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Preliminary Result on Sensitivity of Rogowski Coil Sensor Design for Partial Discharge Measurement

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ABSTRACT

Partial discharge (PD) is a common issue in electrical power equipment. It is a tiny electrical spark which happen in the insulation of electrical assets. Detection and localization of PD is crucial on performance of the equipment. The electrical sensor such as Rogowski coil (RC) sensor is used to detect the PD signal on high voltage (HV) power cable. However, the RC sensor is weak on detecting small PD signal. This paper presents the preliminary assessment on performance analysis in term of sensitivity by determining the mutual inductance of the RC sensor. The main parameters of RC sensors such as height of core, diameter of coil, diameter of wire and number of turns are varied respectively. The HV cable with 240 mm^2 size copper conductor three cores 11 KV unarmoured cable from Tenaga Cable Industries Sdn. Bhd. is selected as a references size. Based on the calculated result, these parameters are important in order to increase the sensitivity of RC sensor.

1.Introduction

Electrical power is vital as it play important role in daily human life. Generated electrical power continues from generating station through substation system where have been stepped up by transformers from low to high voltage until the value match transmission lines capability. Electrical power will pass again via substation system with stepped down before reaching load from transmission. Efficiency of power system is crucial in order to deliver maximum power from generation site to the load. Hence, efficiency power losses through all power systems must be reduced. One of causes of power losses is due to the localized electrical discharge that partially bridges between two conductors, known as PD [1-3]. PD is a situation where the insulation degradation which may bring failures to the power components [4-6]. PD normally appear with presence of void, crack, foreign material or structural changes [7,8].

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RC sensor has become the famous method in measuring PD signal due to low cost, light weight, fast response, easy to construct at laboratory and safely used [9-11]. Commonly, the RC consist of two winding techniques which are return loop wire and return wire in order to avoid magnetic interference [12,13].

2. Methodology

In this paper, 240 mm² of the area of copper conductor three cores 11 KV unarmoured cable from Tenaga Cable Industries Sdn. Bhd., one of cable manufacturer in Malaysia which is 70 mm is applied in order to design the RC sensor. There are few factors need to be considered in order to improve the sensitivity of RC sensor. Hence, few tables are drawn based on the factors:

a) Number of turns
b) Height of core
c) Diameter of coil
d) Diameter of wire

Mutual inductance, M_c is a indicator to measure the sensitivity of RC sensor. There are few shapes of RC sensor such as rectangular, oval and circular. Based on [11], rectangular shape shows has a good sensitivity compare to oval and circular shapes. The M_c of rectangular shape can be calculated by following Equation 1 [14,15].

$$Mc = \frac{\mu_o}{2\pi} Nhln(\frac{Rout}{Rin}) \quad (1)$$

where,
μ_o = 4π x 10^{-7} H
N = Number of turns
h = height of core
R_{in} = Inner radius
R_{out} = Outer radius

2.1 Number of Turns

The winding should be in one direction only as it can minimize the capacitive effects. The winding must generally be shielded as the output voltage is relatively low. By adding the number of turns, the inductance will be increased which will decline the sensitivity of frequency band. In this paper, ten different samples of number of turns used to determine the best mutual inductance which is varied from 10 to 100. Hence, 10 turns of winding are chosen for sensor prototype.

2.2 Height of Core

Mutual Inductance will rise when the height of core is increasing. This is the purpose to make sure that the RC is able to detect a small current. Fig. 1 shows cross-sectional area of rectangular RC sensor with the height of core, h, inner radius, R_{in} and outer radius, R_{out}. Ten different samples of height of core used to determine the best mutual inductance which is from 37mm to 55mm.

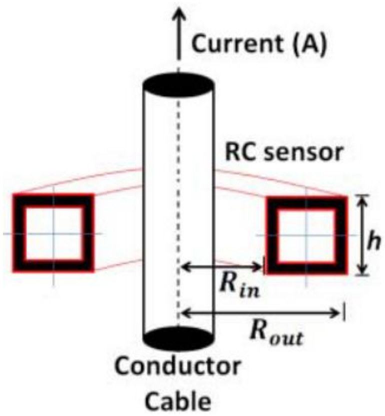

Fig. 1. Cross-Sectional Area of Rectangular RC Sensor [16]

2.3 Diameter of Coil

Generally, in order to improve its frequency characteristics, large RC have to build with several short RC. Ten different samples of diameter of coil used to determine the best mutual inductance which is from 8 mm to 17 mm. Hence, 17 mm of diameter of RC is chosen for sensor prototype.

