ASSESSMENT OF HIGH VOLTAGE UNDERGROUND XLPE CABLES AT TENAGA NASIONAL BERHAD DISTRIBUTION DIVISION (TNBD) KANGAR, PERLIS

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***Abstract*-This paper illustrate the case study on condition assessment of high voltage underground XLPE cables TNBD Kangar. The study is focusing on possible relationship between three routine maintenance tests and the performance of underground high voltage XLPE cables. The tests are insulation resistance test, dielectric absorption ratio test and also partial discharge test. The aim of this project is to make an assessment on the condition of existing high voltage underground XLPE cables that are used by TNBD Kangar in Perlis. At the end of this paper, we can see the data of the performances of XLPE cables that had been used at TNBD Kangar from the tests that are used as a part of routine maintenance at TNBD Kangar.**
***Keywords**:* XLPE, IR Test, DAR Test, PD test

I. INTRODUCTION

Tenaga Nasional Berhad (TNB) is a giant electricity utility in Malaysia and one of the leading profitable companies in Asia. TNB is listed on the Main Board of Bursa Malaysia, where it implies that TNB is one of established companies as this board has more rigid listing standard than the other boards. It owns nearly RM87 billion assets. This huge company holds more than 33.5 thousands employees that serve an approximate number of 8.3 million consumers in not only Peninsular Malaysia, but also Sabah and Labuan. In line with TNB's mandate which is 'Keeping the Lights On', it has served Malaysia ever since it was structured as the Central Electricity Board in 1949. It is sparking national development via the provision of well founded and competent electricity. This corporation deals with three core areas of businesses which are generation and transmission, also including distribution of electricity. Besides those three areas, TNB has expanded its business into a number of sectors which are production of transformers, high voltage cables and switch gears; the supply of white-collar advisor assistance; and civil, architectural, electrical engineering labour and services, rehabilitation and preservation. This organisation is definitely advancing into the surface of markets, concentrating on three regions, Asia-Pacific, North Africa and last but not least Middle East. One of the corporation's core business areas, the distribution section is assigned to supervise two value bonding business movements for the sake of the company [1].

Deregulation and growing demand of electrical power are two of the biggest challenges that the world is facing nowadays. Ideal power passage in the best environmental conditions and on trading terms has extended the power utilities' accountabilities. Thus, it is the duty of the company to produce greatest productive, eco-sensitive, dependable and ideal electricity for consumers [2]. Electricity can be transmitted from generation to load by underground or overhead system. The blooming demand of electricity has led corporation to analyze underground and overhead distribution network by taking the accountability, preservation and locating cost into account [3].

The regional headquarters for TNBD Kangar, Perlis was designed in 1998 and completed in 2000. It is located at Bulatan Jubli Emas, 01000, Kangar, Perlis.

Figure 1.1: Building of TNBD Kangar, Perlis

XLPE is an abbreviation of cross–linked polyethylene, which is proficient in terms of electricity , cheap, and can be simply used. The foremost advantage of it is it exempted in high temperature application, i.e when the temperature is above 75 ℃ [4]. Fig. 1.2 portrayed a group of high voltage underground XLPE cables. XLPE cables are mainly used in building services pipework systems and domestic water piping [5].

Figure 1.2: XLPE cable

So, the objectives of this paper are:

1) To study the background of high voltage underground XLPE cables used in Tenaga Nasional Berhad Distribution Division (TNBD) Kangar.

2) To collect the data of high voltage underground XLPE cables testing in Tenaga Nasional Berhad Distribution Division (TNBD) Kangar.
3) To analyze the tested data of high voltage underground XLPE cables and to recommend the findings.

The problem statement of this project are:

Generally, there are two types of commonly used cables at Tenaga Nasional Berhad Distribution Division (TNBD) Kangar. Those two are PILC and XLPE cables. The latter ones were introduced 20 years ago and now TNB is in the middle of replacing PILC cables with XLPE cables. There are many types of high voltage underground XLPE cables. There are several types of XLPE cables, such as XLPE Insulated Unarmoured PVC Sheathed cables and XLPE Insulated Armoured PVC cables. Different types of high voltage underground XLPE cables have different characteristics. Thus, there are many characteristics of high voltage underground XLPE cables to be analyzed. The data of high voltage underground XLPE cables are quite hard to be collected since the location of the specified place (TNBD Kangar) is quite far. There are many types of tests for high voltage underground XLPE cables to be done too.

