Partial Discharge Detection For Condition Monitoring Of An 11-kV XLPE Cable-Part II

N. A. M. Jamail, A. Ponniran, Q. E. Kamarudin, S. A. Jumaat, N. A. Jalaludin

***Abstract*-High voltage insulation breakdown has been the main cause of high voltage systems for a long time. It is found that this phenomenon occurs due to the existence of partial discharge within voids found in the insulation of XLPE cables, which produced accidentally during the extrusion process of cables. The effect of partial discharge would lead to serious breakdown and electrical apparatus failure. Many appropriate techniques can be used to evaluate the condition of XLPE cables. One of the techniques is partial discharge testing. This study focuses on 11 kV XLPE cables and the partial discharge testing is performing using partial discharge detector, TE 571. The analysis of data shows that the partial discharge test can be used to evaluate the performance and behaviour of the XLPE cable. And if the PD value is more than 10 pC, the XLPE cable should be assumed as fail and not safe to be used anymore.**

***Index Terms*—XLPE cable, Cable insulation, Measured partial discharge.**

I. Introduction

Partial discharge detection is nowadays a very well established method for monitoring the insulation condition of an electrical apparatus. The breakdown of insulation while in service can cause considerable damage to an apparatus and to the system to which it is connected. It has been recognized that failures of this type often may be related to the occurrence and severity of partial discharges within voids and/or on the surface of the insulation. Testing of high voltage apparatus for partial discharges has long been recognized as an important part of quality control for these devices [1].

Partial discharge is an electrical discharge that only partially bridges the dielectric or insulating medium between conductors. There are four types of partial discharge; internal discharges, surface discharges corona discharges and discharge in electrical trees [13]. Internal discharges are discharges in cavities or voids which lie inside the volume of the dielectric or at the edges of conducting inclusions in a solid or liquid insulating medium. Surface discharges are discharges from the conductor into a gas or a liquid medium and form on the surface of the solid insulation not covered by the conductor. Corona is a discharge in a gas or liquid insulation around the conductors that are away or removed from the solid insulation [11]. Electrical trees discharge is a discharge in the hollows, whereby electrical trees start from defects in the insulation and after treeing has progressed for some time, the steam and the larger branches grow hollow [13].

The authors are with the Department of Electrical Power Engineering and Department of Plant and Automotive Engineering, Universiti Tun Hussein Onn Malaysia,
(emails:norakmal@uthm.edu.my,asmar@uthm.edu.my,amely@uthm.edu.my,ezani@uthm.edu.my and nor_anija@yahoo.com).

Therefore, the partial discharge technique is an appropriate technique to evaluate the condition of the XLPE cable. In this study, partial discharge parameter of XLPE cables are being considered on several samples of cables, which are taken from services. Then, certain conclusion and finding regarding the performance of XLPE cables based on partial discharge.

II. Measurement Method

The measurements are carried out to determine the partial discharge value of XLPE cable insulator, to ensure the condition of the cable. The entire measurement are using Partial Discharge detector, model TE 571, which comes with a broadband amplifier as shown in figure 1. This equipment consist essentially of three units that are built into one piece of equipment; PD measurement, PD Digitisation and Data Processing.

Fig. 1: Partial Discharge Detector

The value of partial discharge are measured on four 11 kV XLPE cable with different types of artificial defect. Cable A is a cable in good condition of insulation, cable B is a cable that has void between cable insulation and iron, cable C is a cable that has void between cable insulation and aluminium and cable D is a cable that has void between cable insulation and copper. All samples of cables are taken from service. The length of all the cables is about 5 meter.

A. Measurement Calculation

Before the testing is conducted, the maximum test voltage that could be applied on the test cable has to be calculated. Based on the reference, AS PER IEC 60502-2 (1997), the calculation could be written as below:

Test voltage for PD:
$V_{injected} = 1.73V_o$

Where: $V_o = \frac{11 \times 10^3}{\sqrt{3}}$

Based on the calculation above, the maximum test voltage that can be applied on the test cable is 11kV.

