Partial Discharge Localization in 22kV Cables using Single-end and Dual-end Methods

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Abstract— **This technical paper demonstrates the technique of locating a partial discharge (PD) source in a 491.7-metre-long 22kV cross-linked polyethylene (XLPE) power cable during offline PD measurements. In general, there were two types of localization methods, which are the single-end localization and the dual-end localization. In the single-end localization technique, time-domain reflectometry (TDR) was used, whereas in the dual-end localization technique, a time-of-flight (TOF) method was employed. [5][7] However, before locating the PD source accurately, the length of the cable must be measured by using the commonly used TDR technique.**

With the TDR technique, the time difference between the direct pulse and reflected pulse can be identified using a PD pulse simulator along with a 1nF coupling capacitor to determine the actual cable length. Subsequently, a PD-free voltage source was used to inject a voltage gradually until the system reached either its nominal voltage level or the PD inception voltage, allowing the PD location to be identified [7].

For the single-end localization technique, the TDR was adopted to locate the PD source in the power cable. To reaffirm the location of the PD source, the dual-end localization technique was considered. With the aid of the global positioning system (GPS), it enabled the use of TOF where both ends of the cable were measured at the same time. [5] With the combined data from both ends, the application of TOF technique can facilitate the precise localization of the PD source.

This paper highlights the effectiveness and efficiency of TDR and using TOF methods to support in pinpointing PD sources within the cable system.

Keywords—single-end localization, dual-end localization, time-of-flight, time domain reflectometry

I. Introduction

Partial discharge, also known as PD, is a measurable indicator of developing insulation defects in power cables. PD can be the result of internal weak spots in power cables such as voids, cracks, or contaminant particles. If not detected, PD can cause damaged areas to deteriorate and weaken the insulation to the point of failure. Therefore, PD measurement on power cables is an important method in assessing the integrity of the insulation in power cables. Once PD is detected, it is equally important to determine the PD inception voltage and extinction voltage as well as the location of the PD source to make the necessary repairs in time. [3] Various localization techniques were used to determine the exact location of the PD source in a power cable. Techniques such as single-end and dual-end measurements are very useful techniques to locate the PD source [6].

In a single-end measurement, the use of a common tool such as the time-domain reflectometry (TDR) enabled the PD to be located efficiently and accurately with the actual length of the cable being measured and confirmed. Alternatively, the dual-end measurement technique is another commonly used method for locating the PD. However, if the cable is more than 20 metres long, it will be a challenge to connect two PD sets to measure at the same time. Hence, a global positioning system (GPS) is required and allowed to measure PD at both ends of the long cable at the same time. With these time-synchronised data, the location of the PD can be determined by using the time-of-flight, also known as TOF. [5] With the two localization techniques indicating the location of the PD source, engineers can make the required repair.

II. Cable Length

A. Measure Cable Length with the Remote End Open

Firstly, to locate the PD source in a cable, the length of the cable must be measured. The power cable needs to be unplugged from both ends of the gas-insulated switchgear (GIS) to make sure it is completely separated. This is to ensure that a 100% reflection of the travelling wave in the cable will be able to achieve represented in a clear and distinct reflected pulse. The reflected pulse is vital in measuring the cable length and locating the PD source. [6] To capture both direct and reflected pulses, a 1nF coupling capacitor is needed to be used as the PD sensor.[3] The set-up test configuration can be shown in Fig. 1.

