Sindh Univ. Res. Jour. (Sci. Ser.) Vol. 50 (3D) 48-54 (2018)

SINDH UNIVERSITY RESEARCH JOURNAL (SCIENCE SERIES)

Design of Multistress Environment for Cableaging. Implementation of Tan Delta and Partial Discharge test for aged and un-aged High Voltage Cable

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Received 10th June 2018 and Revised 15th September 2018

Abstract: To ensure the continuity of power supply through high voltage cable system, it is very important to determine the insulation quality of a cable system. This paper proposes the techniques for evaluating problem of time to time failures in different tests for solid insulating mediums, so these techniques have used to measure the insulation life and create the aging environment, which involves de shaping and properties of high voltage cable insulation. While creating the desired multi stress environment as an aging chamber which includes the different elements that have pay role in aging. Like acid rain fall, ultra violet radiations and heat plays wide role in the aging. In the designed chamber this multi stress environment has created artificially. Different tests are performed for estimating the condition of cable insulation to check the remaining life of cable .All tests are applied on different samples of XPLE cables having single core $500mm^2$, three core $300mm^2$, single core $35mm^2$, and three core $120mm^2$, Tan delta/dissipation factor/loss angle testing and partial discharge diagnostic methods have applied to predict the quality of cable's insulation. This paper also provides essential information on tan delta and partial discharge testing along with information on interpretation of test data to access the condition of high voltage cable system.

Keywords: XLPE-insulation, high voltage cables, aging, partial discharge technique, tandelta technique.

1. INTRODUCTION

Power industry is developing by rapid development of the industry so by this development the more and more high voltage cables are acquired. High voltage cable consists of conductor and insulator by varying the rating of the cable insulating material also varies with varying conductor (Wald, *et. al,* 2009). Polymeric composite (XLPE) are widely used insulators in all over the world.

By developing the power industry the porcelain and glass insulator are replaced by the polymeric composite insulators. The advantage of this replacement is in form higher mechanical resistivity, low transportation and installation costs, better with economical perspectives. And important one is the more resistance against heat and rain fall.

However (XLPE) cable insulation has excellent output because of its properties but in power field every component has advantages and disadvantages at a time, same case is there after passing the time being damages occurs in the cable insulation because of the different stress environment like rain, heat ultra violet radiations, humidity. As shown in **(Fig.1).**

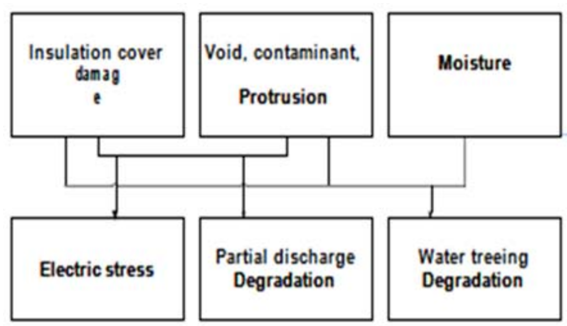

Fig. 1. Factor that causes damages in insulators

These all factors are aging factors that have been done naturally in environment. To justify these entire situations the multi stress environment chamber is created to gain the aging factors. The components involved in the aging of cables in the multi stress chamber are UV radiations, temperature, acid rain and high voltage.

We have different methods to check and compare the performance and remaining life of cables with respect to IEC standards. These tests are Tan Delta, Partial Discharge, time domain reflectometry and

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Damped AC voltage test (DAC). To investigate the cable's insulation quality this paper presents only Tan delta and partial discharge diagnostic methods that has performed in the High voltage and short circuit laboratory, NTDC, Rawalpindi, Pakistan.

The cables for which we have performed the test before and after the aging are as follows:

- Single core 500mm^2 XLPE cable/ 15 Kv cable.
- Three core 300 mm^2 XLPE cable/8.7 Kv cable.
- Single core 35mm^2 XLPE cable/15Kv cable.
- Three core 120 mm^2 XLPE cable/15Kv cable.

