Partial Discharge Detection for Breakdown Identification

Mohd Elmy B Shapie, 2006103367
Faculty of Electrical Engineering, Universiti Teknologi MARA

Supervisor: Assoc. Prof. Dr Ismail Bin Musirin

Abstract – **This paper presents partial discharge detection for breakdown identification of a distribution cable. Partial Discharge is one of the main cause of underground cable failure in operation. Therefore the responsibility to the power utility such as Tenaga Nasional Berhad (TNB) to ensure the continuous and optimum electricity delivery to the consumers.**

The presence of partial discharge in an underground cable need to be detected before it can cause breakdown to the cable insulation. Therefore it is suggested that the jointing quality need to be improved to prevent insulation failure on the jointing of cross-linked polyethylene (XLPE) cable and the aging cable above 20 years need to be replaced for PILC cable.

Keyword: **Partial Discharge (PD), Paper Insulated Lead Cable (PILC), Cross-linked polyethylene (XLPE)**

I. INTRODUCTION

Partial discharges (PD) are small electric sparks or discharges that occur in defects in the insulation, or at interfaces or surfaces, or between a conductor and a floating metal component, or between floating metal components. The discharges do not bridge the insulation between conductors and the defects may be entirely within the insulation, along interfaces between insulating materials (at accessories), along surfaces (terminations or potheads).

Partial discharge characteristics depend on the type, size, and location of the defects, insulating material, applied voltage, cable temperature, and also vary with time. The damage caused by PD depends on several factors and can range from negligible to causing failure within days to years [1]. In particular, due to the importance of HV cables in the distribution network is the knowledge about the initial condition during after-laying as well as the actual condition of HV power cable sections during operation after several years of service of great importance. With regard to partial discharge (PD) processes and dielectric degradation processes in power cables there is still a need for advanced, sensitive and economical attractive tools suitable for non-destructive PD diagnosis on-site: the after-laying testing as well as the service diagnosis [2, 3]. For complete on-site diagnosis of distribution power cables by PD detection and dielectric losses measurement it is necessary to energize the disconnected cable system.

In order to decrease the capacitive power demands for energizing cables as compared to 50Hz test voltages, different energizing methods have been developed in the past. One of the methods available for this purpose is based on applying damped AC voltages [3, 4]. In particular, in the last 8 years [5, 6] the worldwide acceptance of this method has already demonstrated that in the case of power cables up to 40kV by means of advanced PD diagnosis the identification of high risk cable circuits in the network can be achieved and implemented in utility asset management decision process.

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This paper presents partial discharge detection for breakdown identification of a distribution cable. The study involves the assessment of 11kV distribution cable. Results obtained from the cable assessment will be utilized to calculate the Severity Index (SI) to forecast the lifetime of a cable. The study has been conducted on several cable types such as cross-linked polyethylene cable (XLPE), paper insulated lead cable (PILC) and mixture of PILC and XLPE. From the study it was discovered that the presence of partial discharge in PILC is due to the overall insulation failure rather than jointing failure. On other hand, The presence of partial discharge in XLPE cable is due to the jointing failure rather than insulation failure.

II. RESEARCH METHODOLOGY

The methodology implemented for this study is shown in the flowchart of Figure 1.

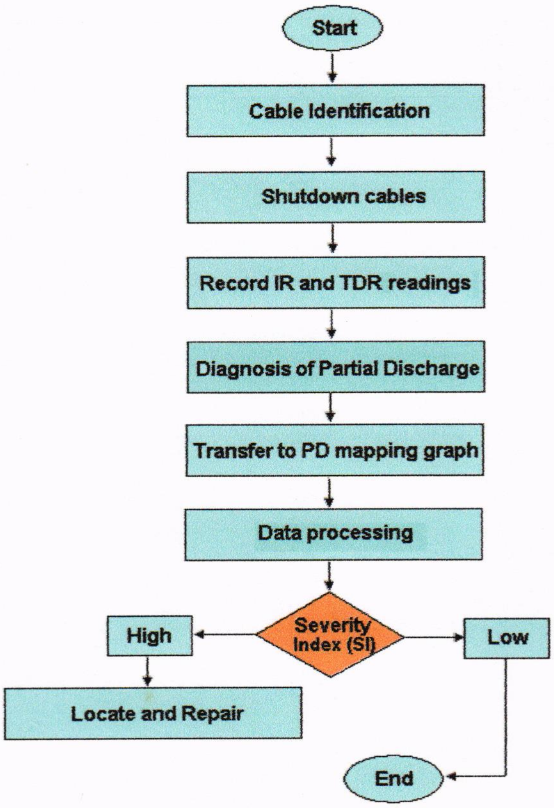


Figure 1 : Flowchart of PD diagnosis for 11kV cable.

