PD PATTERNS RECOGNITION IN XLPE CABLE UNDER VARIOUS THERMAL CONDITIONS USING STATISTICAL TECHNIQUE

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ABSTRACT

Condition monitoring of partial discharge (PD) has become a preferred method in the design of HV apparatus. Power cable is one of the HV apparatus affected by PD activity. Although, the phenomenon of PD in power cables are well known, the effect of soil thermodynamics on PD is not yet well established. Thus, an experiment has been carried out to assess the effect of soil thermal resistivity on various PD parameters at different temperatures. Cable sample studied is an 11kV, single core, 240mm^2 XLPE cable. Classification is firstly carried out using the conventional method "Recognition Rate". A proposed method, which is called "Hitting Pattern", is then introduced to overcome the limitation of "Recognition Rate". Classification using "Hitting Pattern" emphasises on the patterns of discharge, which is not considered by the "Recognition Rate". These two techniques are developed with the help of 27 statistical parameters, so called "classifiers", which are calculated using PD Analyzer Programme developed in-house. The values of classifiers of standard physical condition are used to classify PD patterns of non-standard physical conditions. The authors have also discussed about the simplified version of "Recognition Rate", which is called "Fingerprint", for the easier observation purposes.

Keywords*: Partial discharge, Classification, Statistical technique, Pattern recognition*

1. INTRODUCTION

Partial discharge is identified as a main factor that contributes to the insulation deterioration inside the high voltage (HV) equipment. Failure of HV apparatus due to PD phenomenon may cause million of dollar damages to the power utilities beside interrupting the delivery system and decreasing the reliability of the system [1]. This has led them to employ PD measurement as a method of insulation diagnosis for HV power equipment including power cables. There are so many factors to be considered during the operation of a power cable such as temperature, possibility of over voltage, mechanical forces and adverse soil condition, which contribute to the ageing of insulating material. Therefore, in this paper, the authors have carried out an experiment to find out the effect of one of the factors above, which is not yet well established. Experiment has been carried out on an 11kV, single core, 240mm^2 XLPE cable, to investigate the effect of soil thermal resistivity on the level of PD activity inside the cable at different temperatures.

The experiment is carried out with the help of Haefely Trench TE571, PD Measurement System using straight detection method inside a shielded enclosure. Results obtained are in the form of 2D distributions (as shown in Fig. 1) e.g. the number of PD pulses [Hn(ϕ)] against phase angle, the maximum PD magnitudes [Hqmax (ϕ)] against phase angle, the average PD magnitude [Hqn(ϕ)] against phase angle, discharge magnitude distribution (Hq) and discharge energy distribution (Hp). In this research work, the authors have chosen only three distributions out of five as mentioned above, as three of them consist both positive and negative cycles. They are, the number of PD pulses [Hn(ϕ)] against phase angle, the maximum PD magnitudes [Hqmax (ϕ)] against phase angle and the average PD magnitude [Hqn(ϕ)] against phase angle.

In the past, patterns classification was performed by observing those patterns on an oscilloscope screen by eye [2]. Observation was done without involvement of mathematical aspect. The accuracy of this method definitely only depends on eye observation. Therefore, nowadays, the use of statistical parameters in the classification work has become the preferred classification technique to replace the old style of classification [3]. In this paper, the authors have utilised six well known statistical parameters to be applied for both positive and negative cycles of those distributions. Results are then used to develop the conventional classification technique "Recognition Rate" besides applying two others techniques, "Hitting Pattern" and "Fingerprint", in order to get the best and reliable classification results [2-6,13].

In this research paper, besides applying those classification methods to classify PD patterns, there is also an attempt to find out the effect of soil thermal resisitivity on PD activity in underground power cable at fixed temperature.

Those statistical parameters will also be used to identify whether the variation in the value of soil thermal resistivity yields any the differences in the PD patterns or otherwise.

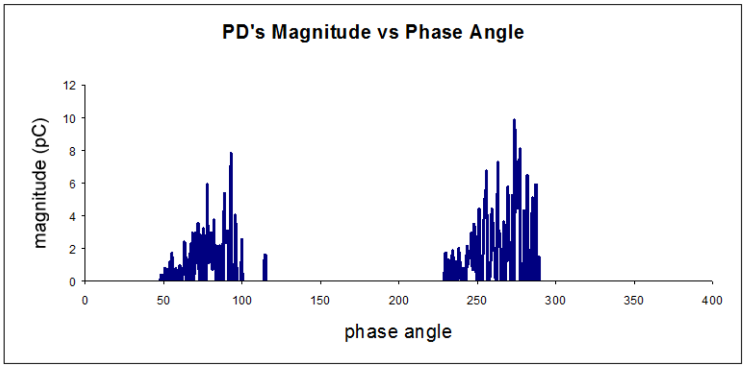

Figure 1. 2D waveform of PD pulse

2. EXPERIMENTAL SET UP AND PROCEDURE

In this experiment, 11 kV single core, 240mm^2 XLPE cable has been used as a test specimen. The length of the cable under test is 6m. The cable is laid in a U-shaped cable trench, which is filled with dry sand. The trench is 1.4m wide, 1.8m height and 5.4 m in total length. To simulate the loading of the cable, the temperature of the cable is varied using an induction current transformer. The whole experimental set up including the cable trench and current transformer is placed inside the shielded enclosure in TNB Research High Voltage Testing Laboratory. The partial discharge measurement is done using Haefely Trench TE571, Partial Discharge Measurement System. The system uses a straight detection method for measuring PD and it is powered by 100kV, 1000kVA, 50Hz Resonant Test System. The equivalent circuit diagram for this PD Measurement System is shown in Fig. 2.

