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Method to Discard Partial Discharge (PD) Pulses from Neighboring High Voltage Equipment

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ABSTRACT

On-line partial discharge (PD) diagnostics data are corrupted by various noise sources and this makes it more challenging to extract the PD signal contained in the raw data. Though the noise sources can be filtered out using signal processing techniques, PDs from neighboring cables and other high voltage equipment make the de-noising process more difficult due to the similar features of these signals with the PD signal of interest. Proposed in this paper is a double-ended partial discharge diagnostic system with dual sensors at each end which uses wireless time triggering using global time reference with the aid of global positioning system (GPS). Using the time of arrival method based on the velocity of propagation on the data, PD pulses originating from other sources can be discarded which reduces the volume of data to be stored and would eventually also reduce the hardware and software requirements of the denoising process thereby improving de-noising efficiency. System design, laboratory tests and on-site measurements are discussed.

Index Terms - Partial Discharges, Time Domain Reflectometry, Time Synchronization

1. Introduction

On-line partial discharge (PD) measurements at cable terminations have been considered to be the most effective diagnostic tool for diagnosing defects in cable insulation. Due to PD, fast varying current pulses flow in the cable core and screen. These pulses can be detected using high frequency current transformers or pre-installed power frequency CT used for protection and measurement purposes [1]. On-line PD measurements are often hampered by various noise sources namely radio transmissions, mobile-phone transmissions, corona from high voltage equipment, PD from adjacent cables etc. These noise sources make the process of extracting PD from the raw data a much more difficult task. Since PD pulses exhibit a wide-band frequency spectrum, classical filtering technique is not effective. Hence multi-resolution analysis using wavelets has been proven to be one of the most effective techniques for de-noising PD signals [2-4]. Various steps are involved in wavelet de-noising of the acquired signal. These are selecting filter kernel or mother wavelet having impulse response similar to the PD pulse shape, decomposition using sub band coding scheme using quadrature mirror filters, thresholding and synthesis. Thresholding plays a vital role in de-noising and is based on the fact that the energy of a signal will often be described by fewer coefficients while the noise energy spectrum spans the entire wavelet coefficients [5]. In on-line PD measurements, PDs from neighboring cables or high voltage equipment, switching noise and cross-talk between the phases of cables often make it more challenging to distinguish PD from these signals due to the similar signature in wavelet decomposition using wavelet basis function. Proposed in this paper is a dual PD measurement system with GPS time stamping. This system can be viewed as an extension of the system described in [6]. Using this system, PDs originating from neighboring cables and switching noise from power electronic circuitry can be discarded using time of arrival between the pulses. Discarding unwanted PD pulses has advantages that PD can be interpreted with high degree of confidence and also the resources required to de-noise the data is minimized due to the reduction in volume of data. Modbus protocol in the proposed design can be used to update the status of the cable to the remote server [7, 8].

The remainder of the paper is organised as follows. Section-2, provides various methods to discard PD pulses from neighboring high voltage equipment. In Section-3, dual measurement setup with circuit simulation is discussed. Hardware description of the system is discussed in section-4 and time synchronization tests are included in section-5. Section-6 provides on-site PD measurements conducted on a cross linked poly ethylene (XLPE) cable network in a wind farm and section 7 concludes the paper.

2. Discarding External PD Pulses

Fast rising pulses resulting from a PD source propagates towards both ends of the cable. Since PD signals can be monitored at the ends of the cable, measured PD pulses are attenuated and dispersed by the characteristics of the propagation channel of the cable. Attenuation leads to a reduction in signal power whereas dispersion leads to a change in signature due to the nonlinear variation of the propagation constant of the cable material with signal frequency. In cables, PD measurements can be done using either single ended or double ended measurement. The former method uses both incident and reflected pulses detected at the same end of the cable to compute the location of the PD source. Accuracy of this method depends upon the high frequency signal characteristics (attenuation and dispersion) of the cable and cable termination impedance. On the other hand, the double-ended method uses incident PD pulses at both ends of the cable. Hence the effect of cable parameters such as attenuation constant, phase constant and characteristic impedance on PD source location is less critical compared to the single ended method. The double-ended method is therefore preferable to locate PD’s in longer cables. In both of the methods, time-offset between incident pulse and reflected pulse in the single-ended method equals the transit time of the cable while time-offset between incident pulses at both-ends of the cable in a double-ended method equals the transit-time of the cable. This is also true when the PD source is present at the termination or away from the cable. Hence it is difficult to discard the pulses originating from sources external to the cable of interest. Lundback et al. proposed a digital directional coupler which separates forward and backward travelling waves on a transmission line. This method is based on two independent wideband measurements of voltage (capacitive coupler) and current (inductive coupler) and frequency-domain digital wave splitting using Fast Fourier Transform (FFT) [9]. Lemke et al. proposed the method of using directional couplers for identifying the PD signals from outside the cable [10]. Both of these methods are intrusive and may not be easily implemented for on-line PD detection.