2. MATERIAL AND METHODS

Multi stress environment is created in form of the chamber using poly methyl methacrylate material normally known as acrylic or Perspex sheets. (Paloniemi, *et. al,* 1990) because of its highly resistivity against most high temperature and very low temperature to make the chamber of the dimensions wit 5'6" length, 4' height and 3' width has sketched in **(Fig 3)** and shown in **(Fig 4).**

Bus bars are placed in the chamber with the distance of 1'9" between phase and neutral .These bus bars are hanged on for aging and have applied on the specimens. High voltages up to 10-kv causes the electrical stress for the high voltage cable. Due to hanging off of the cable between the buss bars, mechanical stress occurs on the cable that also causes to create the void sheath hole and sheath crack in the cables as shown in **(Fig 2)**.

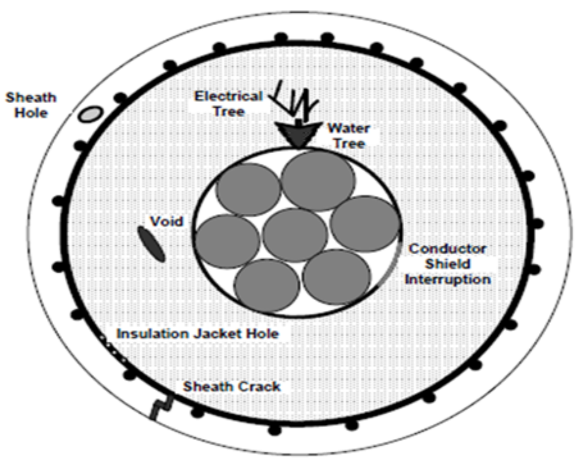

Fig.2. Typical defects in the cables

UV-lights are placed in the chamber because in the field these cables are affected by the sun lights visible and invisible radiations. And the UV radiation is the major component among the invisible sunlight radiations; the exposure of the cable in this UV radiation causes the XLPE molecules in the first inches of the showed surface permanently, and it became the decomposed material that may cause the change in the color of the insulation material. This change in the color is known as sun burn or UV degradations (Paloniemi, *et. al,* 1990). That causes the sheath hole and sheath crack in the cable insulations after passing the insulation material life. So to get that affection we placed the UV-lights in the chamber.

Heaters are placed in the chamber to get the variations of temperature which affects the specimens. This high temperature causes the cracks in the insulation as shown in **(Fig 2)**. Later on, that insulation becomes carbonized. And this carbonized insulator acts as conductor that may causes problems for the system and humans life. This problem takes a long time to occur. After occurrence of this problem the literally poor maintenance leads to a major fault.

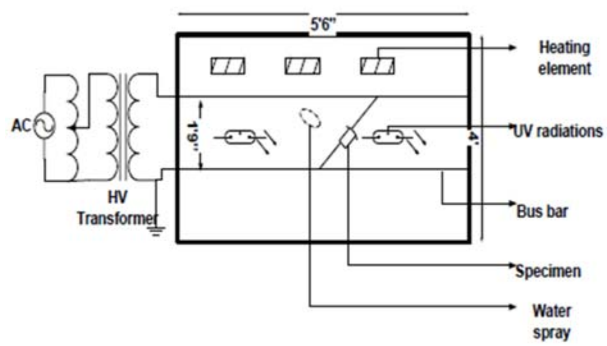

Fig.3. HV ageing chamber

Rain has a major role in the aging of the cables, to get the rain role we place the shower in the chamber with angle of 45^o as sketch in the **(Fig 3)** and shown in **(Fig 4)** To rain on the specimen for 22 minutes after every 3 hours of the UV radiations and thermal treatment (Leguenza, *et. al,* 2005). Humidity causes the water treeing in cables insulation, because the entrance of the water in the insulation of the HV cables while energized with the high voltages is cause of the water treeing in the micro or Nano cracks in the insulation of the cable (Markey, *et. al,* 2000). This will later on disturb the electric field and causes disturbances in the insulation and make the way of conduction in the insulator.