The significance of study of this paper are:

This study is on condition assessment of high voltage underground cable performance at Tenaga Nasional Berhad Distribution Division (TNBD) Kangar. This topic has been chosen as the case study since the cables that are commonly used at Tenaga Nasional Berhad Distribution Division (TNBD) Kangar are PILC cables and XLPE cables. However, the usage of PILC cables are decreasing now since TNB is in the process of replacing the PILC cables to XLPE cables. The testing data of underground high voltage XLPE cables can be used in order to determine the condition of the cables.

The scope of the project:

The scope of it is to collect data regarding condition of high voltage underground cables performance at TNBD Kangar and then analyze them. The condition of the cables can be seen from a few tests done during routine maintenance at TNBD Kangar. The tests are insulation resistance (IR) test, dielectric absorption ratio test (DAR) and partial discharge test. There are two groups of data collected. One of them is the data from 2000 till 2002 (yearly) and the second group is the data from October 2012 till August 2013 (monthly).

II. METHODOLOGY

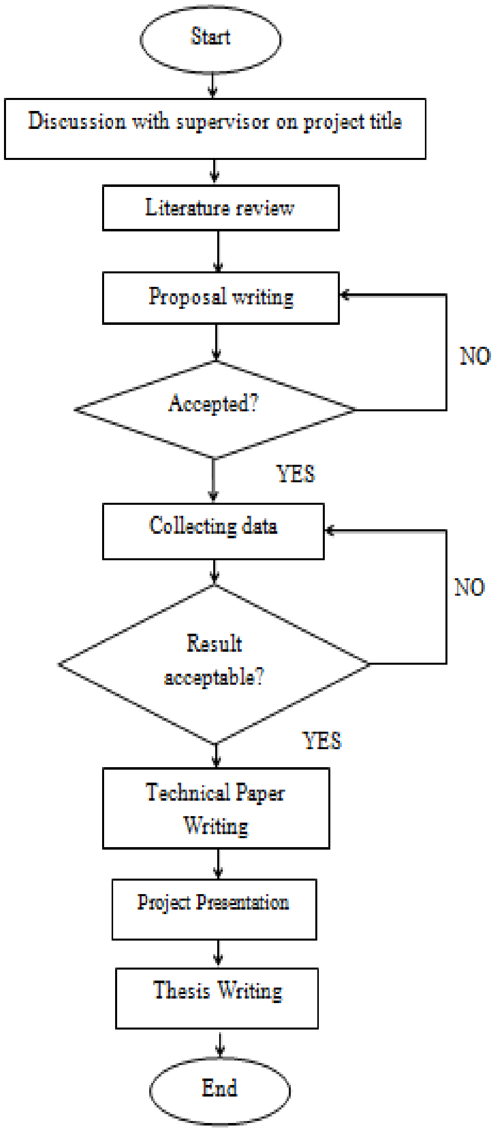

Figure 2.1: Flow chart of the research

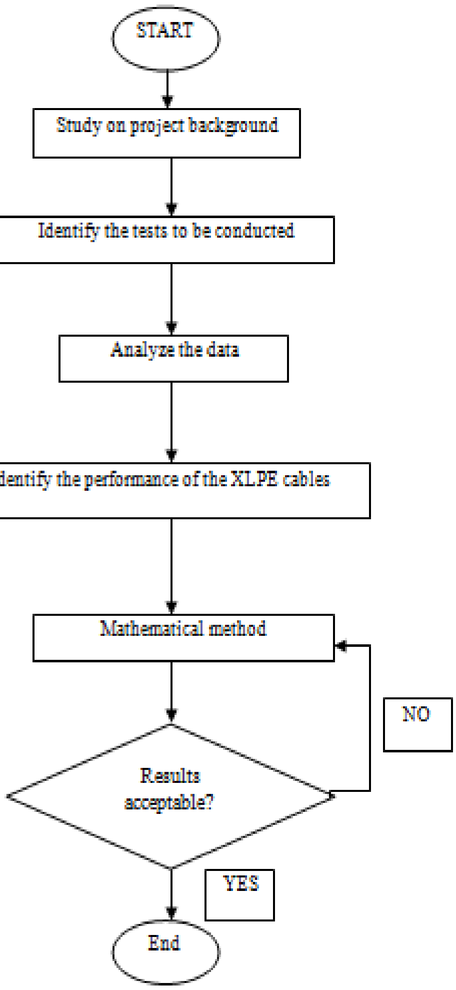

Figure 2.2: Flow chart of the study

A) Data Collection

The data of the underground high voltage cables are collected from the tests done during routine maintenance by Tenaga Nasional Berhad Distribution Division (TNBD) Kangar. The data collected are focusing on high voltage underground XLPE cables at Tenaga Nasional Berhad Distribution Division (TNBD) Kangar.