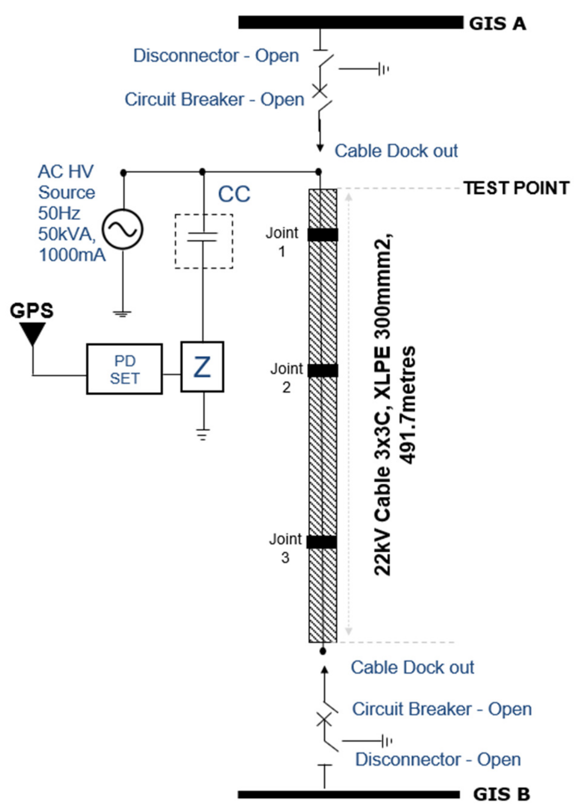

Fig. 1. Test set up for cable length measurement

Fig. 2. Direct and reflected pulse when the remote end is open

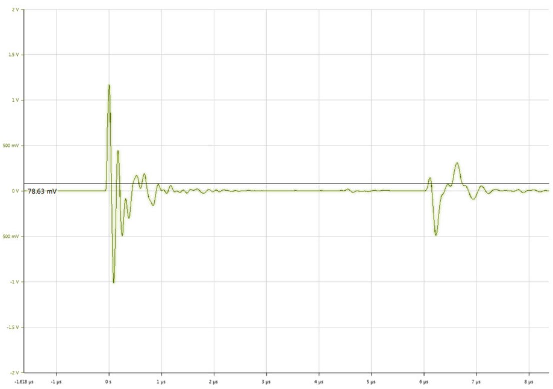

Fig. 3. Direct and reflected pulse when the remote end is closed and grounded

A PD simulator is required at the test point to inject a simulated PD pulse into the cable. By using the TDR method, the direct and reflected pulses are required to determine the time difference, shown in Fig. 2 With the time difference of $6.147\mu s$, the calculated cable length will be 491.7 meters with a propagation speed of $160\,m/\mu s$. To confirm that the calculated cable length is correct, additional verification is needed.

B. *Measure Cable Length with the Remote End Closed and Grounded*

With the same setup, the GIS B end has to be connected to the ground. As a result, the reflected pulse will be shown as the opposite polarity of the direct pulse, shown in Fig. 3. Therefore, with the same reflection pulse being inverted, the exact cable length can be confirmed to be 491.7 metres.

III. Offline PD Measurement

To begin with, a power frequency of 50Hz AC external voltage source is required to energise the power cable. A voltage of 12.7kV (phase-to-ground voltage) is injected into the power cable at GIS A.

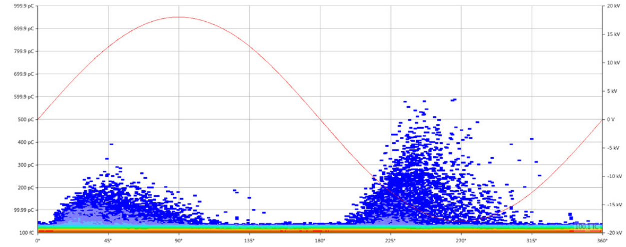

Fig. 4. PRPD for single-end measurement

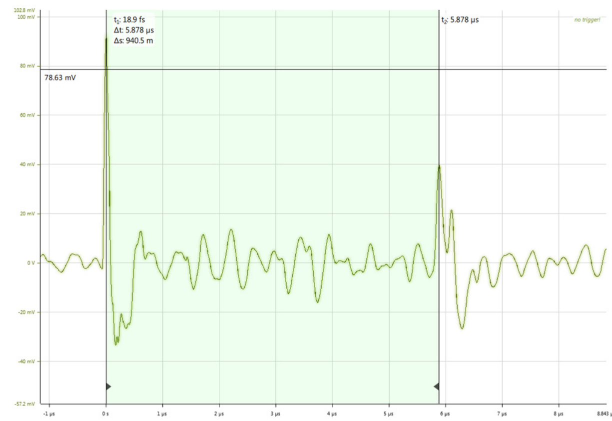

Fig. 5. Direct and reflected pulse of a PD signal

With a phase-resolved PD (PRPD) pattern like Fig. 4, it is important to locate the PD source immediately before it grows and deteriorates the insulation of the cable even further. Also, given that the timeline to a catastrophic failure is inevitably unknown. To locate the PD source, the single-end localization with the use of the TDR was used. [4]

