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Analysis on Partial Discharge Activity in XLPE Cable by using MATLAB Software

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Abstract: Insulation cable plays an important role in high voltage systems for transferring power or electrical signal. Quality of insulation cable should always be monitored and analyzed in order to ensure the electricity can be supplied and also to avoid operating in unhealthy conditions especially due to partial discharge that can lead to breakdown of insulators. According to the standard international of partial discharge test which is IEC 60270, the partial discharge measurement is applicable to measure of partial discharge which occurs in electrical apparatus, systems, and components when tested with DC voltage or AC voltage up to 400 Hz. Besides, partial discharge pulse (PD pulse) is included in the basic test of equipment that is required for measuring the partial discharge according to IEC 60270. The main objective of this project is to develop and simulate partial discharge measurement with the presence of a small void inside the XLPE cable by using MATLAB software. The characteristics of partial discharge are investigated and analyzed in presence of small void with a different dimension of the cylindrical void. The three capacitances void model is used as a test object and the value of capacitances is calculated by using the formula. A circuit diagram of partial discharge measurement is built in MATLAB software with 20 kV applied voltage and a test object with dimension of voids are 2 mm × 1 mm, 2.5 mm × 1.5 mm and 3 mm × 2 mm. The result obtained show the signal of partial discharge increases as the dimension of the void increases. It can be concluded that the partial discharge becomes more serious with presence of voids, which is unfavorable to the XLPE insulation cable.

Keywords: Partial Discharge, XLPE Cable, Insulation Cable

1. Introduction

In the rapid development of the technology around the world, humans are increasingly depending on energy resources to carry out any daily activities. So that, the interruption in electricity supply to humans become top priority in order to ensure the electricity always be supplied. The high voltage

equipment especially insulation cable plays an important role for supplying electricity and should be monitored to avoid any issues occur such as breakdown of insulators. Partial discharge is categorized as a major issue that will lead to breakdown of insulators [1].

Partial discharge can be defined as an electrical discharge occurs across a localized area of the insulation cable between two conducting electrodes, without completely bridging the gap at different potentials which can damage of the insulating material [2]. Partial discharges can occur with the present of gases or voids such as SF6, air and hydrogen with appropriate amount of electrical stress due to high voltage in conductor [3]. Partial discharge is important criteria to measure and analyze for the early detection of degrading insulation quality and the assessment of manufactured, installed, or repaired product quality in order to prevent discontinuities or imperfections in the insulation system [4]. According to the IEC 60270, partial discharge pulse (PD pulse) is one of the basic tests for measuring the partial discharge which is defined as a voltage or current pulse resulting from a partial discharge occurring within the DUT (device under test). Appropriate detection circuits are introduced to the circuit to measure the pulse of partial discharge [5].

This project is carried out to simulate of partial discharge activity due to the presence of different size of small void in XLPE cable as an insulation cable by develop electrical circuit model with an application of a high voltage system using MATLAB SIMULINK and characteristics of the partial discharge are discussed.

2. Methodology

The project methodology focusses on the development of the partial discharge measurement system. The first subsection presents on the overall schematic diagram of the system, the explanation of the void in XLPE cable, followed by the partial discharge measurement including flowchart of the system by using MATLAB software.