B) Data Analysis

Data are analyzed by using the testing data of XLPE cables collected from Tenaga Nasional Berhad Distribution Division (TNBD) Kangar. The data collected are focusing on XLPE cables and the tests used are insulation resistance (IR) test, dielectric absorption ratio test (DAR) and partial discharge test. From all of the testing data, the condition of high voltage underground XLPE cable that are being used by Tenaga Nasional Berhad Distribution Division (TNBD) Kangar can be observed.

Fig. 2.1 shows the flow chart for completing the research. It starts with discussion with supervisor on the project title and proceeds to write the literature review after the title is decided. After that start writing the proposal and once the proposal is accepted, the collecting data session will start by the discussion with the technician about the structure. Once the calculation is accepted by the supervisor, may proceed to technical paper writing and presentation. Finally, the thesis writing starts

Figure 2.2 shows the flow chart of the study in this project. The first step is to do a background study on high voltage underground XLPE cables. It involves the types of the cables to be valued; which is high voltage underground XLPE cables, the construction and the function of the cables, the safety measures of the cable, and also the advantages and the disadvantages of the cable. The next step is to identify the tests to be conducted. After that is to analyze the collected data of high voltage underground XLPE cables, then figure out into which tests the data are going to be classified in. Next is to identify the operation of the specified cables by referring to the results of the tests that also involving mathematical method. Once the results are accepted, the submission of technical paper, presentation and also the submission of the thesis will be conducted.

C) XLPE Cable Testing

The testing process of this type of cable and its accessories are subjected to make sure that the products meet the quality required for optimum problem free performance. They are a part of the routine maintenance that is done by TNB Kangar. This is a list of the tests or measuring methods for XLPE to evaluate the performance of the high voltage underground XLPE cables. They are insulation resistance test, dielectric absorption ratio test, and partial discharge test.

D) **IR Test**

IR test is a short form of Insulation Resistance test. It is a test that is strongly recommended in order to prevent electrical shocks, to assure safety of personal and to reduce or to eliminate down time. This method calculates the resistance of a dielectric or insulation structure when there is an application of high-value direct voltage. The most common instrument used by TNBD Kangar is Megger that consists of hand-driven or motor-driven DC generator (D) -up to 5kV- and a built-in moving coil instrument for measuring the ratio of applied voltage's resistance and the resistance of the current flowing. The Fig. 234 below portrayed the principle of IR test, in which the figure shows the current coil (1) and voltage coil (2). The torques yielded act in contrary senses such that the meter deflection is relying on the ratio of voltage to current [6].

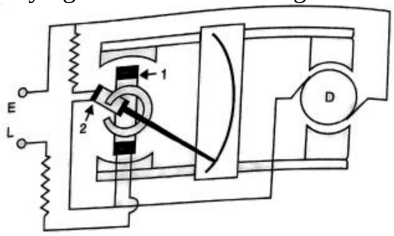

Figure 2.3: Principle of Megger circuit: D-generator, 1-current coil, 2-voltage coil

E) **DAR Test**

DAR test refer to Dielectric Absorption Ratio test which is similar to the polarisation index (PI) method for time rise testing of the insulation. The only difference is the periods for taking the results. The periods are shorter and the first result is captured at 30 seconds and the second result is captured at 1 minute.

$$DAR = \frac{\text{IR}_{60\text{ seconds}}}{\text{IR}_{30\text{ seconds}}} \quad \ldots \ldots\ldots.. \ (2.1)$$

Based on equation 2.1 above, DAR test can be summarized as the ratio of two insulation resistances measured in different time slots; which are in 60 seconds and 30 seconds, during continuous measurement. [10]

Table 2.1: A general guide to interpreting the DAR test results

DAR	Insulation Condition
<1.25	Questionable
$\leq$ 1.6	Adequate
>1.6	Good

Table 2.1 shows the range of the DAR values that will determine the insulation condition. It is the best if the DAR values are higher than 1.6 as the cables are in good condition.

F) **Partial Discharge Test**

IEC Publication 60270 [S2/9] defines partial discharge as localized phenomenon of electricity discharging where it is occurs inside an insulation system. The phenomenon only slightly bridges the insulation system between conductors, and that may or not occur adjacent to a conductor. Based on the standard, partial discharges are generally caused by concentrations of localized pressure in the protection or on its top, pulse discharges having durations less that 1µ in most cases. It is observed that sound, heat, light and also chemical reactions are often produced by partial discharges [6].

