USE OF PULSE PROPAGATION BEHAVIOR FOR MV PD SOURCE LOCALIZATION IN MEDIUM VOLTAGE CABLES

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Abstract— Partial discharge (PD) is caused in the insulation system such as medium and high voltage cable due to a variety of defects. Such discharges, if allowed to continue, can degrade the insulation causing its ultimate breakdown. Online PD (OLPD) measurements are now extensively being used for condition based maintenance programs. The partial discharge initiates a current pulse which propagates simultaneously in the cable core and the cable earth screen with opposite polarities. The PD pulses tend to propagate away from the source and their magnitudes become smaller due to attenuation. Moreover, the high frequency components are attenuated more during propagation in the cable. Thus, PD associated pulses undergo changes in magnitude and waveform during propagation. Direct and reflected pulses can be used for cable length measurement and PD source localization. PD propagation studies in cable networks are useful for online PD source localization purposes. This paper discusses, cable length measurements using direct pulse acquisition in OLPD measurements. In addition to partial discharge pulse polarity tracing method helps to identify the direction of arrival of partial discharge pulses. Such polarities as well as peak pulse magnitudes captured by HFCT sensors during the OLPD measurements are studied in this paper. Lab studies were performed using online PD measurement systems and medium voltage cable networks, and the results are reported in this paper to point out how PD pulse behaves in single core cable and how it can help in PD source localization in OLPD method.

Index Terms—Polarity, Tracing, Direct Pulse, Partial discharge, HFCT, Length.

I. INTRODUCTION

Cables are extensively used in power distribution network in urban centers and thus influence the power supply system reliability. Such cables have finite life and the utilities need to decide which part of the cable network is close to its end of life. Thus, it is important to have conditioned based maintenance (CBM) programs under which the equipment is taken out of service during planned outages for its condition assessment. Due to the growth in the energy demand, the distribution network is expanding globally and hence, it is important to ensure reliability of such a growing cable networks by proper design, installation and diagnostic monitoring. Accordingly, the condition of the network components and the expected remaining service life estimates are important before initiating a replacement request. This is done by applying (CBM) strategies which can result in substantial savings for the service providers and can also increase the power supply reliability by preventing forced outages caused by cable failures. The CBM can be done by monitoring the medium voltage cables after the installation, during the service operation, and towards the end of their life time [1-2]. The chances of breakdown can be reduced significantly if the cable insulation is carefully designed, manufactured and is well maintained. Cable insulation suffers deterioration over time due to a variety of reasons. The common deterioration causes for the XLPE insulation defects are related to aging, environmental factors, mechanical damages, water treeing, manufacturing defects and problems caused by operational stresses [3]. It is well known that the partial discharge (PD) plays a major rule in power cable insulation degradation and can cause a reduction of the cable service life time by insulation breakdown. Partial discharges consist of internal discharge, surface discharge, and coronas [4]. PD activities tend to prematurely fail or break down the cable insulation, if not addressed upon detection. This has led to introduction of online partial discharge detection systems which are considered as valuable diagnostic tools. Online partial discharge (OLPD) system has now become a vital tool for condition assessment of high and medium voltage equipment including XLPE cables. The OLPD is being widely used by the operation and maintenance engineers to perform the diagnostics under service conditions in order to identify the weak spots and get the most useful service from their power networks [1].

When a PD pulse propagates through a MV cable, it faces attenuation and dispersion which lead to a decrease in the magnitude of the pulse and an asymmetry in the shape of the pulse. PD pulses have very wide frequency bandwidth from kHz to GHz, and they propagate in the cable conductor and the earth screen layers and thus, the components of XLPE cables can effect the pulse propagation behavior. The main dielectric material of such cables has much lower capacitance and much greater insulation resistance than the semiconducting layers which limits the PD current pulses through the semiconducting layers. Studies have shown that semiconducting layers can have an impact on the high frequency propagation characteristics of the PD pulse and the impact takes place on the pulse propagation speed as well as the attenuation behavior of the pulse [5].

