

REMOTE CONTROL PARTIAL DISCHARGE ACQUISITION UNIT

M.H. FOO J.J. SORAGHAN W.H. SIEW J.S. PEARSON
University of Strathclyde - United Kingdom
davidf@spd.eee.strath.ac.uk

Abstract: *Online partial discharge (PD) analysis for underground high voltage cables has major advantages over the offline techniques. Online techniques usually involve PD data acquisition, storage and post-processing of the data. However, the data acquisition process can be time consuming and troublesome because of design procedures and protocols required before commencement of data acquisition. This paper presents a robust remote controlled partial discharge acquisition unit for underground high voltage cable networks. This system is uniquely designed to incorporate the difficulties of accessibility, especially for remotely located substations. Real field data from a 33kV network is included in the paper.*

1. INTRODUCTION

The detection of partial discharge (PD) of high voltage (HV) underground cables is normally carried out using either offline or online methods. PD detection is performed by the measurements of the discharge level in the circuit according to the IEC specifications and the acquisition of the voltage signals. Offline method is performed when the cable circuit is de-energised. Some examples of offline detection techniques are acoustic and optical detection, and the very low frequency (VLF) technique. The VLF technique is done by separately energising the circuit with a very low frequency source and gradually increasing the voltage level until the PD is detected [1]. Generally, offline techniques are less preferable due to the power outage caused. Furthermore, some techniques are actually required for the cable to be resurfaced and this can lead to further degradation of the insulation during the process. The online method on the other hand is more desirable since the circuit outages and power disruption are not required. It can be extended into the continuous condition monitoring of PD in the cable circuits. When performing PD signal acquisition, high sampling rates are required in order to capture the characteristics of the PD typically from 10 – 20 MHz [2]. This would usually involve the storage of large PD databases and computationally expensive analysis of the data.

In the online PD acquisition, the main problem is the acquired data is often swamped with heavy noise interference that is coupled into the cable circuit. This noise is due to a combination of RF interferences coupled through the transmission lines, electrical switching circuits, and random noise [3]. The PD signal has a very short duration of pulse width, typically tens of nanoseconds [3]. The PD detection may be difficult as it can be totally masked in the noise. Noise suppression can be performed by adding filters to the

acquisition system. The post processing then involves digital signal processing techniques that are designed to further reduce the noise interference or to enhance the PD components in the signal. However, one major problem is that there is a shortage of real PD data available in the market for research purposes.

An online PD acquisition may be performed at the termination ends of the cable circuits, i.e. through the measuring Current Transformer (CT) installed in the switchbox. In many cases, the acquisition is conducted at the substations or the transformers, which are located in an isolated and remote area. Under the online operation conditions, special access and authorisation is required to conform to the health and safety regulations of the corresponding power company. An important design consideration is appropriate circuit protection regulations at the substation.

This paper proposes a remote controlled partial discharge acquisition unit that will address the problems of the online PD acquisition and PD analysis. In section 2, the remote control partial discharge unit is described in detail. Aspects of PD acquisition unit design and PD analysis will be covered in this section. Results and discussion from the expected field data and analysis is presented in section 3. In section 4 some conclusion are presented.

2. PD ACQUISITION UNIT

The main purpose of the remote control PD acquisition unit (RPDAQ) is to provide PD data for research purposes and ultimately towards the development of an independent system for PD detection and location for HV underground cables. The RPDAQ performs the acquisition of the PD signals from the cable circuits under online conditions. The initial prototype of the system was designed specifically for the 33 kV networks in Scotland. Generally, the circuit configurations of the 33 kV networks are almost identical. The flow chart design of the RPDAQ is shown in fig. 1.

The monitoring of the cable circuit and PD data acquisition begins with the deployment of the RPDAQ at the targeted substation. The RPDAQ is a PC-based system equipped with remote control access features that enables the user to program the acquisition parameters either on site or remotely. The data can be accumulated over days and weeks, depending on the user defined frequency and quantity of data acquisition. The storage of data in a removable medium allows its retrieval by delegated authorised personnel.