The first experiment is carried out on a dry sand of a particular value of thermal resistivity. The reading of the sand thermal resistivity is taken at 6 locations in the cable trench. The first reading of PD is taken at ambient temperature. The reading is repeated for three times. After completing the PD reading as mentioned above, the thermal resistivity of the sand is changed by pouring definite amount of water into the cable inside the cable trench. Then the reading of the new sand thermal resistivity is taken at six locations in the cable trench. Then the whole experimental procedure is repeated at this ambient cable temperature for this new thermal resistivity. The experiment is then repeated for other values of sand thermal resistivity and cable temperature. The sand thermal resistivity is measured by using KD2 Thermal Properties Analyzer. The KD2 Thermal Properties Analyzer will give direct and instantaneous reading of the soil thermal properties. In this experiment, 3 sets of sand thermal resistivity are selected for the analysis e.g. S1=0.977m^{o}CW^{-1}, S2=1.73m^{o}CW^{-1} and S3=2.9m^{o}CW^{-1} simulating from dry to wet soil conditions. The soil thermal resistivity is varied in order to simulate different soil thermal condition in the field. In this experiment, sand is used to fill the cable trench. This is because sand is used as a backfill material in the cable trench in Tenaga Nasional Berhad, Malaysia. For each set, the PD reading is taken and stored in Haefely Trench TE571 PD Measurement System. For the whole experiment, the rate of voltage rise is kept at 1kV/sec, and the test voltage is 11kV$_{rms}$. The voltage is first raised to 18kV$_{rms}$ for 60 seconds, and then the voltage is lowered to 11kV$_{rms}$ for PD measurement. This procedure is following the IEC 885 part 2. During the PD measurement, the test voltage is kept fixed at 11kV$_{rms}$, for simulating the actual operating voltage of the cable.

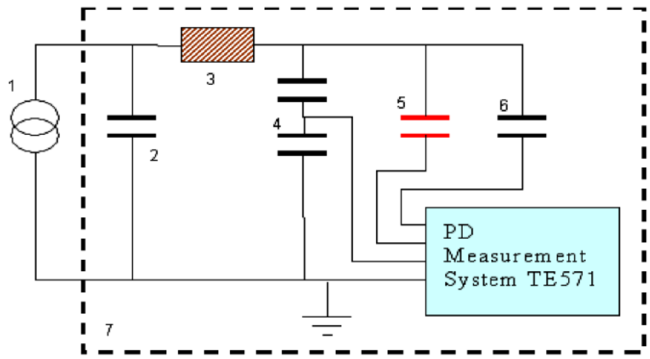

Figure 2. Equivalent Circuit Diagram for PD Measurement.1, 100kV, 1000kVA, 50Hz transformer; 2 & 3, Filters; 4, Capacitive Dividers; 5, Test Sample; 6, Injection Capacitor (PD detector); 7, Shielded Room.

This PD Measurement apparatus is able to produce five different distributions e.g. the number of PD pulses [Hn(ϕ)] against phase angle, the maximum PD magnitudes [Hqmax (ϕ)] against phase angle, the average PD magnitude [Hqn(ϕ)] against phase angle, discharge magnitude distribution (Hq) and discharge energy distribution (Hp) [7]. Out of this five distributions, three of them have been used for this present wok. They are the number of PD pulses [Hn(ϕ)] against phase angle, the maximum PD magnitudes [Hqmax (ϕ)] against phase angle and the average PD magnitude [Hqn(ϕ)] against phase angle. Soil thermal resistivity of 1.73 m^oCW^{-1} (S2) is chosen as the standard. Each measurement of soil thermal resistivity is carried out using three different temperatures e.g. T0=28^{o}C (ambient), T1=40^{o}C and T2=90^{o}C. Temperature at 40^{o}C represents half load condition while 90^{o}C represents full load condition of the cable.

3. VARIATION OF CABLE TEMPERATURE

The variation of the cable temperature is done to replicate the loading of the cable during service. The heating of the cable is done by using a 3-phase, 415V, 50Hz current transformer and the cable temperature is measured using K-type thermocouple. The cable temperature is simulating the percentage of the cable loading during service. The cable loading and the respective temperature is estimated using equation (1)[8]:

$$I = \sqrt{\frac{T_c - T_{RT}}{nrR_{TH}}} \quad (1)$$

Where:

T_c = Conductor (core) temperature (^{o}C), T_{RT} = Surrounding (soil) temperature (^{o}C), n = Number of core,

r = Resistance of the conductor (core),(Ω/m),

R_{TH} = Sum of thermal resistivity (m^oCW^{-1})

Fig. 3 shows the variation of cable loading (A) versus cable temperature (^{o}C). The value of the soil thermal resistivity is taken as 1.2 m^oCW^{-1}, for calculation purposes. In this experiment, 3 sets of cable temperature have been chosen, that is 90^{o}C, 40^{o}C and 28^{o}C (ambient temperature). The cable temperature of 28^{o}C is reflecting ambient temperature, which means the cable is energised without any load. The cable temperature of 90^{o}C is reflecting 100% loading of the cable under normal operating condition while 40^{o}C represents the half load of the cable.

