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Online Partial Discharge Source Localization and Characterization Using Non-Conventional Method

Ammar Anwar Khan, Nissar R. Wani, Nazar Malik, Abdulrehman Al-Arainy,
and Saad Alghuwainem

***Abstract*—** Power cables are vulnerable to failure due to aging or defects that occur with the passage of time under continuous operation and loading stresses. PD detection and characterization provide information on the location, nature, form and extent of the degradation. As a result, PD monitoring has become an important part of condition based maintenance (CBM) program among power utilities. Online partial discharge (PD) localization of defect sources in power cable system is possible using the time of flight method. The information regarding the time difference between the main and reflected pulses and cable length can help in locating the partial discharge source along the cable length. However, if the length of the cable is not known and the defect source is located at the extreme ends of the cable or in the middle of the cable, then double ended measurement is required to indicate the location of PD source. Use of multiple sensors can also help in discriminating the cable PD or local/ external PD. This paper presents the experience and results from online partial discharge measurements conducted in the laboratory and the challenges in partial discharge source localization.

***Keywords*—**Power cables, partial discharge localization, HFCT, condition based monitoring.

I. INTRODUCTION

THE online partial discharge (OLPD) detection system in conjunction with suitable sensors can be successfully applied to accurately locate the PD initiation sites along the length of power cables [1, 2]. The principle of time-of-flight (TOF) measurement of the PD pulses along the cable is often utilized for this purpose. When a PD event occurs, two PD pulses travel outwards in both directions from the initiation site along the cable earth screen (and cable core), [3]. The main pulse, also known as direct pulse travels straight towards the measuring end while the second pulse known as the reflected pulse travels towards the remote end and is reflected back towards the measuring end. This technique is called 'single- ended PD location' and is the simplest and quickest way to provide PD mapping of cables. If both the 'Direct Pulse' and the 'Reflected Pulse' are identifiable, then location of PD initiation site is relatively simple when single-ended location method is employed. The acquired direct and reflected pulses would appear as in Fig. 1.

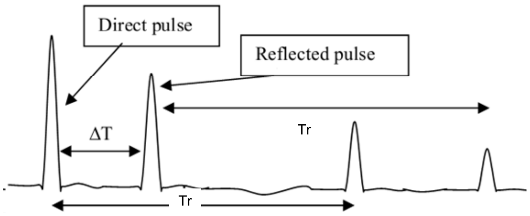

Fig.1 PD pulse train as seen from the measurement end

In Fig. 1 the time difference between the direct and the reflected pulses is referred to as ΔT. The pulses will propagate progressively and will suffer attenuation and reflections and ultimately becomes less than the background noise level. The time that a pulse takes to reflect from the far end and return to measuring end is known as cable return time T_r. This gives rise to a set of pulses of diminishing size, each spaced at the cable return time, T_r. If T_r for the cable length is measured then the location of the PD event is given as [4]:

$$\text{PD source location (pu of Cable Length)} = (1-\Delta T/Tr) \quad (1)$$

If the length of the cable is known then return time of cable can be found easily and hence PD localization can be done reasonably accurate. However, if the cable length is not known, use of time of flight method poses challenges to accurately localize the PD source. This paper presents the results of PD localization when the PD source is present at different locations. Moreover, the problems and challenges commonly faced during PD source mapping using online partial discharge non-conventional method are outlined in this paper.

II. EXPERIMENTAL SETUP

For studying the PD localization and to understand the challenges associated with it for long cables, a 500m long, 50mm^2, 3 core, 15kv rated, XLPE cable was procured it was modified by inserting two heat shrink joints to make it a 1500m long single core cable Fig. 2 below shows the modified cable for this purpose and the available locations for placement of HFCTs for sensing the PD pulse.

Authors are affiliated with Saudi Aramco Chair in Electrical Power, Department of Electrical Engineering, College of Engineering, King Saud University, Riyadh, Saudi Arabia. (*corresponding author: e-mail: amkhan@ ksu.edu.sa).

