INVESTIGATION OF THE HIGH FREQUENCY PROPAGATION CHARACTERISTICS ON XLPE CABLES

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ABSTRACT

This paper presents the measurement results of the PD and high frequency sinusoidal signals propagation in different length of XLPE cables. The results show that the receiving end signal is attenuated more as the frequency increases. The simulation results are comparable with the measurement results and related errors are reasonably small.

I. INTRODUCTION

Due to several technical and economical partial discharges (PD) in voids, either within the advantages cross linked polyethylene (XLPE) insulated cable systems are increasingly used in the industry and the trend is likely to continue since the related cable materials and manufacturing processes are steadily improving. However, various defects, such as void, contaminants and tracking of electrical trees can cause the partial discharge (PD) activity in XLPE power cable [1]. Moreover, XLPE insulation is very sensitive to partial discharge and PD will gradually degrade the materials, eventually leading to final breakdown. To ensure the reliability of the whole cable system, PD testing and location become an essential part of industrial testing of XLPE cable.

Partial discharge in the solid insulation can generate frequencies up to several hundred MHz [2]. In order to detect the PD, it is necessary to understand the PD propagation characteristics and mechanism of high frequency propagation in the cable [3]. The location of PD source is limited by high frequency attenuation of PD pulse as they propagate through the cable. This paper presents the results of such a study, including comparison of experiments.

II. CABLE SPECIFICATION

The power cables used in this experiment are 11 KV XLPE cables. Their insulation usually is sandwiched between two black semi-conducting layers. In order to avoid any voids in the cable that may lead to any PD, these layers are essential to make sure excellent contact between insulation and conductors. The semi-conducting layers are made of semi-conducting material such as polyethylene or ethylene copolymer mixed with conductive carbon black [4]. These semi-conducting layers influence the propagation characteristics, as will be shown below. The center conductor consists usually of a number of strands of Aluminum or Copper wire sufficient to provide good conductivity. The outer conductor of second semi-conducting layer may take several forms. It may be a copper tape wrap or heavier copper strap. All of these details have at least small effects on the propagation characteristics and need to consider in the cable model [6].

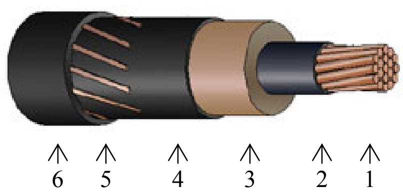


Figure 1: XLPE cable geometry, where: 1. Conductor, 2. Inner semi-conducting layer. 3. XLPE insulation. 4. Outer semi-conducting layer. 5. Screen bed. 6. Jacket [12].

III. THE SETUP OF CABLE MEASUREMENTS

Three cables are employed in the measurements and they are 11KV single core XLPE cables. Cable A, B and C have the length of 136 meters, 45 meters and 4.7 meters.

Three types of measurements are done in this paper. The first one is the high frequency sinusoidal source test. The setup diagram is shown in figure 3. The end of the cable is connected to the ground or open. And two commercial high frequency current transformers (HF-CT) are employed on the send side and received side. There is a need to know the response of open circuit due to the high voltage laboratory test which needs to have open circuit condition.

The second measurement test is the high frequency response on the outer and inner semi-conducting layers of cable. In this setup, it needs to detect the signal response on the semi-conducting layers and the cable end is in short circuit or open circuit, as shown in figure 3.

In final test, the PD calibrating signal is injected to the cable when its end is short circuit, and the sending and receiving ends signals are recorded in order to study the attenuation characteristic of cable and its other information. Two HF-CTs are employed in this test as describe in first test. The setup diagram is shown in figure 4.

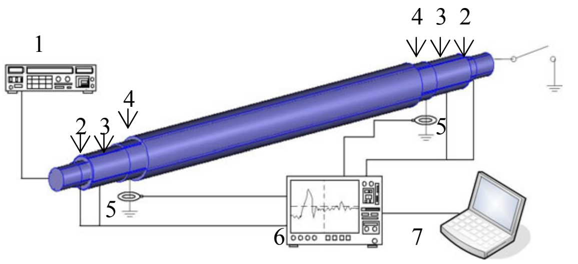


Figure 3: The measurement setup of first and second part of tests, where 1. Digital function generator, 2. Inner semi-conducting layer, 3. Outer semi-conducting layer, 4. Screen bed, 5. High Frequency Current Transformer (HF-CT), 6. Oscilloscope, 7. Computer.