A. Cable Parameter

Cable parameters are important prior to the PD detection activities. Among the required parameters are type of a cables that need to be tested, length of a cable, position of the joints along the cable and installation year of a cable. Missing information about the length of the cable section or about the exact number and the position of joints may influence the quality of the test data and can result in misrepresentation and falsification of test results. For example, wrong information about the cable length results in erroneous TDR calibration, which in its turn may result in incorrect location of PD sites in the cable.

i. Cable Identification

In this paper, special effort was put to highlight the PD in various types of 11kV cables. The study involved several types of 11kV cable. The selected location and the cable is different, but it is in area of TNB distribution in Selangor. To detect PD activities in a cable, a cable with length less than 3km has to be selected for the study. In addition to that, the frequency of damage occurrences and age of the cable need to be also identified. In this study, 3 types of cable has been chosen namely cross-linked polyethylene (XLPE), paper Insulated Lead Cable (PILC) and a mixture of XLPE and PILC.

ii. Shutdown Cables

In order to carry out the testing work on the 11kV cable, the cable which is under operation needs to be shutdown first. To shutdown the cable, it is performed by employees who have a certificate of authorization TNB control for 11kV system and appliances.

iii. Record Insulation Resistance (IR) and TDR Readings

The reading of the insulation resistance (IR) of the cable should be taken first by using Megger Digital Ohm Meter Tester. The position of cable joints and length are taken by using Time Domain Reflectometer (TDR) set as shown in figure 2.

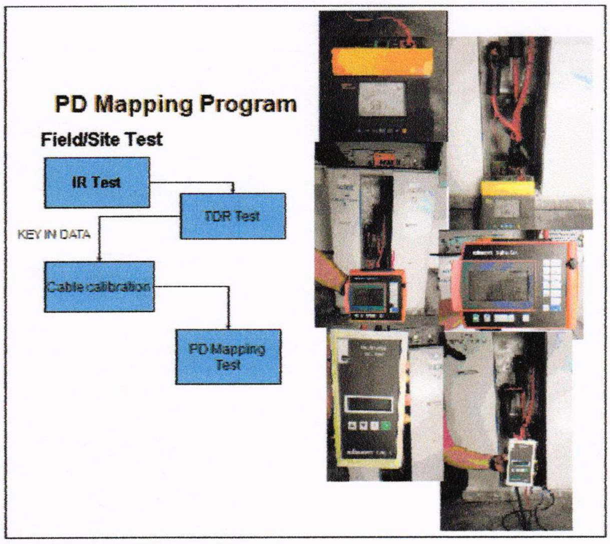


Figure 2 : PD mapping program

B. Experimental Setup of OWTS

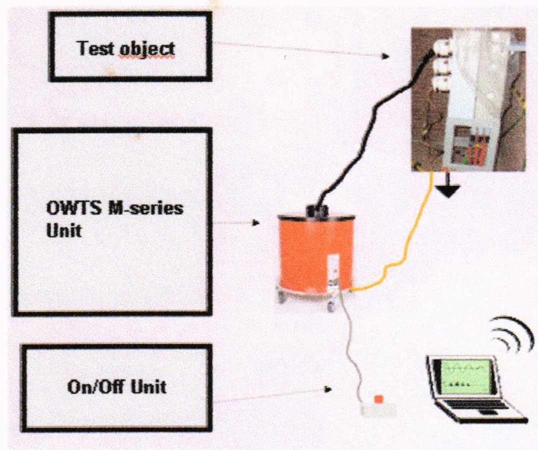


Figure 3 : Complete configuration of OWTS M-Series.

- **Test Object:** In this study, test object refers to the chosen cable for the PD detection. This cable has to be disconnected for the power supply network. During a testing and calibration process, both cable ends of the particular cable section have to be fully disconnected from the network.