2.1 Schematic Diagram

Before developing this project, a basic sketch of schematic diagram of partial discharge measurement inside the insulation cable was designed such as in Figure 1. The schematic diagram is produced by following the fundamental of test circuit for measuring partial discharge as Figure 1 [6]. The circuit diagram of Figure 2 consists of AC source for energized the circuit, filter unit (Z), high voltage measuring capacitor (C_m), coupling capacitor (C_k), void model of solid insulation which is XLPE cable as a test object, detector circuit for measurement of partial discharge (Z_m), MI as measuring instrument, C_a represent as capacitance of healthy part leaving Cc and Cb, C_b represents as capacitance of the healthy part connected in series with the void and C_c represent as capacitance of the void in the test object. The result of partial discharge can be obtained after an AC source of high voltage, V_s is applied across the test object. The voltage across dielectric, V_a is increased thereby and cause the voltage across the cavity, V_c also increases which the void gets charged and breakdown have started [7]. The V_a, V_b and V_c are produced through the test object as shown in Figure 2. Partial discharge measurement is performed by developed the circuit diagram in MATLAB software through supply the circuit with high voltage of AC source to the Device Under Test (DUT) as test object for obtaining the output signal of partial discharge.
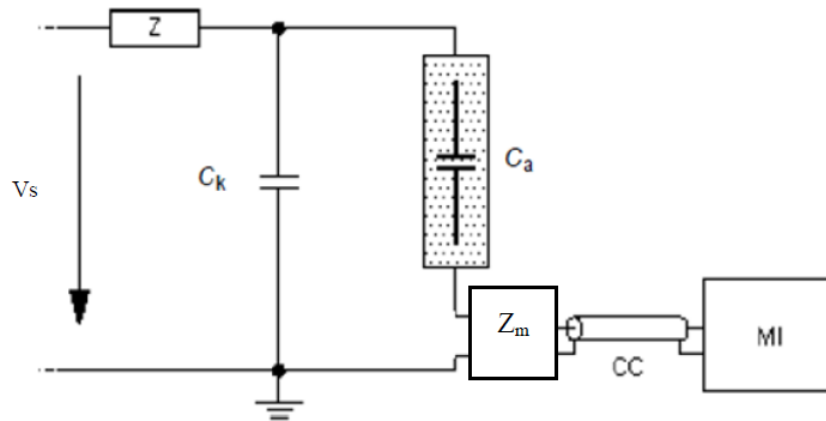
Figure 1: Fundamental test circuit for measuring partial discharge [6].
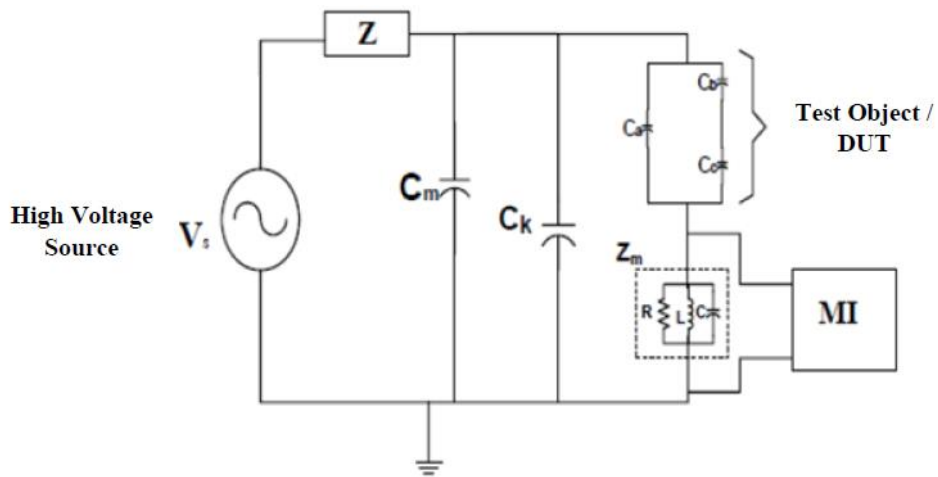

Figure 2: Schematic Diagram of partial discharge measurement

2.2 Void in XLPE cable

The three capacitances void model is used with cylindrical type of void in test object as shown in Figure 3. This model can be used for finding the capacitance values which are C_a, C_b and C_c by using the formula. Test object represent as XLPE insulation materials and relative permittivity of XLPE insulation is taken and used in the calculation.
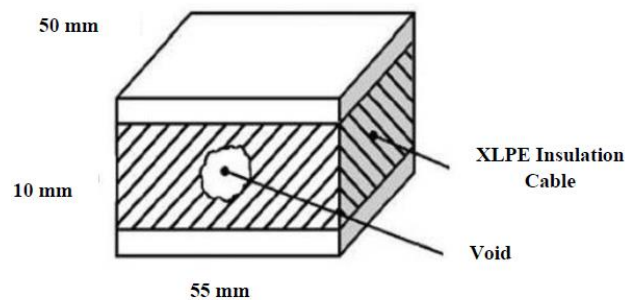