2.4 Diameter of Wire

As known, the self-inductance of a single turn loop depends on wire diameter size. In a multi turn coil, each loop has its self-inductance which depends on wire size as well as the mutual inductance to every other turn in the coil. If there are a lot of turns, the mutual inductance swaps the self-inductance. Ten different samples of diameter of wire used to determine the best mutual inductance which is from 0.7 mm to 7 mm. Hence, 7 mm of diameter of wire is chosen for sensor prototype.

3. Results and Discussion

Generally, factors like number of turns, height of core, diameter of coil and diameter of wire can improve the sensitivity of RC sensor. Hence, these factors are tested with different dimension respectively.

3.1 Number of Turns

During RC sensor development, number of turns is important as it can improve the sensitivity. Nevertheless, the bandwidth will decrease with the large number of turns. Besides, the size of the RC sensor will increase which can limit the possible locations where the sensor can be applied. The graph from Fig. 2 shows that mutual inductance is directly proportional to the number of turns. Hence, 10 turns of winding are chosen for sensor prototype from the Table 1 to get the wide bandwidth of the sensor.

Table 1
Various of number of turns

Number of turns	Inner Radius (mm)	Outer Radius (mm)	Height (mm)	Mutual Inductance (μH)
10	**45**	**62**	**37**	**0.0237**
20	45	62	37	0.0474
30	45	62	37	0.0711
40	45	62	37	0.0948
50	45	62	37	0.1185
60	45	62	37	0.1422
70	45	62	37	0.1660
80	45	62	37	0.1897
90	45	62	37	0.2134
100	45	62	37	0.2371

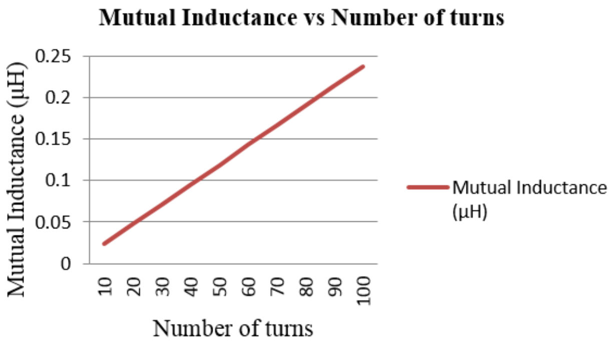

Fig. 2. Relationship between mutual inductance vs numbers of turns

3.2 Height of Core

Different height of core has been applied in Table 2 during modelling RC sensor. The graph from Fig. 3 shows that mutual inductance is directly proportional to the height of core. When the height of sensor is increasing, the mutual inductance is also rising.

Table 2
Different height of sensor

Number of turns	Inner Radius (mm)	Outer Radius (mm)	Height (mm)	Mutual Inductance (μH)
10	**45**	**62**	**37**	**0.0237**
10	45	62	39	0.0249
10	45	62	41	0.0262
10	45	62	43	0.0275
10	45	62	45	0.0288
10	45	62	47	0.0301
10	45	62	49	0.0314
10	45	62	51	0.0326
10	45	62	53	0.0339
10	45	62	55	0.0352

Table 3
Diameter of RC Coil

Number of turns	Inner Radius (mm)	Outer Radius (mm)	Diameter Rogowski Coil (mm)	Height (mm)	Mutual Inductance (μH)
10	36	44	8	37	0.0237
10	37	46	9	37	0.0237
10	38	48	10	37	0.0237
10	39	50	11	37	0.0237
10	40	52	12	37	0.0237
10	41	54	13	37	0.0237
10	42	56	14	37	0.0237
10	43	58	15	37	0.0237
10	44	60	16	37	0.0237
10	**45**	**62**	**17**	**37**	**0.0237**