3.Dual Measurement Method

In this paper, a novel dual measurement method is proposed which uses two similar PD measurement units installed at each end of the cable. At each end of the cable, HFCTs are installed around the cable screens with a spatial separation of 1 meter or higher. Figure 1 shows the simulation schematic generated using PSPICE. In this simulation, transmission line parameters of cross-linked polyethylene (XLPE) cable (Zc:23.43Ω, R:0.001Ω/m, L:162nH/m, G: 0.001mS/m, C:300pF/m, length:1500m, v:1.43×108m/s) were used and these parameters are valid from 10 Hz to 50 MHz [11]. These parameters were applied to a lossy transmission line model in PSPICE as shown in Figure 1.

In this simulation, two data acquisition pairs namely scope A- and scope A+ forming one pair at one-end of the cable; scope B- and scope B+ forming the other pair at the other-end of the cable; and each pair are placed 1 meter apart. The cable under test spans from scope A+ to scope B-. Pulse is injected at cable end prior to scope A-. Simulation results from end A and end B are as given in Figure 2 and Figure 3 respectively. Forward and backward travelling waves were identified using the distance of separation between the pulses which is 1 meter in this case. In this way, neighboring PD pulses can be differentiated. By discarding pulses from external sources, uncertainty caused in wavelet thresholding due to these spurious pulses from external sources can be minimized. Also the reduction in data size can make the process of de-noising faster and will also reduce the hardware resource required for on-line de-noising.