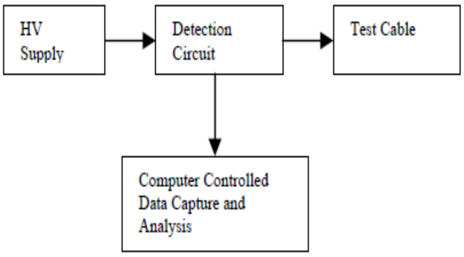

Figure 2.4: Partial Discharge (PD) Mapping

Referring to the block diagram above; Fig. 2.4, it shows how the mapping of partial discharges works. Generally, output of generator is implemented to every single core in order to acquire the results of every phase, separately. Two cores will be earthed while the final one is tested. This simultaneous process will certify the production of both phase to phase or to earth results. While the voltage is increased from none for reproduction of tap changes, the voltage of PD is noted. This system is very advantageous in locating the areas that have probabilities of failures and interpreting the results in simpler form, which is graphical form [7].

G) **Oscillating Wave Test System (OWTS)**

It portrayed the further parts bonds the entire benefits of a non- ruined PD detection structure. The idea of generation of high voltage and the circuit measurement are presented in Fig.2.5 below. OWTS is used by TNB as a measuring method for measurement of partial discharge on underground high voltage XLPE cables.

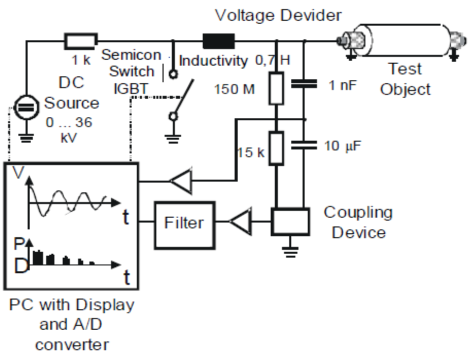

Figure 2.5: OWTS Circuit diagram of PD system

The test target is charged in a few seconds to the desired voltage, after that it is discharged through electronic high - voltage switch and a specifically designed coil of air-core. This generates oscillating decay voltage, the oscillation frequency where it is decided by the inductance of the coil and the volume of the test target in relation to equation 2.2 below.

Frequency of the oscillation for testing voltage,

$$f_o = \frac{1}{2\pi\sqrt{LC}} \quad \text{……………..} \; (2.2)$$

H) **Temperature and Humidity**

In many cases, insulation breakdown is associated to insulation integral degradation for example water treeing within XLPE cables. The failure may also be caused by lower dielectric strength due to ageing process [8]. In a low temperature or humid surrounding, XLPE cables insulation materials are subjected to water treeing, which is a dominant factor when cables fail. In addition, it is able to cause serious faults to XLPE cables [9]

Analysing Technique

Further analysis on the results of the partial discharge test is continued with partial discharge severity technique.

-PARTIAL DISCHARGE SEVERITY TECHNIQUE

Severity Factor can be determined by using the following equations, from 2.3 till 2.8.

The Critical Factor K is calculated by the quation below :

$$K = k1 \; x \; k2 \quad \text{................................} \; (2.3)$$

Where ,

$$k1 = \frac{Vi}{Vo} \quad \text{............................} \; (2.4)$$

$$k2 = \frac{Ve}{Vo} \quad \text{............................} \; (2.5)$$

In which,

k1 = Voltage Factor (Inception) Vi = Voltage (Inception)

k2 = Voltage Factor (Extinction) Ve = Voltage (Extinction)

Vo = Phase Voltage

$$A = \frac{Qm}{Qa} \quad \text{..} \; (2.6)$$

Where :

A = Discharge (Factor)

Qm = Max. Discharge

Qa = Ave. Discharge

$$D = \frac{Nm}{NT} \quad \text{..} \; (2.7)$$

Where,

D = Density (Factor)

N_T =Discharge in Total

Nm = Number of Discharge @ L± 10m

L = Location (Highest Discharge)

$$S = \frac{A \; x \; D}{K} \quad \text{.......................................} \; (2.8)$$

Where :

S = Severity (Factor)

A = Discharge (Factor)

D = Density (Factor)

K = Critical (Factor)

After the severity values of partial discharge and the dielectric absorption ratio have being calculated, specific level of severity were allocated to both of them and then they were grouped accordingly.

In Table 2.2, it shows that L is low, M is medium and H is high. Those portrayed the value of the Partial Discharge and Dielectric Absorption severity. Table 3.3 below shows the range of severity status from partial discharge test, including dielectric absorption test with their combined severity which is Sc.