B. Testing Procedure

After taking all the safety precautions and equipment calibrations, the measurement of partial discharge are ready to begin. The measurement procedure mentioned here is one of the test procedures to test the partial discharge by using Partial Discharge Detector, TE 571. The testing data is automatically recorded into the system whilst this testing is running.

i. The circuit is arranged as in figure 2

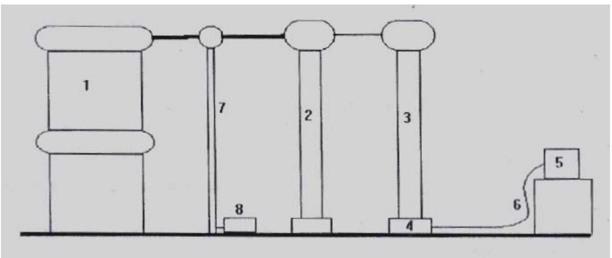

Fig. 2: The partial discharge test circuit arrangement

Where:
1. HV Power Supply
2. Test Object
3. Coupling Capacitor or Discharge Free Capacitor
4. AKV Coupling Quadripole
5. TE 571 Partial Discharge Detector
6. Connection Cable
7. Injection Capacitor
8. KAL 451 Calibrator

ii. The system of the testing and the surrounding of the testing place must be sure at low interference. It is of course essential that the background level of interference is as low as possible prior to the commencement of a test.
iii. The discharge rod must be displaced from the power supply circuit.
iv. The new file is created to save all the testing data by selecting F2 key. The file name is entered and must be less than 8 characters. ENTER key is selected for the next display.
v. Then, the screen display Test Identification. Which all the data about the testing can be mentioned, and F8 key is selected to save all the information that has been set before in Test Identification.
vi. Then, the screen will display all the information that has been set in Test Identification as shown in the result.
vii. The test voltage is applied between conductor and screen. With the voltage of 3.2 kV, 5.5kV,6.4kV, 7.9kV, 8.2kV, 9.6kV and the maximum value of 11kV.
viii. It shall be raised to and held, for not more than 1 min, at a value which 0.25 Vo above the voltage at which the measurement of partial discharge is to be made, where Vo is the rated voltage of the cable.
ix. The test voltage shall then be gradually reduced to, and the measurement of partial discharge made at, the voltage specified for the measurement in the relevant cable.

There were two types of plots on the PD detector that could be observed:
i. Ellipsoid diagram
ii. Two minutes line diagram

All plots were printed using the printer. Analysis measurement or two minutes line diagram will show measurement parameters, measurement values and graphs of measurement values against time/phase. The measurement parameters displayed are noise suppression, PD range and measuring time. These values will not change, with the exception of PD range which may be changed once by the user during the test. The measurement values displayed are PD max. level and voltage. These are "live" values and will change when the PD max. level and test voltage alter during the test.

III. Result And Discussion For Partial Discharge

A. Case A: Cable in Good Condition of Insulation

When the 11 kV was injected to the sample, the voltage reading at PD scope display (ellipsoid diagram) as shown in figure 3 was 10.6 kV and the PD level at this voltage was 6.9 pC. The partial discharge pulses can be seen at the first quadrant (0-90º) and third quadrant (180º- 270º). During the first quarter cycle we are creating a positive charge and the resultant partial discharges. During the third quarter cycle, this positive charge is effectively reversed, resulting in a positive charge in the reverse direction, and the resultant partial discharges.

From the result, it can be concluded that the cable is in good insulation and does not have any defect since the value of PD is below than 10 pC.

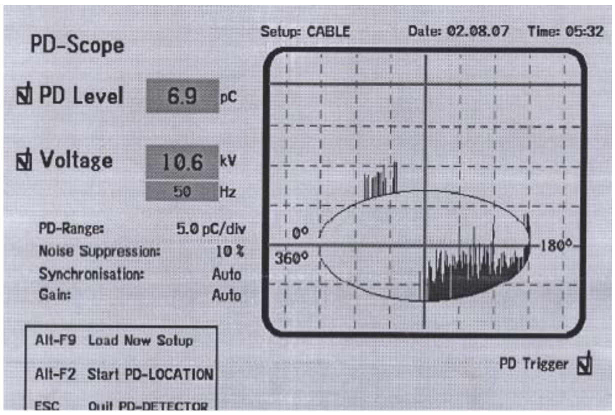

Fig. 3: PD Scope display for cable in good condition of insulation

While from the line diagram in Figure 4, it can be observed that the partial discharge pulse can be seen during the initial rising positive signal and the initial rising negative signal. The maximum level of partial discharge was 9.7 pC and it shows that the cable is in good condition of insulation.