A. *Single-end Localization Technique*

In the single-end localization technique, the TDR, which is a common tool in locating a PD source [8], is used in this paper. The identification of the direct pulse and reflected pulse in TDR is extremely crucial because it might give an error in the time difference; hence, the location of the PD source might be wrong. As shown in Fig. 5, the direct and reflected pulses are clear and distinct to identify.

From the TDR window, the time difference, Δt between the direct and reflected pulse is $5.878\,\mu s$. To derive the equation for the location of the PD source, x, firstly, the length of the cable can be represented as L. The distance from the PD site to Far End can be represented as x whereas v represent the propagation speed of the cable. t_1 represents the arrival time when the PD signal reaches the near end which is also known as the direct pulse and t_2 is the arrival time when the PD signal travels to the far end and reflected back and reached the near end which also known as the reflected pulse, shown in fig 6.

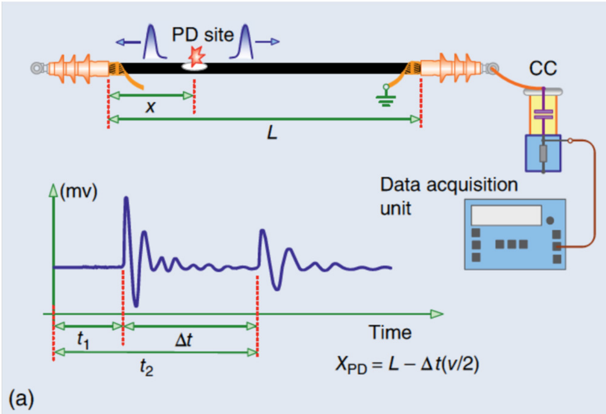

Fig. 6. Application of the CC for PD Localization [3]

$$L - x = v \times t_1 \quad (1)$$

$$L + x = v \times t_2 \quad (2)$$

By using simultaneous equation from the two equations above, the distance of the PD site, x, can be obtain. Hence, the PD source from the far end (GIS B) is given by:

$$x = \frac{\Delta t \times v}{2} \quad (3)$$

In this case, since the cable is an XLPE, the propagation speed of the cable is $160 m/\mu s$. As a result, the calculated distance of the PD source from the far end, GIS B, is 470.2 m, which is also equivalent to 21.5 m (491.7m – 470.2m) from GIS A. With the PD source finally located, an additional technique can be used to verify.

B. Dual-end Localization Technique

In a dual-end localization technique, another 1nF coupling capacitor and a PD acquisition unit are required to set up at the far end or remote end. The challenge for this measurement has to be time-synchronised, and for this paper, a GPS, as shown in Fig. 7, is being used to ensure the measurements at both ends are nearly time-synchronised. [5]

After enabling the GPS, a voltage level of 12.7kV (phase-to-ground) is injected into the power cable. While the power cable is energised, the measurement at both ends has to have the same frequency selection and bandwidth recorded. Upon combining the data, the amplitude and the PD pattern in the PRPD, shown in Fig. 8, should be observed as it might give an indicator of the location of the PD.