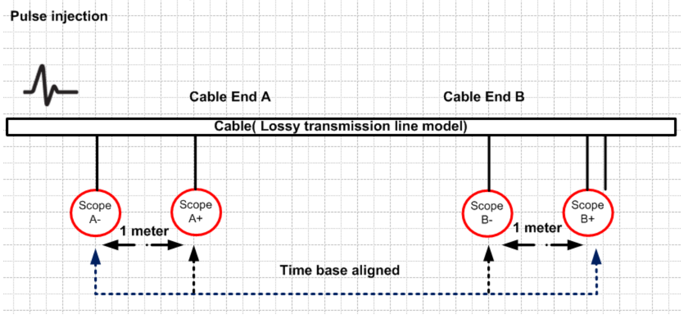

Figure 1 Dual measurement method

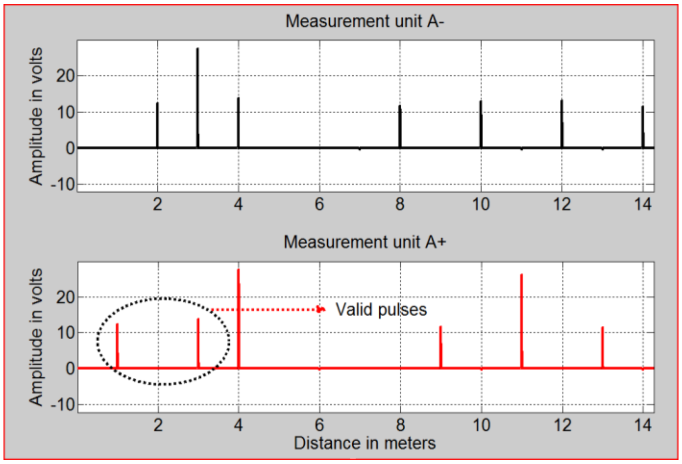

Figure 2 Spatial TDR map End A, dual measurement method

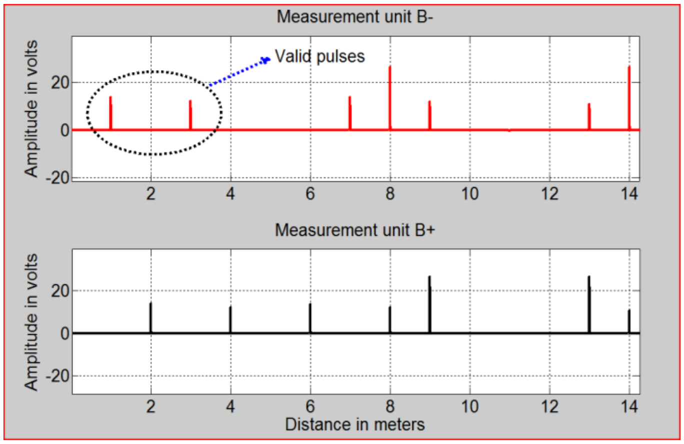

Figure 3 Spatial TDR map End B, dual measurement method

4. Hardware Design

The novel dual measurement method is implemented in a hardware system. The system proposed here is an enhancement of the system presented in other papers [6, 12]. Hardware block diagram of the system is as shown in Figure 4. The system is able to measure PD from three phases of the cable along with the power frequency voltage reference. PD signals from three phases and the power frequency reference voltage at the sensor output are buffered to the analogue to digital converter (ADC) via an attenuator/amplifier module. The buffer circuit provides the necessary termination impedance for the PD sensor while the attenuator/amplifier module provides the required attenuation or amplification depending on the signal level. The embedded processor in this system is a field programmable gate array (FPGA), which is clocked using a 500 MHz crystal oscillator with a high degree of short-time frequency stability. Clock domain of the FPGA is synchronized with the GPS clock. The FPGA stores the digital output of the ADC into memory #1. The FPGA processes the data contained in memory #1 for discarding the pulses from external sources followed by storing the data into memory #2. De-noising and PD parameter extraction of the data contained in memory #2 are carried out by the ARM processor followed by storing the data into the SD card. Using the Modbus protocol, status of the PD measurement is updated to a remote server via a GSM/3G module. The de-noised PD waveform is transferred to the remote server using TCP/IP via the GSM/3G module upon request. The sensor connection diagram is as shown in Figure 5.

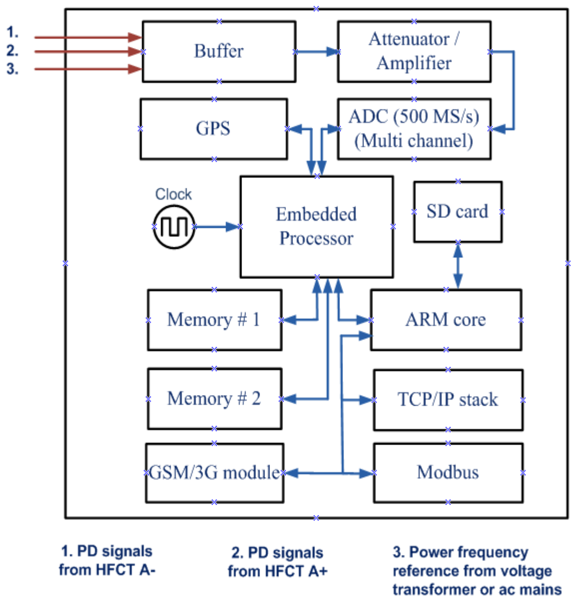

Figure 4 Hardware block diagram

This system can be used in a single ended or a multi-ended PD detection node (PDDN) with signal-level triggering or time-base triggering. Two PD sensors at each end are connected having spatial separation of 1 meter. Since this system is basically a time synchronized data-acquisition for PD measurement, it can be extended to PD data acquisition from other high voltage equipment such as transformers and rotating machines.