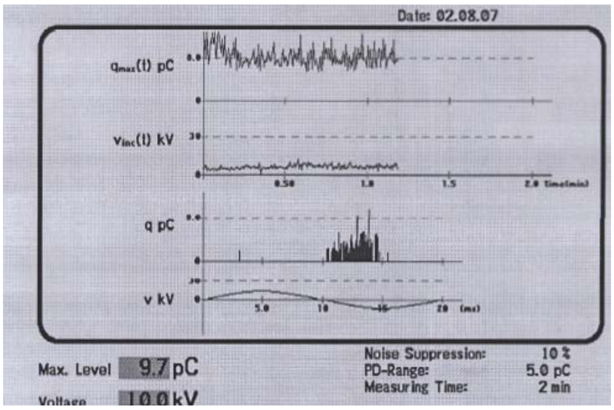

Fig. 4: Line diagram for testing the cable in good condition of insulation

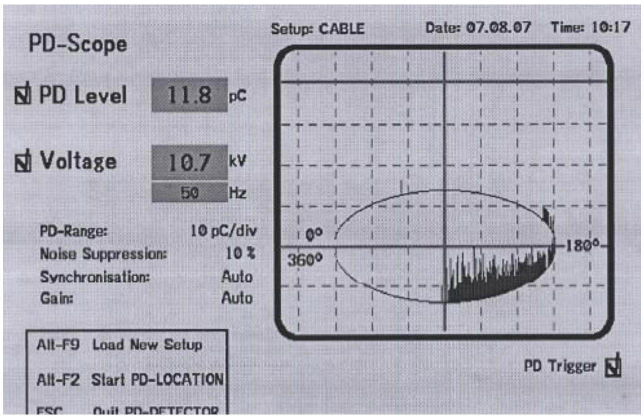

Fig 5: PD Scope display for void between cable insulation and iron

B. Case B: Void between Cable Insulation and Iron

This is typical of voids found in solid material and some cast component. The discharge occurs in advance of the voltage peaks on negative halves of the waveform. Discharges are of the same amplitude and same number on negative halves side of the ellipse, although differences of 3:l in magnitude from one side of the display to the other are normal.

The result is shown in Figure 5. When the 11 kV was injected to the sample, the voltage reading at PD scope display was 10.7 kV and the PD level at this voltage was 11.8 pC. The partial discharge pulses can be seen at the third quadrant (180º-270º).

There is a concept that partial discharges are measured as voltage pulses; therefore, during the positive waveform cycle, a discharge, or a partial short circuit, results in a negative, downward oriented pulse. This is referred to as a partial discharge with a negative polarity, and occurs during the first quarter-cycle of increasing positive voltage applied to the void.

In this case, the partial discharge pulses can be seen at third quadrant. During the third quarter-cycle, a partial short-circuit results in a positive, upward oriented pulse. This is referred to as a partial discharge with a positive polarity and occurs during the third quarter-cycle of the increasing negative voltage applied. For the positive

polarity pulses, occurring during the third quarter cycle, the insulation acts as a cathode across voids in the insulation-to-iron space. During these positive polarity pulses, a greater tendency of discharges will occur in this area near the iron. Therefore if positive polarity pulses greatly exceed the negative polarity pulses, then the root cause is considered to be voids in the insulation-to-iron area.

From the result it can be concluded that the cable insulation has a defect and the condition of the insulation under test was fail because the PD level was above 10 pC. So the cable cannot be used anymore.

