Partial Discharge Detection using Rogowski Coil Sensor on Medium Voltage Aerial Bundle Cable

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Abstract— **It is well known that the internal partial discharge (PD) are small electric sparks that occurred due to defect in power cable insulation. This will be lead to premature failure of cable which consequently interrupt the supply on the distribution lines. In this paper, the results of internal partial discharge detected by rogowski coil (RC) sensor were presented. The RC sensors were designed, fabricated and tested in the laboratory with varying high frequency sinusoidal and impulse signals. An artificial PD defect was also created inside a straight through joint (STJ), medium voltage aerial bundle cable (MVABC) to generate PD signals. PD testing data in the laboratory were collected and analysed. Results indicates that the RC sensors able to detects injected continuos sinusoidal signal at lower frequencies ranging from 0.5 MHz to 10 MHz. The detected PD signal generated from artificial PD defect from RC sensor were found to be slightly higher amplitude as compared to commercial PD sensor, High Frequency Current Transformer (HFCT). Thus findings shows that the RC sensor able to be used as sensor to detect the internal partial discharge at MVABC specifically at STJs.**

***Index Terms*—Medium voltage aerial bundle cable, Partial discharge, Rogowski coil, Straight through joint**

I. Introduction

Partial discharges (PD) are small electric sparks or discharges that occur due to defect in electrical insulation. In medium voltage (MV) cable systems, PD mostly occur at the cable joints due to poor workmanship during the cable jointing, aging or exposed to surrounding environment [1-5]. Consequently, PD can cause damage to the insulation of cable joint leading to unexpected premature failure of cable [6, 7].

In TNB Distribution Network (DN), medium voltage aerial bundle cables (MVABC) are installed on the overhead system [8,9]. Up to year of 2019, this installation covers 18, 595 km MVABC for voltage level 11 kV and 33 kV.

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On top of that, the MVABC have also been in-service for more than 15 years which may have experienced aging that might be lead to the degradation of the cable joints.

A lot of work and study has been done to detect and locate the partial discharge at medium voltage (MV) cable [10-12]. It includes the measuring method and analyzing techniques to identify the PD activities which mostly for the medium voltage underground cable. However, little information had been carried out regarding the PD detection for MVABC overhead system. MVABC at the overhead system are insulated cable that have similar construction to MV underground cable. Its consists of aluminium conductor, conductor screen, XLPE insulation, insulation screen, metallic screen, separator and the outer sheath. The only difference between them are MVABC at the overhead system consist a messenger wire which functional to provide mechanical strength and assist fault current return when system exposed to the short circuit. The MVABC cables are hanging at the pole which exposed with the sunlight, wind and usually long length installation.

Due to long length installation, it is difficult to measure PD at the end of the cable as PD signal tend to attenuate and disperse whilst propagating along the long length cable. Hence, alternative devices to detect or measure the internal discharge need to be explored on the MVABC overhead system specifically at STJs in order to avoid the unexpected premature failure. Therefore, this paper discuss on partial discharge detection device using RC sensor on MVABC STJs.

II. Development of RC sensor

When a partial discharge pulse occurs, there is a very fast flow of electrons from one site of the gas filled void to the other side. The moving flow of these electrons causes a PD current and voltage pulses that flow away from the PD sites. Typically these pulses are very short duration, mostly in range few nanoseconds. In other word, the PD signal represent a pulses with very short duration of high frequency signal. This signal shall be detected by alternative device sensor whereby the this signal can be sensed from energised released method such as electrical charge, electromagnetic wave and acoustic noise [13]. For MV cable, the electrical charge seems reasonable sensed since the detection methods are either in current or voltage pulses detection whereby the RC sensor is belongs to the group of current pulse detection. Details on the development of the RC sensor explained in next section.