Besides that, Table 2.3 exhibits the matrix of combination severity level partial discharge and dielectric absorption. The combined severity is important to determine the more accurate condition of XLPE cable.

Table 2.2: Partial Discharge and Dielectric Absorption Severity Range

PD Severity		DAR severity		Combined Severity (Sc)
S_L	< 2.0	DAR_H	> 1.5	Good
S_M	2.0 ~ 5.0	DAR_M	1.0 ~ 1.5	Fair
S_H	> 5.0	DAR_L	< 1	Bad

Table 2.3: Combined Severity Matrix of Dielectric Absorption and Partial Discharge Severities

PD Test Severity	DAR Test Severity	Combined Severity (Sc)
S_H	DAR_H	Fair
S_H	DAR_M	Fair
S_H	DAR_L	Bad
S_M	DAR_H	Fair
S_M	DAR_M	Fair
S_M	DAR_L	Bad
S_L	DAR_H	Good
S_L	DAR_M	Fair
S_L	DAR_L	Bad

III. RESULTS AND DISCUSSION

a) SIZES OF XLPE CABLES USED AT TNBD KANGAR

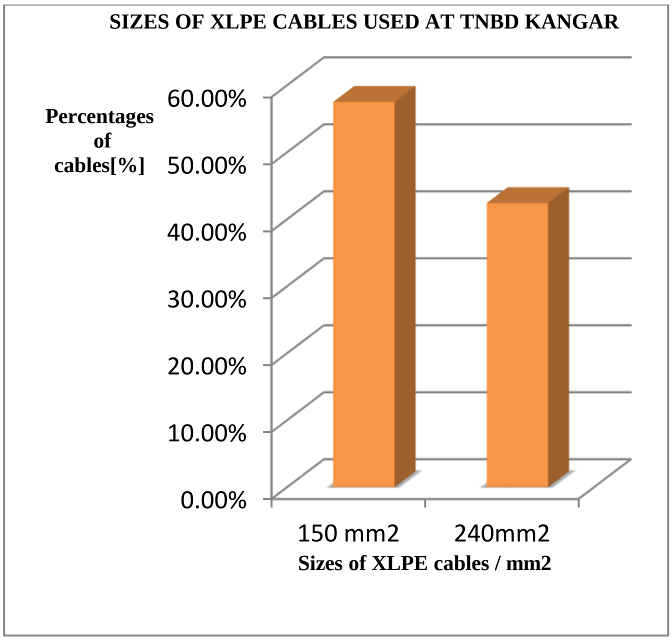

Figure 3.1: Percentage of sizes of XLPE cables used at TNBD Kangar

TNBD Kangar is in the middle of eliminating other cables such as PILC cables with XLPE cables in all areas in Perlis. TNBD Kangar is using two types of sizes of XLPE cables which are 150 mm^2 and 240mm^2. As we can see from the above figure, the usage of 150mm^2 XLPE cables are higher as the number is 19 cables (57.5%) meanwhile 240mm^2 cables are slightly lower with the number of 14 cables (42.4%).

b) DATA AND RESULTS OF INSULATION RESISTANCE FROM OCTOBER 2012 TILL JULY 2013

TEST (IR TEST) (MΩ) FOR XLPE CABLE WITH SIZES OF 150mm² AND 240mm²

Table 3.1: Table of DAR Test and Month/Year Commissioning of XLPE Cable at Kangar with Sizes of 240 mm² and 150 mm²

MONTH/YEAR	IR TEST		
	R	Y	B
OCT 2012	56.7	66.8	34.2
NOV 2012	256.7	268.5	299.7
DEC 2012	202.5	276.8	210.6
JAN 2013	1240.0	2432.3	1540.7
FEB 2013	1235.3	2422.7	5400.4
MARCH 2013	2700	3665	4655
APRIL 2013	791.4	872.6	545.3
MAY 2013	3470	4720	6691
JULY 2013	8104	6300	5320

