Improved Algorithm for on-line Partial Discharge Location in Cables

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ABSTRACT

Partial discharge diagnostics is the most widely used tool to assess the insulation condition of medium voltage cables which allows informed maintenance planning so that such ageing assets can be in service even after the designed life span. Basically PD diagnostics may be divided into three phases namely Detection, Location and Decision making. Pulses generated due to PD activity are fast varying pulses having pulse widths of the order of a few hundreds of nano seconds. High frequency current probes calibrated in apparent charge are used to detect these fast varying pulses. The discharge site needs to be located after detection to enable cable repair. Accuracy of the discharge site location reduces the cost and repair time. Conventional single ended PD location method is well suited for off-line PD location. Global positioning system (GPS) and pulse injection techniques have been used by other researchers to synchronize double sided PD detection systems. In the long term these methods are less accurate which leads to an error in PD location. Proposed in this paper is a remote double sided PD detection system with GPS time synchronization using time based triggering rather than event based.Time based triggering reduces the uncertainty in PD location caused by GPS inaccuracy., also correlation between PD activity and loading of the cable is achieved.

Keywords: Partial discharges, FPGA, GPS, PPS, NMEA

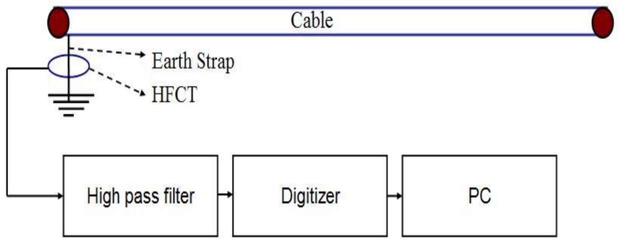
I. INTRODUCTION

Power transmission and distribution is achieved using a network of overhead lines and underground cables. Underground cable designs vary with the age, voltage and capacity of the particular circuit. The majority of the existing medium voltage (11kV to 33kV) cables in the UK are of a paper insulated, mass impregnated, lead sheathed design which was used, for more than 100 years, since the latter part of the 19th century up to the present day. At this stage, informed maintenance planning through on-line condition monitoring is an efficient tool which can avoid any forced outages thereby cables can be continue to remain in service. Main business driver' in the development of the condition based maintenance technologies is the UK regulatory incentives which require all electricity utility company to continuously improve network performance to operate the network smarter and to reduce operational costs which presses the need for informed maintenance planning through on-line condition monitoring to avoid unplanned outages. Purpose of on-line condition monitoring of cables or any electrical equipment is to predict failures before actually they occur. Those assets which are in the verge of failure can then be replaced or repaired, thereby reducing the forced outages. Partial discharge monitoring is most widely used on line condition monitoring tool for insulation integrity assessment of cables. Due to PD fast varying pulses are generated. PD occurs in regular power cycles with varying intensity which depends on circuit conditions, weather conditions also it is asset specific. Load current dependence of PD activity is discussed in [1] which necessitates the need of measuring PD in frequent intervals. PD monitoring is divided to three phases namely detection, location and decision making. High frequency current probes installed in earth strap of cable are widely used to detect these fast varying PD pulses. Accurate location of PD source in the cables favours the network owners by reducing cost and man hours required for the repair. This paper is focused on PD location using double side measurement

This paper is organized into five sections. Introduction has been provided in section I. Section II includes various PD location methods, including single ended and double ended methods. Section III has various time synchronization methods namely GPS and pulse injection methods. Remotely controlled double ended time based triggering system design is discussed in section IV. Section V concludes the paper.

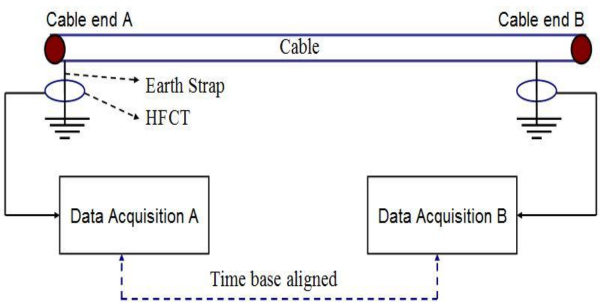
II. PD LOCATION METHODS

Various PD location techniques based on time delay estimators has been presented [2-5]. These techniques include level crossing, signal subspace methods, non-linear maximum likelihood techniques and generalized cross correlators. Most of them need to have a prior knowledge of PD signature. On-line PD measurements in cables are done at the cable terminations either at the switch gear end or transformer end. PD signal should travel from the discharge source towards the sensors which are installed near to the cable termination. On its way towards terminations these signals undergoes attenuation and dispersion. Attenuation and dispersion are frequency dependent which often alters the PD signal shape. Time domain reflectometry is widely used to locate the discharge source by means of single ended measurement or double ended measurement. Simplified single ended PD location system is as shown in figure (1) which has of high frequency current probe, high pass filter, digitizer followed by PC for data storage and analysis. PD location is computed based on the time of arrival estimate between incident PD pulse and reflected PD pulse. For successful application of the single ended method, it is important that attenuation and dispersion in the



