CONDITION ASSESSMENT OF IN SEVICE MEDIUM VOLTAGE UNDERGROUND PILC CABLES USING PARTIAL DISCHARGE MAPPING AND POLARIZATION INDEX TEST RESULTS

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ABSTRACT

In general, the main degradation of underground power cable is due to partial discharge and water treeing for both PILC and XLPE type of cable. Partial Discharge can occur primarily in cavities in the insulation of cables and cable accessories. In PILC cable, voids may result due to insulating oil migration due to elevation differences, cracks in the lead sheath, incorrect assembly of terminations or splices. Wet can be due to water ingress through a crack in the lead sheath of a PILC cable. When partial discharge occurs, it will corrode the insulating material in such away that carbonized path will be formed and grow, then the electrical treeing will take place and lead to breakdown.

However, most cable experts are convinced that wet paper insulation does not initially produce Partial Discharge. The probability of failure by moisture penetration in the cable insulation is also dependent on the geographical condition. In such areas where the ground water level is high, if the water barrier in the cable system e.g. splices, is leaking, it will also allow the water to penetrate easily. If the previous cavities within the paper insulation are becoming wet, no partial discharge activity will take place. Moisture ingress in hygroscopic paper insulation will cause adverse affect in the dielectric properties thus changes in the dielectric strength. The breakdown strength of paper insulation is decrease with increase of moisture content. Partial discharge might not detect from this kind of circuit even the breakdown strength has been reducing tremendously.

INTRODUCTION

TNB has begun its journey towards the use of XLPE cable in early 1980. Presently, PILC cables are used for repair of faults as well as extension of the existing paper cable only. However there are certainly a huge percentage of PILC (>50%) cables still in the network. TNB Research as the research arm of Tenaga Nasional Berhad has been performing the partial discharge off line testing since 1988 and recently has also included the polarization index measurement for PILC cables. The conventional method measuring Insulation Resistance was found not so reliable as the reading are very much dependent on the circuit length. Consistencies of Insulation Resistance of all the three phases were used as healthy indication instead of the ohmic resistance value.Therefore measurement of polarization index has more meaningful information compared to the insulation resistance alone. With the help of above-mentioned diagnostic tests, TNB has diagnosed more than 100 in-service PILC cable circuits in the distribution network. Most of the tested cables were 22kV belted PILC cables ranging from 100m to 3000m. In this paper an attempt has been made to compute severity indices for partial discharge mapping and polarization index testing results. These two severity indices will then be combined to come out with one condition assessment index to facilitate decision making process for cable maintenance.

MEASURING METHOD

Partial Discharge Mapping

Partial discharge is defined by IEC 60270 as an electrical discharge phenomenon – taking place within an insulation system and a major cause of long-term degradation. This paper stresses on the internal discharge, which is the most common type of electrical discharges occurring in void or cavities of power cable insulation system. When a particular void experiences potential gradient greater than its breakdown strength, discharge bridging will take place between the two affected surfaces of the void. The effect is localized burning of the insulation [2].

The mapping system allows measurement of the location and magnitude of partial discharge within the insulation. The equipment consists of three main components to build up the complete system. The block diagram of the complete system is shown in Figure 1.

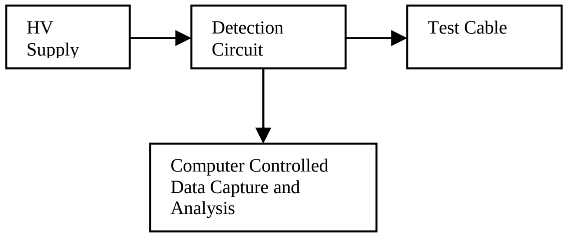


Figure 1: Block Diagram of PD Mapping System

The system uses a very low frequency (VLF) high voltage AC supply source to energize the cable. The VLF source can be operated at frequency down to 0.05Hz and up to ~ 1.0Hz depending on the cable capacitance with a maximum generating voltage of 40kV(peak).

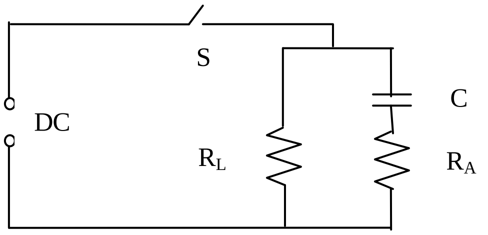
Partial discharges are measured via a high voltage blocking capacitor, which is connected to the test cable. A filter and a buffer amplifier are used as the detection impedance. The detected signal is sent through a 50 ohms coaxial cable. The partial discharge activities are recorded on an oscilloscope and transferred to disc storage. The data is processed to determine the magnitude and location of the discharges.

Insulation resistance Testing of Insulation

When dc voltage is applied to insulation the electric field stress gives rise to current conduction and electrical polarization. Considering an elementary circuit as shown in Figure 2, when the switch is closed, the insulation become electrified and a very high current will flow. However, these currents immediately drop in value, and decreases at slower rate until it reaches a nearly constant value. The current drawn by the insulation may be analyzed into several components namely Capacitance charging current, Dielectric absorption current, Surface leakage current, Partial Discharge current and Volumetric current. In general this test may be conducted at applied voltage of 100 – 15,000 V.