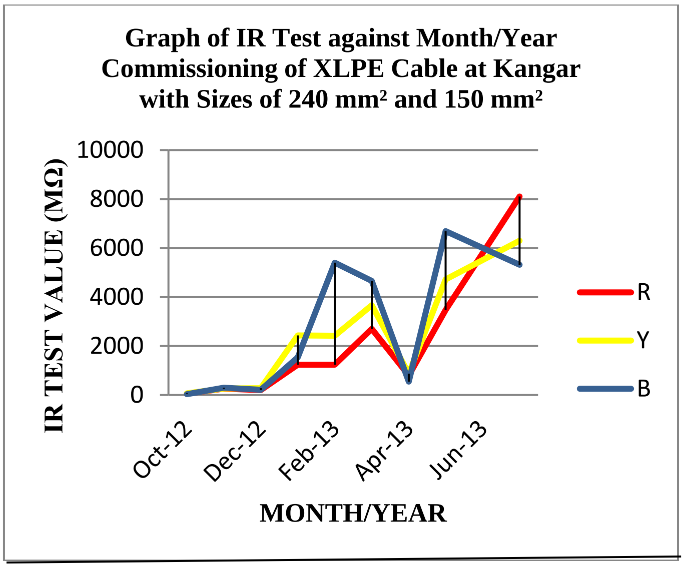

Figure 3.2: Graph of IR Test against Month/Year Commissioning of XLPE Cable at Kangar with Sizes of 240 mm² and 150 mm²

Fig. 3.2 above shows that when the cable is aging (increases in month/year), the insulation resistance (IR) test values decreases for both sizes of high voltage underground XLPE cables. The result shows that how much dependent the value of the insulation resistance towards the age of the cables. The temperature and humidity also may affect the insulation resistance value.

c) DATA AND RESULTS OF DIELECTRIC ABSORPTION RATIO TEST (DAR TEST) (MΩ) FOR XLPE CABLE WITH SIZES OF 150mm² AND 240mm² FROM OCTOBER 2012 TILL JULY 2013

Table 3.2: Table of DAR Test and Month/Year Commissioning of XLPE Cable at Kangar with Size 240 mm²

MONTH/YEAR	DAR TEST		
	R	Y	B
OCT 2012	1.049	1.077	1.020
NOV 2012	1.057	1.037	1.017
DEC 2012	1.534	1.687	1.657
JAN 2013	1.662	1.445	1.474
FEB 2013	1.45	1.363	1.190
MARCH 2013	1.014	0.949	1.043
APRIL 2013	1.197	1.209	1.235
MAY 2013	0.865	1.157	1.168
JULY 2013	1.361	1.361	1.379

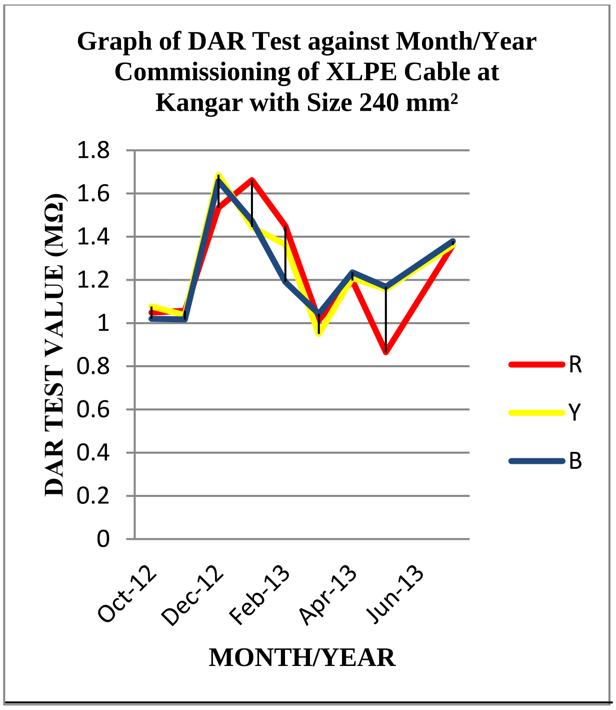

Figure 3.3: Graph of DAR Test against Month/Year Commissioning of XLPE Cable at Kangar with Size 240 mm²

Table 3.3: Table of DAR Test and Month/Year Commissioning of XLPE Cable at Kangar with Size 150 mm²

MONTH/YEAR	DAR TEST		
	R	Y	B
OCT 2012	1.250	1.667	1.000
NOV 2012	1.363	1.371	1.234
DEC 2012	1.098	1.124	1.049
JAN 2013	1.065	1.199	1.049
FEB 2013	1.000	1.000	1.000
MARCH 2013	1.414	1.148	1.439
APRIL 2013	1.053	1.036	1.029
MAY 2013	1.282	1.213	1.272
JULY 2013	1.376	1.521	1.475