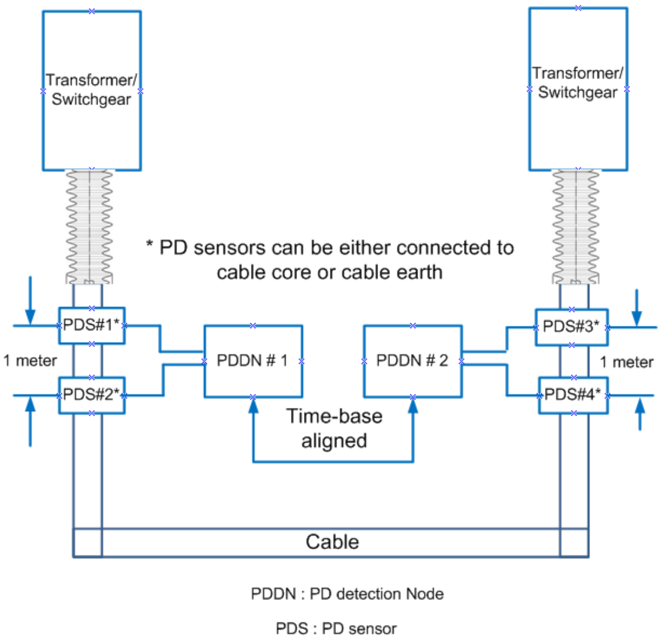

Figure 5 PD sensor connections

5. Laboratory Testing

Timing accuracy of the system is crucial for discarding external PDs and for PD location. A Crystal oscillator having high frequency stability of 1 part per million (PPM) is used as a primary clock source for the embedded processor (FPGA). Also, the ADC having a sampling rate of 500 MSamples/s shown in Figure 4 can differentiate the pulses having a spatial distance offset of 1 meter. However it was required to verify the spatial/timing accuracy in high electromagnetic environment like a substation. Hence, preliminary testing was conducted in a substation to quantify the drift caused by EMI between the measurements. Two HFCTs were clamped adjacent to each other around the earth screen of the 11 kV Paper Insulated Lead Covered (PILC) cable as shown in Figure 6. PDDNs setup is shown in Figure 7.

Figure 6 HFCT connection at the substation earth

Figure 7 Testing in substation

The drift between the measurement points was measured by triggering the system at the same time from the GPS signal. Pulses extracted from the measurement data are as shown in Figure 8. Accumulated drift over an 80ms window is as shown in Figure 9. This drift is equivalent to an error of 6m in a PD location outcome based on velocity of propagation of electromagnetic signal in PILC cable. Hence using this system, PDs can be located within ± 6m accuracy after discarding external PDs

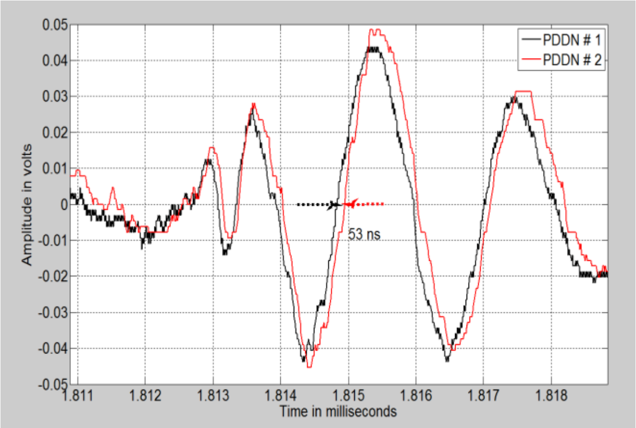

Figure 8 Drift measurement

6. On-site Measurements

Multi-ended PD location capability of the system was tested in a wind farm in Scotland. A PDDN was installed at each end of the XLPE cable having a length of 579 meters connected between two wind-turbines. In this measurement, two sensors at each-end are not used due to the unavailability of a second channel in PDDNs during the test. However based on simulation, hardware configuration and preliminary site trials, authors believe that the two sensor method can be implemented which can be able to discard PD from an external high voltage component. Transit time of the cable was calculated to be 4.02 microseconds using the velocity of signal propagation in XLPE cables [6, 11, 13, 14]. The photograph of the measurement set-up at one-end is shown in Figure 10.

Data acquired from both ends of the cable are as shown in Figure 11. In PDDN # 1, repetitive spikes having higher amplitudes than the background were found. Frequency spectrum of the data acquired using both PDDNs are as shown in Figure 11. Based on Figure 12, higher order frequency components up to 25 MHz were found in the data acquired using PDDN # 1 while in PDDN # 2, maximum frequency components around 5 MHz were recorded. Figure 13 shows a typical pulse extracted from Figure 11 which shows a time offset of 4 µs between the pulses from both PDDNs. The degree of similarity between these pulses is not high and this is due to the fact that higher frequency components were not recorded by PDDN # 2 due to cable attenuation as is evident from Figure 12. Such attenuation will alter the pulse dramatically. Furthermore, frequency dependent dispersion will cause temporal wave spreading which also altered the time domain signature. Since the time-offset between these pulses is in agreement with the predicted transit time of the cable, it could be inferred that the pulses originated either at the point where PDDN # 1 was installed or from outside the cable. The acquired data gives confidence that the system can be used to locate PD in a multi-ended ended configuration and can also