Fig.4. Designed chamber for multi-stress Aging

2.1Tan delta and Partial Discharge Technique (Hernandez, et. al, 2009), (Apiratikul, *et. al,* 2007)

Different tests are performed to check the insulation performance of the cable with sequence. In the achievement of limits, if any of them fails then there is no need to perform the further tests. A sequential step for performing the tests is as follow:

- Bending test and partial discharge test
- Tan delta measurement as a function of temperature and voltage.
- Heating cycle and partial discharge test.
- Lighting impulse voltage withstand test at 95Kv.
- Power frequency voltage test at 30.5 Kv(15 min)
- Power frequency voltage test at 35Kv (4 Hrs)

Here our focus is on the Tan delta technique and partial discharge test, Tan delta is a diagnostic method of testing cable is used to determine the quality of cable insulation and the prediction of the remaining life expectancy of cable. Tan delta is also known as loss angle and dissipation factor test.

Fig.5. Standard capacitor to balance shearing bridge

In this test if the cable is free of electrical trees, water trees, and sheath hole and sheath cracks, the cable acts as pure capacitor.

Fig.6. Shearing bridge control desk

If the cable insulation consists of impurity the cables acts as the RC parallel circuits. In this case the phase angle is less than 90^{o} and the angle between the capacitive current and resultant current is shown in **(Fig 7 b).** This angle is loss angle or dissipation factor. If there is no impurities in the cable the voltage and current have angle of 90^{o} shown in **(Fig 7 a).**

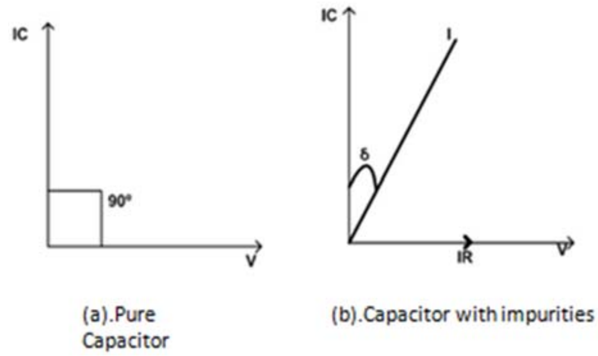

Fig.7. δ measurement in tan δ technique

The tangent of the angle delta is measured; this tangent of angle indicates the level of resistance in insulations. This means that the brand new cable has an infinite (maximum) resistance of insulation. And if the cables are serviced or aged cable the delta decreases so the resistance decreases by increasing the age of cables. **(Fig 8)** shows analysis of TD for cables. Tan delta is basically a analytical test which is applied on the insulation of windings and gives us idea of aging phenomenon. In this analysis three conditions are presented for testing a cable. If TD for cable is not greater than IEC standard it means condition is false then second condition is check either TD is very steep or not if it is steep then attention is require if it is not steep means cable is in a good condition, otherwise other multiple conditions are check in parallel way as shown in **(Fig 8).**