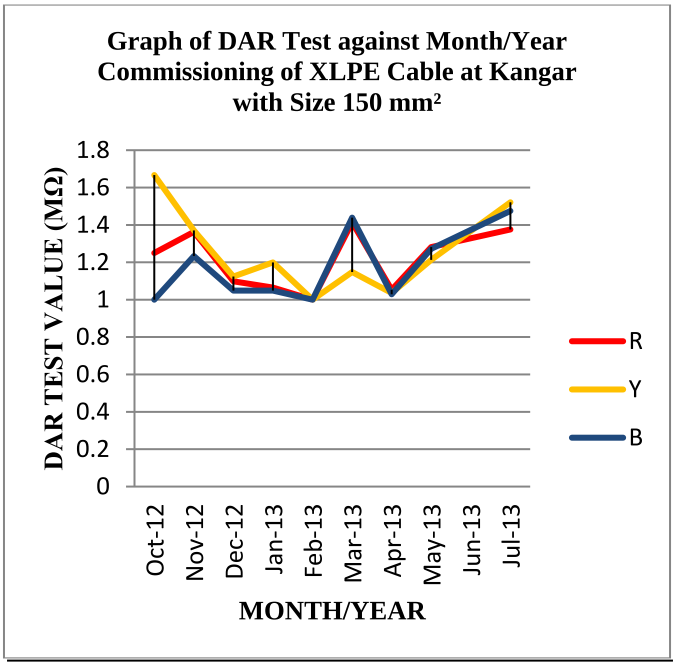

Figure 3.4: Graph of DAR Test against Month/Year Commissioning of XLPE Cable at Kangar with Size 150 mm²

Fig. 3.3 and fig. 3.4 shows result of dielectric absorption ratio test of 150mm^2 and 240mm2 XLPE cables, respectively. In order to determine the insulation condition of the cables, the DAR value must be more than 1.6. The cables are in questionable or adequate state if their DAR values show that they are less than 1.25 or less and equals to 1.6, respectively. This test needs to be conducted frequently in order to obtain more accurate results.

d) DATA AND RESULTS OF PARTIAL DISCHARGE (MΩ) FOR XLPE CABLE WITH SIZES OF 150mm^2 AND 240mm^2 FROM YEAR 2000 TILL 2002

Table 4.4: Criteria that will be used for Partial Discharge (PD) Mapping

Type	Result DAR	Result IR Test
1	< 1	< 100M
2	> 1	< 100M
3	< 1	> 100M
4	Imbalance Phase Ratio >30%	

Table 3.5: Table of Partial Discharge and Year Commissioning of XLPE Cables in Perlis with Size 240 mm² based on collected data of OWTS Measurement

Year	Phase	PD Mapping results					IR Test [MΩ]	DAR Test
		PDmax [pC] (PDIV)	PDmax [pC] (Uo)	Capacitance [uF]	Freq. [Hz]	L [m]		
2000	R	78	229	0.547	145.25	1610	131	1.04
	Y	264	246	0.553	144.41	1610	114	0.98
	B	326	1516	0.558	143.78	1610	181	1.00
2001	R	199	164	0.438	162.36	1280	60.2	1.10
	Y	208	333	0.448	160.52	1280	111	1.04
	B	502	274	0.445	161.03	1280	275	1.05
2002	R	1039	1054	0.698	128.70	2015	192	1.01
	Y	3245	3176	0.695	128.87	2015	217	0.97
	B	1737	2295	0.703	128.13	2015	256	1.01

The criteria that will be used to analyze the partial discharge mapping are by determining both values from DAR test and IR test. From table 4.4, it can be seen that if the result of DAR is less than 1 while the result of IR test is less than 100M, it will point to type 1.The list goes on till when both of DAR test and IR test show result of imbalance phase ratio (type 4) where the values are both more than 30%.

Table 3.6 represents the DAR index and the Severity index value for XLPE cable in Perlis with Size 240 mm, in Perlis. These combination results of both DAR index and the Severity index will show the more accurate condition of the XLPE cables. Having this combination of DAR test value and PD test value for XLPE cables, confirmation on the health and weaknesses of the XLPE cables can be identified.

Table 3.6: DAR index and the Severity index value for XLPE cable in Perlis with Size 240 mm²

Year	Phase	PD Mapping results				S	DAR Test
		K	A	D	L [m]		
2000	R	0	0	0	1610	0	1.04
	Y	0.91	6.42	1	1610	7.05	0.98
	B	0.90	2.77	1	1610	3.08	1.00
2001	R	0.53	1.72	1	1280	3.25	1.10
	Y	0	0	0	1280	0	1.04
	B	0	0	1	1280	0	1.05
2002	R	0	0	0	2015	0	1.01
	Y	0.93	2.13	1	2015	2,29	0.97
	B	1.40	2.29	0.39	2015	0.64	1.01

Table 3.7: Combined Severity index value for XLPE cable in Perlis with Size 240 mm²