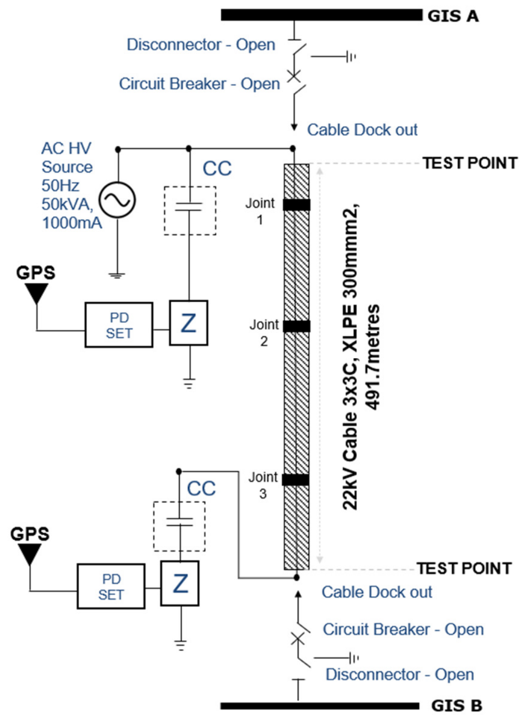

Fig. 7. Test set-up for dual-end localization technique

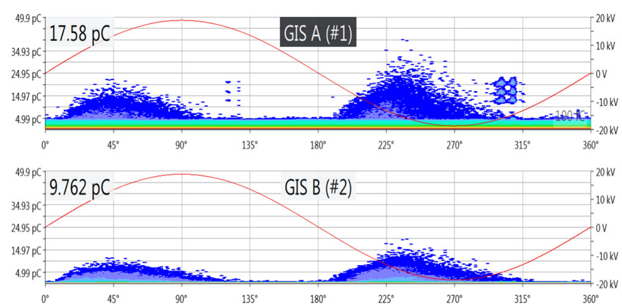

Fig. 8. PRPD for dual-end measurement

By taking note of the amplitude and PRPD pattern in Fig. 8, it shows that the PD is most likely located nearer to GIS A. To confirm the PD's position, the time-of-flight (TOF) is another useful tool to pinpoint the PD in the power cable. [3] To use the TOF method, the area of PD has to be selected in the PRPD, as shown in Fig. 9. Subsequently, the cable length of 492 metres and a propagation speed of 160m/μs is selected, as shown in Fig. 10. In conclusion, it shows that the PD source is located about 15 metres away from GIS A.

Furthermore, the TOF can also be used to verify the location of the PD from GIS B by selecting it as the reference, as shown in Fig. 11.

Upon selecting the PD in the PRPD window, as shown in Fig. 12, the TOF will be able to obtain the location of the PD from GIS B, which indicates 479 metres. However, with the use of the GPS feature, there is a synchronisation deviation of 10ns to 100ns which is equivalent to deviation of 1.6 metres to 16 metres in distance. [Omicron] This deviation has to be taken into consideration. Hence, it can be sure that the location of the PD source is about 15 metres to 21 metres from GIS A. Here is a summary table, Table I, of the location of the PD determined by the two localization methods: (1) single-end localization and (2) dual-end localization method.