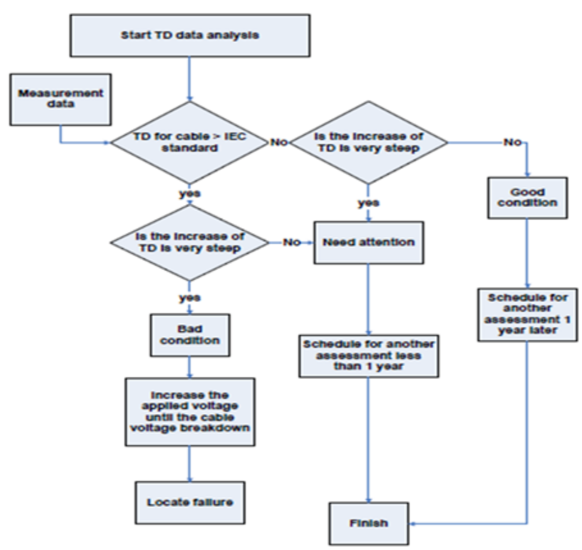

Fig-8 TD Analysis of cable system flow chart

Partial discharge method is used to analyze the quality of high voltage cable insulation. It is essentially a dielectric breakdown of small portion of a solid or liquid insulation that is subjected to high voltage / electrical stress.

Sometimes there may be a void/ cavity inside cable system. These voids may lead to electrical breakdown to partial discharge due to presence of internal weak spots in high voltage cable such as cavity, void or cracks etc.

2.2 Test setup for Tan Delta and Partial Discharge Technique

Normally Schering shown in **(Fig 9).** is used to measure the unknown capacitance of the cable to measure tan delta values (Ponniran, *et. al,* 2008).

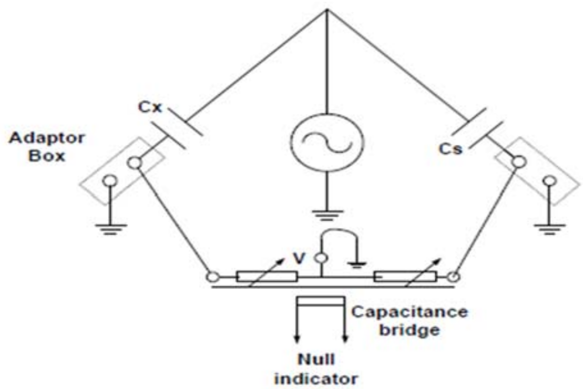

Fig.9. Shearing bridge schematic

Take 15 m long HV cable and then heat up cable up to 95^0C for minimum 3 hours according to IEC standard using the step down transformer as shown in **(Fig 11).**

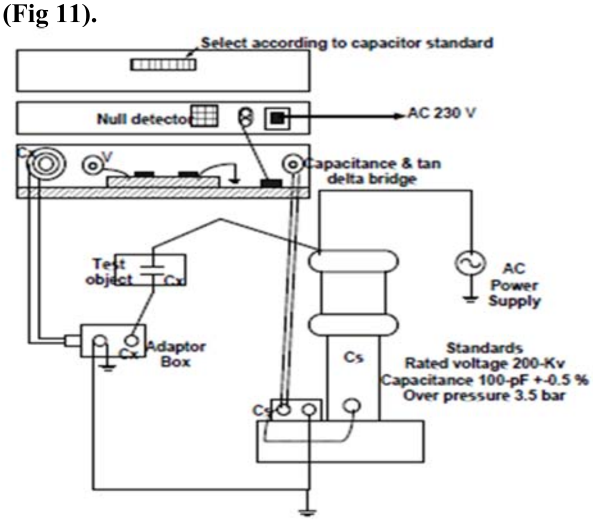

Fig.10. Connection of measuring circuit

Then place the standard capacitor of 100 pF shown in **(Fig 5).** in the shearing bridge and then set the null point by varying the capacitance placed in bridge from the control desk as shown in **(Fig 6).** and the connection for the shearing bridge with control desk is shown in **(Fig 10)** (Ponniran, *et. al,* 2008).

