Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage:
https://semarakilmu.com.my/journals/index.php/applied_sciences_eng_tech/index
ISSN: 2462-1943

Measurement and Identification of Partial Discharge in 11kV XLPE Cable Jointing

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ARTICLE INFO

Article history:
Received 28 April 2023
Received in revised form 18 July 2023
Accepted 26 July 2023
Available online 10 August 2023

Keywords:
Partial Discharge; Rogowski Coil; Jointing Cable; XLPE

ABSTRACT

The reliability of power networks can be compromised by failures in cable connections, which are often caused by poor insulation quality. The use of different insulating materials during the connection process can result in defects, leading to partial discharge (PD) in high voltage equipment. PD measurements using a Rogowski Coil sensor and a high-efficiency Oscilloscope, following the IEC-60270 guidelines, are a widely recognized method for evaluating the quality of insulation systems. Experimental measurement was performed at university high voltage laboratory. This paper focuses on measuring PDs in extension (joint) cables, where they typically occur, specifically in 11kV XLPE jointing cables, and comparing them with ordinary cables without jointing. The project aims to analyze PD signal characteristics and identify partial discharge patterns in the time and frequency domains using MATLAB.

1. Introduction

Electricity supply is essential in daily human life. Generating, transmitting, distributing, and supplying electricity provides convenience and comfort to human life. Power stations generate electricity, which is then sent and distributed to consumers in Malaysia. Cables play a crucial role in the transmission and distribution of power as they connect the electrical supply network to consumers. Cable joints are necessary in an electrical distribution system because factory-produced cables have specific sizes and lengths. The standard production length for 11kV XLPE cable in the factory is 250 meters. Consequently, there are several cable joints in Malaysia's electricity distribution network. Cable joints are typically the weakest areas in the insulation of power cables and often experience damage due to partial discharge. According to a report conducted by the Energy Commission of Malaysia in 2019, cable damage and cable connection damage were identified as leading causes of power outages [1,2].

The issue of power outages in the distribution system is a recurring problem every year. Power cable failures, connections, and terminations contribute to serious power system problems and result

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https://doi.org/10.37934/araset.31.3.145154

in power loss. The primary cause of power cable failure is the breakdown of cable insulation, leading to insulation damage [3-5]. Many cable system failures stem from manufacturing issues, such as voids, insulation contamination, improper armour material selection, armour protrusion, and improper jacket selection [6]. These factors exacerbate local stress, leading to premature failure or an accelerated aging process. Additionally, water infiltration occurs due to natural movement through polymeric materials, seal failures, and metal corrosion, further reducing the dielectric strength and increasing pressure in the vicinity of moisture.

Partial discharge (PD) is typically a spark occurring at a high voltage defect on the insulating material. It is termed "partial discharge" because it only occurs in a specific area between the conductors. PDs are often detected in connections and accessories where cable flaws or voids exist due to improper installation or long-term equipment corrosion. By measuring partial discharges, the insulation state of high-voltage devices can be analysed, and any electrical implants in the dielectric can be identified and addressed [7-9]. PD measurements help pinpoint damaged areas within the insulation system. The collected data from various removal tests are compared with the measured data obtained during acceptance testing or manufacturing quality control standards. This approach enables a swift and straightforward evaluation of the dielectric characteristics (original, aged, faulty) of the tested device, allowing for the planning and preparation of suitable maintenance procedures in advance. Regular measurement of partial discharge parameters is crucial for assessing the condition of the insulating system [10].

PD measurements play a crucial role in assessing the insulation capability before implementing it in actual applications. In this work, particular attention is given to studying PD patterns associated with different types of flaws to analyse the partial discharge conditions at cable connections [10-12]. PD measurement can be conducted using both offline and online approaches [13]. These characteristics will be examined in depth using a High Voltage Frequency Oscilloscope manufactured by Agilent Technology, and the presence of PD will be determined using a Rogowski Coil sensor.

PD occurs at fault areas such as cracks, cavities, joints, or voids in high-voltage component insulation systems, including power generators, power transformers, power transmission lines, and power cables [14-15]. The presence of PDs leads to degradation of the insulation system, which can ultimately result in insulation system failure and impact the efficiency of the in-service insulation system [16]. Consequently, the high-voltage equipment experiences degradation. Insulation failure necessitates costly and time-consuming maintenance as the entire section needs to be replaced. The breakdown strength of the insulating material is higher than that of the fault site [17-20]. PD is most commonly observed at locations with flaws in the insulating system. The majority of insulating system flaws develop in the form of gas-filled gaps, which are not detectable during factory testing.