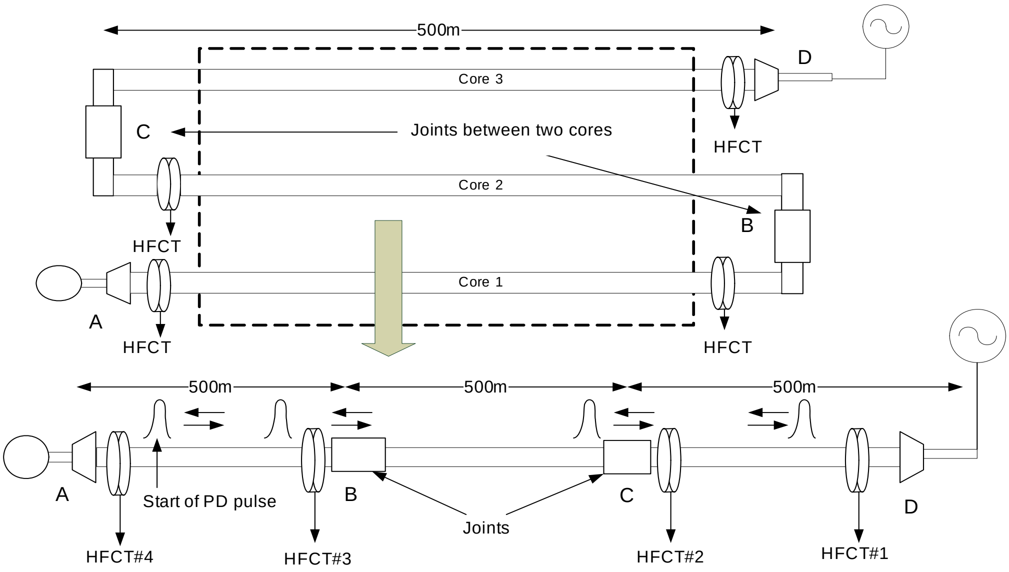

Fig. 2 The experimental setup for a 500m long three core cable transformed to a 1500m long single core cable.

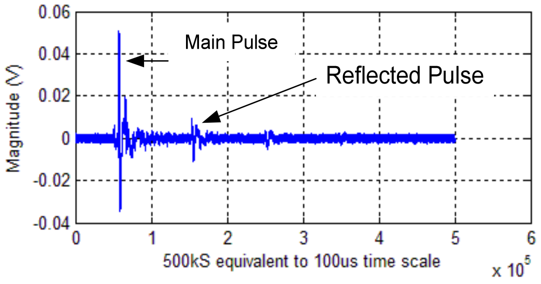

Fig. 3 PD mapping for defect created at the location D on the 1500m cable. HFCT is located at the location D.

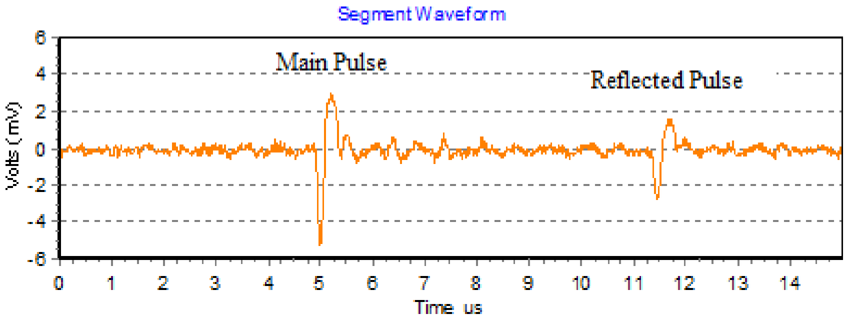

Fig. 4 PD localization of knife cut defect at location B (66.7% of the length) from location D. HFCT is located at the location D of the cable.

III. RESULTS AND DISCUSSION

A. PD Localization

Laboratory experiments were performed to generate and subsequently detect & localize the PD source for the three artificially created defects that led to the PD generation. These were;

a) defect at the location D of the cable
b) defect at the location C (66.67% of the length) of the cable
c) defect at the location A of the cable.

PD localization was done for the cable sample shown in Fig. 2, 3, 4 show the resulting PD waveforms of various pulse mappings done for the cases mentioned, using HFCT sensors at selected locations. It is known that the absolute propagation speed of PD signal in XLPE cable depends on effective dielectric constant ε. The dielectric constant depends upon cable insulation material as well as the screen material. For

XLPE cables, ε is in the range of 2.3-5.2 and propagation speed is in the range of 132m/µs-198m/µs [4]. This propagation velocity is related to the combined dielectric constant by the following equation.

$$Vf = \frac{Vs}{\sqrt{\varepsilon}} \tag{2}$$

where, Vf is propagation velocity in the cable in m/µs

Vs is propagation velocity in free space (300 m/µs)

ε is effective relative permittivity of cable dielectric and semiconducting screen layers.

For this work, if the propagation velocity in XLPE cable is taken approximately as 150 m/µs, then the calculated time difference between the main and the reflected pulse when the defect is located at location A or location D is 19.2µs, whereas the time difference is 6.4us when the defect is location at location C.

Fig. 3 shows the localization map of the defect located at location A or location D. HFCT was clamped at the location D. The time difference between the main and the reflected pulse was around 19µs (almost equal to the theoretically calculated value of 19.2 µs) which corresponds to propagation distance of 1500m.