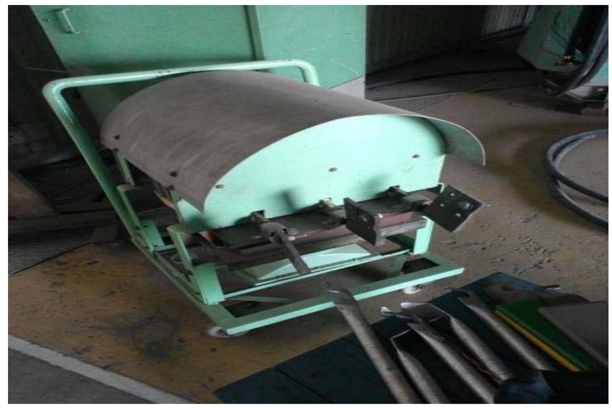

Fig.11. Step down transformer for cable heating

3. RESULTS AND DISCUSSION

Diagnostic methods which are applied on the brand new Single core $35mm^2$ XLPE cable/15Kv cable are presented for the partial discharge and Tan delta tests (Hernandez, *et. al,* 2009).

According to IEC (502:1994) standard for the mentioned specimen the partial discharge value is less than the 20 PC and in case of tan value must be less than 0.2

phase	Applied voltage	Measured value (PC)	Result
A	0.9Kv	1.5 PC	
	13Kv	17 PC	Within specified limits
	15Kv	19 PC	

Fig.12 (a). PD test for single core $35mm^2$ un-aged cables

phase	Applied voltage	Tan δ	Capacitance	Result
A	$0.5U_0$=4.3 Kv	$0.852x10^{-3}$	2557.5pF	
	$1U_0$=8.6Kv	$0.852x10^{-3}$	2558.5pF	Within specified limits
	$2U_0$=17.2Kv	$1.452x10^{-3}$	2561.5pF	

Fig.12 (b). Tan delta single core $35mm^2$ un-aged cable test

(Fig 13 a) shows the graph between tan and applied voltage for single core 35 mm^2 un aged cable .Value of tan should not increase rapidly, as we can observe that at 4.3Kv tan is $0.852{\times}10^{-3}$ .similarly when applied voltage is 8.6Kv tan approaches to

0.852×10^{-3} and in last case of phase A, value of Schering bridge is 1.452×10^{-3}. It means that tan values are within specified limits.

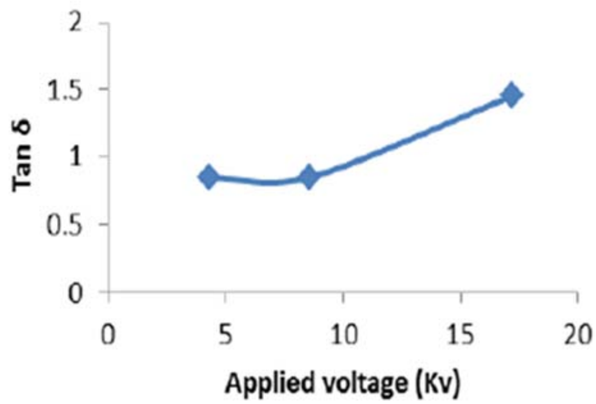

Fig.13(a). Tan delta single core 35mm^2 un-aged cable test results

PD test for single core un-aged cable in phase A is presented in **(Fig 13 b).** At 0.9Kv measured value of PD is 1.5PC, similarly when applied voltage is 13Kv it gets value of 17PC, and finally at 15Kv measured value of PD approaches to 19PC. All these values are within a specified limit.

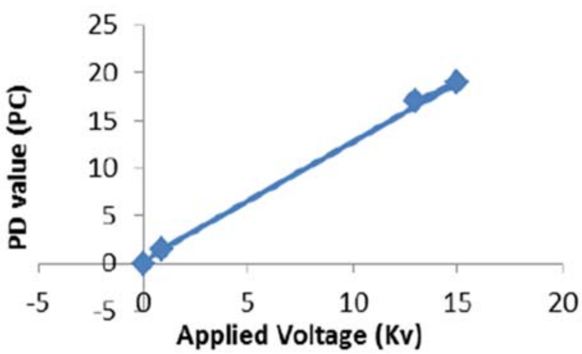

Fig.13 (b). PD test for single core un-aged cable

After ageing of the 35mm^2 single core cable the value of Tan δ and partial discharge as shown in **(Fig 12 a & b) .**

phase	Applied voltage	Tan δ	Capacitance	Result
A	$0.5U_0$=4.3 Kv	$1.011\text{x}10^{-3}$	2557.5pF	Within specified limits
	$1U_0$=8.6Kv	$1.187\text{ x}10^{-3}$	2558.5pF	
	$2U_0$=17.2Kv	$1.743\text{x}10^{-3}$	2561.5pF	