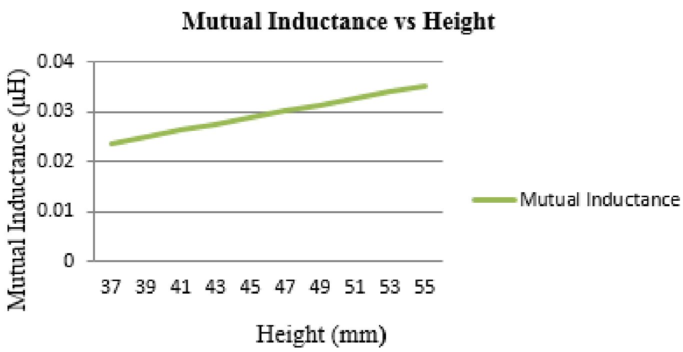

Fig. 3. Relationship between mutual inductance vs height.

3.3 Diameter of Rogowski Coil

The diameter of RC is the result from the subtraction from outer and inner radius as shown in Table 3. From calculated result, mutual inductance is kept constant although the diameter of RC is different as in Fig. 4. This is because mutual inductance is not much effect by the changes of diameter of rogowski coil.

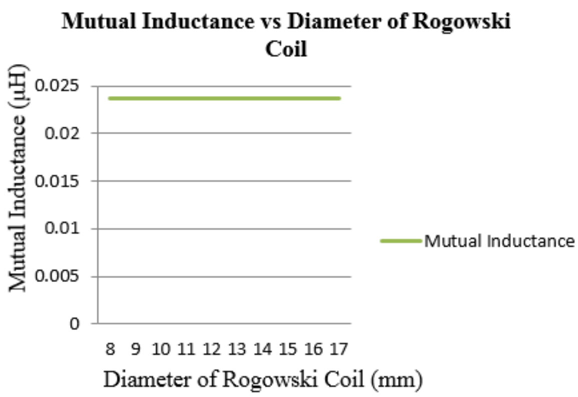

Fig. 4. Relationship between mutual inductance vs diameter of coil.

3.4 Diameter of Wire

Different diameter of wire is applied in Table 4. From calculated result, mutual inductance is kept constant although the diameter of wire is different as in Fig. 5. This is because mutual inductance is not much effect by the changes of diameter of RC sensor.

Table 4
Diameter of wire

Number of turns	Inner Radius (mm)	Outer Radius (mm)	Diameter of wire (mm)	Height (mm)	Mutual Inductance (μH)
10	45	62	0.7	37	0.0237
10	45	62	1.4	37	0.0237
10	45	62	2.1	37	0.0237
10	45	62	2.8	37	0.0237
10	45	62	3.5	37	0.0237
10	45	62	4.2	37	0.0237
10	45	62	4.9	37	0.0237
10	45	62	5.6	37	0.0237
10	45	62	6.3	37	0.0237
10	45	62	7	37	0.0237

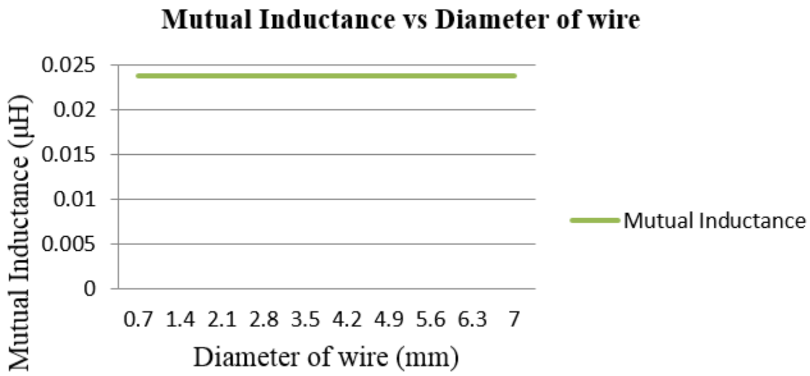

Fig. 5. Relationship between mutual inductance vs diameter of wire

4. Conclusions

In this paper, the modelling of RC sensor is said to be success especially investigate the performance of HV cable in PD detection. Overall, mutual inductance is influenced by the number of turns and height of core. In addition, the optimization of the RC sensor has improvement with the previous research.

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