Figure(i) Single ended PD measurement

cable under measurement should not be too large, the substation or ring main unit (RMU) impedance should differ considerable from the characteristic impedance of cable under measurement, there should not be any cable branches and also the cable under measurement should not be connected to adjacent cables. All these requirements are not often met in-situ measurements. Also the digitizer should have better dynamic range to detect the reflected pulses. Accuracy of defect location depends on the error margin in the time-of-arrival estimate of each PD pulse and on how precise the propagation time of the entire cable is known. So single ended method is mostly suited for off-line PD location [6]. Drawback in single ended method can overcome by measuring PD at both ends of the cable with highly accurate time base alignment in the measuring system. Block diagram of a double ended method is as shown in figure (iii). To locate PD difference in time of arrival of first pulse in both measurement systems is used together with propagation velocity and cable length. Attenuation and dispersion effects are reduced to 50 percent and the effect of substation or RMU impedance has been cancelled. With the use of double sided method there is a good possibility of identifying PD source with respect to the cable under measurement. This method can be used to locate PD in longer cables of length in the order of 4 km .Accuracy of this method depends upon the resolution of the time base alignment



Figure(ii) double ended PD measurement

III. TIME SYNCHRONIZATION

Time synchronization between two systems in double ended PD location is the key factor which determines the accuracy of the PD location. For e.g 100 ns error in time synchronization leads to location error of approximately 10 meters. Time synchronization involves a common reference pulses for both measurement systems thereby time bases of both systems can be aligned. Most widely used method of time synchronization is using global positioning system (GPS) which is used in [7]. .GPS provides signals necessary for position determination and precise timing information. Time synchronization by this method requires GPS receiver and GPS antennae. GPS receiver outputs 1 pulse per second (PPS) which is aligned to top of second in UTC time followed time stamp information based National Marine Electronics Association (NMEA) protocol which is a data protocol for communications between marine instrumentation. [8]. Both 1PPS and NMEA are required for time synchronization.

Time synchronization by pulse injection technique is reported [9-10] which involves injecting pulses from one end of the cable which requires a high frequency inductive coupler and a high frequency pulse injection source. During pulse injection high frequency signal undergoes attenuation and dispersion like the required PD pulses. Jitter, wander or the frequency stability of injecting pulses in longer term is not reported in these references.

IV.PROPOSED SYSTEM

Basic building blocks of the proposed system are Field Programmable Gate Arrays (FPGA), Analogue to Digital Converter (ADC), external memory and GPS receiver and PC with broadband. The block diagram of the system is as shown in figure (iii).

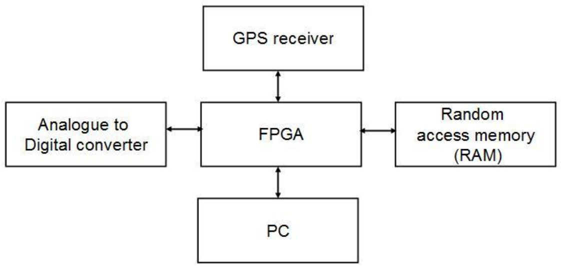


Figure (iii). Proposed system for double side PD measurement

The system should be installed as one at each cable end with both systems being controlled by a control room PC via broadband as shown in figure (iv). The objective of the proposed method is to acquire data from both cable ends by these systems at the same time. Starting time is provided from the control room PC which is of a high degree of resolution in the order of tens of nano seconds. The starting time of the system is given by