Figure 3: Test object with present a center cylindrical void

The voltage value across capacitance C_c with the void can be calculated as:

$$V_c = \frac{V_a \times C_b}{C_a + C_b} \qquad Eq. 1$$

The values for the three capacitors which are C_a, C_b, C_c can be calculated by using the equations:

$$C_a = \frac{\varepsilon_0 \varepsilon_r (a - 2r)b}{c} \qquad Eq. 2$$

Where C is the capacitance, ε_0 is permittivity of free space and ε_r is the relative permittivity, a is the length of the test object (mm), b is breadth of the test object (mm), c is thickness of the test object (mm), and r is radius of the cylindrical void (mm).

$$C_b = \frac{\varepsilon_0 \varepsilon_r r^2 \pi}{c - h} \qquad Eq. 3$$

Where h is the height of the cylindrical void (mm).

$$C_c = \frac{\varepsilon_0 r^2 \pi}{h} \qquad Eq. 4$$

The dimension of the test object and dimension of the cylindrical void shown in Table 1 is used to obtain the value of the three capacitances which are C_a, C_b and C_c.

Table 1: Dimension of test object with different dimension of void

Dimension of Test Object	Dimension of Cylindrical Void	
	Height	Radius
55 mm × 50 mm × 10 mm	2 mm	1 mm
	2.5 mm	1.5 mm
	3 mm	2 mm

The value of three capacitances have been obtained by using *Eq.2*, *Eq.3* and *Eq.4* above. The capacitances values for three different dimensions of voids are shown in Table 2.

Table 2: Capacitance value of C_a, C_b and C_c with different dimension of void

Capacitance	Dimension of Cylindrical Void 2 mm × 1 mm
C_a	2.1576×10^{-13} F
C_b	3.1974×10^{-14} F
C_c	1.3902×10^{-14} F

(a)

Capacitance	Dimension of Cylindrical Void 2.5 mm × 1.5 mm
C_a	2.1169×10^{-13} F
C_b	5.7552×10^{-14} F

C_c	2.5023×10^{-14} F

(b)

Capacitance	Dimension of Cylindrical Void 3 mm × 2 mm
C_a	2.0762×10^{-13} F
C_b	8.5263×10^{-14} F
C_c	3.7071×10^{-14} F

(c)

2.3 Partial Discharge Measurement

The circuit diagram of partial discharge measurement has been developed in the MATLAB Software according to the schematic diagram of test circuit for measuring the partial discharge as shown in Figure 1 and all the function of each component been elaborated in Table 3. The parameter that had been used for developing a circuit diagram of partial discharge measurement as shown in Table 4. The flowchart as shown in Figure 4 is used for showing the overall work flow in MATLAB software to obtain the results and operation to complete this work.

Table 3: Explanation the function of each component [8]

Component	Explanation
High voltage AC source supply (V_s)	The applied voltage for this project is used for energizing the circuit and also void in the test object with 20 kV.
Filter unit (Z)	The input of power supply contains some noise. This noise can be reduced by using a high voltage filter and also will improve the voltage stability.
Coupling capacitor (C_k)	If the coupling capacitor connected in series with measuring system. It holds up a low level of partial discharge at particular applied voltage due to low impedance for measuring a partial discharge. A higher level of partial discharge can be measured when coupling capacitor and measuring system is connected in parallel while the measuring system is connected in series with the test object.
Test object	The Device Under Test (DUT) contain of three capacitors which is C_a, C_b and C_c. C_a is capacitance of the sound part, C_b is capacitance of the piece of the test item and C_c is a capacitance of the void. The arrangement for these three capacitances is C_a in parallel with C_b and C_c while C_b and C_c in series.
Detector circuit (Z_m)	Contain of resistor, capacitor and inductor components in order to utilize for collecting incomplete release signal which goes about as an upper piece of the estimation framework.

Measuring impedance (MI)	Utilized in order to produce an output such as graphs, to watch the result and to recognize the electrical signal release from test object.

