DESIGN AND FIELD TEST OF LOW-COST ONLINE MONITORING SYSTEM IN MEDIUM VOLTAGE UNDERGROUND CABLES

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ABSTRACT

This paper presents work carried out to characterize partial discharge activity in medium voltage power cables. The project developed is a data acquisition equipment based on current and voltage sensors and an industrial PC. Data acquired has been processed offline.
Furthermore, a Rogowski coil current transducer has been designed with the capability of measuring currents in a wide bandwidth between 50 Hz and 1MHz.
The results will be used to analyze the capability of both systems working together as an online monitoring system of medium voltage power cables.

INTRODUCTION

This research present some partial results of the DENISE project, led by the electric company ENDESA and a consortium of over 30 firms and research centres, developing various technologies related to the concept of intelligent electricity networks. HC Energia and the Electrical Engineering Department of Universidad de Oviedo have developed the present work.

The final aim is to make an online monitoring system capable of measuring partial discharge activity in medium voltage power cables and other events in the whole frequency range since 50 Hz.

With this purpose, a data acquisition system has been designed. In addition, a current transducer prototype based on a Rogowski coil has been developed with the objective of putting both systems together working as a cheap and flexible online monitoring system.

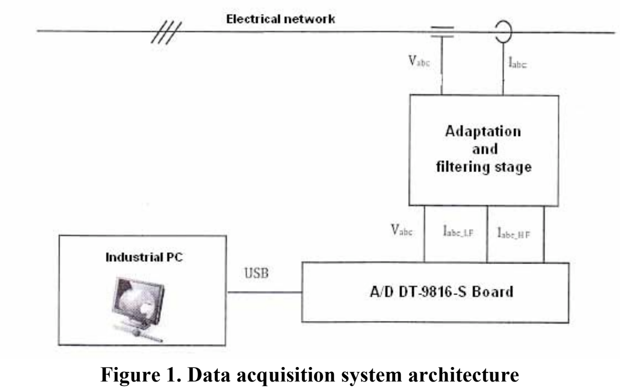

Figure 1. Data acquisition system architecture

This project has been worked out in order to realize possible defects at underground cables from the partial discharge activity measurement, as well as detect usual 50 Hz signal, making able to analyze harmonic distortion and other low frequency events related to the power quality disturbances.

PARTIAL DISCHARGES

Many problems of underground cable systems are caused by internal defects, mostly concentrated in the joints, which causes partial discharges. A partial discharge (PD) can be defined as a localised dielectric breakdown of a small portion of solid or fluid electrical insulation system under high voltage stress, which does not bridge the space between two conductors.

Once the PD activity has started there is a progressive deterioration of insulating materials of the cable, increasing the number and intensity of discharges. This cascade process my lead de cable breakdown.

When partial discharge is initiated, high frequency transient current pulses will appear and persist for a small amount of time that could be from nano-seconds to micro-seconds. Electromagnetic waves propagate away from the discharge site in all directions. Detection of the high-frequency pulses can identify the existence and location of the partial discharge [1].

DATA ACQUISITION SYSTEM

<u>Industrial PC</u>

A PC is needed to hold the capture software and store the data acquired from the cable signal. An industrial PC is preferred rather than a domestic one because the system will be located in a dusty environment sensitive to electromagnetic interference. The PC must have two USB ports to connect the data acquisition cards.

A Pentium IV has been used for the prototype, with a microprocessor speed of 3GHz, 1Gbyte of RAM and a hard drive of 500 Gbytes, which is dedicated exclusively to store data, acquired from the cable. With the acquisition frequency that has been configured, until 18 hours of data can be stored.

Sensors

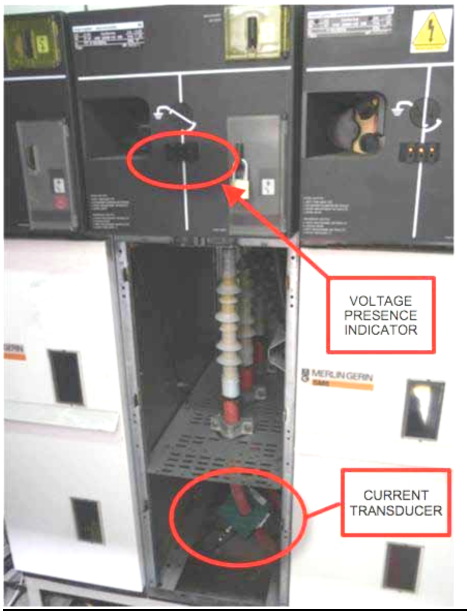

Figure 2. MT cublicle and sensors location

Voltage sensors

Measuring voltage from underground cables an be achieved by using a continuously voltage presence indicator located in MT/BT substations cubicles. Nevertheless, a self-made resistive divider is used to attenuate the signal that will be sent to the electronic filters.

Current sensors

In a first approach, a commercial current transducer, Pearson Electronics 3525 model has been used to test the data acquisition system whose features are shown in Table 1.