A. RC sensor design

The RC sensor will be used to detect partial discharge from MV power cable. Since the rate of change of the magnetic field is directly proportional to the number of turn per length of the coil, the output voltage of a RC sensor can be defined by Eq. (1)

$$V_0 = N\frac{dB}{dt} \tag{1}$$

Whereby V_0 is the output voltage, N is the number of turns per length and B is the magnetic field. Taking into consideration of permeability of the core, following Eq. (2) to (5) are obtained.

$$V_0 = N\frac{d(BA)}{dt} \tag{2}$$

$$V_0 = NA\frac{dB}{dt} \tag{3}$$

$$V_0 = NA\frac{d}{dt}\left(\frac{\mu_0\mu_r}{2\pi r}\right) \tag{4}$$

$$V_0 = NA\left(\frac{\mu_0\mu_r}{2\pi r}\right)\frac{di}{dt} \tag{5}$$

Whereby r is the radius of coil, μ_0 is the permeability of air, μ_r the relative permeability of coil, A is the cross sectional area and i is the current flowing in the conductor due to the mutual inductance.

Substitute inductance K, angular frequency ω and current i into Eq. (5), the simplified output voltage equation as shown in Eq. (6)

$$V_0 = jK\omega i \tag{6}$$

Thus, sensitivity design of the RC sensor, K based on the Eq. (7)

$$K = NA\left(\frac{\mu_0\mu_r}{2\pi r}\right) \tag{7}$$

Whereby r is the radius of coil, μ_0 is the permeability of air, μ_r the relative permeability of coil, A is the cross sectional area and N is the numbers of turn.

By increasing the number of turns and cross-sectional area of the core, the sensitivity of the RC will be increased which consequently able to detect lower amplitude signal. In this design, a solid ferrite core with a permeability of 100-1000 H/m and 1 cm diameter was selected. As shown in Fig.1, ten pieces of solid ferrite core that made up a length of 40 cm was prepared and coiled with two loops of conductors.

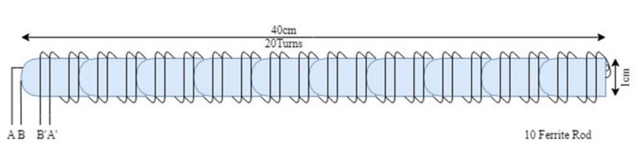


Fig. 1. The structural design of RC sensor

With the use of ten (10) pieces solid ferrite core, the structural design was considered to be flexible RC as shown in Fig.2.

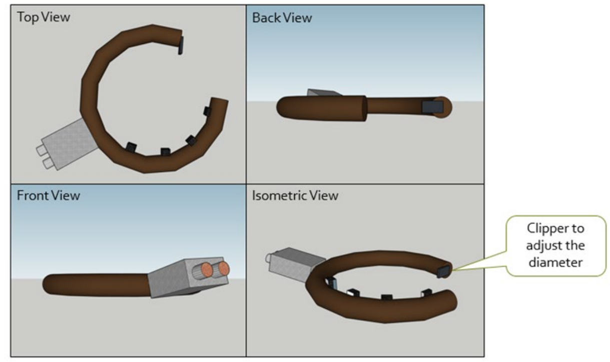


Fig. 2. Flexible RC sensor design

B. Fabrication of RC sensor

In total, fifteen (15) RC sensors were fabricated. Fig. 3 shows the prototype of RC sensor and casing are made of Acrylonitrile Styrene Acrylate (ASA) using a 3D printer. The prototype RC sensor employed exceptional strength, rigidity and rated as IP65 ingress protection. The core of the coil are protected by two layers of heatsink and wrapped in poly tape with 80°C maximum operating temperature.

Fig. 3. Prototype of RC sensor

III. Laboratory Test For RC Sensor

The laboratory test was performed to verify the functionality of the RC sensor as a PD detection sensor. This test includes;

- Laboratory test using the continuos sinusoidal test waveform at different high frequencies
- Laboratory test using the impulse test waveform at different high frequencies
- Laboratory test using the artificial PD defect signal

A. Laboratory test using continuos sinusoidal test waveform at different high frequencies

In total, fifteen (15) RC sensors were fabricated and tested in laboratory. These test is to verify whether the RC sensors can detect high frequencies continuos sinusoidal signal and the performances were compared with HFCT. The continuos sinusoidal test waveform were injected to cable using a waveform generator with an amplitude of 3 V p-p and frequencies were varies from 0.5 MHz to 30 MHz. The RC sensors were connected onto a differential amplifier as it uses a centre tap design where the detected amplitude will be doubled in order to increase sensor sensitivity. All detected and measured signals from waveform generator via RC sensors were analysed.