The RPDAQ was designed to address the difficulties and challenges produced by the online PD detection conditions. Major factors considered in the design were the type of detection, whether narrowband or wideband, heavy noise interferences, bandwidth requirements for PD detection, and the type of post processing analysis. It was planned that the PD data was to be interrogated with a combination of time and spectral domain analysis through advanced digital signal processing methodologies.

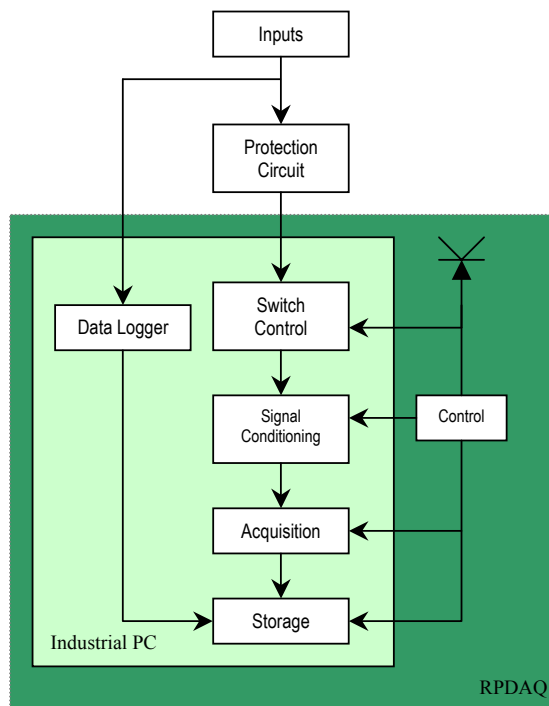


Figure 1 :- RPDAQ system flow chart

At the site, the input connections are made to the corresponding auxiliary CT's of the 3-phase circuit. These CT's are required to have a wide bandwidth and high frequency response to facilitate transient and PD detection. Auxiliary CT's are usually not used, or rather kept for condition monitoring purposes. In total, there will be three outputs from the three phase CT's fed into the RPDAQ. When a PD occurs, the PD current pulse will propagate along the cable towards the terminations of the cable. The arrival of the PD pulse at the CT's will be detected and coupled into the RPDAQ.

Since the RPDAQ will have permanent connection to the CT's for the period of observation and data acquisition, a protection circuit is required to accommodate surge over voltages and system failure. In the event of surge over voltage or fault in the RPDAQ, the protection circuit acts as isolation between the RPDAQ and the CT's. If a fault occurs on the RPDAQ, this would avoid the protection mechanism of the substation from being activated. The protection circuit is custom built according to the specified requirements of the

collaborating power distribution company.

The protection circuit of the RPDAQ is illustrated in fig. 2. The main input to the protection circuit is divided into low frequency and high frequency content. This design was to incorporate the difficulties of protection against fast transient over voltages. The low pass filter has a cut-off frequency (f_{c1}) designed to preserve a clean 50 Hz power frequency, which is used for triggering purposes and phase alignment with the PD. The high pass filter separates the high frequency components from the power signal at a cut-off frequency (f_{c2}) of 100kHz where the PD components together with the noise interferences are preserved. The outputs of the protection circuit are sent to the RPDAQ.

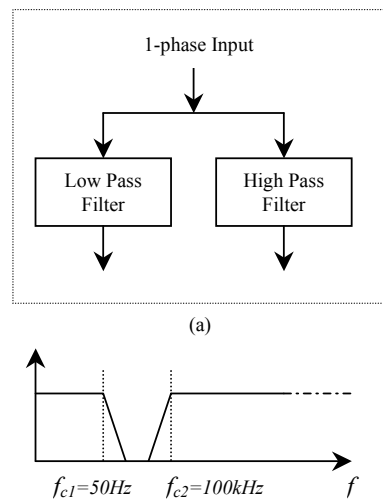


Figure 2 :- Breakdown of protection circuit

The RPDAQ comprises of a custom built industrial PC mounted into a weatherproof-shielded box. The custom built industrial PC comprises of a data logger, the switching unit, signal conditioning unit, data acquisition unit, storage, and transmission or control unit. The PC is equipped with pre-processing capabilities for on-site of signal analysis, if required.

