Technical Document

Innovative PD site location optimized for FAT in the cable industry

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Innovative PD site location optimized for FAT in the cable industry

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ABSTRACT

In this paper, the theory of PD site location is described and discussed. A novel method introducing an innovative PD cable location procedure enabling fast, easy and accurate triggering on the PD pulse in the well-established Pulse Diagram (charge over phase) is presented. This approach ensures easy and accurate triggering of the investigated PD pulse and its reflections. Several practical examples of fault location in field are presented and discussed, including difficult failure localization, less than 20 meters from the far end of the cable. In conclusion, a reference is drawn to a new innovative approach enabling users to accurately discriminate failures located at the near and far end of the cable.

KEYWORDS

Partial discharge; fault location; failure location; time domain reflectometry; cable

INTRODUCTION

Apparent charge measurement according to IEC 60270 is performed during high-voltage cable routine tests. In case the partial discharge (PD) level exceeds the specified acceptance limits, PD cable site location functionality enables the operator to locate the position of the failure. Due to various types of cable construction, different insulating materials and insulation wall thicknesses, and variable background noise levels it is difficult to determine an absolute value for the required accuracy of PD site location. However, experience has shown that an accuracy of 1% of the full cable length is achievable. Using commercially available PD site location analyzing systems it is more difficult or even impossible to locate faults closer than 20 m from the far end of the cable. This issue is caused by pulse superposition resulting from the limited PD bandwidth of the test arrangement. An increase of the PD measurement bandwidth will lead to augmented noise levels and sensitivity to high-voltage connection lengths and local reflections.

In this paper the theory of PD site location on high-voltage cables is described and discussed. We present a novel approach for site location enabling the user to trigger on the PD pulse level in the well-established pulse diagram (charge over phase) and hence perform PD site location in a fast, easy and accurate manner.

THEORY

Cable fault location mainly consists of measuring the time between partial discharge pulses. This section covers the basic theory to characterize the relevant parameters for faults located close to the cable ends.

Bandwidth and pulse separation

The Nyquist theorem defines the main relationship between signal bandwidth (BW) and the maximum pulse rate which can be transmitted over a cable. The most well-known application of this theorem is the Nyquist filter – a digital filter used to transmit data in a limited BW reaching the theoretical limit of Equation 1. This limit applies as well to pulses that can be separated and detected without (positive) superposition in PD site location applications.

$$PRF = 2 \times BW \qquad (1)$$

Where:

BW = available bandwidth in Hertz (Hz)
PRF = pulse repetition frequency in Hertz

The optimum BW in time domain PD measurement for distribution cables is up to 20 MHz (but can be less depending on the cable length) which allows to separate pulses as close as 25 ns resulting in a spatial resolution of 2.5 m [1,2,3]. Increased cable attenuation at higher frequencies as well as the influence of the coupling capacitor are the main limiting factors. After each PD event reflections at both cable ends generate short bursts of PD pulses. When PD activity is located close to one end of the cable pulses can superimpose because of the limited BW. In that case, comparison of the pulse widths still allows detecting the presence of two pulses and even determining at which end the pulse activity occurs.

Near and far end pulse patterns

Depending on the PD event location the recorded pulse sequence starts with a single isolated pulse or a pair of pulses.

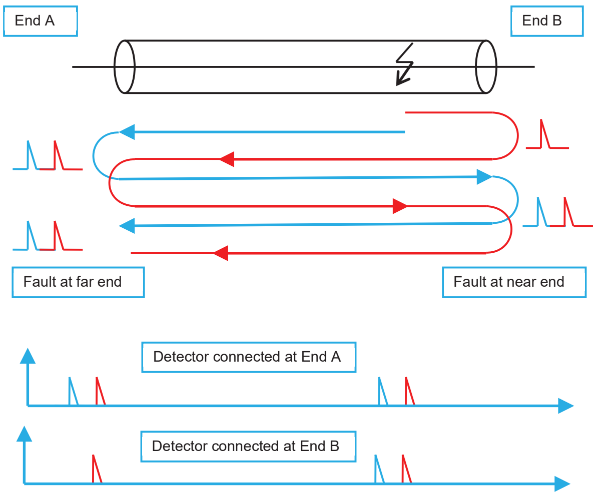

Fig. 1: Near end vs. far end pulse patterns

The subsequent pulses always appear as a pair of pulses. The time between the two pulses of a pair of pulses is proportional to the distance of the fault from the cable end.