2. Methodology

According to Ampere's and Faraday's laws, the Rogowski coil is a device used to measure alternating current (AC) or high-speed impulsive current in an electrical appliance known as the Walter Rogowski. Rogowski coils as shown on Figure 1 are now capable of measuring low-level currents because to the invention of electric gadgets. Because it does not have a ferromagnetic core, the linear feature of this coil is preserved. Because of their linear features and the accuracy of their electrical devices, Rogowski coils are capable of monitoring currents ranging from milliamperes to megaamperes. The Rogowski coil, on the other hand, is an excellent device for measuring large amplitude transient currents because it is relatively inexpensive when compared to other measurement methods [21].

Figure 1 displays the Rogowski coil used in this study. The decision to utilize the Rogowski coil without an integrator was made to directly capture the voltage signals generated by PDs, rather than relying on an integrator. In a typical PD sensor, the frequency band range is determined by the capacitance of the test circuit, which is usually limited in relation to the sensor. However, the frequency band of the Rogowski coil remains unaffected by the power of the test circuit. This study extensively investigates the capacitance, self-inductance, and signal of the Rogowski coil and its cable. Using the Rogowski coil to measure PD offers several advantages, including an extremely wide frequency response, no conductive link between the coil sensors and the HV test circuits, immunity to saturation compared to other coils, high linearity due to the absence of magnetic compounds, fast response, and cost-effectiveness.

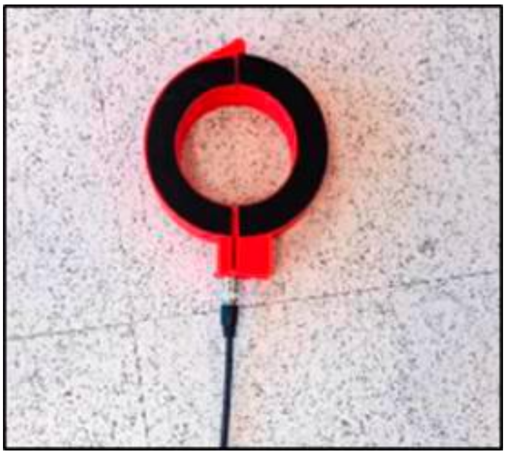


Fig. 1. Rogowski Coil sensor for partial discharge detection

2.1 Cable Selection and IR Test

This study focused on using the 300mm XLPE cable with a voltage rating of 11kV. The first cable used was a standard cable without any joints, while the second cable was a jointed cable. The objective of selecting these cables was to examine their condition, determining whether they were damaged or in good working order. This research is crucial for analysing PD in cable insulation and gaining insights into its behaviour.

Insulation resistance (IR) testing is a widely used and traditional method for assessing insulation quality. This test involves measuring the insulation resistance of the test equipment by short-circuiting the phases together or the phase to ground. The measured resistance should exceed the specified threshold set by international standards. An IR tester meter is employed to measure the resistive value of a well-conductive insulator under direct voltage. The purpose of the IR test is to provide information about the overall quality of the bulk insulation material rather than detecting localized insulation defects. The initial step in insulation testing is to ensure that the panel is disconnected or isolated from the power source. The wiring and cables, including the ground cable, should be tested for phase-to-phase continuity.

2.2 PD Measurement Using RC For 11kV Power Cable

PD measurements were conducted at the High Voltage Laboratory, Faculty of Electrical Engineering Technology, Universiti Malaysia Perlis (UniMAP). Figure 2 illustrates a schematic diagram of the experimental PD measurement setup, following the guidelines of the IEC 60270 standard. The diagram features Cs, which represents a coupling capacitor system used to transmit high frequencies from the measurement point to the input of the measuring device, and Ca, which represents the object under test (in this case, the cable). For the experimental measurement, the RC sensor was securely attached to a 2.2-meter length of a 3-core 300mm XLPE 11kV underground cable. A 100MHz, 2GS/s InfiniiVision WaveSurfer high-frequency oscilloscope (model 2012A) and a function generator were employed in conjunction with the RC sensor.