- **OWTS M Series unit:** OWTS unit is an equipment to do a high voltage testing. It is consist of the HV coil, HV divider, HV switch, the PD coupling capacitor and coupling device and the PD detector. The upper black color cover is the HV electrode of the system having the full voltage charged. The result from this unit will be stored in a laptop.
- **Laptop unit:** This unit will control the entire process of a PD detection. In other hand, all the data analysis and the data storage will be controlled by this unit..
- **On/Off unit:** In order to charge the cable with the high voltage supply, this unit has to be switch on.

i. Oscillating Wave Test System (OWTS)

The schematic diagram of oscillating wave test system is shown in figure 4.

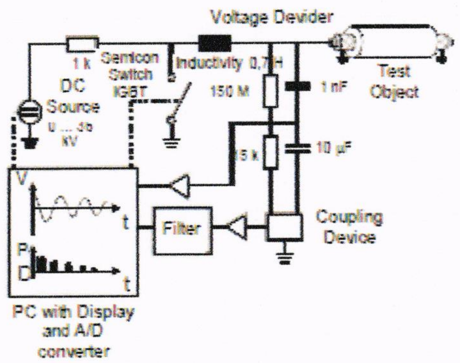


Figure 4 : Schematic diagram of the OWTS

Using the circuit shown in figure 4, the cable under test is gently charged up to working voltage, over a period of a couple of seconds, using a DC source. At this point a solid state switch with fast closure time creates a series resonant circuit from the test object and an air-cored inductor. This circuit begins to oscillate at the frequency:

$$f_o = \frac{1}{2\pi\sqrt{LC}} \qquad \text{(eq.1)}$$

The inductance of the air core is selected such that the resonant frequency (within the range 50 to 1000Hz) is similar to the power frequency of the service voltage. Medium voltage cable insulation usually has a relatively low dissipation factor and this combines with the low loss factor of the air-core inductor to produce a high Q (30 to 100) resonant circuit. The result is an oscillating wave at the resonant frequency f with a decay time of 0.3 to 1 second. This produces a few tens of cycles to energize the test object and PD is initiated in a similar fashion to 50 (60)Hz inception conditions.

The specially developed measurement circuit detects all PD pulses occurred during the oscillating wave in accordance with IEC 60270 recommendations. Determination of PD pulses is performed by traveling wave method and a fault map of the cable can be produce [8].

C. *Software Implementation*

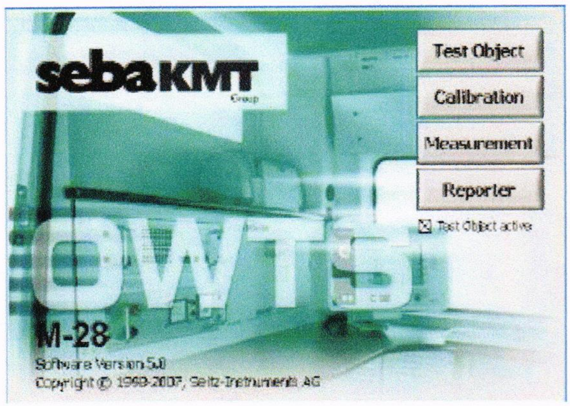


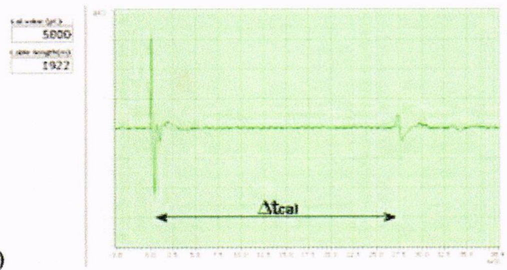
Figure 5 : OWTS M series version 5.0 start screen

In order to conduct the equipment in this study, OWTS is used to run and record all the required data. The results recorded by the OWTS will be sent to the recording computer via Bluetooth wireless system. This software is known as the OWTS SOFTWARE 5.0. The need for the raw data from each test site is important. It is because the information will be used to assess the condition of a cable. Results of the cable capability to operate will be determined from the readings taken during testing.

D. *Calibration*

In this study, the purpose of calibration is to determine the value (in pC) of the smallest PD signal detection under the test conditions. For this step, there are two calibration procedures need to be considered.

(a)



(b)

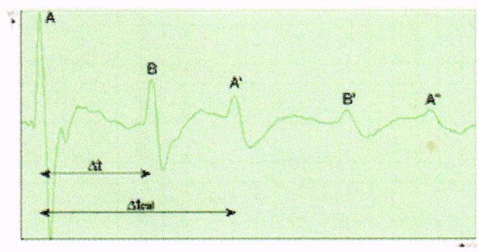


Figure 6 : PD pulse propagation examples : (a) example of the calibration of the propagation velocity in a XLPE cable system, (b) example of the localisation of a PD source by analysing the PD wave time differences.