When the fault is close to one of the cable ends the pair of pulses appears as a single pulse due to superposition.

FAULT LOCATION USING PD DETECTORS

Starting in the 1960's or even earlier classical oscilloscopes together with appropriate measuring impedances (RLC quadripoles) were used to visualize PD pulses and their reflections travelling along the cable and hence perform PD site location using the well-known time domain reflectometry (TDR) method. This approach was limited by relatively low sensitivity (signal-to-noise ratio – SNR) and low immunity against flashovers. Those issues have been solved by using the TDR method in combination with PD detectors integrating low noise amplifiers (LNA) and flashover protection circuits. However, the core of the site location method did not change and in fact does not differ from the method utilizing oscilloscopes. Setting of the correct trigger level could only be managed by a trial-and-error approach. In some cases, it is virtually impossible to trigger on the correct pulse because the PD signal is close to the noise level. Therefore, the idea arose to use the PD level as a trigger source to record the PD pulse. The applied measuring hardware provides a low noise amplifier to ensure sufficient amplification of low PD levels. After analog-to-digital conversion two separate operations are performed – pulse detection providing a time stamp related to the recognized pulse and separate bandpass filtering to determine the PD level (charge Q). The corresponding functional block diagram of the PD detector is illustrated in Figure 2.

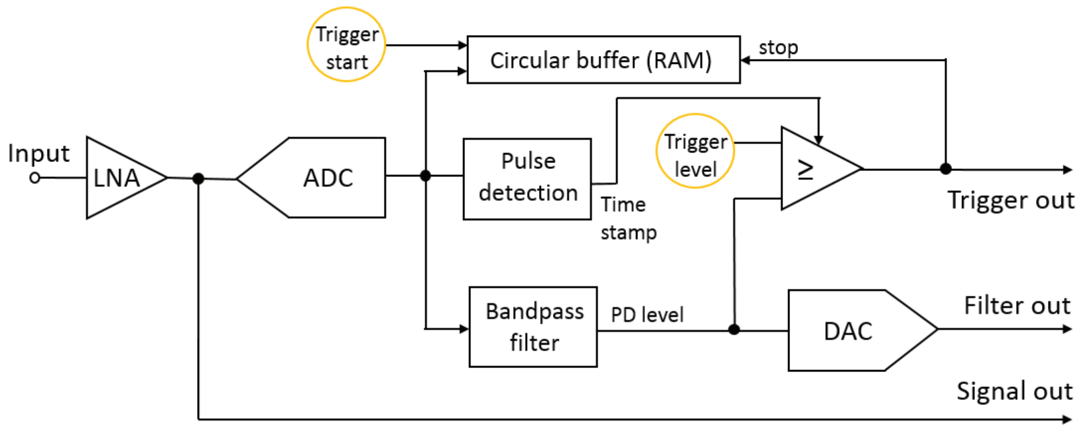

Fig. 2: Functional block diagram of PD detector with pulse detection and trigger logic for integrated PD pulses.

Integrated PD pulses are displayed in the classical pulse diagram. The related software enables the user to trigger directly on the integrated (charge) pulses simply by entering the charge value. A comparator (≥) is used to compare the measured PD level with the PD trigger level (charge) specified in the software. The use of the known time stamp ensures correct pulse triggering on the raw (unfiltered) PD pulse using a circular buffer (RAM), which is required for accurate site location. Hence, site location is significantly simplified and requires only basic operation steps from the user side. Those steps are

1. System calibration (propagation speed):
   - Connect the PD calibrator to the cable.
   - Enter the cable length.
   - Enter 80-90% of the PD calibration level in the Trigger Level input field and press the trigger by PD level button.
   - Propagation speed is automatically calculated using TDR method.
2. Fault location process:
   - By applying the test voltage PD activity can be recorded in case of a faulty cable.
   - The user just needs to enter 80-90% of the actual maximum PD level and press the trigger by level button.
   - Failure location is automatically calculated based on the propagation speed calculated during the system calibration step.