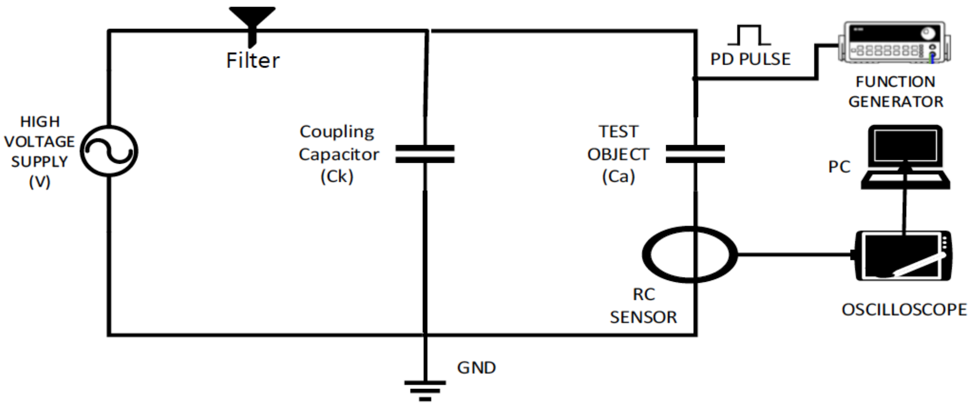


Fig. 2. Schematic diagram PD using RC sensor

The voltage supply unit that is currently in use is being measured online. It was discovered that the RC sensor prototype was being used in MV power distribution systems during the detection of online PD measurement set up. This RC is an inductive sensor as illustrated in Figure 1, can be easily clamped around the earth wire or an independent conductor for convenient installation. This allows the system to remain operational while the setup is being completed. In this work, measurements were made on a 300mm^2 XLPE, 11kV three-core power cable three times at each phase, for a total of six measures. As shown in Figure 3, the RC is clamped around the wire to capture the actual PD signal, and the high-frequency oscilloscope is connected to the RC through the coaxial cable to capture the high-speed PD signal discovered. The distance between the RC and the oscilloscope is approximately 3 meters, and this distance is maintained to prevent data loss. Following that, the data in the MATLAB environment is used and analysed in the following procedures. When this measurement is carried out, it is also possible to see the pattern of the PD signal that has been detected.

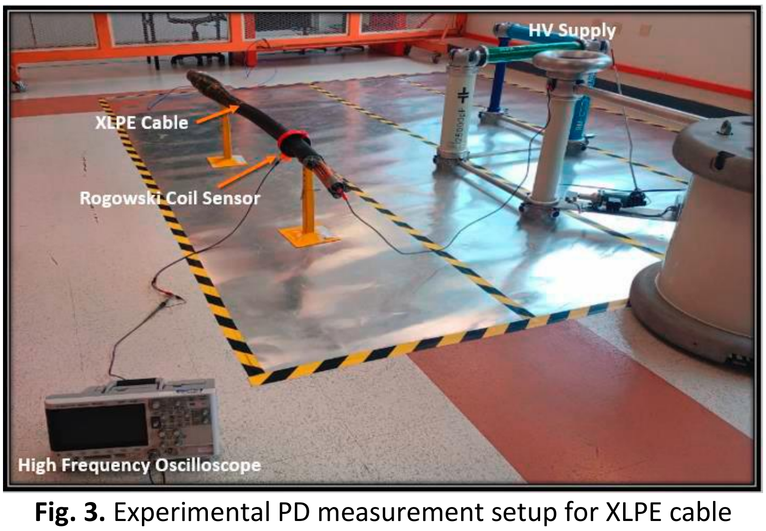


Fig. 3. Experimental PD measurement setup for XLPE cable

2.3 Partial Discharge Characterization

The method of detecting signal is dependent on the knowledge of the signal to be obtained; the nature of the cable influences the presence of a PD signal on a power cable. The PD characteristics that occur on the cable are discussed in this section. The flowchart in Figure 4 depicted the experimentally determined PD signal characterization. Following completion of the experiment, the data collected from the oscilloscope will export to the MATLAB programmed for analysis. The location algorithm is one of the algorithms that must be implemented when using this software. These characteristics were examined in detail, with particular attention paid to the highest value between time and amplitude in the waveform; in other words, the value analysed is the spike value of the resulting waveform. However, to obtain the PD pattern results for this period, the signal was plotted using Microsoft Excel. Within the context of time, the information gathered is examined and analysed.