Year	Phase	S	DAR Test	SC
2000	R	0	1.04	Fair
	Y	7.05	0.98	Bad
	B	3.08	1.00	Fair
2001	R	3.25	1.10	Fair
	Y	0	1.04	Fair
	B	0	1.05	Fair
2002	R	0	1.01	Fair
	Y	2.29	0.97	Bad
	B	0.64	1.01	Fair

Based on the guide on table 2.3 that shows the combined severity matrix of dielectric absorption and partial discharge severities, it can be seen from table 4.7 that the cables have two reading for the combined severity (Sc). Most of the cables are fair, while the remaining two are bad.

e) AFFECT OF TEMPERATURE AND HUMIDITY ON DEGRADATION

Table 3.8: Data on temperature and humidity of XLPE Cables in Perlis with Size 240 mm²

Year	Length [m]	Temperature [˚C]	Humidity [%]
2000	1610	40	32
2001	1280	38	35
2002	2015	34.70	47

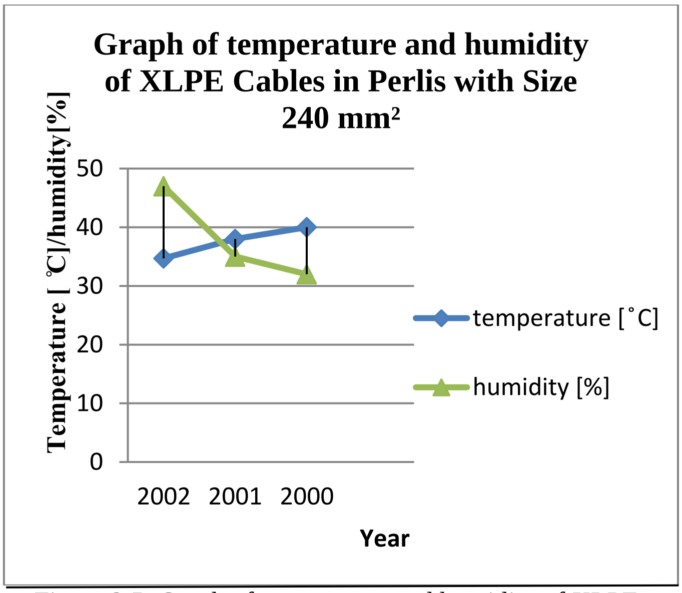

Figure 3.5: Graph of temperature and humidity of XLPE Cables in Perlis with Size 240 mm²

Both table 3.8 and Fig. 3.5 above shows the relationship between temperature and humidity with year that will show the ageing of the cables. As the temperature decreases, from the year 2000 till 2002 and the humidity increases, the ageing also increases.

IV. CONCLUSION

This case study is being conducted to study the background of high voltage underground XLPE cables used in TNBD Kangar by collecting the data of high voltage underground XLPE cables testing in TNBD Kangar then analysing the testing data of high voltage underground XLPE cables. The study is aiming for the possible relationship between three routine maintenance tests and the performance of underground high voltage XLPE cables. Based on the results obtained, all three tests are relatable to the performance of high voltage underground XLPE cables. The longer the XLPE cables have been used; the insulation test values are decreasing, showing that the performances of the XLPE cables are also decreasing. The results obtained for the dielectric absorption test also show similar pattern with IR test. Even though the values of

DAR test are not very stable, but declined performance of the XLPE cables can still be seen.

The main aim of this project to make an assessment on the condition of existing high voltage underground XLPE cables that are used by TNBD Kangar in Perlis is successful. Based on the objectives, it can be concluded that there are two sizes of high voltage underground XLPE cables used by TNBD Kangar; 150mm^2 and 240mm ^{2}.57.5% of the cables are 150mm^2 while the remaining belongs to 240mm $^{2.}$ In addition, the data of high voltage underground XLPE cables used by TNBD Kangar that have been collected are based on insulation resistance (IR) test, dielectric absorption ratio (DAR) test and partial discharge (PD) test. As the cable is aging the insulation resistance (IR) test values decreases for both sizes of high voltage underground XLPE cables. For DAR test, the DAR value must be more than 1.6. The cables are in questionable or adequate state if their DAR values show that they are less than 1.25 or less and equals to 1.6, respectively.

All three tests are very important in order to determine the performance of the XLPE cables as from the tests, the decision making for maintenance of XLPE cables can be done.

V. RECOMMENDATIONS AND FUTURE STUDY

The suggestions for the recommendations and future study are:

1. Performance of both XLPE and PILC cables.
2. To do a simulation tests for both XLPE and PILC cables.
3. To compare the performance of both XLPE and PILC cables.

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