Table 4: Parameter of the simulation circuit partial discharge measurement

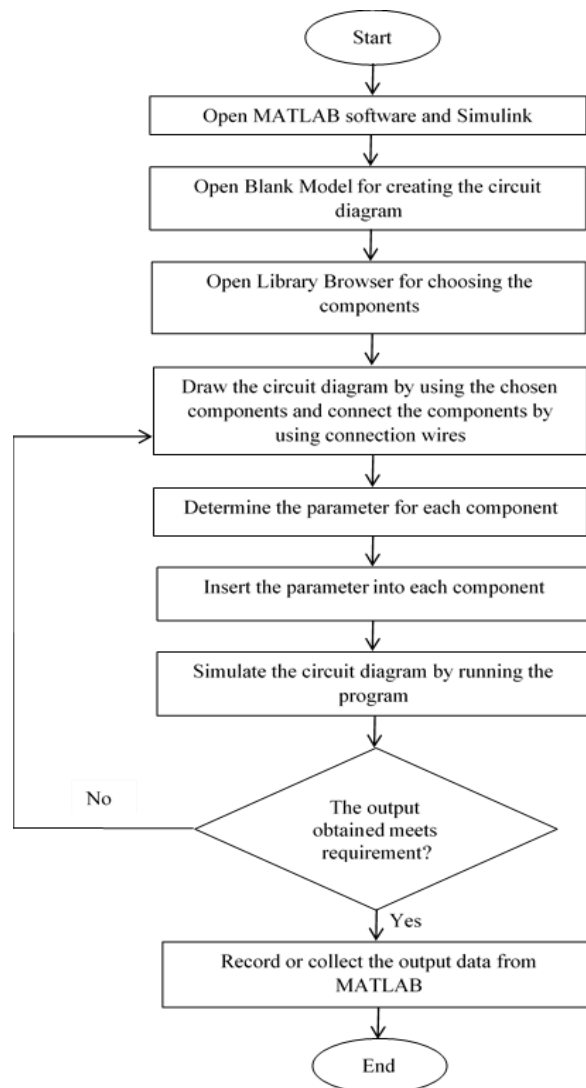| No.	Parameter	Symbol	Value
1	HV measuring capacitor	C_m	1000 pF
2	Coupling capacitor	C_k	1000 μF
3	Permittivity	ε_0	8.854×10^{-12} F/m
4	Relative permittivity of XLPE insulation	ε_r	2.3
5	Resistance	R	50 Ohm
6	Inductance	L	0.6 mH
7	Capacitance	C	0.45μF

Figure 4: Flowchart development of partial discharge measurement in MATLAB

3. Results and Discussion

All the result that obtained through the simulation of partial discharge measurement which had been modelled by using the MATLAB Simulink software had shown in this part. Besides, this part had analyzed and discussed the findings from the simulation of partial discharge measurement with elaborated thoroughly, especially about the signal that are produced from the simulation that obtained through MATLAB software.

After AC source is supplied in circuit diagram of partial discharge measurement with 20 kV as shown in Figure 5, the result of partial discharge pulse is obtained after simulated the circuit in MATLAB software with different dimension of cylindrical void. The partial discharge signal was observed in one cycle of AC source with 50 Hz of frequency and during 0 until 0.02 s of time. The maximum amplitude of partial discharge signal is observed by using a peak fender in MATLAB software. The maximum amplitude of partial discharge pulse is obtained with the dimension of cylindrical void (2 mm $\times$ 1 mm) was 3.138×10^{-5} V during 0.007 s as shown in Figure 6. The maximum amplitude of partial discharge signal with the dimension of cylindrical void (2.5 mm $\times$ 1.5 mm) was 3.784×10^{-5} V during 0.012 s as shown in Figure 7. The graph of maximum amplitude of partial discharge signal with the dimension of cylindrical void (3 mm $\times$ 2 mm) was 6.427×10^{-5} V during 0.014 s as shown in Figure 8.
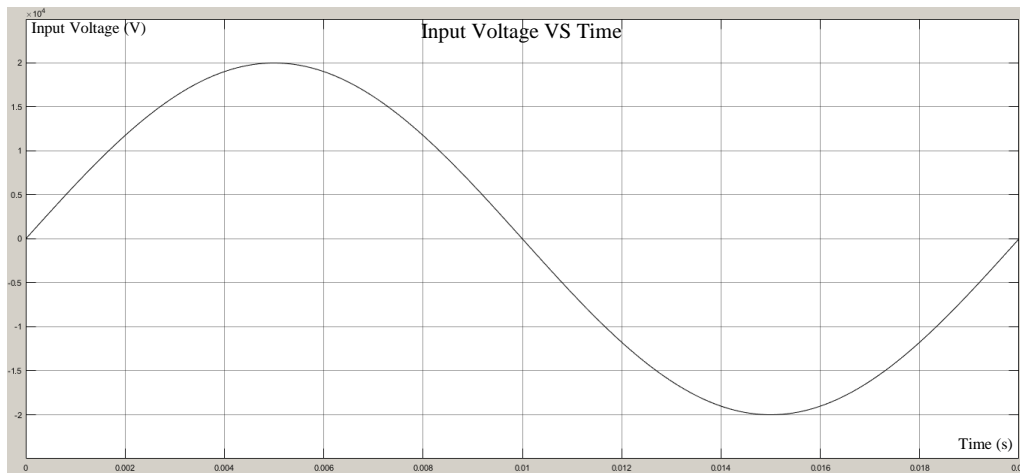