This paper presents experimental study which consists of two parts. The first set of experiments is used to make cable length measurements based on the study of direct pulse propagation behavior. In the second set of experiments, the flow of PD pulses along the cable conductor and the earth screen are studied in order to determine the direction of pulse arrival. It is believed that such information can play a useful role to trace the PD source in a cable network system which consists of multiple interconnected cables.

II. OLPD SENSORS

High frequency current transformer (HFCT) sensors are the most common type of coupling sensors which are used for capturing the PD current pulses during OLPD measurement. Any change in the primary current through the HFCT induces a voltage at its output port, and this can be interpreted as the PD event [6]. The HFCT is made of ferrite core wound with several rounds of electric wire and is also referred to as a Rogowski coil [3]. In order to effectively capture the PD pulses, the HFCT must be clamped properly on the cable. Figure 1 shows three different options for effectively clamping the HFCT at the cable terminations. In option 1 and 3 HFCT encircles effectively the cable core and samples current flowing in the high voltage conductor whereas in option 2, it surrounds cable earth screen and monitors the current flowing in the cable earth screen only. If HFCT surrounds both the high voltage conductor and the earth screen the net current through HFCT is zero and thus such a placement option is useless as it does not provide the desired information about PD events.

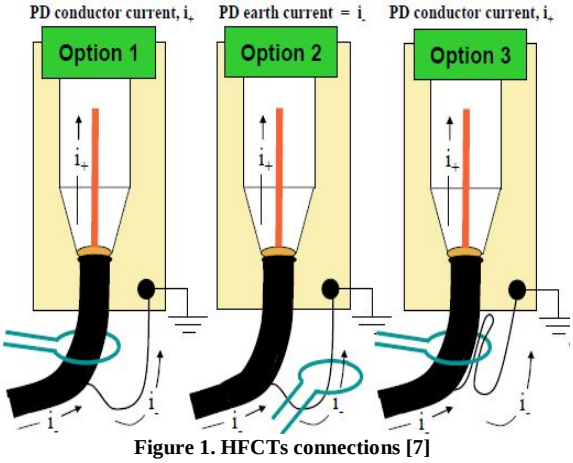


Figure 1. HFCTs connections [7]

III. CABLE LENGTH MEASUREMENT

Cable length measurement concept has many useful applications especially in PD source localization and positioning. The length of the cable can be measured by physical distance measurements. A portable device, with positioning techniques, can either self-calculate the cable length or else the cable length can be determined from pulse measurements on an oscilloscope and using the pulse propagation properties. It is important to measure the cable length accurately and economically by applying non-destructive method. Time Domain Reflectometry (TDR) is one such method [8]. The cable length can be obtained by measuring the time interval between the injected pulse at the near end and the captured pulses at the far end, assuming the propagation speed v_p is constant. Cable length $l\,(m)$ can then be calculated by the following equation:

$$l\,(m) = v_p * \Delta t \qquad (1)$$

where v_p for medium voltage XLPE cables of typical cross section is equal to 160 m/μs, and Δt is the time interval between the injected pulse at near end and the measured pulse at the far end in micro second. Equation 1 is applied if the length measurement is based on direct pulse measurements at the two ends. The experiment reported here was performed using a 20m long, single core, 50 mm^2 Cu/XLPE/PVC, 8.7/15 kV rated cable. Two HFCTs were used. The bandwidths of both HFCTs used are 76 kHz to 16 MHz with transfer impedance of 4.0 Ω. One was placed at the near end and connected to channel 1 of OLPD measurement system and the other was placed at the far end and connected to the channel 2 of the OLPD measurement system. A pulse generator was used to inject a pulse into the cable earth screen located at the near end as shown in Figure 2 and measured at both ends to determine Δt. The waveforms recorded by the measurement system are shown in Figure 3. The time interval between the pulse at the near end and the pulse at the far end is obtained as $\Delta t = 0.125$ μs.