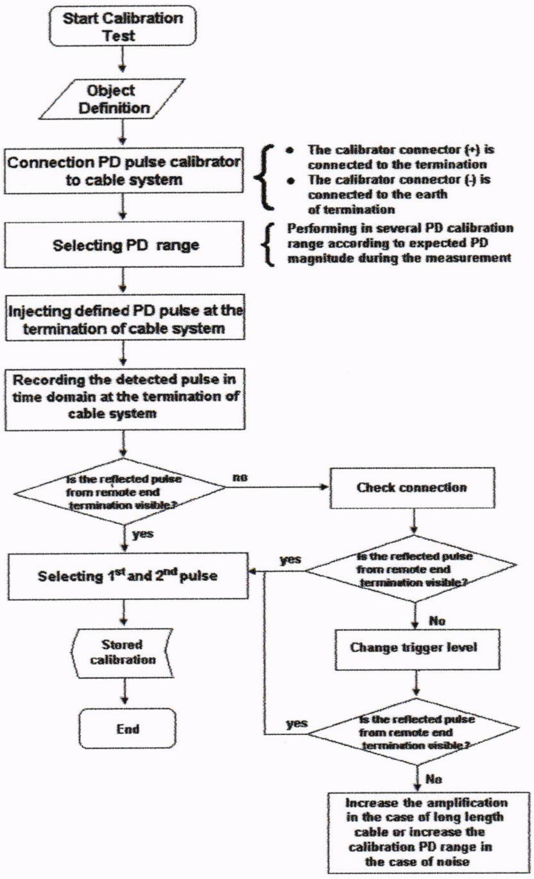


Figure 7 : Flowchart of calibration procedure of power cables.

- ➢ *Calibration of the PD reading in [pC]*; This calibration is made by injecting defined current pulse to the termination of the cable system. A certain PD pulse, for example 50pC is injected to the cable system and the reading of the PD detector is calibrated.
- ➢ *Calibration of the PD pulse propagation velocity in [m/µs] reading* ; This calibration is to localize PD sites using time domain reflectometry (TDR) analysis. The PD pulse propagation for different PD magnitudes has to be determined. In this calibration, PD pulse is injected to the cable system, original pulse and reflected pulse are detected by PD detector as shown in Figure 6. The propagation velocity of the pulse in a particular cable system is calculated by the time difference between the original PD pulse recorded at the near end and the reflection pulse [9].

As a result, standardized calibration is very important to determine the PD reading of a cable to made the performance check of the whole circuit. In order to support the correct calibration that can be used in performing PD measurement, a procedure is shown in Figure 7.

III. RESULTS AND DISCUSSION

During the testing, the PD activities will be recorded in the OWTS SOFTWARE 5.0. The initial voltage value on the PD activities first appeared has to be recorded. This process is called **PDIV (PD Inception Voltage).** This is shown at the smallest voltage level, there is a PD in the cable being tested. Figure 8 shows the initial voltage of PD displayed and recorded.

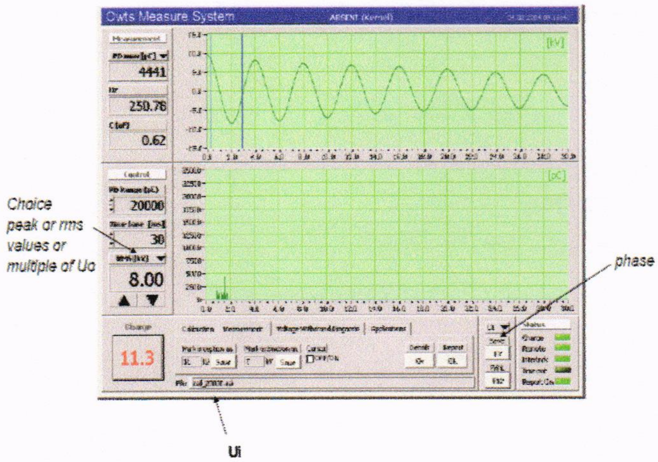


Figure 8 : PD measurement (PDIV)

Figure 8 shows the presence of PD activities begins at 8kV voltage level (RMS). Numerical value of PD is set at the rate of 20000 (pC). At this level, the value of PD detected is 4441 (pC). During the diagnostic tests, the PD activities will be recorded. The screen on the laptop will display a graph of the magnitude of the voltage and the discharge is recorded.