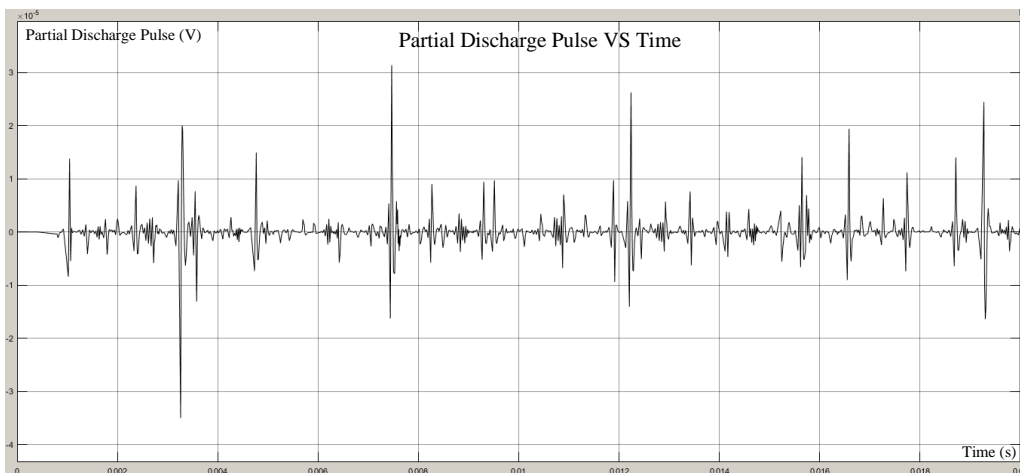**Figure 5: Input voltage with 20 kV**

Figure 6: Partial discharge pulse with dimension of void 2 mm $\times$ 1 mm
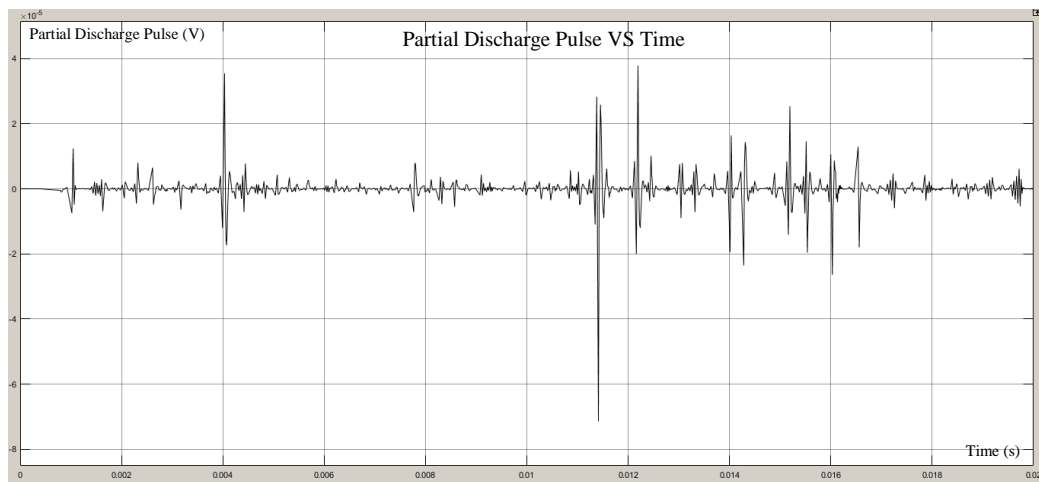
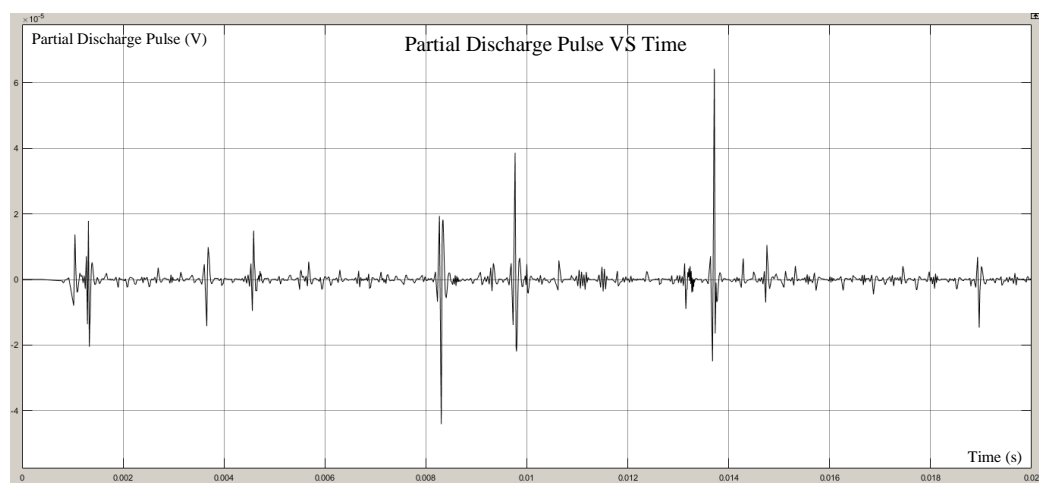**Figure 7: Partial discharge pulse with dimension of void 2.5 mm × 1.5 mm**

Figure 8: Partial discharge pulse with dimension of void 3 mm × 2 mm

The characteristics of partial discharge inside an insulation cable which was XLPE cable as solid insulation is found out by using MATLAB software. The characteristics that had been observed in this project is about the signal of partial discharge after a XLPE insulation cable as test object is contained different dimension of cylindrical voids. A maximum amplitude of partial discharge signal at each dimension of void been recorded and illustrated as shown in Figure 9. Based on Figure 9, the signal of partial discharge obtained through this simulation was increased when the dimension of the void was