B. Laboratory test using impulse test waveform at different high frequencies

During partial discharge occurrence, a current pulse is produced. In order to simulate a partial discharge, the Waveform Generator is set to generate pulse wave with amplitude of 3 V_{p-p}. The frequency repetitive of the set-up circuit is constant at 10 kHz with pulse width is varied from 0.1 µs (10 MHz) to 1 µs (1MHz) as shown in Fig.4. All detected and measured signal from waveform generator via RC sensors were analysed.

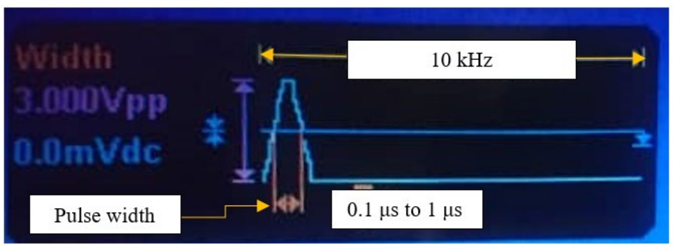
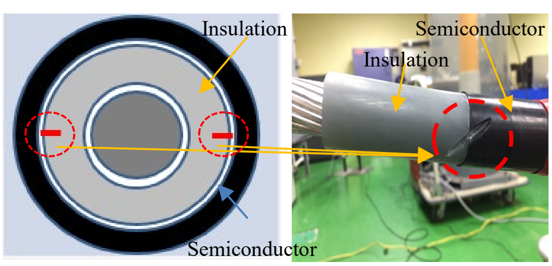


Fig. 4. Input impulse test waveform

C. Laboratory test using the artificial PD defect

The artificial PD defect as shown in Fig. 5 was created in the MVABC joint of 11 kV 3C X 240 mm^2 + 50 mm^2 MVABC cable. The artificial PD defect was created by damaging the insulation screen cut back of the cable. The insulation screen cut back of the cable were indented to create an air pocket later covered by the insulation layer of the joint.



(a) Illustration view- defects created at both end of joints

(b) MVABC joint-defects created at both end of joints, slicing between insulation and semiconductor

Fig. 5. Artificial PD defect at MVABC joint

MVABC with PD defect was tested at the laboratory as shown in Fig. 6. Both RC sensor and HFCT were clamped at the earth braid of the cable. The MVABC cable was injected with U_0 test voltage. The PD signal was captured by RC and HFCT, connected to the oscilloscope and analysed.

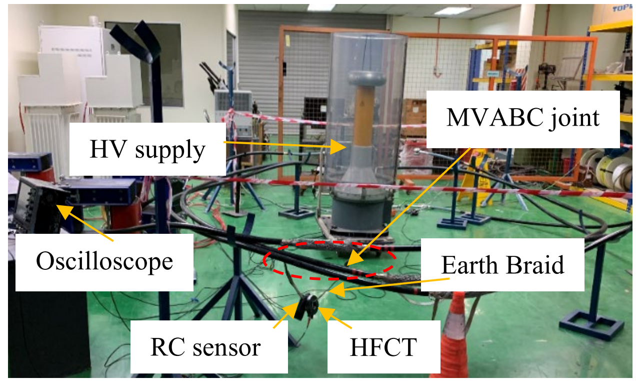


Fig. 6. Laboratory test set-up for artificial PD defect at MVABC joint

IV. Results and Discussions

Results and discussions in this paper covers the laboratory test using continuos sinusoidal test waveform at different high frequencies input signal, impulse test waveform at different high frequencies input signal and PD signal from the artificial PD defect to verify the functionality of the RC sensor as a PD detection sensor.