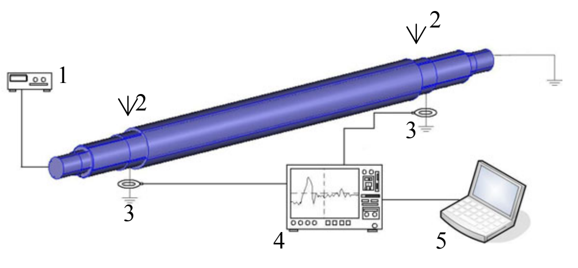


Figure 4: The measurement setup of third part of test, where 1. Calibrator voltage signal generator, 2. Screen bed, 3. High Frequency Current Transformer (HF-CT), 4. Oscilloscope, 5. Computer.

IV. HIGH FREQUENCY SINUSOIDAL SOURCE MEASUREMENT

The measurements were conducted at several frequencies from 0.1 to 200 M Hz with a sinusoidal waveform by using digital function generator. The variation of source voltage is relatively negligible [5]. The propagated signals the cables which are first terminated with a short circuit and then it is considered open circuit. Typical plots of ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ versus frequency are shown in figure 5 to 12. There are two different types of high frequency current transformers (HF-CT, with different frequency response characteristic) to detect the current signals. From each type of HF-CT two is selected for measuring the receiving side and sending side currents. HF-CT of type A is a commercial one and type B is a home-made HF-CT. Type A has better characteristics than Type B. However type B has a better sensitivity which is more suitable for the high voltage testing environment.

Figure 5 and 6 shows the ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ of 136 m, 45m and 4.7m length of cables in short circuit with increasing frequency. In figure 7 and 8 the ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ of three different lengths of cables in open circuit is plotted versus frequency. The short circuit measurement results show that the receiving end signal is more attenuated as the frequency increases. In figure 6, the ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ starts at higher value when the length of cable are longer. Regardless the values of ratio, all the cables show the similar characteristics in frequency range up to 60 M Hz in short circuit as well as in open circuit. The receiving loss increases dramatically with increase of frequency. All the graphs show that the signal propagation thought the cable are more depend on the frequency rather the length of cable. The attenuation may be affected by the permittivity of the materials in cable which is also affected by other factors like the temperature and the pressure of semi-conducting layers [6] [7].

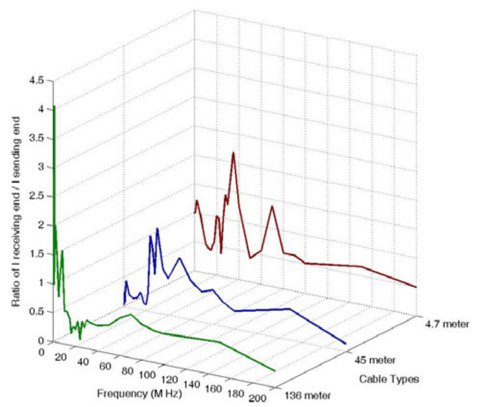


Figure 5: The graph of ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ versus frequency on three different lengths of cables, short circuit and type-A HF-CT.

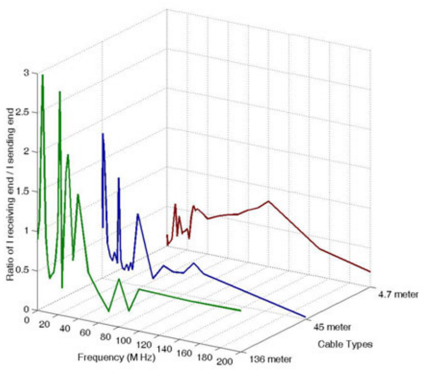


Figure 6: The graph of ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency on three different lengths of cables, short circuit and type-B HF-CT.