4. VARIATION OF SOIL THERMAL RESISTIVITY

The soil thermal resistivity is varied in order to simulate different soil thermal condition in the field. In this experiment, sand is used to fill the cable trench. This is because sand is used as a backfill material in the cable trench in Tenaga Nasional Berhad, Malaysia. The sand thermal resistivity is varied by pouring water into the cable trench. The measurement of sand thermal resistivity is taken by using KD2 Thermal Properties Analyzer. The KD2 Thermal Properties Analyzer will give direct and instantaneous reading of the soil thermal properties. In this experiment, 3 sets of sand thermal resistivity is selected e.g. S1=0.977m^oCW^{-1}, S2=1.73 m^oCW^{-1} and S3=2.9m^oCW^{-1} simulating very dry to very wet soil conditions.

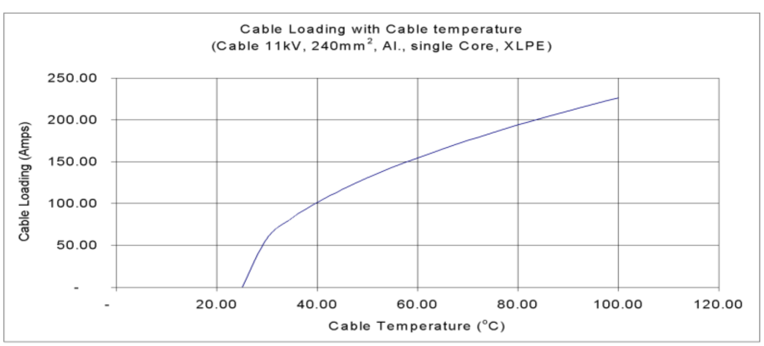

Figure 3. Cable loading with cable temperature.

5. STATISTICAL PARAMETERS

Pattern Recognition (PR) method is one of the established techniques in classifying various patterns. It is also, nowadays, widely used in classifying PD signals. In this research work, 27 statistical parameters have been used as classifiers after considering both positive and negative cycles of the distributions. These parameters are produced as each of the three distributions mentioned earlier consists 9 statistical parameters. Mathematical expressions associated with the statistical parameters used in this work are tabled in Table 1 [9-12].
As the experiment on a particular soil condition is repeated three times, the results are useable to develop the standard database. From the values of statistical parameters of each trial, the standard error of the confidence interval is calculated using equation (2)[2][9];

$$\left| S_{\bar{x}} \right| = \frac{t.s}{\sqrt{N}} \tag{2}$$

Where s is the standard deviation of the statistical parameter from a series of N observations of one and the same type of soil conditions at a given cable temperature and t is a statistical test parameter depending on N.

Table 1. Statistical Parameters.

Statistical Parameter	**Mathematical Expression**
Skewness	$S_k = \frac{\sum (X_i - \mu)^3 P_i}{\sigma^3}$
Kurtosis	$K_u = \frac{\sum (X_i - \mu)^4 P_i}{\sigma^4}$
Number of Local Tops	–
Cross Correlation	$cc = \frac{\sum X_i Y_i - \sum X_i \sum Y_i / n}{\sqrt{\left[\sum X_i^2 - (\sum X_i)^2 / n\right]\left[\sum Y_i^2 - (\sum Y_i)^2 / n\right]}}$
Discharge Factor	$Q = \frac{Q_s^- / N^-}{Q_s^+ / N^+}$
Modified Cross Correlation	mcc = Q.cc
Asymmetry	Quotient of the mean level in the positive and negative halves of voltage cycle.

6. METHODOLOGY OF CLASSIFICATION

In this research work, classification using statistical technique is implemented by choosing S2=1.73m^{o}CW^{-1} as the standard soil thermal resistivity at three different temperatures, as discussed earlier, while another two soil thermal resistivities are taken as non-standard parameters. Each pair of soil thermal resistivities and cable temperatures is shown in Table 2.

Table 2. Soil Thermal Resistivities and Cable Temperatures.

Standard	**Non-standard**	
S2T0	S1T0	S3T0
S2T1	S1T1	S3T1
S2T2	S1T2	S3T2

The objective of the experiment is to measure the PD severity for the standard value and other two non-standard values of soil thermal resistivities at three different temperatures. Then, 27 statistical descriptors or classifiers are used to analyze the standard and non-standard patterns. To compare the signal between the standard and non-standard physical conditions, three approaches are used. They are “Recognition Rate”, “Hitting Pattern” and “Fingerprint” [6].

