillation is damped at Rx = 800 ohm (fig. 5.d.). These decreasing input resistance in oscilloscope by connected in parallel make oscillation decrease. However, decreased amplitude causes low sensitivity in reading magnitudes. This can be solved by optimizing Volt/div scale in Oscilloscope.

4. Conclusions
The duration of oscillation strongly determines the reading of the peak values of partial discharge signals with the HFCT sensor. This includes number and time of oscillation which are influenced by the value of input impedance at the measuring instrument. The proposed way to reduce the number of oscillations and to shorten the time of oscillations is by connecting the resistor in parallel to reduce the value of input resistance

5. References
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