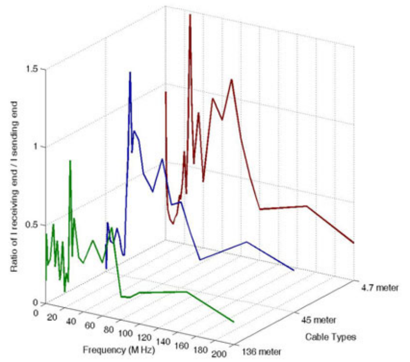


Figure 7: The graph of ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency on three different lengths of cables, open circuit and type-A HF-CT.

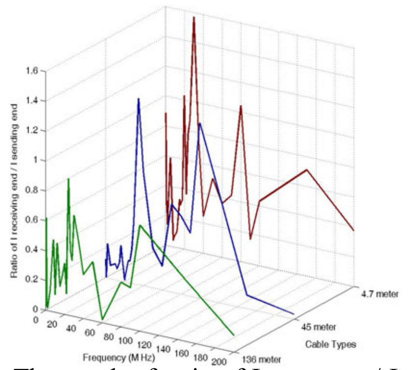


Figure 8: The graph of ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency on three different lengths of cables, open circuit and type-B HF-CT.

V. HF SINUSOIDAL SOURCE MEASUREMENT ON SEMI-CONDUCTING LAYERS

The second part of tests is the semi-conducting layer response on the cables. The semi-conducting layers in the cable can decrease the electric field and protect any void happen between the conductor and insulation or between the insulation and the screen bed [6]. Moreover, the semi-conducting layers have the effect on the propagation characteristics of the cable in terms of attenuation and velocity. The measurement setups are similar to those of previous part however in this setup access is provided to the inner and outer of semi-conducting layers. Figure 9 and 10 show the ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency graph on inner semi-conducting layer and outer semi-conducting layer of 136 m XLPE cable and the outer semi-conducting layer of 45 m XLPE cable. The results give the receiving end signal is more attenuated as the frequency increases. Figure 11 and 12 shows the graphs of semi-conducting layer voltage at the receiving end versus frequency. the results show that the voltage value are increasing as frequency increasing to 40 M Hz. the whole tests can show the semi-conducting layer have the high sensitivity of high frequency partial discharge, specifically the inner semi-conducting layer.

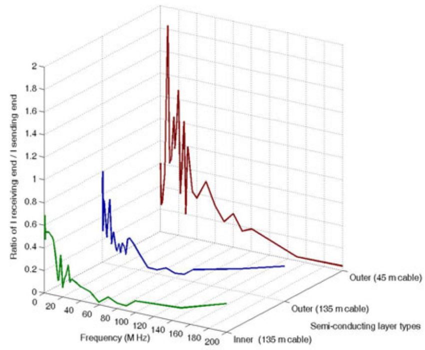


Figure 9: The graph of ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency on outer semi-conducting layer of 45 m cable, Inner and outer semi-conducting layer of 136 m cable, short circuit.

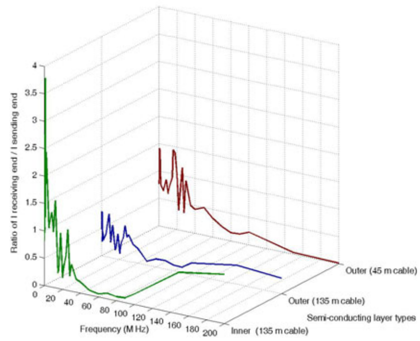


Figure 10: The graph of ratio of I $_{receiving\ end}$ / I $_{sending\ end}$ versus frequency on outer semi-conducting layer of 45 m cable, Inner and outer semi-conducting layer of 136 m cable, open circuit.