Once the values of statistical parameters for standard and non-standard physical conditions are completely calculated, classification is carried out using “Recognition Rate”. “Recognition Rate” is obtained from the summation of the number of statistical parameters of non-standard physical condition, which are in the range of statistical parameters of standard physical condition. According to the concept of “Recognition Rate”, if the value of “Recognition Rate” of non-standard physical is same as the standard physical condition, then the signals are similar. Otherwise, they are different. But, if two different non-standard signals sharing the same value of “Recognition Rate”, it is insignificant to conclude that they are the same without observing the pattern of both signals. This is obviously shows the limitation of this technique and indirectly tells us that “Recognition Rate” technique is only applicable for two or more signals with the different “Recognition Rate”. Therefore in this research work, other techniques has been introduced, that is “Hitting Pattern”.“Hitting Pattern” is an alternative technique to overcome the limitation of “Recognition Rate”.

“Hitting Pattern” is the extension of “Recognition Rate” technique. Based on the values of statistical parameters for both standard and non-standard physical condition, “Hitting Pattern” is developed to observe the actual patterns of both signals. This enables us to continue the classification work more accurate and reliable as well as overcoming the limitation given by “Recognition Rate” technique.

7. RESULT ANALYSIS

In the methodology, the authors have mentioned about the purpose of using “Hitting Pattern” technique. This technique is an alternative if “Recognition Rate” technique is unable to classify PD patterns due to the similarity in the values of “Recognition Rate”.

In the earlier discussion, it has been mentioned that experiments have been carried out on an 11kV, single core, 240mm^2 XLPE cable at three soil thermal resistivities and temperatures. Combination of these soil thermal resistivity and temperatures is shown in Table 2. S2=1.73 m^{o}CW^{-1} is chosen as the standard soil thermal resistivity based on the information obtained from the cable manufacturer, which is using soil thermal resistivity 1.8m^{o}CW^{-1} in designing this type of cable. T0=28^{o}C represents the ambient temperature (no load condition), T1=40^{o}C represents the operating temperature at half load condition while T2=90^{o}C represents the full load condition of cable. Results obtained from the calculation of 27 statistical parameters for each statistical distribution e.g. number of PD pulses [Hn(ϕ)] against phase angle, the maximum PD magnitudes [Hqmax (ϕ)] against phase angle and the average PD magnitude [Hqn(ϕ)] against phase angle are tabled based on temperature.

In this section, the interpretation of results is done separately for “Recognition Rate” technique and “Hitting Pattern” technique. This is to show the effectiveness of the proposed “Hitting Pattern” technique in overcoming the limitation of “Recognition Rate”.

7.1 Classification using “Recognition Rate” technique.

The results obtained from the calculation of statistical parameters for standard and non-standard PD distributions occur at ambient temperature are recorded in Table 3. Standard parameters are defined by lower and upper limits. To develop these limits, 95% of confidence level has been chosen. These limits are used to determine whether the comparison between the values of statistical parameters of non-standard and standard physical conditions produce “hit” or “miss”. Every value of statistical parameters of non-standard physical conditions, which are in the range of upper and lower limits, will produce “hit”, marked as (/). Otherwise “miss”, marked as (X). Then, the “Recognition Rate” is obtained from the summation of number of “hit”. Table 3 obviously shows that the “Recognition Rate” value for S1T0 and S3T0 are the same that is 11. Since they are sharing the same value of “Recognition Rate”, the only conclusion can be made is both discharges are coming from the same source. But the truth could be only known after investigating both patterns so called “Hitting Pattern”, which will be described in 7.2.

Table 3. The values of Statistical Parameters of Standard and Non-Standard Physical Condition at Ambient Temperature.

PD Pulses	Statistical Parameter	Standard		Non-standard			
		S2T0		S1T0	Hit (/) or Miss (X)	S3T0	Hit (/) or Miss (X)
		Lower Limit	Upper Limit				
Average Value (Hqn)	Sk+	0.2603	0.8721	0.4033	/	0.642	/
	Sk-	0.3094	0.9211	0.1958	X	0.3256	/
	Kur+	-1.1466	-0.5348	-0.6111	/	-0.4558	X
	Kur-	-1.1466	-0.5348	-0.8901	/	-1.1293	/
	Local Top +	6.3608	6.9725	9.6667	X	7.6667	X
	Local Top -	6.3608	6.9725	11.3333	X	10.3333	X
	CC	-0.3053	0.3065	0.0007	/	0.0008	/
	Modified CC	-0.3052	0.3065	0.0008	/	0.0009	/
	Asymmetry	-1.2196	-0.6079	-0.8304	/	-0.747	/
Max Value (Hqmax)	Sk+	0.256	0.441	0.5646	X	0.4485	X
	Sk-	0.2236	0.4087	0.5658	X	0.6732	X
	Kur+	-1.4886	-1.3036	-0.9822	X	-1.4821	/
	Kur-	-1.4886	-1.3036	-0.8964	X	-0.9003	X
	Local Top +	5.5741	5.7592	8.6667	X	6.6667	X
	Local Top -	6.5741	6.7592	7.6667	X	10	X
	CC	-0.0924	0.0927	0.0001	/	0.0001	/
	Modified CC	-0.0923	0.0927	0.0002	/	0.0002	/
	Asymmetry	-0.8782	-0.6932	-0.6252	X	-0.5214	X
Number of Discharge (Hn)	Sk+	0.9877	1.1182	1.0484	/	1.3171	X
	Sk-	0.7813	0.9118	0.9736	X	1.2372	X
	Kur+	-0.3656	-0.2352	-0.2061	X	0.5746	X
	Kur-	-0.3656	-0.2352	-0.5459	X	0.4604	X
	Local Top +	4.6015	4.7319	7.3333	X	5	X
	Local Top -	5.2681	5.3985	7.3333	X	5.6667	X
	CC	-0.0652	0.0652	0	/	0	/
	Modified CC	-0.0652	0.0652	0	/	0	/
	Asymmetry	-0.6766	-0.5462	-0.3099	X	-0.3123	X
	Recognition Rate				11		11

Table 4. The values of Statistical Parameters of Standard and Non-Standard Physical Condition at T=40^{o}C.