Fig.14.(a) Tan delta single core 35mm^2 aged cable tests

(Fig 14 b) is presenting graph between tan δ and applied voltage for single core 35 mm^2 aged cable, in which value of tan δ is 1.011×10^{-3} at 4.3Kv. When applied voltage is 8.6Kv then tan δ gets value of 1.187×10^{-3}. At 17.2Kv tan δ approaches to 1.743×10^{-3} . So this graph shows that all values of tan delta are in defined range.

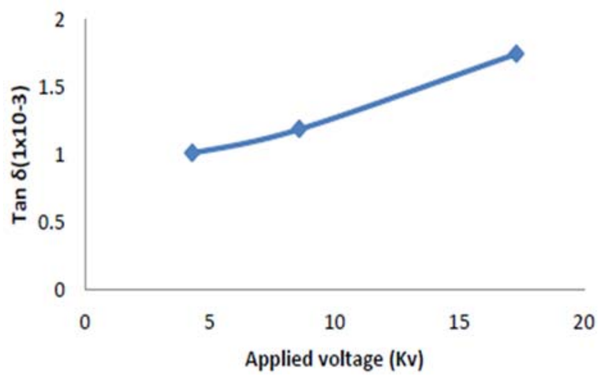

Fig.14.(b) Tan delta single core 35mm^2 aged cable test results

phase	Applied voltage	Tan δ	Capacitance	Result
A	4.3 Kv	$0.028\text{x}10^{-1}$	5370 pF	Within specified limits
	8.7Kv	$0.028\text{x}10^{-1}$	5750pF	
	17.4Kv	$0.078\text{x}10^{-1}$	5340pF	

Fig.15.(a) Tan delta single core 300mm^2 un-aged cable tests

Tan δ test for single core 300 mm^2 un aged cable is show on (**Fig15 b).** This graph indicates that, in Phase A when applied voltage is 4.3Kv value of Schering bridge approaches to 0.028×10^{-1} , at 8.7Kv it gets value of 0.028×10^{-1} and when applied voltage is 17.4Kv it does not rapidly increases and obtain value of 0.078×10^{-1} . So this graph shows all values of tan delta are not rapidly increasing.

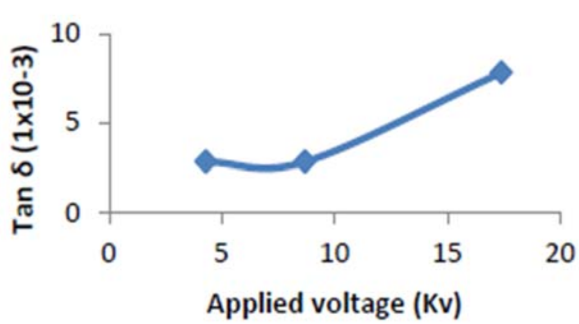

Fig.15 (b). Tan delta single core 300mm^2 un-aged cable tests

phase	Applied voltage	Tan δ	Capacitance	Result
	0.8Kv	21.2x10^{-4}	3910 pF	
A	1Kv	22.5x10^{-4}	3890.2 pF	Within specified limits
	2kv	29x10^{-4}	3880.5pF	
	0.8kv	27.4x10^{-4}	3885 pF	
B	1kv	28.2x10^{-4}	3880 pF	Within specified limits
	2kv	30x10^{-4}	3870 pF	
	0.8kv	9.1x10^{-4}	3840 pF	
C	1kv	9.4x10^{-4}	3842 pF	Within specified limits
	2kv	10x10^{-4}	3850 pF	