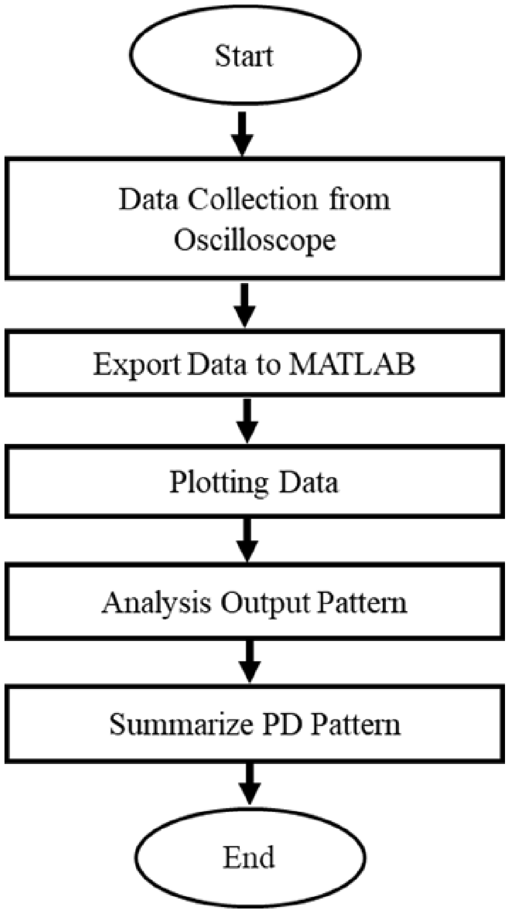


Fig. 4. Flowchart of pattern PD signal characteristic using MATLAB

3. Results

It is important to note that such cables are typically the type embedded in the ground in operation. Usually, the insulation test would be done first, followed by the PD measurement. A good insulation reading value is above 2MΩ. When the insulation reading is less than 2MΩ, the cable is considered damaged insulation. In addition, the findings of the studies that have been conducted will be discussed in this section. This work focuses on PD characteristics in wave patterns, which is accomplished through MATLAB tools.

3.1 Insulation Resistance Test Result

The first step is to conduct an insulation resistance test on each of the two cables indicated. It has already been stated that PD manifests itself when the insulating resistance value is lower than the standard value. In this test, the results revealed that the cable is in good condition, with an insulation test reading value exceeding the required reading and a minimum value of less than 2MΩ. All insulation test readings have been passed, showing high resistance readings i.e., exceeding Giga units as shown in Table 1 below.

Table 1
Insulation resistance test result

Cable Type	Phase	Resistance (Ω)
XLPE Cable Without Joint	R-Y	136 G
	R-B	690 G
	B-Y	665 G
	R-G	11.1 G
	Y-G	1.26 T
	B-G	87.5 G
XLPE Joint Cable	R-Y	86 G
	R-B	540 G
	B-Y	565 G
	R-G	368 G
	Y-G	1.1 G
	B-G	123 G

3.2. Partial Discharge Measurement Result

Most PD occurs when there is a defect or damage to the insulation of a cable. The connection of a cable can be considered a defect that occurs in the insulation. However, cables that do not have a connection can still occur PD due to insulation damage during manufacturing or laying work in the ground. The factors including cable temperature, lifespan and environmental conditions. Furthermore, the presence of a competent cable jointer can resolve this. A competent and efficient cable connector can reduce this problem, although PD can still occur.

The results of PD measurements on power cables show that all cables tested in this experiment are in good condition, with good insulation values. However, when PD observations and experiments were carried out, it was discovered that the presence of PD was far too minimal for each cable and phase. The experiment was carried out with different voltage input values of 2.4 kV and 3.6 kV on each cable. This experiment was carried out on two different types of cables nearly the same length of three meters. MATLAB software was used to analyses the data obtained by looking at the wavelet pattern during the occurrence of PD. It was found that the PD pattern could not be seen clearly on the cable 'without cable joint' because the cable insulation was in good condition. As can be seen in Figure 5 the amplitude reading is in a stable state at the reading 19.7mV in condition 2.4kV is entered.