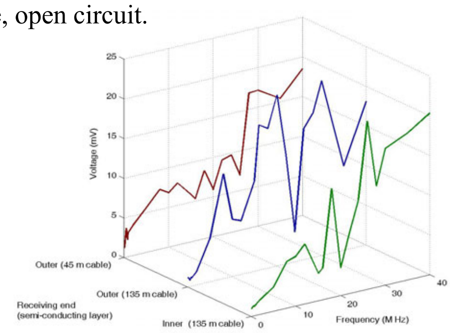


Figure 11: The graph of semi-conducting layer voltage at the receiving end versus frequency on outer semi-conducting layer of 45 m cable, Inner and outer semi-conducting layer of 136 m cable, short circuit.

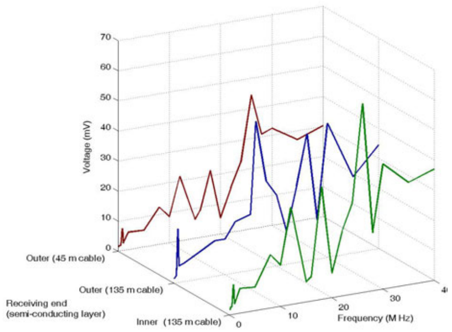


Figure 12: The graph of semi-conducting layer voltage at the receiving end versus frequency on outer semi-conducting layer of 45 m cable, Inner and outer semi-conducting layer of 136 m cable, open circuit.

VI. PD CALIBRATING SIGNAL MEASUREMENT

A calibrator voltage signal, simulating 1000pC partial discharge is applied to the sending end of cables. The receiving end is short circuited. The calibrator voltage signal is attenuated during propagation. The measured output current of the high frequency current transformer (Type A) at the sending end and receiving end of 136 m XLPE cable are shown in figure 13 and 14. From the measurement the ratio of $I_{receiving\ end} / I_{sending\ end}$ is 1.028 and the travel time of signal is 923 nano-seconds. The traveling speed from measurement [10]:

$$v = \frac{l}{t}$$

Where l is length of cable, t is the measurement travel time. Therefore the traveling speed on this cable is v = 136 / (923 x 10^{-9}) = 1.47 x 10^{8} m/sec and the traveling speed is less than the speed of light: 3 x 10^{8} m/s

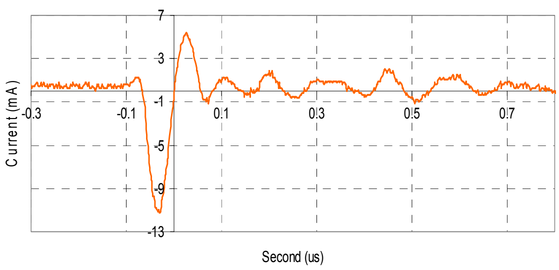


Figure 13: The measured result at the sending end of 136 m XLPE cable.

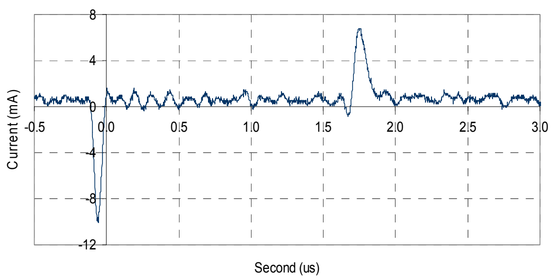
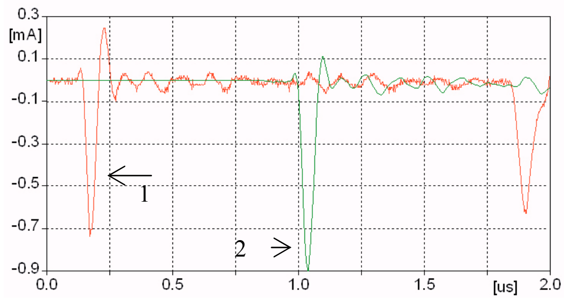


Figure 14: The measured result at the receiving end of 136 m XLPE cable.