From the analysis measurement as shown in Figure 6, it can be observed that partial discharge pulse can be seen during the initial rising negative signal. The maximum level of partial discharge was 12 pC. When the voltage was 11 kV and it shows that the cable is not in good condition of insulation.

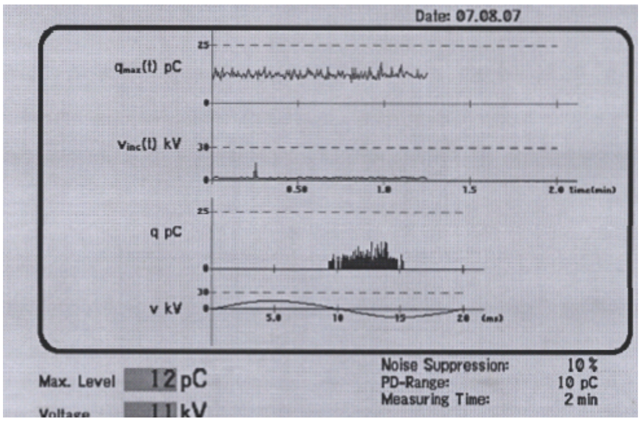

Fig 6: Line diagram for void between cable insulation and iron

C. Case C: Void between Cable Insulation and Aluminium

This case can be as same as Case B but the different was that the void was between cable insulation and aluminium. Although the type of defect was same but the different material between the void will affect the cable insulation and will give different PD level at the same voltage.

The result is shown in Figure 7. When the 11 kV was injected to the sample, the voltage reading at PD scope display was 11.1 kV and the PD level at this voltage was 10.4 pC. The partial discharge pulses can be seen at the third quadrant (180º-270º). Discharges occur in advance of the voltage peaks and are often similar in number of magnitude, although differences of 3:1 are normal.

Concept of the partial discharge activity was same with the case B because the PD pulses can be observe at third quadrant which is referred to as a partial discharge with a positive polarity and occurs during the third quarter-cycle of the increasing negative voltage applied.

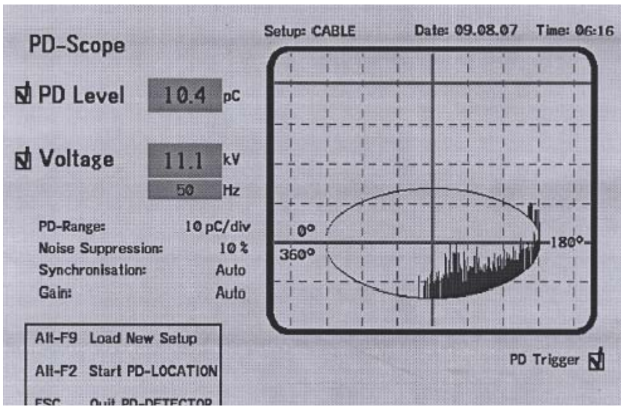

Fig 7: PD Scope display for void between cable insulation and aluminium

From the analysis measurement as shown in Figure 8, it can be observed that partial discharge pulse can be seen during the initial rising negative signal. The maximum level of partial discharge was 10 pC when the voltage was 11 kV and it shows that the cable is not in good condition of insulation.

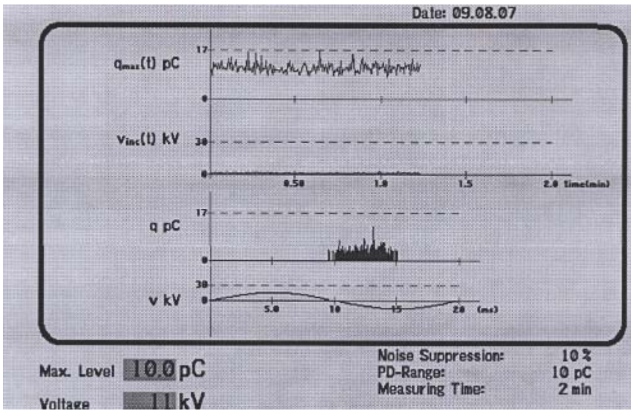

Fig 8: Line diagram for void between cable insulation and aluminium

D. Case D: Void between Cable Insulation and Copper

This observation can typically similar to Case B and Case C but the material used between the void was cable insulation and copper. The result is shown in Figure 9. When the 11 kV was injected to the sample, the voltage reading at PD scope display was 11.1 kV and the PD level at this voltage was more than 12.1 pC. The partial discharge pulses can be seen at the third quadrant (180º-270º). Discharges occur in advance of the voltage peaks and are often similar in number of magnitude, although differences of 3:1 are normal.