Polarization Index

In good insulation, the effect of absorption current decreases as time increases. In bad insulation, the absorption effect is prevailed by high leakage current. Therefore, a good insulation system shows a continued increase in its insulation resistance value over the period of time in which voltage is applied. The time resistance method is less dependent of temperature and equipment size. It can provide conclusive results as to the condition of the insulation.



C – Represents charging current
R_A – Represents absorpsition current
R_L – Represents volumetric leakage current
Figure 2**:** Electric circuit of insulation under dc voltage test.

Polarization index (PI) test is carried out using an electronic megohmmeter that give an indication of insulation resistance in Mohms and Gohm. Cable terminations at both ends are cleaned before making the measurement with special cleaning solvent. Subsequently after the cleaning, grounding mechanism via cable sheath was also checked and verified through the conductor resistance measuring devices. Insulation resistance measurement values are recorded at 1 minute and 10 minutes of voltage application. The ratio at 10 minutes to 1 minute determines the PI.

ANALYZING TECHNIQUE

The results obtained from the partial discharge measurement are further analyzed using the following technique for condition assessment of the tested cables.

PD Severity Technique

The related parameters are shown in equations 1, 2, 3, 4, 5 and 6.

$$S = (A \cdot D)/K \qquad (1)$$

where,
S = Severity Factor, A = Discharge Factor, D = Density Factor and K = Critical Factor

The critical factor K is calculated as follows:

$$K = k1 * k2 \qquad (2)$$
$$k1 = Vi/Vo \qquad (3)$$
$$k2 = Ve/Vo \qquad (4)$$

where,
k1 = Inception Voltage Factor & k2 = Extinction Voltage Factor
Vi = Inception Voltage, Ve = Extinction Voltage and
Vo = Phase Voltage

$$A = Qm/Qa \qquad (5)$$

where,
A = Discharge Factor
Qm = Maximum Discharge
Qa = Average Discharge

$$D = N_m/N_T \qquad (6)$$

where,
D = Density Factor
N_m = Number of Discharges @ L ± 10m
N_T = Total Number of Discharges
L = Location of Highest Discharge

Having got all the severity value of partial discharge and the polarization index test result, specific level severity were assigned to both of them and categorized them based on this range.

PD Severity		PI Severity		Combined Severity (S_C)
S_L	<2.0	PI_H	>2.5	Good
S_M	2.0~5.0	PI_M	1.5~2.0	Fair
S_H	>5.0	PI_L	<1.5	Bad

Table 1: Partial Discharge and Polarization Index Severity Range

L, M and H represent the Low, Medium and High value of respective severity. Table 1 shows the assigned severity level of partial discharge and polarization index as well as their combine severity, S_C. The matrix of combine severity level was also developed as shown in the Table 2 below.

PD Severity	PI Severity	Combined Severity(S_C)
S_H	PI_H	Fair
S_H	PI_M	Fair
S_H	PI_L	Bad
S_M	PI_H	Fair
S_M	PI_M	Fair
S_M	PI_L	Bad
S_L	PI_H	Good
S_L	PI_M	Fair
S_L	PI_L	Bad

Table 2: Combined Severity Matrix based on Partial Discharge and Polarization Index Severities

CASE STUDY

In this paper, the cables that are going to be discussed are three cores PILC rated at 22kV and are in service ranging between 7 to 15 years. The information on the cables is presented in Table 3.

CABLE	AGE (YRS)	LENGTH (KM)
C1	~15	108
C2	~15	309
C3	~10	632
C4	~7	1064
C5	~7	640
C6	~8	776
C7	~15	552

Table 3: General Information on Cables under Study

Partial discharges were measured up to the test voltage ($1.3U_o$ or 16.5kV). The cable termination parts are excluded from the measurement due to equipment limitation. Severity technique was applied for the analysis.

Figure 3 shows the graph of partial discharge mapping for cable C1. Each point represents the discharge magnitude in pC at the relevant cable location (L) which is in meter. Standard procedures are also followed to obtain inception and extinction voltages. System provides the measurement for number of discharges.

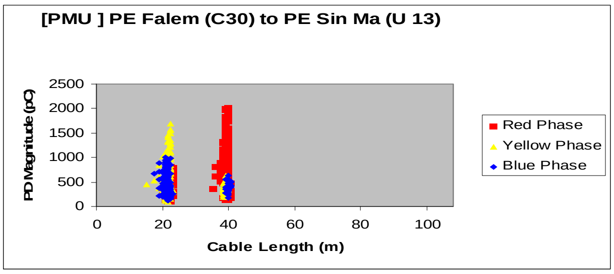


Figure 3: Partial Discharge Mapping for Cable C1

Similar measurements are also taken for cable circuits C2 to C7. Based on the results and using the analyzing technique mentioned the PD severity index values for all the cable circuits under analysis are calculated. The cable circuits are also tested for polarization index following the technique mentioned earlier. The computed values of PD severity index and measured value of PI are presented in the Table 4.