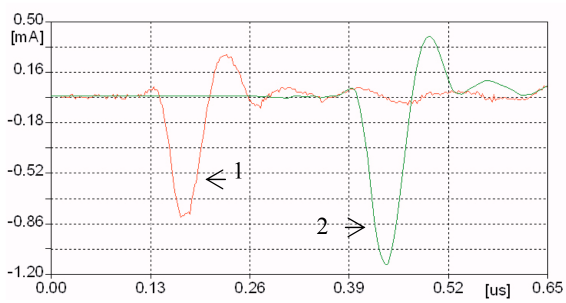
VII. SIMULATION RESULT

It is important to model the frequency dependence of power cables accurately in order to minimize the cost of construction. The simulation results are based on application of a frequency dependent cable model (J-Marti's model) and are simulated by using EMTP (Electro-Magnetic Transients Program) on the MS Windows platform. The reason to use EMTP is that this program has the strong single core frequency dependence cable model. In order to model the XLPE cable accurately in J-Marti's model, the two semi-conducting layers of XLPE cables need to be included in the simulation [9]. The cable model demonstrated that XLPE cable can be fully modeled which included the conductor, two semi-conducting layers, XLPE-insulation and the wire screen, as shown in figure 15 to 17. It is significant to verify the simulation model and the measurement data [10], [12]. From the simulation result of 136 m XLPE cable, the travel time is 866 nano-seconds and ratio of $I_{receiving\ end} / I_{sending\ end}$ is 1.04. Comparing the simulation result and measurement result, there is 1% error of ratio and 6.5% of travel time. The high travel time error may due to the reflection coefficient in the measurement. The EMTP is assumed all the common grounds are perfectly ground. However, in the realistic, the ground can not have perfectly ground. This may affect the percentage of error.



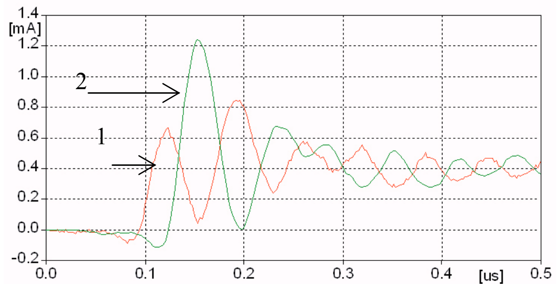
1: Sending end current 2: Receiving end current

Figure 15: The simulated result at the sending end and receiving end of 136 m XLPE cable.



1: Sending end current 2: Receiving end current

Figure 16: The simulated result at the sending end and receiving end of 45 m XLPE cable.



1: Sending end current 2: Receiving end current

Figure 17: The simulated result at the sending end and receiving end of 4.7 m XLPE cable.

Length of XLPE cable:		Ratio of I receiving end / I sending end	Travel time (s)	Traveling speed (m /sec)
136 m	Simulation:	1.04	866ns	$1.53\ x10^8$
	Measurement:	1.028	923ns	$1.47\ x10^8$
	Error:	1%	6.50%	4%
45m	Simulation:	1.4	265ns	$1.69\ x10^8$
	Measurement:	1.33	277ns	$1.62\ x10^8$
	Error:	5%	4.50%	4.1%
4.7m	Simulation:	1.55	77ns	$0.61\ x10^8$
	Measurement:	1.42	72.5ns	$0.65\ x10^8$
	Error:	8%	5.80%	6%

Table 1: Brief comparison of measurement and simulation results for cal. PD signal of 1000 pC.

The summary result of the three different lengths of cables is shown in table 1. The 4.7 meter length of cable has the highest percentage of error. The reason may be due to the fast reflection in the short length of cable. The 45 meter of XLPE cable has very thin inner semi-conducting layers; this may cause difficultly in modeling the cable since it is not exactly known and this may generate some errors [5].

VIII. CONCLUSION

This paper presents the characteristics of partial discharge and high frequency signal response in different length of XLPE cables and their semi-conducting layers. It demonstrates the EMTP cable model can model the single core cable. However, the measurement result and simulation results do not match perfectly since at present the EMTP cannot model the realistic environments, for example, the ground. The high frequency response results show that the attenuation is increasing (the ratio of $I_{\text{receiving end}} / I_{\text{sending end}}$ is decreasing) as frequency increases. The semi-conducting voltage is increasing as frequency increasing. This shows that the semi-conducting layer have the high sensitivity to partial discharge and need to consider this when designing the cable model.

IX. REFERENCES

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