The current data logger was installed in the design to facilitate the analysis of the relationship between the line current and partial discharge activity. The effects of current loading are taken into consideration by monitoring the line current and its loading conditions. For this purpose, the current on one phase of the circuit is sufficient. A current transducer is connected to one of the inputs to RPDAQ. The line current can be monitored at a programmed time interval and stored in the hard drive of the PC.

In the switching control section, a software-controlled switch is used to select the desired phase(s) of acquisition. It can be classified into two categories i.e. single or dual phase measurements. In the single-phase measurements, the switch is programmed to select one of the three phase inputs for acquisition and two phases out of the three phase inputs for the dual phase measurement, depending on the choices of signal acquisition. The chosen signal is then fed into the

signal-conditioning unit.

The signal-conditioning unit is represented by a band pass filter that has a bandwidth of 100 kHz to 30 MHz. It is electronically controlled hence the choice of band pass window size is adjustable and can be modified according to the desired window size. The purpose of this section is to enable the user to select any particular bandwidth of the signal for PD analysis or noise analysis. This is an important feature in the detection of PD's because it allows a robust selection of narrowband detection or wideband detection and for enhancing the PD analysis or noise rejection.

The processed signal is then fed into the acquisition section, which consists of a high-speed analogue-to-digital converter card within the PC. It has a maximum sampling rate of 100 MSamples/sec on a single channel and 50Msamples/s on dual channel mode, with a 14 bit resolution. Based on previous PD acquisition experience, high sampling rates are required together with a reasonably good resolution to capture the effects of the PD signal [4]. In this case, the acquired signal can have content up to a maximum of 50 MHz (on single channel mode). It is very advantageous when applied for time domain reflectometry (TDR) purposes as it provides a balance of good time and amplitude resolution. The ADC card has 8 Mbytes of onboard buffer memory. At high sampling rates, this allows the continuous acquisition of data until the complete buffer is filled, then it is dumped into storage unit. At low sampling rates, long continuous acquisition of data can be performed, usually for statistical analysis.

When the ADC buffer is filled, the data is stored into the hard disk of the PC in binary format. The filenames of the data are stored in a systematic method to provide identification to the acquisition settings. The RPDAQ has one designated removable hard disk drives installed. It is estimated that with a 40 Gbytes capacity hard drive, 400 seconds of PD data is available (acquired at 50 MS/s).

The RPDAQ is controlled by central controlled software that can be operated on-site or remotely. For the remote connection a GSM modem is used as the means of the remote communication device. The remote user is allowed to perform a connection through a dial up system, with a secured authorisation access. The software runs under a layer of TCP/IP communication modules. When the connection is established, the RPDAQ enables the user to insert or modify all the acquisition parameters on the system, for instance the sampling rates and the selection of circuits. The system is programmed to store reports and log files. Log files that are automatically sent back to the remote user.

3. PD DATA SIGNALS

The binary data files saved by the RPDAQ are primarily analysed under the Matlab environment. Advanced digital signal processing such as wavelet analysis, neural networks, fuzzy logic, etc, can be implemented on the data signals [5].

Therefore, for certain types of analysis, the acquisition parameters of the RPDAQ have to be set to provide the necessary required data. For example, in the PD statistical analysis the observation of the PD characteristics i.e. amplitude, repetition rates, phase location, PD pulse shapes, requires a continuous sequenced multiple cycles of PD data. Thus, the sampling rate of the RPDAQ can be set to a lower value in order to fulfill the requirements.

The expected data signals from the RPDAQ can be illustrated in fig 3. The full signal shown in fig 3a provides the relative phase of the PD to the 50Hz signal. In fig 3b, the signal without the 50Hz power frequency is depicted. The amplitude of the PD indicates a distinct fluctuation, which may be due to the combination of the nature of the discharge and the noise interference levels.