PD Pulses	Statistical Parameter	Standard		Non-standard			
		S2T1		S1T1	Hit (/) or Miss (X)	S3T1	Hit (/) or Miss (X)
		Lower Limit	Upper Limit				
Average Value (Hqn)	Sk+	0.4329	0.706	0.7289	X	1.0025	X
	Sk-	0.8691	1.1422	0.7094	X	0.6755	X
	Kur+	-1.0492	-0.7762	-0.1528	X	0.0049	X
	Kur-	-1.0492	-0.7762	1.1511	X	-0.1646	X
	Local Top +	6.1968	6.4699	10	X	4	X
	Local Top -	5.1968	5.4699	10.6667	X	6.3333	X
	CC	-0.1351	0.138	0.0005	/	0.0006	/
	Modified CC	-0.1347	0.1384	0.0004	/	0.0005	/
	Asymmetry	-0.8479	-0.5748	-1.0536	X	-1.0591	X
Max Value (Hqmax)	Sk+	0.3699	1.195	0.3985	/	0.6592	/
	Sk-	0.2836	1.1088	0.6353	/	0.3491	/
	Kur+	-0.9518	-0.1267	-1.1852	X	-0.9967	X
	Kur-	-0.9518	-0.1267	-0.815	/	-1.3402	X
	Local Top +	4.2541	5.0792	7.3333	X	8.6667	X
	Local Top -	6.9208	7.7459	7.3333	/	8	X
	CC	-0.412	0.4132	0.0002	/	0.0002	/
	Modified CC	-0.4117	0.4134	0.0002	/	0.0003	/
	Asymmetry	-1.0277	-0.2025	-0.802	/	-0.859	/
Number of Discharge (Hn)	Sk+	0.961	1.8369	2.0185	X	0.8924	X
	Sk-	0.8579	1.7339	1.4465	/	1.2804	/
	Kur+	0.4469	1.3228	4.2697	X	-0.5139	X
	Kur-	0.4469	1.3228	0.9904	/	0.5427	/
	Local Top +	4.2287	5.1046	5.6667	X	6	X
	Local Top -	4.562	5.438	5	/	5.3	/
	CC	-0.4379	0.438	0	/	0.0001	/
	Modified CC	-0.4379	0.438	0	/	0.0002	/
	Asymmetry	-0.9345	-0.0586	-0.6395	/	-0.5808	/
	Recognition Rate				15		13

Table 4 shows the results obtained from the S1, S2, and S3 at T=40^{o}C. The "Recognition Rate" for S1T1 is 15 and "Recognition Rate" for S3T1 is 13. Table 5 contains the results obtained for S1, S2 and S3 at the temperature of 90^{o}C, where the "Recognition Rate" for S1T2 is 20 while S3T2 is 21. Since the value of "Recognition Rate" for both pairs of discharges are different, it is therefore simply to conclude that they are coming from the different source of discharges. But it is recommended to use "Hitting Pattern" to support the result from the earlier classification work.

Table 5. The values of Statistical Parameters of Standard and Non-Standard Physical Condition at T=90°C.

PD Pulses	Statistical Parameter	Standard S2T2 Lower Limit	Standard S2T2 Upper Limit	Non-standard S1T2	Hit (/) or Miss (X)	Non-standard S3T2	Hit (/) or Miss (X)
Average Value (Hqn)	Sk+	-0.076	1.1028	0.5904	/	0.5161	/
	Sk-	-0.3656	0.8133	0.4175	/	0.2864	/
	Kur+	-1.5369	-0.3581	-0.6712	/	-0.9632	/
	Kur-	-1.5369	-0.3581	-1.0412	/	-1.3021	/
	Local Top +	5.4106	6.5894	6.6667	X	7.3333	X
	Local Top -	6.4106	7.5894	8	X	10.3333	X
	CC	-0.5883	0.5906	0.0003	/	0.0004	/
	Modified CC	-0.5882	0.5906	0.0004	/	0.0004	/
	Asymmetry	-1.5362	-0.3574	-0.5395	/	-0.7675	/
Max Value (Hqmax)	Sk+	0.1848	0.5656	0.4572	/	0.5051	/
	Sk-	0.3731	0.7538	0.356	X	0.4554	/
	Kur+	-1.5992	-1.2184	-1.4163	/	-1.261	/
	Kur-	-1.5992	-1.2184	-1.4196	/	1.3668	X
	Local Top +	7.8096	8.1904	6.6667	X	6.3333	X
	Local Top -	10.4763	10.8571	8.6667	X	8	X
	CC	-0.1901	0.1907	0.0001	/	0.0001	/
	Modified CC	-0.19	0.1908	0.0001	/	0.0001	/
	Asymmetry	-0.9358	-0.555	-0.4728	X	-0.6553	/
Number of Discharge (Hn)	Sk+	0.574	2.9311	1.6941	/	1.7049	/
	Sk-	-0.03	2.3272	1.3093	/	1.6172	/
	Kur+	1.173	3.5301	2.2767	/	1.9891	/
	Kur-	1.173	3.5301	1.3618	/	2.2142	/
	Local Top +	3.8214	6.1786	3.3333	X	3.3333	X
	Local Top -	3.4881	5.8452	5.3333	/	5	/
	CC	-1.1786	1.1786	0.0389	/	0	/
	Modified CC	-1.1786	1.1786	0.1355	/	0	/
	Asymmetry	-1.8733	0.4839	-0.4937	/	-0.6719	/
	Recognition Rate				20		21