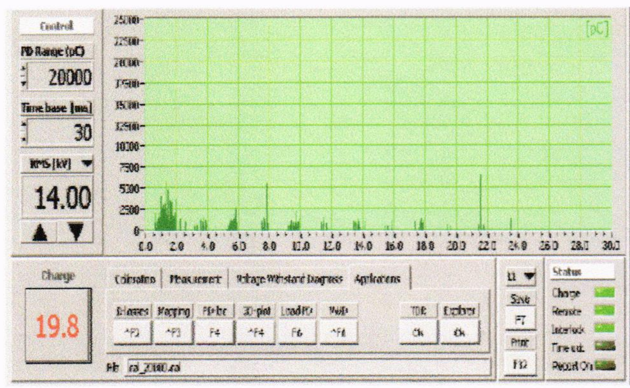


Figure 9 : PD measurement

Figure 9 shows the presence of PD activities in a cable. At this level, the voltage is set to 14kV voltage (rms). In real practice diagnosis, the voltage is set to 6.35 kV (rms) at (1.0U₀) where the supply voltage (11kV) is divided by the square root of 3 and 8.25 kV voltage level at (1.3U₀). Numerical value of PD is set at the rate of 20000 (pC). At this moment, the PD maximum level detected is 6508 (pC).

In the final stage of testing, the lowest voltage level at the end of PD activities will be recorded. This voltage is known as **PDEV (PD Extinction Voltage).** Figure 10 shows the lowest voltage level at the end of PD activities on the tested cable.

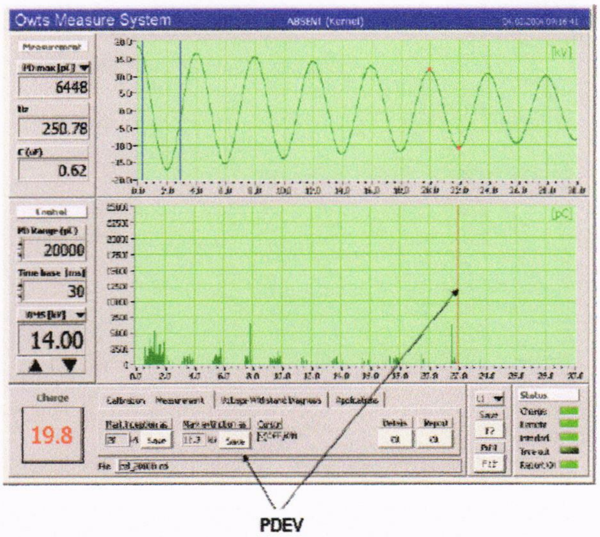


Figure 10 : PD measurement (PDEV)

It shows that the PD activities are ended on a high voltage of 14kV (RMS). Numerical value of PD is set at the rate of 20000 pC. At this level, the value of the detected PD is 6448 pC. All the PD are stored in a file available and these will be processed into a location graph known as "Partial Discharge Mapping". Before determining the location of PD, not all the PD activities will be stored. Only the actual PD signals are required. The unwanted signals which are called as noise will be removed. This is to ensure only the presence which the real PD activities will be processed and finally determined its position in the cable being tested. Figure 11 shows the signal for PD activities before it is transferred to graph the location of PD.

Figure 11 : Process of PD activity

The first spike is the reference for the PD activities and the second spike is the actual PD activities. If the second graph corresponds to the first graph and in a range of cable length, then the data will be stored and otherwise it will be discarded.

After all the PD activities detected by the OWTS have processed, the data of PD activities will be transferred to the location graph of PD (Partial Discharge Mapping). From this location graph, each of PD activities can be seen in locations that have been transferred.