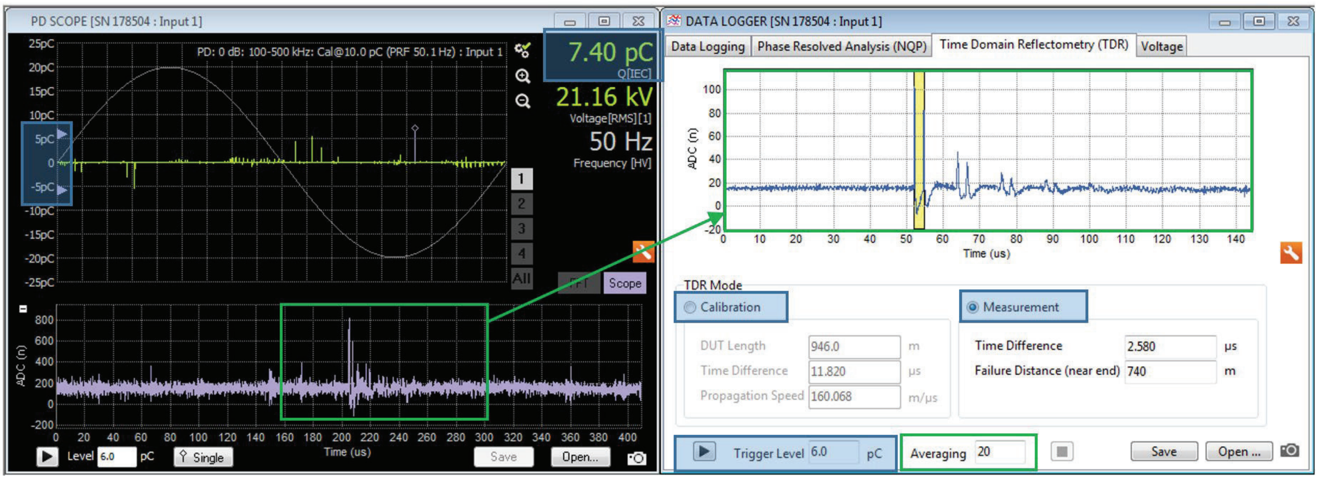

Fig. 3: PD detector cable site location with PD level triggering and signal averaging.

The selected trigger level should be close to the actual PD level to ensure exact triggering on the maximum peak. Correct triggering allows the SW to take advantage of averaging several PD pulses to increase the signal-to-noise ratio, i.e. to remove most of the noise from the measurement as shown in Figure 3 with an averaging of 20.

In addition, the presented hardware configuration offers the possibility of using two analog and one digital output as shown in Figure 4.

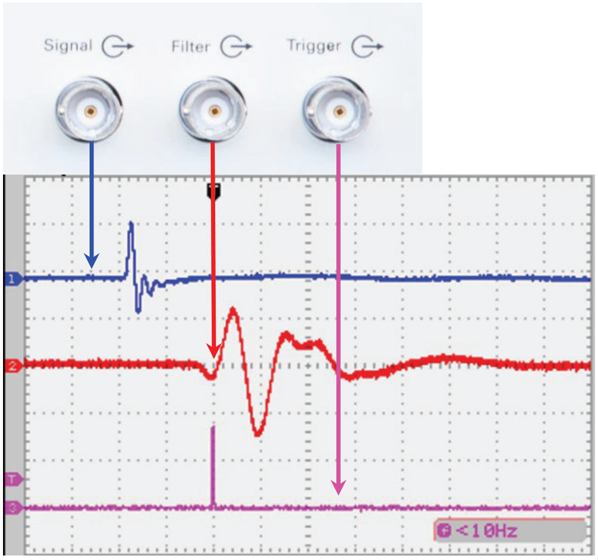

Fig. 4: PD detector output connectors and their corresponding signal waveforms.

Signal Output

The signal output provides access to the full bandwidth signal of the PD pulse via the front panel connector of the detector. In order to visualize the full bandwidth this signal can be used together with the trigger feature to locate failures less than 20 m from the cable end.

Filter Output

The filter output provides the opportunity to look at the filtered PD pulse as per the IEC digital filter settings defined by the user in the software. The adjustment of the filter settings can either be done by moving the filter control window in the FFT view of the detector's PD scope or by manually entering the desired center frequency and bandwidth.

Trigger Output

The trigger output provides an easy possibility to synchronize PD pulse measurements acquired by more than one device/method. Using the BNC 'Trigger' output on the front-panel of the detector one can synchronize the PD pulses coming from different sources. This is useful not only for cable applications. For example, with the detectors signal output, acoustic sensor and UHF sensor outputs connected to an external oscilloscope, the pulse acquisitions can be synchronized by using the detector's trigger output as external trigger. The trigger output is a TTL signal with an amplitude of 3.6 V.