7.2 Classification using "Hitting Pattern" technique.

In section 7.1, it has been explained that two or more discharges with the same value of "Recognition Rate" will not able to give us a good classification results if only "Recognition Rate" technique is applied. The classification task ends without getting the desired results, which is might be true or otherwise. Therefore, in this section, a proposed classification method, which is called "Hitting Pattern", will be used to verify the classification results given by the method of "Recognition Rate". Based on the patterns of "hit" and "miss", "Hitting Pattern" is then developed. The "Hitting Pattern" of S1T0 and S3T0 are respectively shown in Fig. 4 and Fig. 5. It is clearly showing that both discharges that are sharing the same "Recognition Rate" that is 11 are having different patterns. The difference in pattern can be easily determined through observation on the patterns. Therefore, through this proposed technique, the limitation produced by the "Recognition Rate" will not restrict the classification task. Two or more patterns are possible to have the same "Recognition Rate" value. But either they are from the same source of discharge or otherwise can be verified or confirmed using "Hitting Pattern". In this case, it has be proven that "Hitting Pattern" is capable to differentiate the source of discharges from two patterns that are having the same "Recognition Rate" Value.

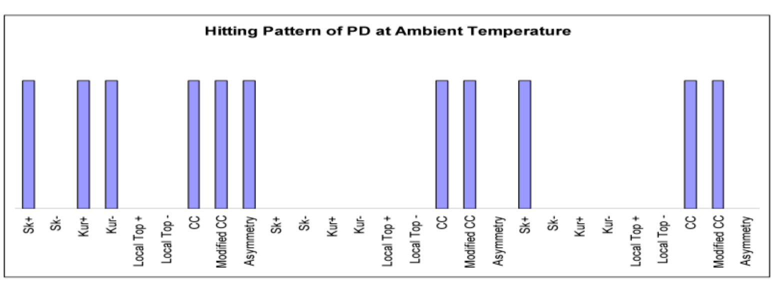

Figure 4. Hitting Pattern Of PD at S1T0

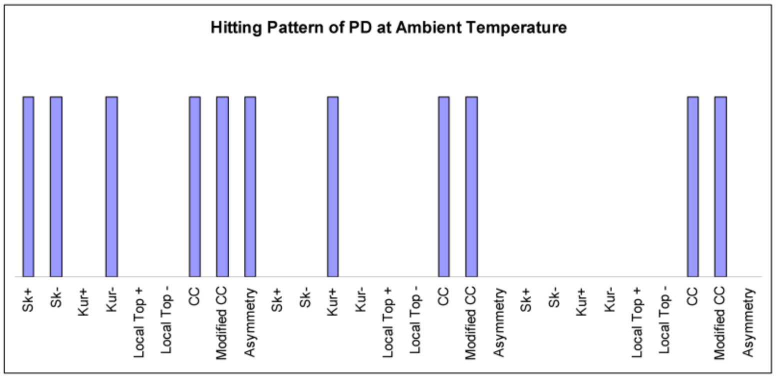

Figure 5. Hitting Pattern Of PD at S3T0

Fig. 6 and 7 are the “Hitting Pattern” for discharges occur at S1T1 and S3T1, while Fig. 8 and 9 represent the discharges occur at S1T2 and S3T2. It clearly shows that the “Hitting Pattern” is always different for discharges occur due to the different sources even though they are similar in term of “Recognition Rate”.

In this paper, the use of “Fingerprint” technique is also described. “Fingerprint” is capable to be used as a comparison mechanism. This technique is similar to the “Recognition Rate” technique but it is expressed in an easier form of observation instead of tabular form as shown in Table 3, 4 and 5. To determine whether the parameters of non-standard are in the range of lower and upper limits, we can observe the dot, which represent the parameters of non-standard physical condition. “Hit” occurs when the dot lie within the standard “Fingerprint” and there it is a “miss” when the dot is outside the standard “Fingerprint”. Therefore, it is easily to verify the “hit” and “miss” condition. Fig. 10 represents the “Fingerprint” for S1T0.