The values indicate the severity of partial discharge activity on the tested cables. A tested cable can be considered in a more severe condition with higher S value. The inception and extinction voltage, the maximum discharge, and the charge density become the important parameters to determine the cable or phase condition. Comparison between the cables as well as the phases can be obtained from the measurement.

The corresponding values of polarization index are also listed next to the partial discharge severity.

In the case of low polarization index, the focus are not only to the area or location of high partial discharge but more toward the overall condition of the cable with respect to the leakage current due to dc testing.. It is suspected that the low value of polarization may be due to the moisture or carbonization affects that forming a significant leakage path.

Table 4 shows the computed severity value for all the tested cable in this case study as well as their corresponding polarization index value.

CABLE	PHASE	PD MAPPING RESULTS				S	PI
		K	A	D	L (m)		
C 1	1	0.4	2.98	0.56	38	4.21	1.01
	2	0.2	3.88	0.91	21	18.1	1.04
	3	0.4	2.43	0.85	21	5.15	1.05
C 2	1	0.5	1.67	0.86	50	2.71	1.11
	2	0.2	1.34	0.76	75	3.52	1.10
	3	0.6	1.35	0.50	37	1.14	1.11
C 3	1	0.5	2.08	0.97	154	3.47	1.61
	2	0.4	1.65	0.84	530	3.41	1.88
	3	0.5	4.62	0.20	379	1.63	1.78
C 4	1	0.7	1.85	0.51	175	1.35	1.29
	2	Na	Na	Na	Na	Na	1.94
	3	1.0	2.88	0.58	828	1.67	1.86
C 5	1	0.5	2.29	1.00	127	4.23	2.66
	2	Na	Na	Na	Na	Na	2.63
	3	0.5	1.58	1.00	127	2.84	2.61
C 6	1	0.9	1.97	1.00	83	2.20	3.42
	2	0.6	3.02	1.00	83	5.07	2.35
	3	0.6	2.83	1.00	83	4.39	3.24
C 7	1	0.3	2.49	0.74	56	6.27	3.94
	2	0.6	2.02	0.50	242	1.70	3.96
	3	0.5	2.05	0.07	401	0.30	4.00

Table 4: Partial Discharge Severity and PI values

Table 5 below shows the combination of both PD and PI severity level. Based on this combination, it provides what action should be taken on the respective cable.

CABLE	PHASE	S	PI	S_C
C1	1	4.21	1.01	Bad
	2	18.09	1.04	Bad
	3	5.15	1.05	Bad
C2	1	2.71	1.11	Bad
	2	3.52	1.10	Bad
	3	1.14	1.11	Bad
C3	1	3.47	1.61	Fair
	2	3.41	1.88	Fair
	3	1.63	1.78	Fair
C4	1	1.35	1.29	Bad
	2	Na	1.94	Fair
	3	1.67	1.86	Fair
C5	1	4.23	2.66	Fair
	2	Na	2.63	Good
	3	2.84	2.61	Fair
C6	1	2.70	3.42	Fair
	2	5.07	2.35	Fair
	3	4.39	3.24	Fair
C7	1	6.27	3.94	Fair
	2	1.70	3.96	Good
	3	0.30	4.00	Good

Table 5: Combined Severity for condition assessment

From Table 4 and Table 5, it is evident that PD severity might have shown low severity with PI value is also low. In some cases PD severity is showing high value that needs immediate action. However when compared to the PI it has indicated that the cable lies in the fair severity level as it has shown high PI value. Having this combination, confirmation on the weaknesses and the health of such insulation system can be obtained.

5. CONCLUSIONS

The polarization index measurements are non-destructive testing that enable to evaluate the cable system insulation condition. Partial discharge mapping on the other hand is very effective for PILC. It locates partial discharge activities and indicates the level of partial discharge. Polarization index and partial discharge mapping can complement each other in diagnosing defects especially in the insulation of the PILC cables. One can identify insulation quality, while the latter can also spot local defects. A maintenance program can be developed based on the condition of the cables. Priority can be given to cables having the higher severity combination. The cables with less deterioration should be monitored periodically based on the historical data.

Polarization index measurement is a very useful and simple testing tool in determining cable condition. It provides valuable information for any cable defect in term of leakage current and the analysis can look into each particular cable phase. However, further study should be undertaken to classify the various frequencies representation for measurement on cable. Severity technique provides information on cable condition in term of partial discharge. Partial discharge may exist anywhere in PILC cable due to the nature of its design. Even though partial discharge mapping is used for locating defect, it can also be applied to evaluate cable condition. The information can be utilized to support decision making for any further action on preventive maintenance. It is clearly shown that the health condition will be more accurate with using this combine severity of partial discharge and polarization index. Having this combination will enable network operator to confidently energize the cable.

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