From the Figure 9, we can observe that the PD level was the highest value comparing with Case B and Case C even though the type of defect was same but the material used was different. From the result we can also observe that copper will give the worst effect to the cable insulation because the PD level of the copper effect was the highest.

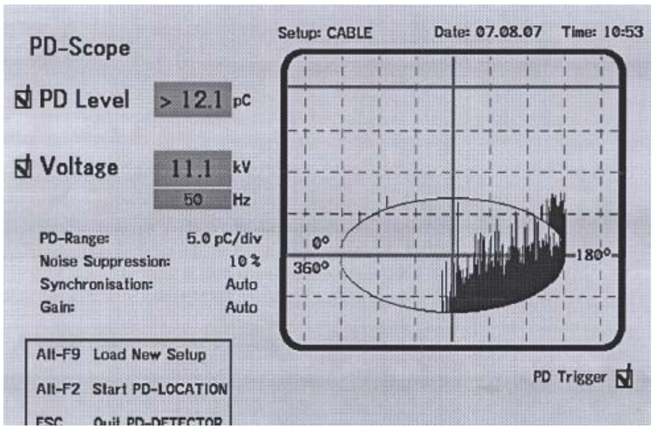

Fig 9: PD Scope display for void between cable insulation and copper

Figure 10 shows the line diagram for void between cable insulation and copper. From the graph, we can observe that the partial discharge pulse can be seen during the initial rising negative signal. The maximum level of partial discharge was 12 pC when the voltage was 11 kV and it shows that the cable is not in good condition of insulation.

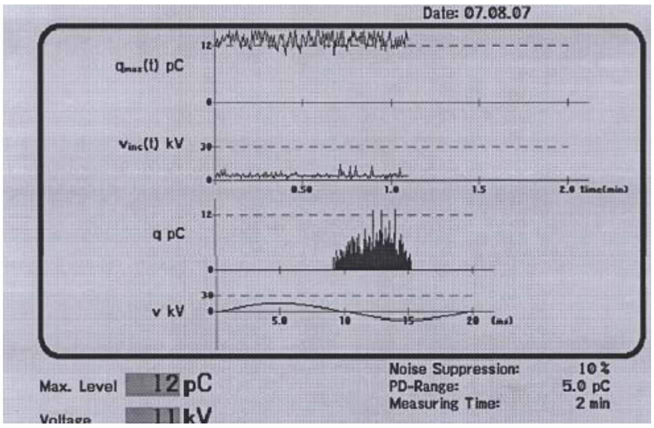

Fig 10: Line diagram for void between cable insulation and copper

Case B, Case C and Case D are the interesting phenomenon which are related to the applied voltage level to the test cable, the void's geometric shape and the specific materials that are acting as the anode and cathode. The critical material is the cathode, since the cathode supplies free electrons to allow the partial discharges to continue. From the three cases, the void's geometric shape and the applied voltage level to the test cable were same but the different was the material being used between the void. The material used will affect the result of the testing.

Depending on the part of the power cycle, the material representing the cathode differs. The cathode material is most important since the cathode will supply the electrons to support partial discharge activity. The characteristics of copper, aluminium and iron are defined in their role of a cathode, related to their conducting characteristics. Copper will give more effect to the test cable comparing with aluminium and iron. This is because the PD level is the highest at the same applied voltage during the test.

From the results, it can be say that different material that was covering the insulation can give different reading of PD level.