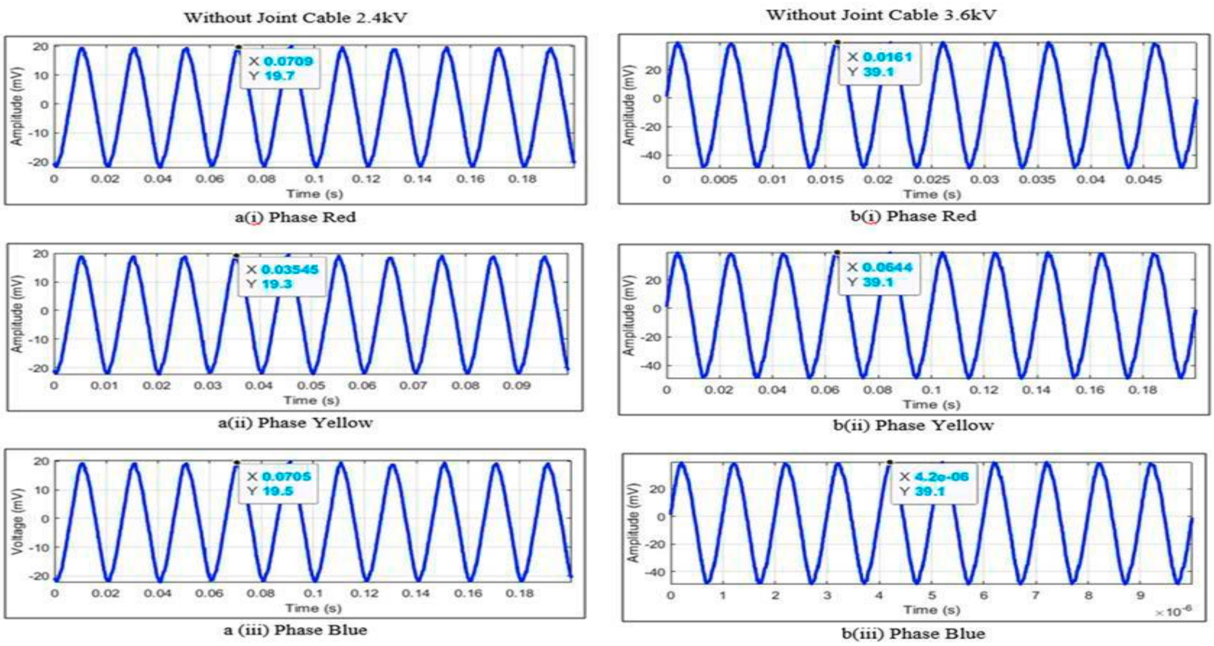


Fig. 5. Output PD measurement of normal cable with injection voltage supply 2.4kV and 3.6kV

The test results on the jointing cable show the occurrence of PD as shown in Figure 6. The signal pattern shows a high amplitude value increase and is undulating when the voltage is 2.4kV through the cable jointing. The amplitude increases to the maximum level and the amplitude waveform decreases unevenly. In time domain plotting graph, the highest amplitude value was recorded on the yellow phase cable with a value of 99.3mV.