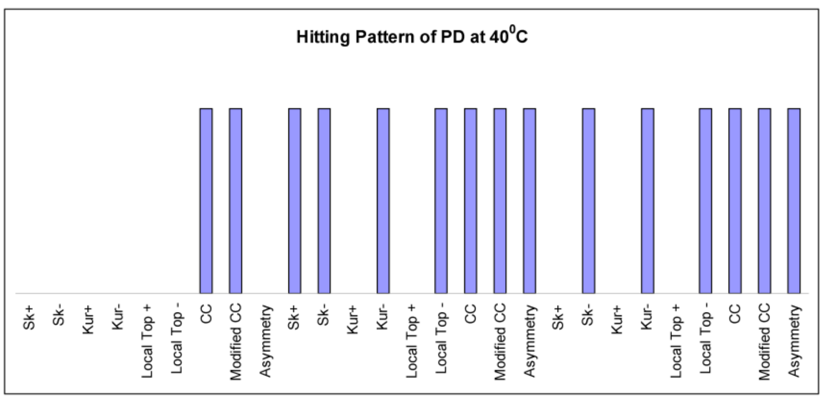

Figure 6. Hitting Pattern Of PD at S1T1

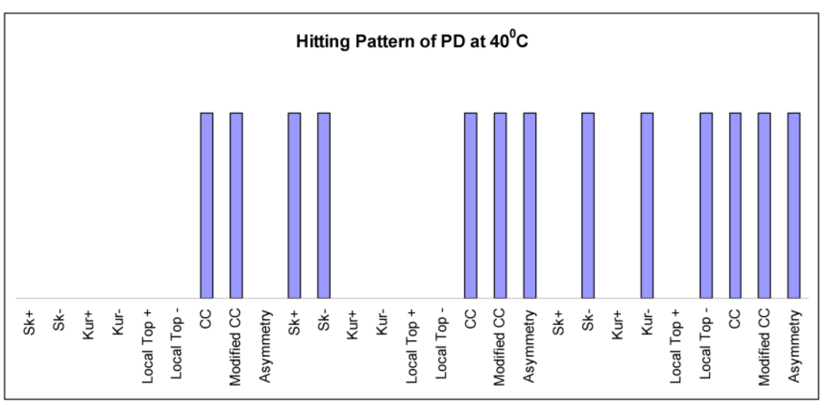

Figure 7. Hitting Pattern of PD at S3T1

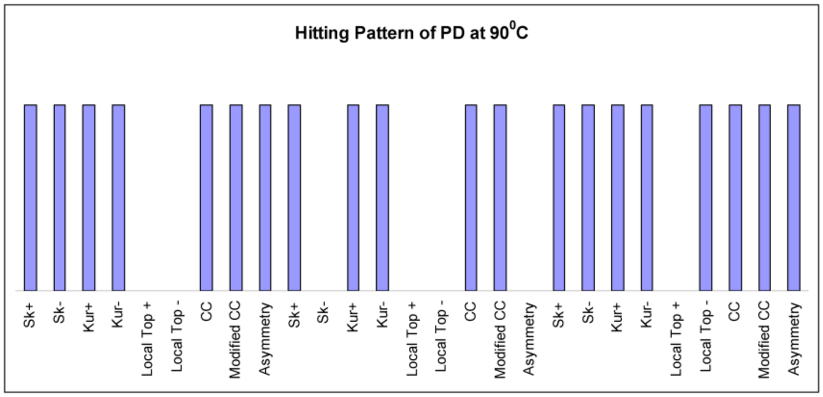

Figure 8. Hitting Pattern of PD at S1T2

In this paper, temperature is fixed at certain value while varying the values of soil thermal resistivity. The purpose is to find the effect of soil thermal resistivity on PD activities in power cable. From Table 3, 4 and 5, it can be observed that the values of statistical parameters for standard and non-standard physical condition from different soil thermal resistivity are different. For example, at T1=40^{o}C, the parameters value for S2T1 and S3T1 are different. It means that at fixed temperature, PD activity in power cable varies when the value of soil thermal resistivity changes. Therefore, it shows that soil thermal resistivity is one of the factors that contribute to PD activities in underground cable.