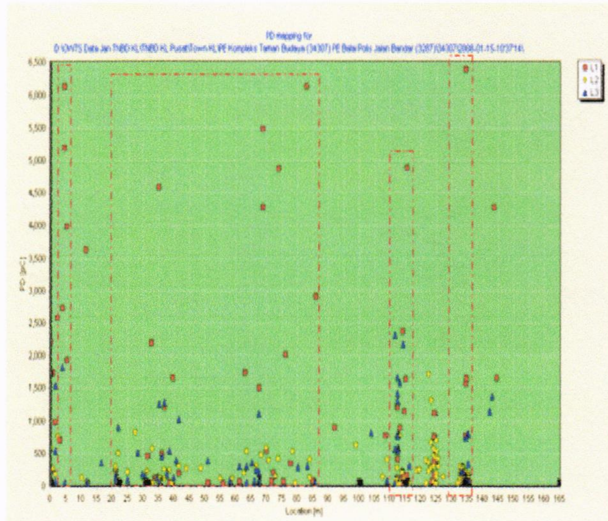


Figure 12 : Location graph of PD activity

Figure 12 shows the location for activities of PD (pC). The red sign shows the PD activities in the red phase and a *yellow sign shows the PD activities in the yellow phase* and blue sign shows the PD activities in the blue phase. This graph shows the PD value together with the location of tested cable. The density of PD activities in a cable shown in a graph known as the "Histogram" which is shown in Figure 13. This graph shows the number of PD activities in each location where the presence of PD can be detected.

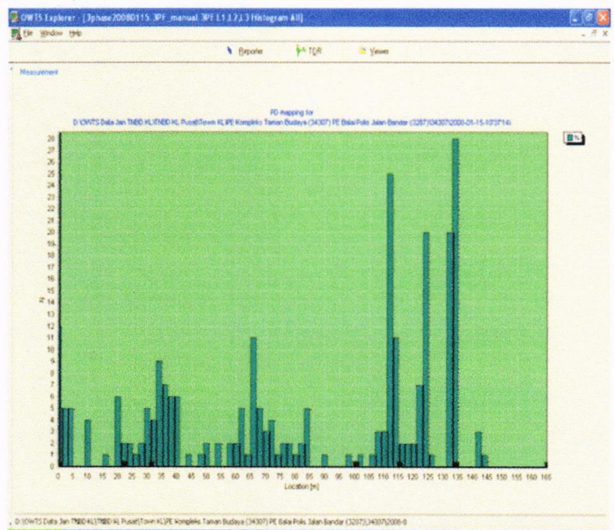


Figure 13 : Histogram graph

For the location of 135m, the number of detected partial discharges is 28. From the "Histogram" graph., it shows that on average there is partial discharge in the entire cable.

IV. DATA ANALYSIS

After the data obtained from the location and "Histogram" graph, the data will be included in the table for the purpose of analysis. The data required for analysis are:

i. Cable Type

ii. The maximum value of PD on a cable connection

iii. The maximum value of PD in the cable

iv. Number of valid PD

v. Cable length

vi. Age Cable

The analysis was carried out to transfer the data available to the "Bar Chart" graph. In the "Bar Chart", the data shown is the maximum value of partial discharge (PC) against the cable age (years) according to the type of cable being tested. There is also a "Bar Chart" which shows the percentage of occurrence of partial discharges against the type of cable being tested. Finally, all data will be used to calculate the severity index (SI) in order to determine the state of the cable. Further action will be made whether to repair the cable or repeat the tests if necessary. Table 1 shows the measurement range of severity index.

Results for the diagnosis of partial discharges consist 17 circuit of cables. The type of cables are cross-linked polyethylene (XLPE), paper insulated lead cable (PILC) and a mixture of XLPE and PILC. Total cable from the circuit is 14000 which is available in TNB Distribution in Selangor. It consists of 6 samples of XLPE cable, 5 samples of PILC cable and 6 samples of mixture XLPE / PILC. Cables tested only about 0.12% of cable installed in the TNB Distribution in Selangor. Decisions is made based on the graph which refers to the location of partial discharges, "Partial Discharge Mapping". From the graph location of partial discharge data, such as cable length, maximum value of partial discharges in cables and cable connections, the initial / final partial discharge activity and voltage (rms) at the beginning of the partial discharge test cables can be determined.

Table 1: Severity Index (SI)

Results	**S core Adjustment**	**Action**
Severity index < 2	Subtract 0	Normal. The monitoring periodicity of all Tier 1 tests can be *maintained at* 24 months. Practice partial discharge test if necessary.
2 < Severity Index < 5	Subtract 0.5	Retest the cable for partial discharge after 6 months. The monitoring periodicity of all Tier 1 tests should be revised to 6 months.
5 < Severity Index < 7	Subtract 1.0	Retest the cable for partial discharge after 3 months. Replace the cable or accessories at section that have PD.
Severity Index < 7	Subtract 1.5	Cable has major defect. Need to referred to Engineering Department.