increased. Therefore, with the increase of void diameter, the partial discharge is becoming more and more serious, which is unfavorable to the XLPE insulation cable. This situation can occur due to the cavity or defects of insulation cable are typically filled with a gas that have a lower breakdown strength than the surrounding of material. Furthermore, the permittivity of the gas is invariably lower than the solid insulation, resulting in a higher electric field intensity in the cavity than in the surrounding dielectric. As a result, under normal working stress conditions of the insulation, the voltage across the cavity may exceed the breakdown value and cause an electrical breakdown occur, or partial discharge due to the void which causing on partial discharge will increase if the void inside the insulation is increase [9].
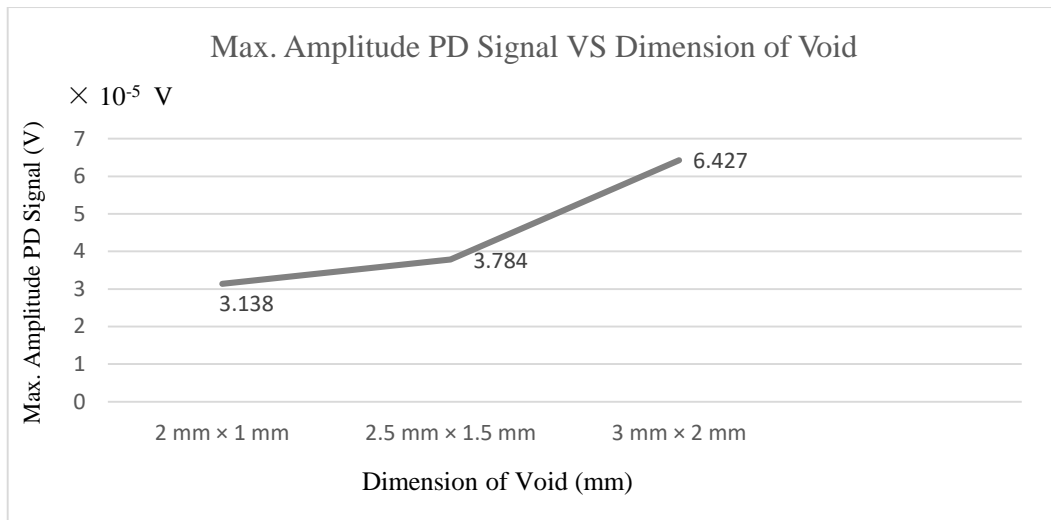
Figure 9: Graph of maximum amplitude of partial discharge signal with different dimension of cylindrical voids