Fig. 7 shows the comparison of voltage amplitude detected by RC sensor and HFCT using continuos sinusoidal test waveform at different high frequencies input signal. The frequency was varied from 0.5 MHz to 30 MHz.

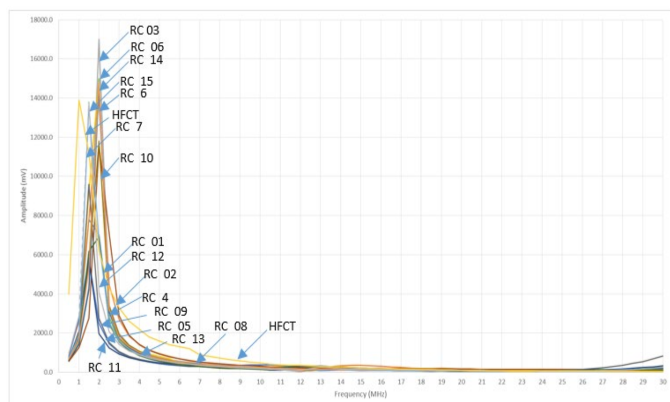


Fig. 7. voltage amplitude detectin by RC and HFCT sensor at various frequency

From figure above, both of the sensors, RC sensors and HFCT successfully detects injected continuos sinusoidal signal amplitude at lower frequencies, 0.5 MHz to 10.0 MHz. It was observed that the amplitude detected decreases as the frequency increase. The result also shows that the RC and HFCT sensor reached highest amplitude at frequency range of 1.5 MHz to 3 MHz which indicate that the RC and HFCT sensors have higher sensitivity at low frequencies of continuos sinusoidal signal.

Fig. 8 shows the voltage amplitude in each impulse test duration. The pulse wave width were varied from 0.1 µs (10 MHz) to 1 µs (1MHz) injected to a cable. HFCT and several RC sensors were clamped onto the cable to observe and assess the sensor detectability. The results shows that the voltage amplitude increase as the pulse duration increase. Thus indicates that the sensor able to detect signal frequency from 1 MHz to 10 MHz with high gain on the lower frequency range.

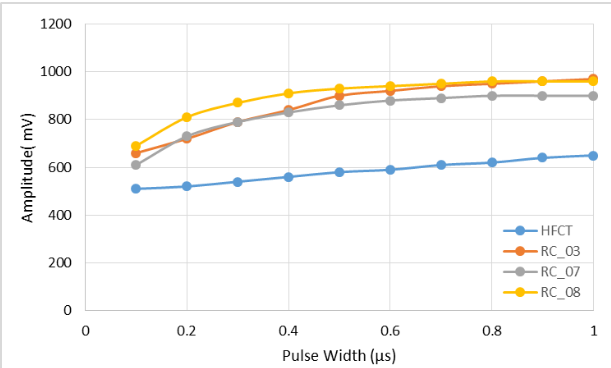


Fig. 8- Pulse duration set versus voltage amplitude

For HFCT, the amplitude gain was observed to be more stabe as only slightly increases throughout the test frequency range as compared to RC sensor. However amplitude gain for RC sensor at higher frequency range was observed to be higher compared to the HFCT thus exhibited better sensitivity. Table I shows the detected pulse signals waveform of the sensors at 0.1µs (10 MHz) and 1µs (1MHz).