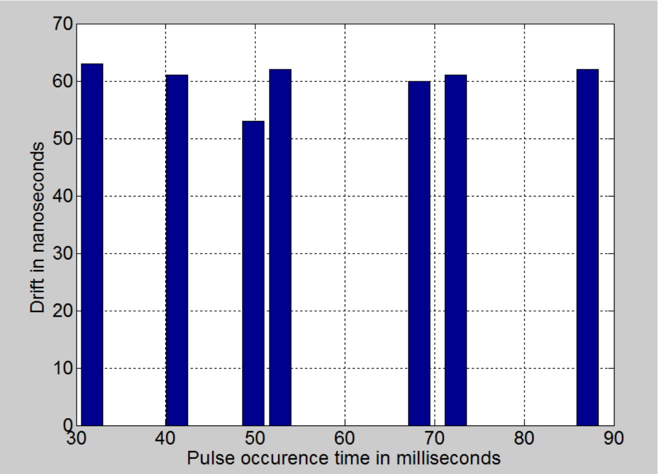

Figure 9 Drift vs time[6]

Figure 10 Site trials in wind farm, Scotland

be used to discard through-pulses in cables based on simulation and preliminary site trial discussed in Section 5.

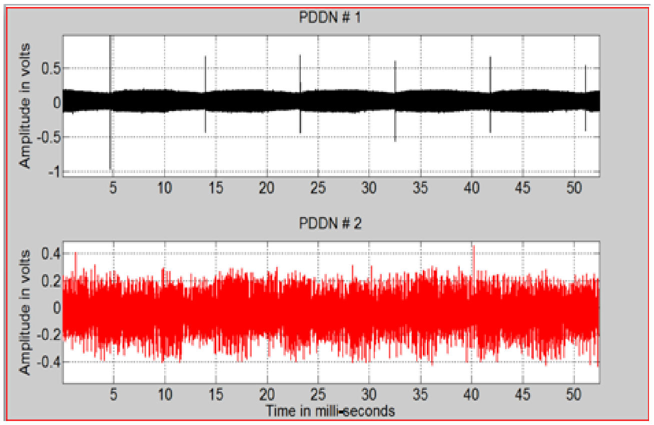

Figure 11 Raw data from both ends of the cable

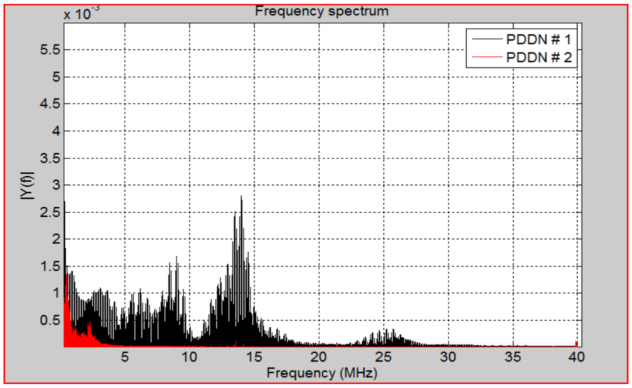

Figure 12 Frequency spectrum of raw data from both ends of the cable

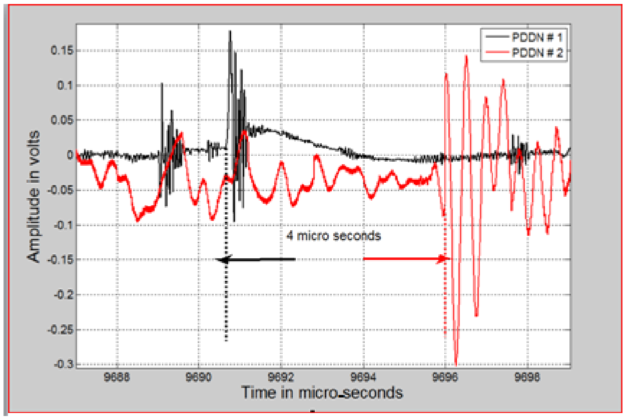

Figure 13 Double-ended measurements

7. Conclusions

On-line PD signals are corrupted by various noise sources. Wavelet based de-noising techniques are used to remove the noise using wavelet decomposition via the selection of an appropriate mother wavelet and thresholding level. PDs from neighboring cables make this process more challenging in wavelet thresholding. Some times this leads to a misinterpretation of the existence of a PD. A novel multi-ended PD monitoring system with GPS time synchronization is proposed to overcome the challenge. A PD discarding algorithm implemented in FPGA can discard PD pulses from neighboring cables using the time of arrival between forward and reverse travelling waves. Using this algorithm, conducted interferences and PDs from neighboring cables can also be discarded. Laboratory and on-site trials have demonstrated that the novel technique could be confidently applied. Further work includes more site trials and case studies to increase the level of confidence in this novel method.

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Biographies

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