Fig.16(a). Partial discharge three core 300mm2 un-aged cable tests

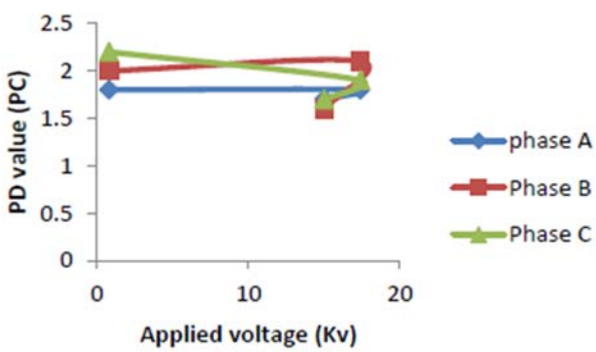

Fig.16.(b) Partial discharge test for three core 300 mm^2 un-aged cable

This graph has plotted between PD value and applied voltage in phase A phase B and Phase C.In phase A applied voltages are 0.8Kv, 1.74Kv and 15.0Kv respectively and measured value of PD at 0.8Kv is 1.8PC at 1.74Kv. Similarly in Phase B and Phase C measured value of PD is shown in **(Fig 16 a).**

phase	Applied voltage	Tan δ	Capacitance	Result
	0.8Kv	21.2x10^{-4}	3910 pF	
A	1Kv	22.5x10^{-4}	3890.2 pF	Within specified limits
	2kv	29x10^{-4}	3880.5pF	
	0.8kv	27.4x10^{-4}	3885 pF	
B	1kv	28.2x10^{-4}	3880 pF	Within specified limits
	2kv	30x10^{-4}	3870 pF	
	0.8kv	9.1x10^{-4}	3840 pF	
C	1kv	9.4x10^{-4}	3842 pF	Within specified limits
	2kv	10x10^{-4}	3850 pF	

Fig.17(a). Tan delta three core 300mm2 un-aged cable test

Tan δ three core 300 mm^2 un aged cable test in phase A, phase B and Phase C is shown in **(Fig 17 b).** Applied voltages in phase A are 0.8Kv, 1Kv and 2Kv.At 0.8kV value of Schering bridge is 21.2×10^{-4} .when applied voltage is 1Kv tan delta approaches to 22.5×10^{-4} ,and gets value of 29×10^{-4} at 2Kv .In phase B and C this test has performed ,and it's results are given in **(Fig 17 a).** All values of tan delta are in a specified limits .it means that these values are not increasing rapidly.

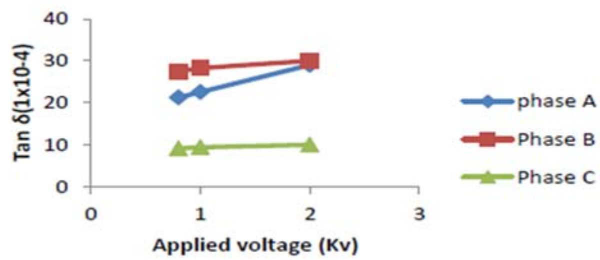

Fig.17 (b). Tan delta three core 300mm^2 un-aged cable tests

phase	Applied voltage	Tan δ	Capacitance	Result
	0.8Kv	0.71x10^{-4}	3128 pF	
A	1Kv	0.75x10^{-4}	3130 pF	Within specified limits
	2kv	0.78x10^{-4}	3134 pF	
	0.8kv	0.10x10^{-4}	3650 pF	
B	1kv	0.12x10^{-4}	3653 pF	Within specified limits
	2kv	0.16x10^{-4}	3656 pF	
	0.8kv	0.47x10^{-4}	3575 pF	
C	1kv	0.49x10^{-4}	3578 pF	Within specified limits
	2kv	0.53x10^{-4}	3586 pF	

Fig.18(a). Tan three core 500mm2 un-aged cable test

(Fig 18 b) is presenting tan delta test for three cores 500 mm^2 un aged cable in three phases which are phase A, Phase B and Phase Values of Schering bridge in all phases is within a specified limits.