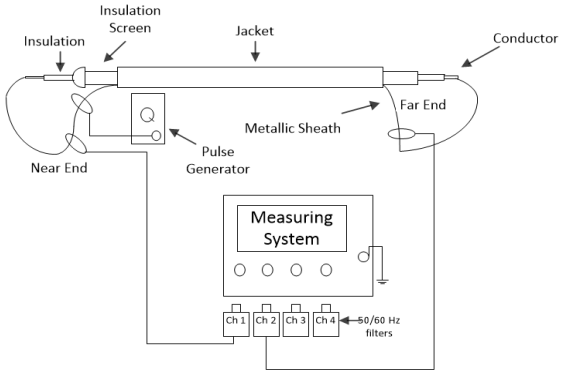


Figure 2. Length Measurement Setup.

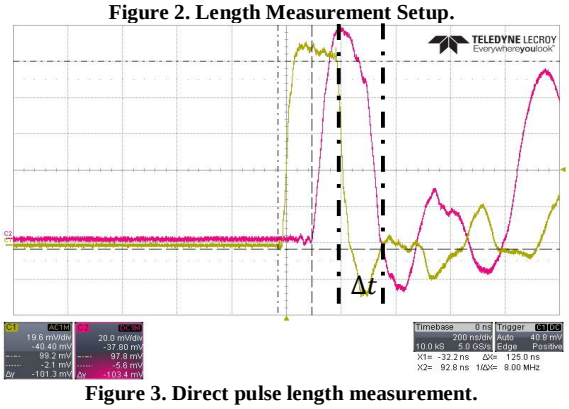


Figure 3. Direct pulse length measurement.

Thus, assuming the propagation speed of the XLPE cable is constant and is equal to 160 m/μs [9], the cable length estimated from equation 1 gives length = 20m which is exactly the length of cable used in the experiment.

III. PD PULSE POLARITY TRACING IN SINGLE CORE CABLE

When there is a PD event in the cable, it produces a high frequency current pulse. As a result two pulse streams of same polarity and half of the magnitude of the peak pulse flow towards the opposite directions from the PD site. These pulses flow towards both ends of the cable through the conductor core. Also at the same time, PD pulses with opposite polarity are induced in the earth screen at the same location and these will flow through the earth screens of the cable, which provides a low impedance path to the ground [6]. An investigation on a single core cable is made to understand the PD pulse propagation, especially its polarity through the cable using the on-line studies. For this study a pulse generator is used for injecting nano-second duration pulses into the cable to simulate PD events. HFCTs are placed at four different locations and their outputs are connected to a high bandwidth digital OLPD measuring system. To fully understand the polarity concept, it is important to place all the HFCTs in a manner so that the earth directional arrows indicated on all of the HFCTs point towards the same direction. The HFCTs are placed around the earth screen and around the conductor core at both ends as shown in Figure 4. Their outputs are connected to assigned measuring channels in the OLPD measuring system as shown in Table I.

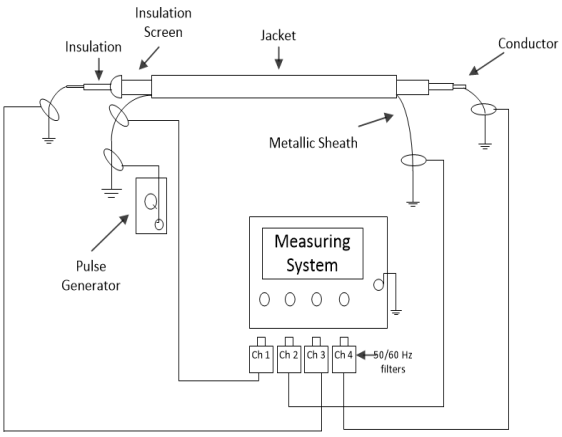
TABLE I.
ASSIGNED CHANNELS FOR HFCTS.