4. Conclusion

In conclusion, partial discharge detection and measurement of partial discharge is important to develop in order to keep the high voltage equipment especially insulation cable in healthy condition especially during their operation as partial discharge also categorized as a main problem in high voltage equipment. In this project, the analysis on partial discharge activity in XLPE cable as solid insulation cable had been conducted for analyzing the characteristics of partial discharge in presented of different dimension of voids in insulation cable. The three capacitances void model is taken as a test object and also as a solid insulation cable. The values of the capacitance had been calculated by using the formula and the MATLAB software is used for developed the circuit diagram of partial discharge measurement and to generate the output of partial discharge signal. A test object contained different dimension of cylindrical void with 2 mm × 1 mm, 2.5 mm × 1.5 mm and 3 mm × 2 mm are used in order to analyze the characteristics of partial discharge. The characteristics of partial discharge is successfully been analyzed after obtained the result through MATLAB software and can be concluded that the signal of partial discharge increased when the dimension of the void is increased.

Acknowledgement

References

[1]   Suwarno Harjo, "Partial Discharge in High Voltage Insulating Materials," International Journal on Electrical Engineering and Informatics, 8(1):147-163, March 2016

[2]   Rasha Abdul-nafaa Mohammed, Ali NathemHamoodi, Bahar M.Salih, "Partial Discharge measurement in solid dielectric of H.V cross-linked polyethylene (XLPE) submarine cable," Indonesian Journal of Electrical Engineering and Computer Science, vol. 17, no. 3, pp 1578-1583, 2020

[3]   Tim Erwin, "Introduction to Partial Discharge (Causes, Effects and Detection)," IEEE, [Online], Available: https://site.ieee.org/sas-pesias/files/2020/05/IEEE-Alberta_Partial-Discharge.pdf, 2020, [18 June 2021]

[4]   C Sunil Kumar, Hariska K S, Gouthami N, Harshitha V, Madhu C, "Partial Discharge Analysis of a Solid Dielectric Using MATLAB Simulink," International Journal of Innovative Research in Electrical. Electronic, Instrumentation and Control Engineering, vol. 6, issue 6, June 2016

[5]   Advanced Test Equipment Corporation, "IEC 60270: Partial Discharge Measurements," [Online], Available: https://www.atecorp.com/compliance-standards/iec/iec-60270, 2021, [08 July 2021]

[6]   Engr. Manzoor Ahmad Khan, Dr. Amjadullah, "Measurement of Partial Discharge (PD) in High Voltage Power Equipment," First International Conference on Emerging Trends in Engineering, Management and Scineces, December 2014

[7]   Aditya Kumar Gupta, Sachet Ray, "Modeling of Calibration Circuit for Partial Discharge Measurement," Department of Electrical Engineering National Institute of Technology Rourkela-769008 (ODISHA), May 2013

[8]   Anusha A. Bongale, Dr. H.C Mouneshwarachar," Partial Discharge Investigation of Insulators using Simulation," International Research Journal of Engineering and Technology (IRJET), August 2019

[9]   IPEC, "Partial Discharge," [Online], Available: https://ipec.co.uk/about-partial-discharge/, 2020, [18 June 2021]