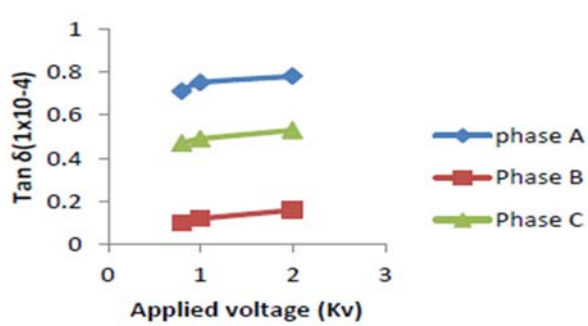

Fig.18(b). Tan δ three core 500mm^2 un-aged cable test

phase	Applied voltage	Tan δ	Capacitance	Result
	0.0 Kv	$0.29x10^{-3}$	1579 pF	
A				
	0.8 Kv	$0.29x10^{-3}$	1579 pF	Within specified limits
	1 Kv	$0.29x10^{-3}$	1579 pF	
	2.6 Kv	$0.29x10^{-3}$	1579 pF	

Fig-19(a). tan δ single core 35mm2 un-aged cable tests in term of voltages

phase	Applied voltage	Tanδ	Capacitance	Result
	0.0 Kv	$0.25x10^{-3}$	1579pF	
A				
	0.8 Kv	$0.28x10^{-3}$	1574pF	Within specified limits
	1 Kv	$0.35x10^{-3}$	1571pF	
	2.6 Kv	$0.7x10^{-3}$	1570pF	

Fig. 19(b).Tan δsingle core 35mm^2 aged cable tests in term of Voltages

(Fig 19 b) presents comparison of tanδtest for un aged and aged cable single core 35mm^2 .Which shows that value of Schering bridge for aged cable is within specified values .It means it is not increasing rapidly and un aged cable dos not possess such characteristics.

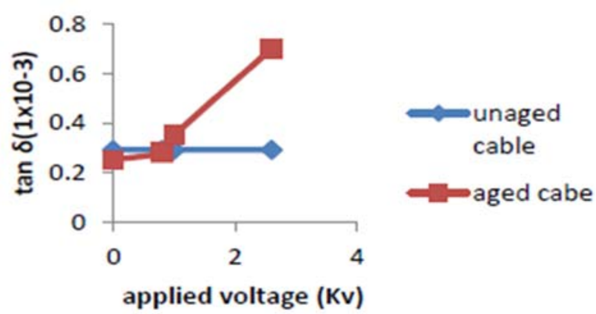

Fig.19(b). Tan δ single core 35mm^2 aged cables and un-aged cables results comparison.

4. CONCLUSION

In this paper, it has illustrated that it is possible to choose the cable condition by performing tan δ and partial discharge test under any complex situations (Hernandez, *et. al*, 2009). Due to aging factor moisture is added to insulator that causes a damage of the insulator and the very worst case is that the water treeing start occurs in the insulators which later on damage the cable insulations. The ability of both testing method tan delta and partial discharge testing to assess the future performance of high voltage cable system is continuously improving. The best accuracy in assessing the future performance is achieved on “very good” or “very bad” cable systems.

Further improvements may occur as more data are collected, test and analysis procedures are standardized, and if measurements on particular cable circuits are repeated on a periodic basis.

5. ACKNOWLEDGEMENTS

This research was supported by entire staff of National Transmission and Dispatch Company where these testing methods were performed and analyzed. Entire work was guided by Dr. Abdur Rashid (HODEE) COMSATS Institute of Information Technology Abbottabad, Pakistan.

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