INTERPRETATION OF FAULT LOCATION RESULTS

When the failure is located further than ca. 20 m from the cable end the accuracy of the TDR algorithm is relatively precise and reaches the actual minimum resolution of 1m. However, it is challenging to recognize failures close to the cable ends when the pulses and their reflections are superimposed as described in section "Near and far end pulse patterns".

A qualitative sequence of pulse patterns for the case of near end and far end failures is shown in Figure 5. When the time between pulses #1-#2 and #2-#3 is close to the propagation time of a single cable length, this is an indication for superimposed pulses. The magnitude pattern shown in Figure 5 can give some hints to the location of the fault.

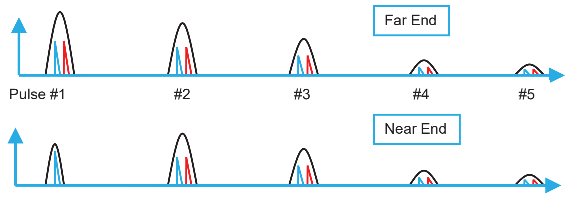

Fig. 5: Near end vs. far end pulse patterns.

Case 1) The first pulse is lower than the second pulse. In that case, the fault is most probably at the near end.

Case 2) The first pulse is higher than the second pulse. In that case, the fault is most probably at the far end.

Case 1) can also occur for far end failures, depending on how the pulses are superimposed and reflected at the cable end. An open far end always has some stray capacitance and forms a stub caused by removing the cable shielding. This means that the termination cannot be considered as an ideal open circuit. The above theoretical findings are confirmed by practical measurements in the following sections.

Failure more than 20 m from the cable end

The following examples are for failure locations 25 m from the given cable end.

Failure at the far end of the cable

Both the first recorded pulse but also its reflection exhibits a double peak which clearly shows pulse superposition typical of far end failures according to Figure 5. Initially, the system automatically places cursors to the first peak and its reflection (see Figure 6). However, to get the correct reading cursors need to be placed on the first double peak according to Figure 7.

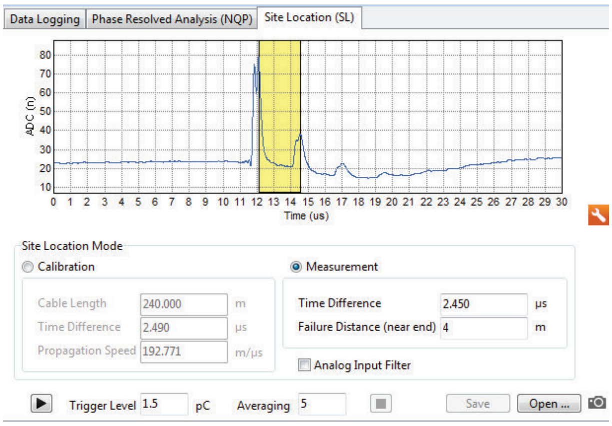

Fig. 6: Failure at the far end of the cable.

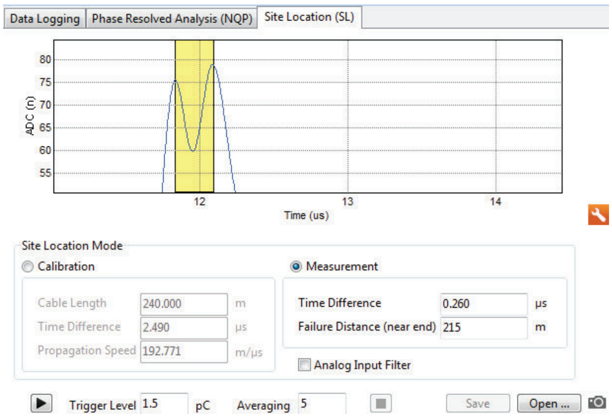

Fig. 7: Failure at the far end of the cable – detailed view of the first peak.

Failure at the near end of the cable

The first recorded pulse shows no pulse superposition, but its first reflection exhibits a double peak which indicates pulse superposition typical of the near end failure pattern according to Figure 5. Cursors are automatically and correctly placed to the highest peak of the "first reflection" (second recorded pulse) as shown in Figure 8.