TABLE I
PULSE SIGNAL DETECTED COMPARISON

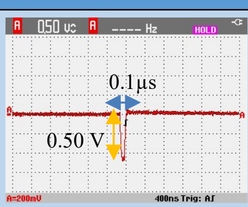
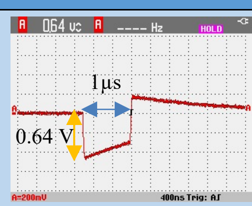
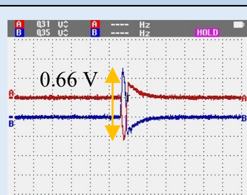
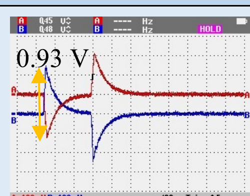
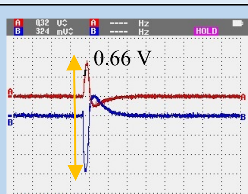
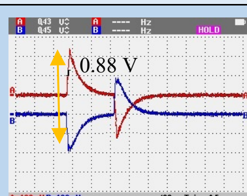
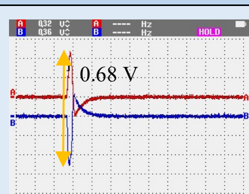
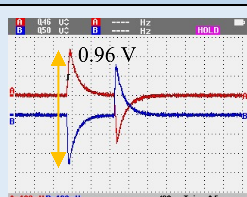
Pulse Width	0.1µs	1µs
HFCT		
RC_03		
RC_07		
RC_08		

Fig. 9 shows the results of RC sensor detecting the PD signal from artificial PD defect. The oscilloscope was used to display PD signals which indicate that the RC sensors able to detect the artificial PD defect signal as well as the HFCT sensor. PD testing was repeated for five (5) times (D1 to D5). The test results were tabulated in Table II. The average detected PD signal amplitude from artificial PD detected by RC sensor is 5.38 mV and 4.07mV for HFCT sensor. The detected PD signal frequency is 2.5 MHz or 0.4 µs pulse width. This is in line with previous impulse voltage test where at 0.4 µs, RC sensors have higher amplitude gain compared to HFCT sensor.

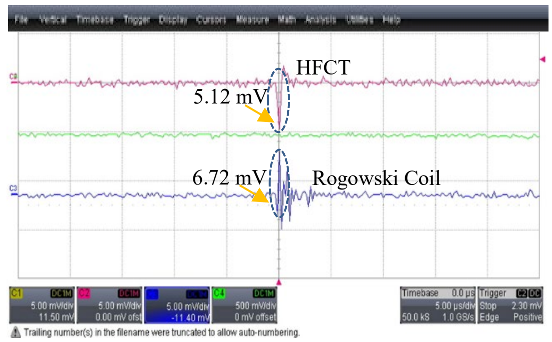


Fig. 9. Artificial PD defects result detected using RC and HFCT sensor

TABLE II
DATA COLLECTED USING THE ARTIFICIAL PD DEFECT

Data	Oscilloscope Channel (CH)	Max Peak (mV)
D1	CH 2- HFCT sensor	3.84
	CH 3- RC	5.44
D2	CH 2- HFCT sensor	5.12
	CH 3- RC	6.72
D3	CH 2- HFCT sensor	4.03
	CH 3- RC	5.76
D4	CH 2- HFCT sensor	4.16
	CH 3- RC	5.12
D5	CH 2- HFCT sensor	3.20
	CH 3- RC	3.84
Average for 5 data collected	CH 2- HFCT sensor	4.07
	CH 3- RC	5.38

In this study, the functionality of RC sensors as a PD detection sensor were tested and verified in the laboratory via continuos sinusoidal waveform, impulse waveform and PD signal generated from artificial created PD defect in actual high voltage cable. Further verification shall be carried out at actual MVABC in utility distribution network. The sensitivity of the RC sensor can be further improved by increasing the numbers of turn and diameter core thus able to increase the sensitivity. However low level surrounding noise signal need to be considered if to develop high sensitive sensor. An appropriate signal filteration is needed to reject those unwanted low level noise signal.

V. CONCLUSIONS

Partial discharge detection using Rogowski Coil sensor on the Medium Voltage Aerial Bundle Cable was found to be able to detect the internal partial discharge, specifically at the MVABC joint. Based on laboratory test, the sensor comfortably able to detect frequency range from 0.5 MHz to 10 MHz. Based on laboratory experiment using actual high voltage cable sample with artificially created PD defect, the newly developed RC sensor is expected can be used to detect PD signal in MVABC joint.

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