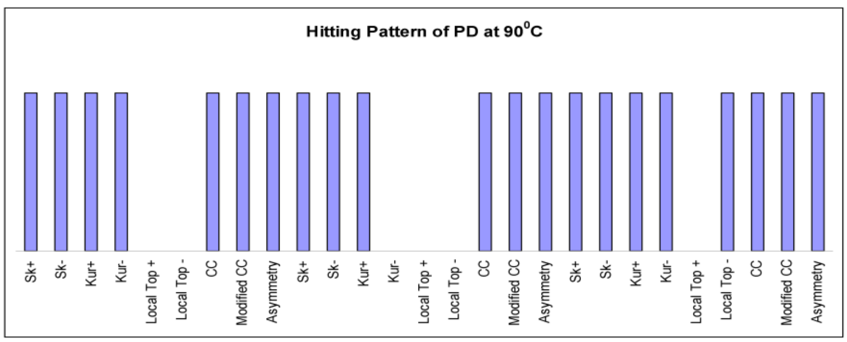

Figure 9. Hitting Pattern of PD at S3T2

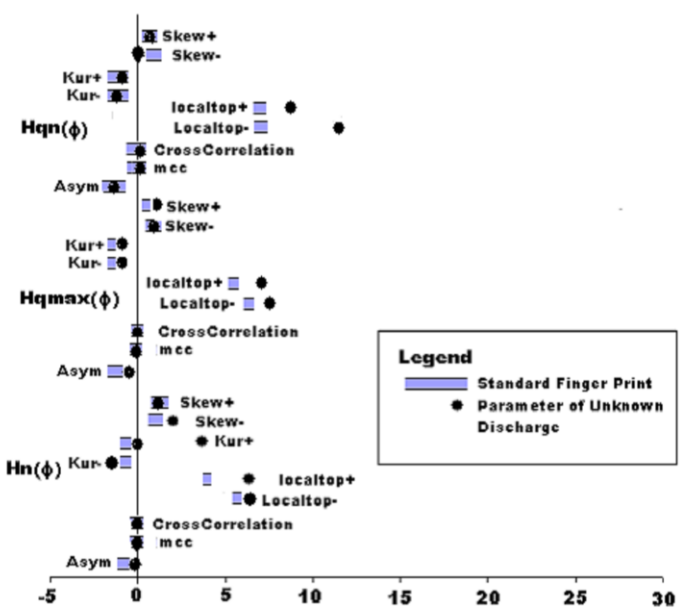

Figure 10. Fingerprint of PD at S1T0

8. CONCLUSION

Instead of classifying PD patterns through eye observation at the oscilloscope screen, patterns classification using statistical parameters gives more accurate and reliable results. Parameters such as skewness, kurtosis, local top (peak), cross correlation, modified cross correlation and asymmetry are useful in describing the behaviour of a distribution. Conventional method of classification provides us with the "Recognition Rate" values, which obviously has a limitation if the values of "Recognition Rate" of two or more distributions from different physical conditions are the same. It is insignificant to classify PD pattern when such a condition occur. Therefore, it is important to have the second classification technique, which is called "Hitting Pattern". "Hitting Pattern" technique is an extension of "Recognition Rate" technique. Through this method, classification can be done further by comparing the patterns of those distributions. From this work, it is proven that different distribution from the different physical conditions produce the different "Hitting Pattern". In this paper also, the authors have discussed about the use of "Fingerprint" technique. It provides us information whether the parameters of non-standard of physical condition are in the range of lower and upper limits or not. Determination of "hit" or "miss" can be easily done through observation. It is also emphasized that when the value of soil thermal resistivity is changed, PD activities in underground power cable vary. This verifies that soil condition is one of the factors that affect partial discharge activities.

9. REFERENCES

[1] F.H. Kreuger, and S. Shibab, Partial Discharge Measurement of Three-core Belted Power Cables, IEEE Trans. on Power Delivery, Vol. 4. No. 2 (1989) 927-931.

[2] F.H. Kreuger, E. Gulski, A. Krivda, Classification of Partial Discharges, IEEE Trans. EI. Vol. 28. No. 6, (1993) 917-931.

[3] Jiang Lei, Zhu Deheng, Li Fuqi, Tan Kexiong, Qin Gangli,Jian Xianhe, Wang Changchang, T.C Cheng, Partial Discharge Pattern Recognition of Insulation Models of Power Transformer, Proceedings of The 6th International Conference on Properties and Applications of Dielectric Materials, June 21-26, (2000) 129-132.

[4] Muhamad Mansor, Ahmad Basri, Dr. Prodipto Sankar Ghosh, Classification of PD Patterns in XLPE Cables Under Various Soil Conditions using Statistical Technique, IEEE Proceeding on International Symposium on Electrical Insulation, (2002) 74-78.

[5] Muhamad Mansor, Ahmad Basri, Dr. Prodipto Sankar Ghosh, Partial Discharge Pattern Analysis using Statistical Technique in XLPE Cable under various Soil Condition, IEEE Proceeding on Conference on Electrical Insulation and Dielectric Phenomena, (2002) 707-711.

[6] Muhamad Mansor, Ahmad Basri, Noor Azlan, Dr. Prodipto Sankar Ghosh, Classification of Partial Discharge Patterns using Statistical Pattern Recognition Technique, IEEE ACE Proceeding, (2002) 359-362.

[7] T. Tanaka, Partial Discharge Pulse Distribution Pattern Analysis, IEE Proceedings on Science, Measurement and Technology, Vol. 142. Issue. 1, (1995) 46-50.

[8] G.F. Moore, Electric Cables Handbook, BICC Cables Ltd., 3rd edition, Blackwell Science Inc., 1997.

[9] Murray, R.Spiegel, Statistics, 2/ed, McGraw Hill,London, 1992.

[10] Menahem Friedman, Abraham Kandel, Introduction to Pattern Recognition, Statistical Structural, Neural and Fuzzy Logic Approaches, World Scientific, New Jersey, 1999.

[11] Robert Schalkoff, Pattern Recognition, Statistical, Structural and Neural Approaches, John Wiley & Sons Inc.,New York, 1992.

[12] R.H. Linderman, P.F. Merenda, R.Z. Gold, Introduction to Bivariate and Multivariate Analysis, Scott, Foresman and Company, 1980, pp. 203-204.

[13] F.H. Kreuger,Discharge Detection in High Voltage Equipment, American Elsevier Publishing Company,Inc., New York.