	HFCT location	Measuring channel
1.	Around earth screen at end 1	Channel 1 (yellow)
2.	Around earth screen at end 2	Channel 2 (red)
3.	Around cable core at end 1	Channel 3 (blue)
4.	Around cable core at end 2	Channel 4 (green)

The pulse generator injects pulses of 100ns width through HFCT into the earth screen of the cable at one end. The measurement results of the pulses recorded at both ends are given in Table II. It is observed that the injected pulse captured by the first HFCT (channel 1) enters the earth screen with a negative polarity and propagates through the earth screen until it exits the other end with a positive polarity where it is captured by the second HFCT (channel 2). The pulse then enters the ground network and is returned back to the core conductor where it is captured by the fourth HFCT (channel 4) with a negative polarity and continues to propagate through the core until it exits the core to the earth network where it is captured by the third HFCT (channel 3) with a positive polarity. The pulse train continues this behavior until it gets totally attenuated as shown in Figure 5. During their travel through the network, pulses get attenuated and dispersion occurs. This attenuation causes a decrease in the amplitude of these pulses. Due to this reason, the captured pulse in third and fourth HFCTs have lower peak values compared to the values of first two channels. Thus, if we place the HFCT around the cable, the captured pulse will have the differences in pulse peak values as indicated in Table III and Figure 6. However, during online measurements, the PD current pulse which propagates in the core has the same pulse peak value as that of the one which propagates through the earth screen but with opposite polarity i.e. $I_c = -I_e$. For this reason the HFCTs sensor is placed either on the core or on the earth screen of the cable and should not be placed around the complete cable due to the fact that the two opposite current pulses will cancel each other and the HFCT output will reduce to zero.

TABLE II.
PULSE POLARITY TRACING RESULTS.

Channel	Peak pulse magnitude (mV)	Polarity
Chanel 1	12	Negative
Chanel 2	12	Positive
Chanel 3	7.5	Positive
Chanel 4	7.5	Negative



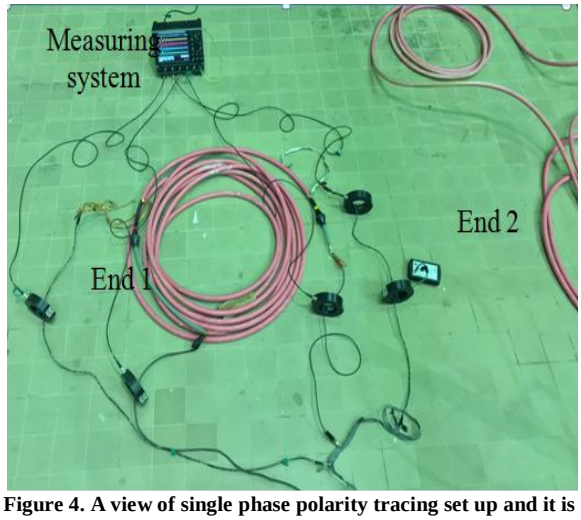


Figure 4. A view of single phase polarity tracing set up and it is schematic arrangement.

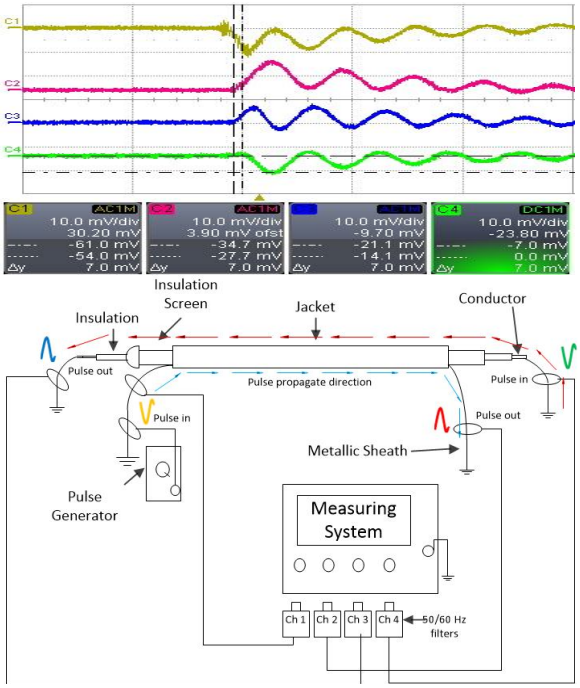


Figure 5. Oscilloscope channels and pulse propagation routes.