For studying of the defects away from the cable ends, a defect was introduced at 2/3 or 66.67 % of the length (at location C) of 1500 m cable. The captured waveform shown in Fig. 4, gives the time difference between the main and the reflected pulse of 6.4µs which is almost equal to the calculated one. Thus it corresponds to a defect located at 66.7 % of the cable length. Hence defects under all the cases considered above were precisely localized.

However, PD mapping sometimes poses challenges. For example, noise can play its part in distorting waveform, making it difficult to recognize the reflected pulse. Also for some defects, the oscillating nature of the PD pulse can make it difficult to recognize the reflected pulse. If the length of the cable segment is very small, then the reflected and the main pulse can merge, thereby making it impossible to map the location of the defect accurately.

B. Differentiation of Near End or Far End Defects

If the defect is located along the length of the cable, then the source can be localized according to the time difference between the main and the reflected pulse. However, if the defect is located at the ends of the cable, then it becomes difficult to locate the source based upon time difference between the main and the reflected pulses. For both case (a) HFCT at location D with defect source at location D, and, (b) HFCT at location A with defect source at the location A, the time difference between both the main and the reflected pulses will be the same. In the laboratory one can easily clamp HFCTs at both ends simultaneously; the main and reflected pulses at both HFCTs can give the location of defect source. The HFCT which detects the pulse first is near the discharge source. Moreover, the difference of magnitudes will give an indication of main pulse and attenuated main pulse that has travelled the entire length of the cable. Also the rise time of the pulse received first will be lesser than the same pulse at other end due to attenuation of high frequency components of pulse which result in the dilation of the pulse. So any defect at 100% of the location (location A) or 0% of the location (location D) can be detected by sampling PD pulses at both ends one after the other. The end, where the rise time of PD pulse is lesser is the actual location of the defect.

C. PD Source Localization When Cable Length Is Not Known

When cable length is not precisely known then challenges are faced when carrying out PD source localization using time of flight method. This is specially the case if defect source is located at:

1. Extreme ends (location A or D), or,
2. At the center of the cable (50% of the cable length).

For either cases, the (2) gives the location of PD source at 50% of the distance from measuring end. This is because, the time difference between direct and reflected pulse is half of the time difference between direct and reflected direct pulse. In this case, the knowledge of length of cable is essential. Alternately double ended measurements are employed. In this method, systems are employed at both ends of the cable for simultaneous measurement. Both systems at ends are synchronized simultaneously by using precise methods; atomic clocks or GPS. By comparing the time of arrival of pulses at both the systems gives the location of PD source.

D. Differentiation of Internal or External PD

The external PD signals induced in metallic earth screen are also captured by the clamped HFCT. In order to differentiate between the internal PD and the external PD, multi sensor technique is useful. In this regards, HFCT can help in acquisition of pulse inside the cable while TEV (transient earth voltage) or UHF (ultra high frequency) sensor can acquire the external discharges. If TEV sensor is placed near the termination, i.e., within 30cm of termination, it can acquire the external PD that are induced in the metallic earth screen. TEV sensor is a capacitive coupler that can acquire transient voltages induced in the metallic earth screen. Fig. 5 shows an example of one such case. HFCT was clamped at location D and TEV sensor was placed 30cm near to the termination. Both HFCT and TEV sensors captured the pulses. It was investigated that PD source was located inside the transformer not the cable. If the pulses are captured by HFCT and TEV simultaneously or alone by TEV sensor then this PD is due to some external source not inside the cable or if only HFCT captures the PD pulse while TEV sensor does not, it means that PD source is inside the cable. This is the techniques, when multiple sensors are utilized to localize the PD site.

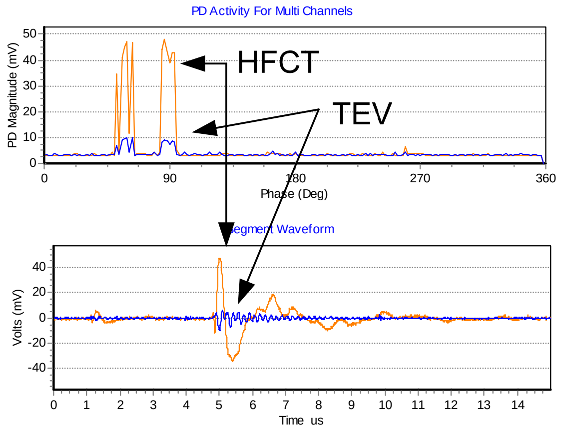

Fig. 5 Application of HFCT and TEV sensor for discriminating internal and external PD