$$T_s = T_i + \delta_t$$

Where

T_s : Starting time of the data acquisition

T_i : time interval between two successive data acquisition

δ_t : time delay between two systems

δ_t is calculated based on the time delay between two systems using GPS. Accuracy of GPS can be very high, but in longer term the accuracy is not maintained due to several reasons such as number of satellite visibility, variations in velocity of propagation of signals in ionosphere, multi path effects of signals. Once the GPS receiver get locked with sufficient number of satellites, receiver starts outputting 1 PPS followed by corresponding NMEA stream. 1PPS pulse is of normally 100 micro seconds duration and the repetition frequency is 1 HZ as shown in figure (v). It is very important to consider the jitter in 1PPS which has direct influence on the accuracy of time synchronization .Maximum time interval error (MTIE) of 1pps is as shown in figure (IV) which is measured by calculating the drift between 1pps and Caesium atomic clock [8]. Operating region of the proposed system is selected carefully where the accuracy is more which is as shown in figure (v). Also the input clocks of FPGA chips are normally provided by crystal oscillators which have higher frequency stabilities .But due to ageing, temperature variation, input voltage fluctuation, frequency stability is reduced. In order to have higher degree of accuracy in PD location, time delay calculation of both systems is repeated after several hours.

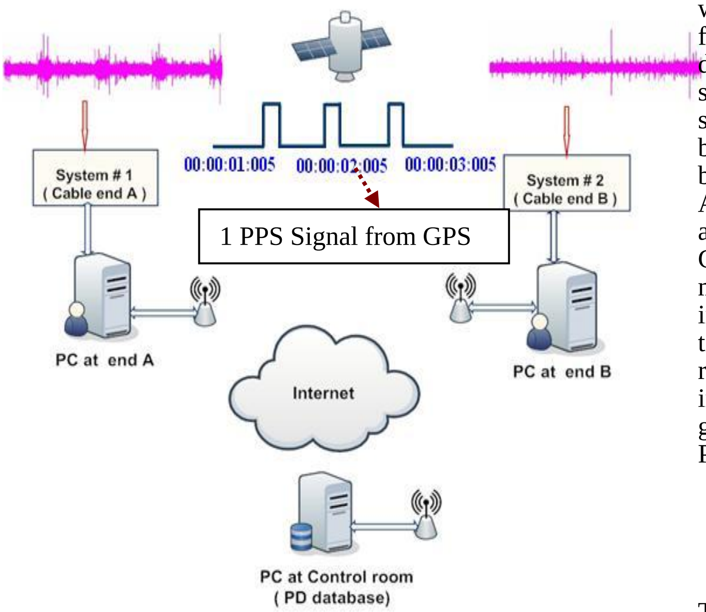


Figure (iv) Double sided PD detection system

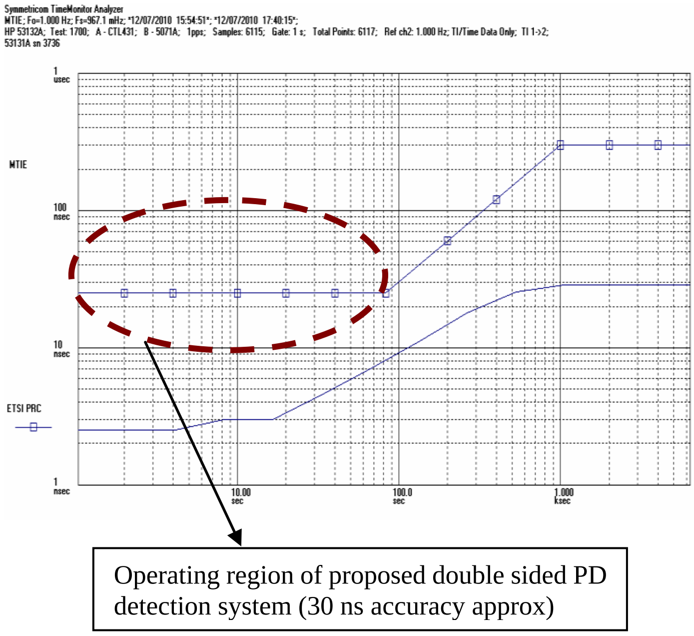


Figure (v) MTIE performance of typical GPS receiver

V.CONCLUSION

Partial discharge diagnostics is the most widely used tool to assess the insulation condition of medium voltage cables which allows informed maintenance planning so that any forced outages can be prevented. The success rates of PD diagnostics rely on accurate identification of the discharge source. A remote controlled double sided PD detection system was proposed using GPS time synchronization but based on time based triggering by measuring the time delay between two systems rather than event based triggering. Also the time delay is determined within the higher accuracy region of the 1pulse/s pulse-train generated by the GPS (MTIE performance of GPS receiver). Frequent measurement of the time delay between two systems increases the accuracy of the PD location. With the ease of time based triggering; correlation of PD activity with respect to load current can be obtained. Also Error introduce by PD pulses from the neighbouring cable is greatly reduced and this method cane be applied to locate PD in cables of length of the order of 4km.

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