TABLE III.

RESULTS FOR DIFFERENT CHANNELS

Channel	Peak pulse magnitude (mV)	Polarity
Chanel 1	12	Negative
Chanel 3	7.5	Positive
Chanel 4	4.5	Negative

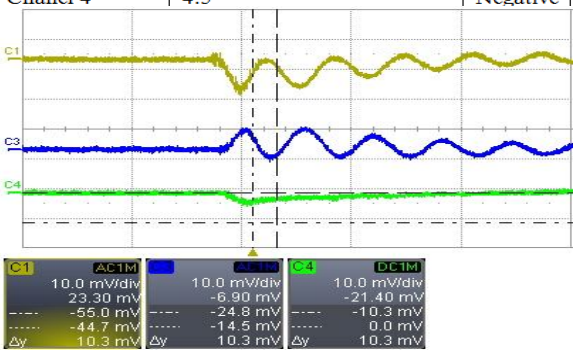


Figure 6. Channel 4 readings from the cable.

DISCUSSION

As illustrated in the preceding sections, the cable length measurement can be made by using equation 1 in case direct pulse measurements are possible. However, in case that the reflected pulse is used, the interval between the injected pulse and the reflected pulse (Δt) in equation 1 will be divided by 2 to obtain the total cable length since total distance between the direct and the reflected pulse corresponds to $2l$. If a short cable length is used, the reflection pulses result in difficulties to segregate the injected pulse from the reelected ones. This suggests a strong reason to use direct pulse monitoring at both ends for length measurement. The method used here for cable length measurement is driven from Time Domain Reflectometry (TDR) which is considered as a useful tool for PD localization. Likewise the propagation speed can be calculated from equation 1 if the length is known and Δt is measured. Due to the presence of high interfering noise signals in the outside environment during field measurements, PD measurements become challenging and segregation of PD discharges from the interfering noise becomes quite difficult. In such cases, the concept of PD pulse polarity measured at the conductor and at the earth screen can be used effectively to determine the PD travel direction in cable network where there are more than two cables are jointed together. This technique can be helpful in first locating the direction of where PD originates and then one can perform localization by using supplementary measurements. When PD occurs in the middle of cable, its peak pulse magnitude will be divided and it will propagate in both directions. The resulting current pulse will enter the power equipment i.e. ring main units (RMU) or branch joint (BJ) from the defective side and leave from the other sides as shown in Figure 7 below. The defective side will give higher peak and different polarity than the other sides. After identifying the section that generates the PD pulse, a conventional localization method such as TDR can be applied to localize the PD source site.

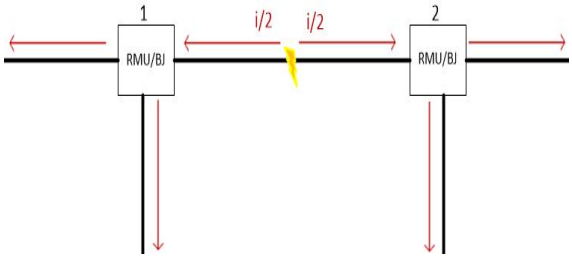


Figure 7. Pulse tracing in cable network.

CONCLUSION

This paper reports on cable length measurement and on an investigation on partial discharge current pulse polarity behavior for single core cable. It is shown that the pulse gets attenuated and thus its magnitude is reduced after propagating certain distance. In case of three core cable the same principle will be valid. Placement of PD sensor must be either around the earth screen or the cable conductor. PD pulse polarity and its peak magnitude can be used for PD source localization in medium voltage cable networks using OLPD measurement system since at multiple connection points, the PD current pulse will come from the defective side and will go out to the healthy sides. This will result in opposite polarities for the PD current pulses on the two sides. Thus once can identify the defective section in the network. Subsequently one can use the TDR method on the defective section to effectively localize the PD source.

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