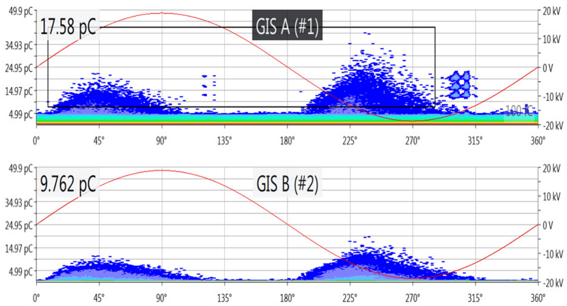

Fig. 9. Selecting the PD pattern at GIS A

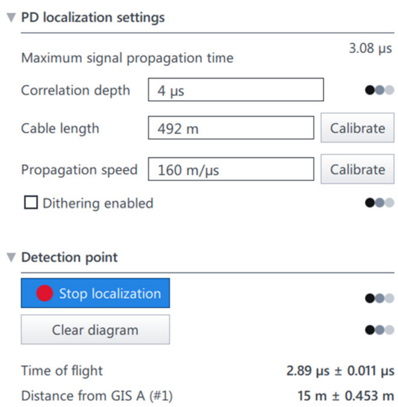

Fig. 10. TOF at the GIS A

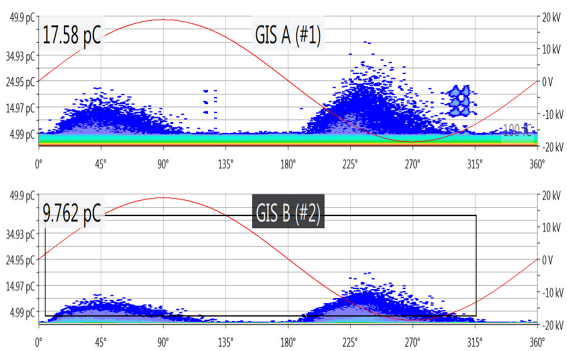

Fig. 11. Selecting the PD pattern at GIS B

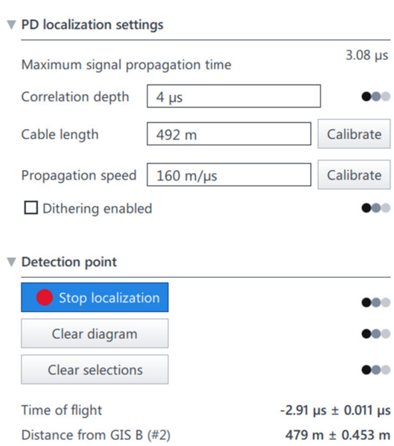

Fig. 12. TOF at GIS B

TABLE I. SUMMARY OF THE LOCATION OF PD SOURCE USING TWO LOCALIZATION METHODS

Localization Method	**Cable Length: 491.7m**		
	Measurement Point	***GIS A***	***GIS B***
Single-End	TDR	21.5m	470.2m
Dual-End	sTOF	15m	479m

Fig. 13. Large localized hump at the semiconductor layer of the cable

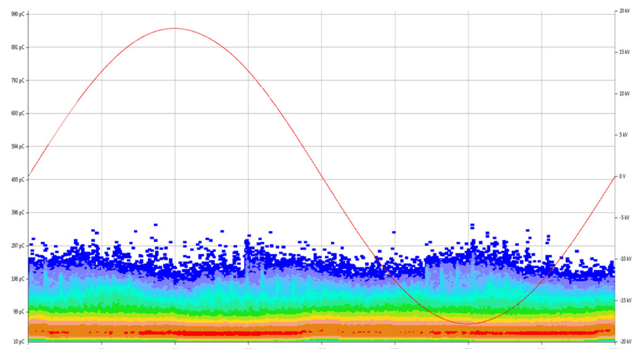

Fig. 14. PRPD after rectification

C. *The Defect Caused by PD*

After ensuring the location of the PD, a cable jointer is required to investigate the area which was firmly believed to be the PD source. Upon carefully taking apart the pieces and layers of the cable, it was found that the semiconductor layer of the cable was not smooth and had a large localized hump, shown in Fig. 13.

This could be another catastrophic accident if the location of the PD was ignored. This paper reiterates the accuracy and efficiency of locating a PD source by using the TDR in a single-end localization method and TOF in a dual-end measurement method.

D. *After Rectification of the PD*

After the cable jointer replaces and re-terminates a new cable joint, an offline cable PD measurement has to be conducted to ensure that the PD has been solved. The same set-up as shown in Fig. 1 and a voltage of 12.7kV (phase-to-ground) has been injected into the cable, and by observing the PRPD, shown in Fig. 14, it shows that there is no PD presence on the cable after rectification.

IV. Conclusion

This paper summarises that locating the PD source in a 22kV power cable accurately is extremely possible when using the single-end localization methods, Time-Domain Reflectometry. With these methods, the engineer or maintenance operator can make a better and cost-effective decision on rectifying the issue. Similarly, it prevents power outages or any flashover incidents caused by PD. Therefore, with the aid of artificial intelligence (AI) in future, these methods can be integrated with 24-hour continuous mode online PD Measurement.

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