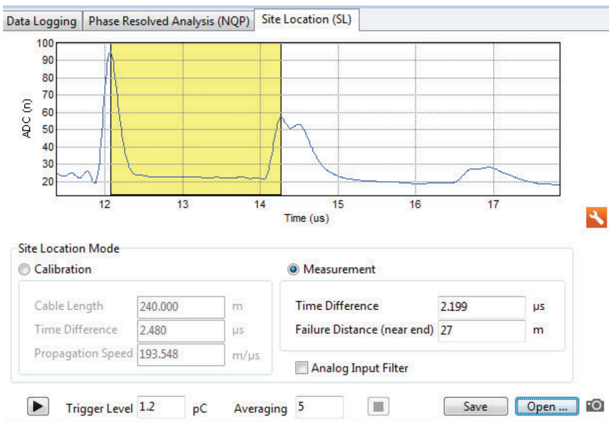

Fig. 8: Failure at the near end of the cable.

Failure less than 20 m from the cable end

The following examples are for failure locations 5 m from the given cable end.

Failure at the far end of the cable

In Figure 9 the measuring system indicates quite precisely a failure location of 0 m, even though PD activity can be recorded. There is no possibility of estimating the exact failure location. However, this result indicates a failure located at the far end of the cable which confirms the assumptions described in Figure 5. I.e. both the original pulse and its reflection are composed of two pulses with a similar effect on the total pulse width. A novel technique how to approach such challenging situations by comparing the width of the pulses is described in [4].

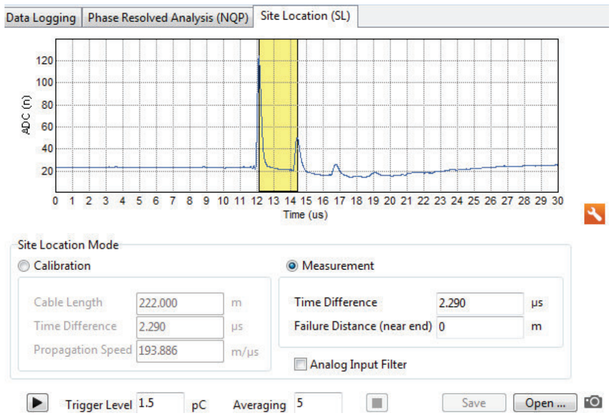

Fig. 9: Failure at the far end of the cable.

Failure at the near end of the cable

In Figure 10 the measuring system indicates a failure located 4 m from the near end. The failure location can be recognized thanks to the pulse width of the reflection – two pulses are superimposed (refer to Figure 5). Hence, the reflected pulse is wider, and the peak is shifted accordingly. However, accuracy might fluctuate and sometimes a specific correction factor has to be applied.

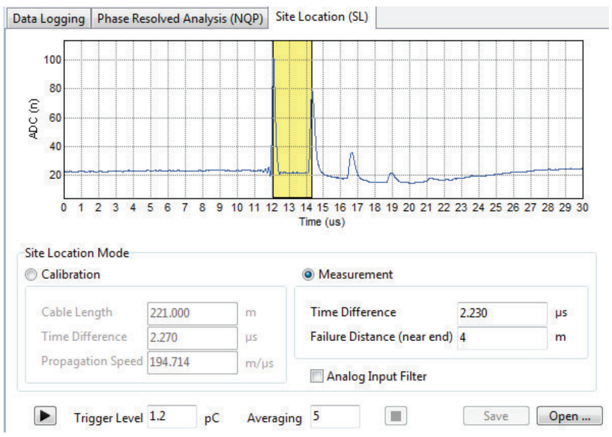

Fig. 10: Failure at the near end of the cable.

CONCLUSION

The application of PD measurements for site location is a fail-safe and non-destructive method to detect cable faults before the occurrence of flashovers. This technique is clearly to be preferred to methods that allow the localization of cable faults only after the event of a flashover. After recalling the basic PD site location theory, a new method to trigger on the PD level was introduced. This allows stable recording and averaging with the key advantages of reducing the noise level and acquiring clean pulse recordings. Cable fault location requires the detection of PD pulses with very low levels, in fact just above the noise level. The presented method helps to automatically and quickly localize faults at very low PD levels. This is mandatory for cable testing in order to avoid flashovers and the high probability of damages that could occur due to the steepness of the pulses in that case. Even without further improvement using the correlation analysis described in [4] the presented method already ensures reliable results.

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GLOSSARY

ADC: Analog-to-digital converter
DAC: Digital-to-analog converter
BW: Bandwidth
FAT: Factory acceptance test
FFT: Fast Fourier transform
LNA: Low noise amplifier
PD: Partial discharge
PRF: Pulse repetition frequency
SNR: Signal-to-noise ratio
TDR: Time domain reflectometry

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