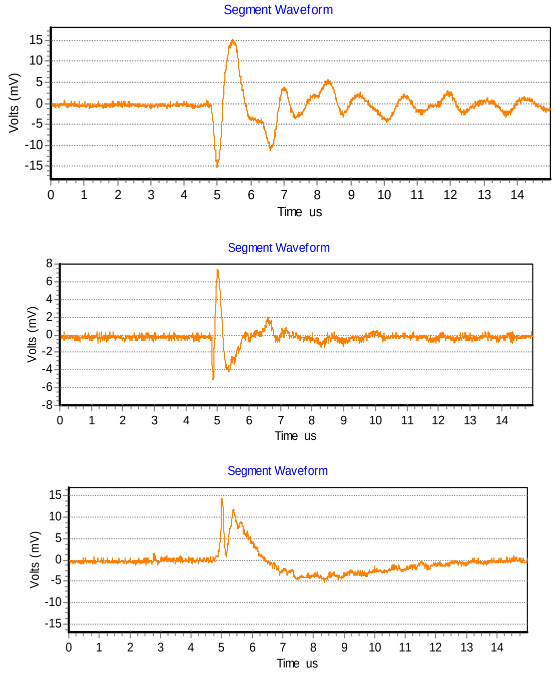

Fig. 6 Different pulse shapes for slipped stress cone defect of 1500m cable measured on different days

E. Surface Discharge Variation

Surface discharges are greatly influenced by ambient conditions. PDIV (partial discharge inception voltage), pulse shape or characteristics can vary with varying ambient conditions. Cable loading, humidity, temperature, discharge area and surface condition can contribute to the variation of characteristics of PD pulses. Fig. 6 shows the pulse shapes of surface discharge due to slipped stress cone defect at location D (HFCT at location D) for 1500m cables as acquired on different days. It is clear that the pulse shape is not unique for this type of defect for the same sample of the cable. Hence the characterization of PD source based on pulse shape, its rise or fall times and amplitude is not possible.

IV. CONCLUSIONS

Following conclusions can be drawn from the above discussion:

1. Use of multi-sensor technique can help in differentiating between the cable and external PD source.
2. Information about the length of the cable or expected cable return time of pulse is important for PD site localization using time of flight method. If the PD source is present at the middle or at extreme ends then the mathematical equation used for PD source localization can confuse between both the cases, in case of non-availability of information regarding cable length.
3. In case, the PD source is present at either ends and cable length is known, then time difference between the main and reflected pulses will be the same. Such condition can be solved by performing measurement at both ends and analyzing the frequency components and rise times of the pulses.

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Ammar A. Khan, is MS Electrical Power student at King Saud University, Riyadh, Saudi Arabia. His main interests are condition assessment and online PD monitoring of underground power cables. His MSc research focuses towards "Online Partial Discharge Detection in Underground Power Cables". He is an IEEE student member.

Nissar Rasool Wani is presently working as Deputy Laboratory Manager of the High Voltage Laboratory, Electrical Engineering Department, College of Engineering, King Saud University. He obtained his B.E degree in Electrical Engineering from India in 1986 and worked for around 9 years in electrical utilities & industry and was mostly involved in Design, Testing and Commissioning of Electrical Substations and allied equipment for up to 132 kV. He joined King Saud University in 1995 and since then has been in-charge engineer of the HV lab and has been actively involved in teaching, research and commercial testing of HV electrical power equipment carried out in the lab. He is a certified professional engineer and his main field of research interest being HV testing and diagnostics.

Nazar Hussain Malik is Professor of Electrical Engineering, College of Engineering, King Saud University. He specializes in High Voltage and Power System. He has coauthored more than 170 papers in International Journals and Conferences dealing with a broad range of technical topics. He is also coauthor of 4 text and reference books. He has been involved in many research and consultancy studies in different fields related to Electrical Power and High Voltage Engineering.

Abdulrehman Al-Arainy, is Professor of Electrical Engineering at King Saud University. He obtained Ph.D. degree in High Voltage from University of Toronto, Canada in 1982. He was Chairman of Electrical Engineering Department, King Saud University during 1991-1995. He also served on many academic committees during his career at the King Saud University. He has extensive teaching, research and consultancy experience He is a senior member of IEEE, USA and has published about 100 papers, several books and numerous technical reports.

Saad M. Alghuwainem, is Professor of Electrical Engineering, King Saud University, Saudi Arabia. He received the B.sc. degree from King Saud University, Riyadh in 1974, the M.sc. degree from University of Colorado, Boulder, in 1978, and the Ph.D. degree from The University of Michigan, Ann Arbor, in 1986, all in Electrical Engineering. His research interests include computer methods in power systems, power system protection, power system transients, wind and solar energy systems, and power quality. Prof. Alghuwainem is a Senior Member of IEEE.