Figure 14 shows the location for PD activities of one sample cable. The presence of PD activities occurred at red, yellow and blue phase.

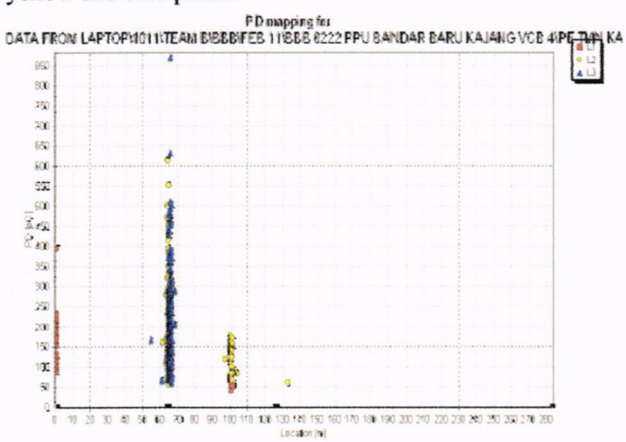


Figure 14 : Partial Discharge Result

Table 2 : Result of partial discharge diagnosis cable PE Tmn. Kajang Utama No.12 to PE Tmn. Mewah No.9

PD Measurement	Red	Yellow	Blue
Date of testing	22 Feb 2011		
Cable type - Length	XLPE/240mm²/3C/11kV – 284m		
Phase Voltage (kV)	6.35	6.35	6.35
PDIV (kV)	11.6	8.08	6.29
PDEV (kV)	11.0	7.7	9.0
Maximum magnitude of PD (pC)	2	70	69
No. of PD events (Ni)	16	158	231
Total No. of PD events (N_T)	23	185	232
Average magnitude of PD (pC)	160	175	199
Severity Index (SI)	1.09	3.86	6.18

Below is the equation to calculate the severity index:

$$SI = \frac{\frac{P_D\,max}{P_D\,Ave} \times \frac{N_i}{N_T}}{\frac{\frac{PDIV}{\sqrt{2}}}{U_o} \times \frac{\frac{PDEV}{\sqrt{2}}}{U_o}} \quad \text{(eq. 2)}$$

V. CONCLUSION

This paper has presented partial discharge on XLPE, PILC and mixture of XLPE/PILC. Several samples are chosen for the test. Results obtained from this study will be utilized to make a decision whether there is an urgency to repair the cable.

VI. ACKNOWLEDGEMENT

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VII. REFERENCES

[1] E. Gulski, P.P.Seitz, Ben Quak, Huber Schlapp, *"Advanced Solution For On-Site Diagnosis of Distribution Power Cables"*. International T&D Asset Management Conference CIRED KL 2008.

[2] CIGRE WG 21.05, *"Diagnostic Methods for HV Paper Cables and Accessories"*, Electra No. 176, February 1998.

[3] IEC 60840, *"Power Cables with Extruded Insulation and their accessories for ratted voltages above 30kV- Test methods and requirements"*.

[4] IEC 60060-3, *"High Voltage Test Techniques – Part 3: Definitions and Requirements for On-site Testing"*.

[5] IEEE 400.3, *"Guide for PD Testing of Shielded Power Cable Systems in a Field Environment "*.

[6] E. Gulski, J J Smit, P.N. Seitz, R.F.F. Koning, M. Turner, *"On-site Partial Discharge Diagnostics of Medium Voltage Power Cables"*. Proceedings Jicable '99. 5th International Conference on Insulated Power Cables, France, Versailles, June 1999, p. 283-290.

[7] Wester F.J., E Gulski, J J Smit, *"Electrical and Acoustical PD On-site Diagnostics of service aged Medium Voltage Power Cables"*. Proceedings Jicable '99. 5th International Conference on Insulated Power Cables, France, Versailles, June 1999 p. 896-901.

[8] M. Tuner, *"A New Method for Diagnosis of Installed Medium Voltage Power Cables"*, Haefly Test AG, Tettex Division, Dietikon, Switzerland.

[9] E.Gulski, E.J.Sinambela, P.Cichecki, J.J.Smit, F.Petzold, F. de Vries, P.P.Seitz, *"Optimal Partial Discharge Diagnosis of Medium Voltage Power Cables"*, Delft University of Technology, Netherlands.