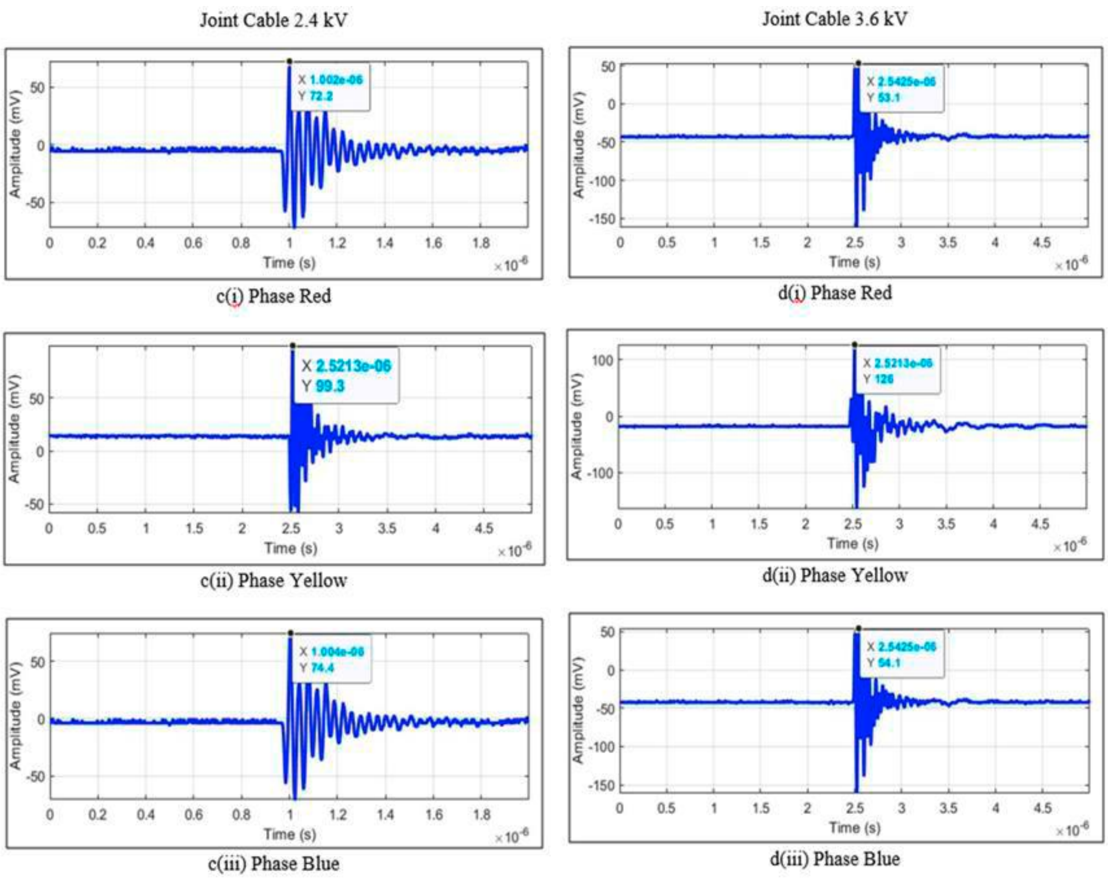


Fig. 6. Output PD measurement of Jointing cable at supply 2.4kV and 3.6kV in time domain

In Table 2, the highest amplitude reading value was recorded. Clearly indicates the amplitude value will increase as the supply voltage is increased. On a normal cable without jointing, the amplitude value is uniform with a reading value between 19.5mV to 19.7mV at 2.4kV. At a voltage of 3.6kV, the amplitude reading increased to 39.1. Measurements at the cable jointing show that the readings are not the same for each phase. At 2.4kV supply the lowest amplitude value is in the red phase with a value of 72.2 mV, while the highest value in the yellow phase is 99.3mV. Once the voltage value is raised to 3.6kV the amplitude value also increases. The red phase records the lowest amplitude value with a value of 53.1mV and the yellow phase still shows the highest amplitude reading value with 126mV.

Table 2
Highest amplitude of PD measurement

Cable Type	Voltage Inject	Phase	Max Amplitude (mV)
XLPE Cable Without Joint	2.4 kV	R-Y	19.7
	2.4 kV	R-B	19.3
	2.4 kV	B-Y	19.5
	3.6 kV	R-G	39.1
	3.6 kV	Y-G	39.1
	3.6 kV	B-G	39.1
XLPE Joint Cable		R-Y	72.2
		R-B	99.3
		B-Y	74.4
		R-G	53.1
		Y-G	126.0
		B-G	54.1

The following analysis showed the PD pattern in frequency domain. This frequency domain provides for measures that can be utilized to determine system stability. The time domain graph depicts the signal's evolution through time. The frequency domain graph displays the number of signals in each frequency band within the frequency range. Only the results of the greatest amplitude value of 126.0mV were used in this work to see the PD pattern in the form of FFT frequency. On the FFT plot, there was evidence of clutter as seen in Figure 7. The presence of a curve on this joint cable indicates the presence of PD.