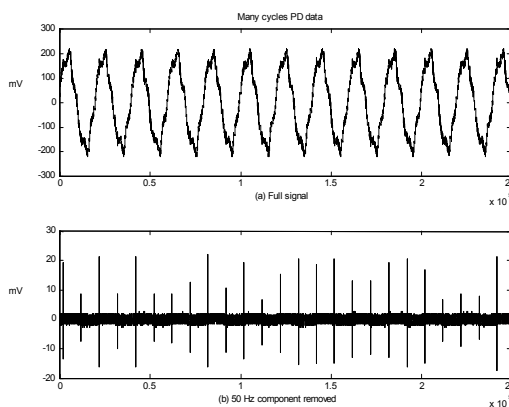


Figure 3 :- Statistical PD analysis data

This data is obtained from a pre-prototype measurement conducted on one of the phases of a typical 33kV network substation in Scotland. The measurement set up is illustrated in fig. 4. The connections were made to the auxiliary CT. The connection was separated into 2 channels for acquisition, one with the 50Hz power frequency and one with the high frequency components.

The high frequency component was separated by a series connection of a high pass filter with a 50Hz cut-off frequency and a band pass filter windowed at 300kHz to 20MHz. The signals were then fed into an oscilloscope with 8-bits resolution and a maximum sampling rate of 2 GSamples/s.

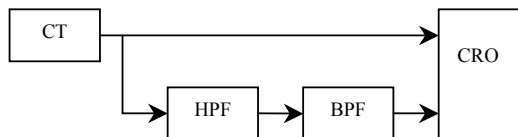


Figure 4 :- Pre-prototype acquisition set up

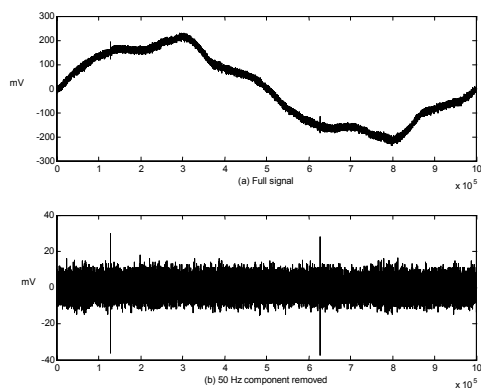


Figure 5 :- One cycle PD data

Figure 5 depicts the acquisition of one cycle of PD data for the red phase. This was performed at a sampling rate of 50MS/s. The applications associated with this type of data are mainly for PD detection and location, PD signature analysis, and noise reduction techniques.

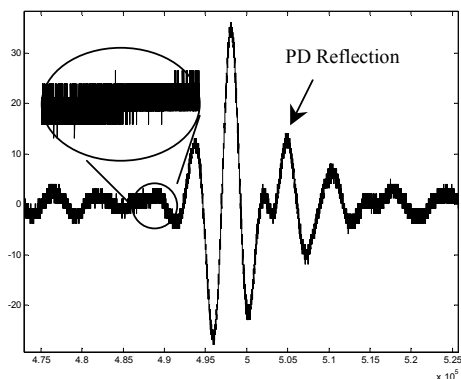


Figure 6 :- Zoomed PD structure

In figure 6, the zoomed PD structure is depicted with the sampling rate at 2GS/s. The magnitude of the PD in this circuit was significantly higher than the noise level, but generally it may be comparable with the noise interferences. The spectra analysis exhibits a band pass type signature thus suggesting a band pass filter should be utilised in the acquisition process for signal enhancement. The effect due to superposition of the reflected PD signal and the original PD signal is indicated in the fig 6. One major research challenge is to extract the reflected PD signal from the raw data itself in the noisy condition for PD location.

In fig. 6, an important observation was the quantisation error produced by insufficient amplitude resolution caused by combination of the 2GS/s sampling rate with the 8-bit data acquisition. The reduction of quantisation errors is beneficial to the event where a PD reflection is comparable with the noise levels of the signal.

4. CONCLUSIONS

In this paper, a remote controlled PD acquisition unit has been presented together with some preliminary results from this system. The features of online PD acquisition were highlighted and some important factors of considerations were the sampling rates, resolution of acquisition, and noise reduction or PD enhancement techniques. In the long run, the RPDAQ will be enhanced to incorporate automatic detection and possibly location of PD in underground cable networks.

5. ACKNOWLEDGEMENT

The project is financially supported by the University of Strathclyde and is done in collaboration with Diagnostic Monitoring System Ltd. (DMS) and Scottish Power Plc. The assistance provided by Fraser McPherson from SP Power Systems, by David Templeton and Tom Pahnke from DMS is gratefully acknowledged.

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