IV. DISCUSSION

Seven values below the maximum test voltage were chosen to determine the corresponding PD value, which were 3.2 kV, 5.5 kV, 6.4 kV, 7.9 kV, 8.2 kV, 9.6 kV and 11 kV. The first value of voltage that was injected across the test cable in order to trace the first PD value is known as the inception voltage and the value of the inception voltage is obviously 3.2 kV. As the testing was repeated with these seven values for testing four different conditions of cable, the results are shown in Figure 11. The graphs show the PD level in pico Coulomb versus injected voltage in kilo Volt.

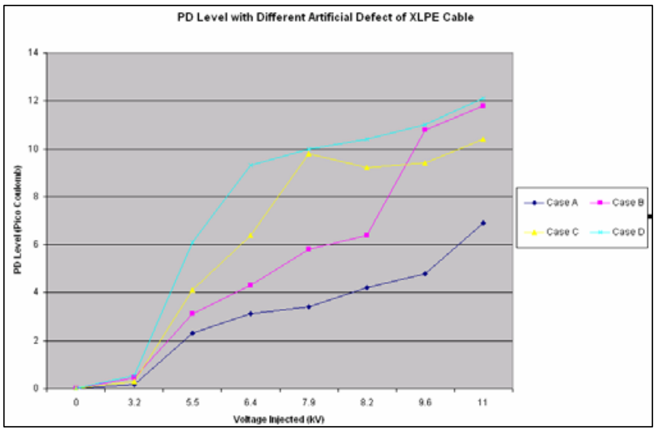

Fig 11: PD values and cable performance of XLPE cable according to different voltages

From Figure 11, it can be observed that there is some variation in magnitude with a fairly rapid increase in voltage. Based on Figure 11, it could be observed that for lower test voltage (3.2kV or the inception voltage), the PD values were smaller if compared to most of the PD values for higher voltage. We can also observe that different condition of cable will give different values of PD although the inception voltage was same. There was a steady increase of the PD level for Case A and the PD value at 11 kV was below 10 pC. From the graph it can be concluded that Case A was a good condition of insulation for XLPE cable under test. While Case B, C and D show an upward trend and the PD values at 11 kV were above 10 pC. This shows that the condition of insulation for the cable was not good and the cable had some defect.

Thus, from the results, it can be seen that the performance of the test cable depend on a requirement of British Standard that if the PD value for a certain voltage value on a particular cable is more than 10 pC, the cable is considered as fail and it is has a defect and if the partial discharge maximum level is below 10 pC, the cable is in a good condition of insulation.

The illustration of the partial discharge activity relative to the 360 degrees of an AC cycle allows for identifying the prominent root cause of partial discharges, therefore appropriate corrective actions can be implemented.

V. CONCLUSION

In this testing, the insulation condition of an 11kV XLPE cable was assessed by subjecting it to partial discharge test. In particular, the partial discharge tests were carried out to determine the quality of the cable whether its insulation material was in good condition or whether it had a defect. The quality of the XLPE cable can be determined based on the PD value, where a low PD value indicates an XLPE cable in a good condition. This is concomitant with the TNB requirement which states that if the PD value is more than 10 pC, the XLPE cable should be assumed as fail and not safe to be used anymore. The partial discharge magnitude is related to the extent of damaging discharges occurring, and therefore related to the amount of damage being inflected into the insulation. The pulse repetition rate indicates the quantity of discharges occurring, at the various maximum magnitude levels. Both play a role in determining the condition of the insulation under test.

In conclusion, the partial discharge test can be used to evaluate the performance and behavior of the XLPE cable. For this reason the techniques of PD measurements is a very valuable in-house means of reviewing and improving the design of electrical cables. The PD inception levels serve as a very important measure to indicate the insulation condition of the cable and thus can be used to improve its quality of the manufacturer and also the user.

VI. ACKNOWLEDGMENT

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VIII. BIOGRAPHY

Nor Akmal Mohd Jamail was born in Negeri Sembilan, Malaysia on 1982. She graduated from the Universiti Teknoloi Malaysia (UTM) with honours degree in B. Eng (Hons) Electrical Power in 2005 and Masters of Electrical Engineering (Power), UTHM in 2007. She is currently is Lecturer at University Tun Hussein Onn Malaysia. Her research interests include power system, high voltage and transformer analysis.