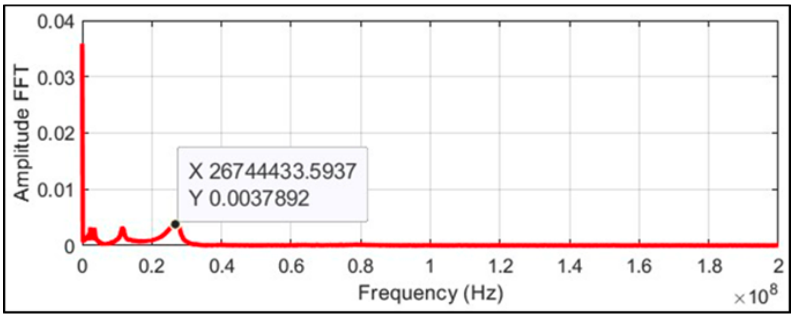
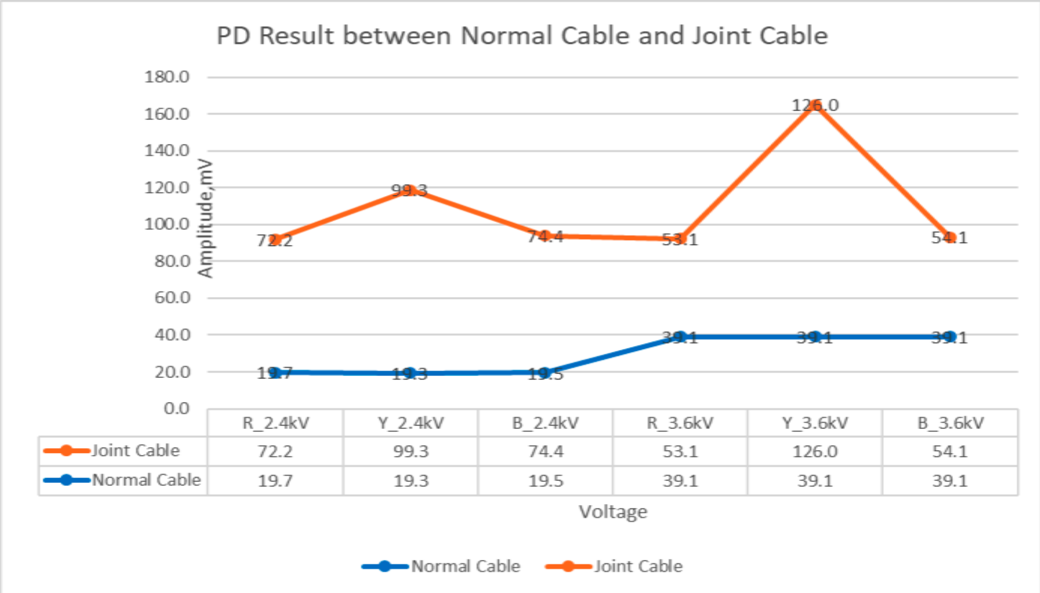


Fig. 7. Fast Fourier Transform (FFT) for the highest amplitude signal

The comparison result between normal and joint cable are shown in Figure 8. It was clear shows that the PD pattern in all cable joints. The yellow phase is the highest amplitude reading compared to the red and blue phases. This high amplitude value is due to the cable connection that is not very good in the yellow phase. PD is not visible on Normal Cable (cable without joint), indicating this insulation is in good condition and able to preserve the cable while making electrical transmission.



	R_2.4kV	Y_2.4kV	B_2.4kV	R_3.6kV	Y_3.6kV	B_3.6kV
Joint Cable	72.2	99.3	74.4	53.1	126.0	54.1
Normal Cable	19.7	19.3	19.5	39.1	39.1	39.1

Fig. 8. Comparison PD measurement between normal cable and joint cable

Overall, these experiments have successfully proved the existence of PD on the cable joint with the resulting wave pattern in the form of the times domain and frequency domain.

4. Conclusions

PD signal analysis was conducted, focusing on the pattern between normal and joint cable. During PD occurrence, the amplitude wave pattern condition increases to the maximum level and the amplitude waveform decreases unevenly. The presence of PD on cable joint are clearly figured, although the supply injection only 2.4kV and 3.6kV. The fact that PD occurs in the air and deep voids on the cable joint has been briefly discussed in theory and observations on the PD Pattern. Since there are air gaps in the cable join due to defects during cable connection work, it is clear that the PD pattern is clear compared to the normal cable without jointing, which is perfect without defects.

Acknowledgement
This research was not funded by any grant.

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