Sensitivity	0,1 V /A
Peak current	5000 A
Current (RMS)	100 A
Output connection	BNC
Bandwidth (-3dB)	From 5 Hz to 15 MHz

Table 1. Current sensor features

Another alternative is to install a Rogowski coil current transducer that has been developed whose features and results are exposed later in this paper.

Filters

The output signal from the sensors has been brought under an electronic process to separate low and high frequency signals.

The electronic system consists of two filters, a low-pass and a high-pass one. Both have been designed with a cutoff frequency of 11,3 kHz.

Figure shows the scheme of the low-pass filter, designed in Sallen-Key structure. A preliminary stage is included to give the possibility to amplify the signal as a function of resistances R1 and R2.

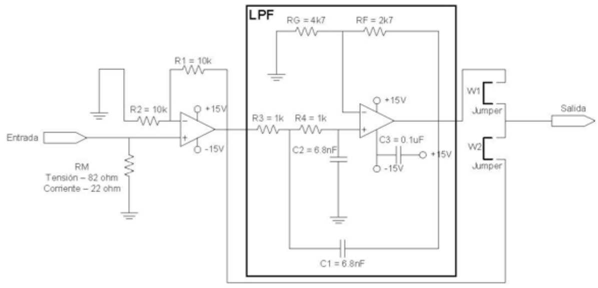

Figure 3. Low-pass filter scheme

The high-pass filter configuration is achieved by simply exchanging resistances and capacitors in the Sallen-Key structure (R3, R4 and C1, C2).

Data acquisition cards

To obtain voltage and current measurements two acquisition cards, (DataTranslation, DT9816-*S* model) have been used, with 6 input channels each one. These inputs are connected to the outputs signals from the filters.

These cards have an A/D conversion time of 950 ns, an acquisition time of 1 us per channel, a sampling frequency of 750 kHz and a bandwidth (-3 dB) of 40 MHz.

Data transfer and storage

An industrial 3G modem has been used to connect the industrial PC with a remote computer where the signal processing software is installed.

The modem has been configured to give access to the industrial PC to a FTP server and a VNC service. Then it is allowed for servers to enter from the remote computer and download the data acquired or manage the industrial PC.

Data processing software

Virtual Scope

The software Virtual Scope should be installed in the industrial PC as an interface between the computer and the data acquisition cards that have been used in the prototype.

The main function of the software is to obtain the data from the acquisition cards. It allows the user to configure the number of cards, sampling frequency, capture time and time between one captures. It is also allowed to stop and start the captures.

Partial discharges detection

Several algorithms have been designed to analyze waveforms and detect partial discharges activity based on [1,2]. The software is programmed in MATLAB and it allows the user to analyze the signal either in time or frequency domain, as well as make a wavelet analysis.

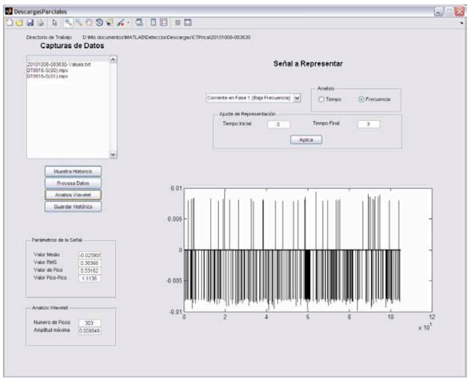

Figure 3. Software designed to detect PD activity

ROGOWSKI COIL CURRENT TRANSDUCER

An electrical model with lumped parameters has been used to study the theoretical frequency response of the Rogowski coil [3,4].

The transfer function of the coil can be determined from

$$\frac{V_{out}}{I} = \frac{ZMs}{ZCLs^2 + (ZCR + L)s + R + Z}$$

Where Z is an external resistor connected between coil terminals, which is needed to avoid resonances at high frequencies, and i is the current to be measured. Therefore, the typical frequency response of a Rogowski coil is shown in figura 5.

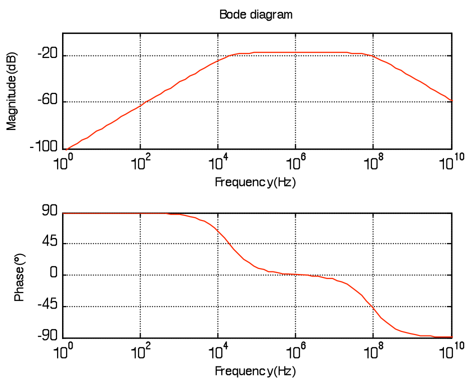

Figure 5. Typical frequency response of Rogowski coil

The objective is to design a Rogowski coil with the suitable geometric features to obtain enough sensitivity at 50 Hz and a wide bandwidth at high frequencies. Then, low frequency signals will be processed by an electronic integrator so the final result will be a plane response with zero phase angle at both high and low frequency ranges. The electronic system designed is based on operational amplifiers and it is shown in figure 6.

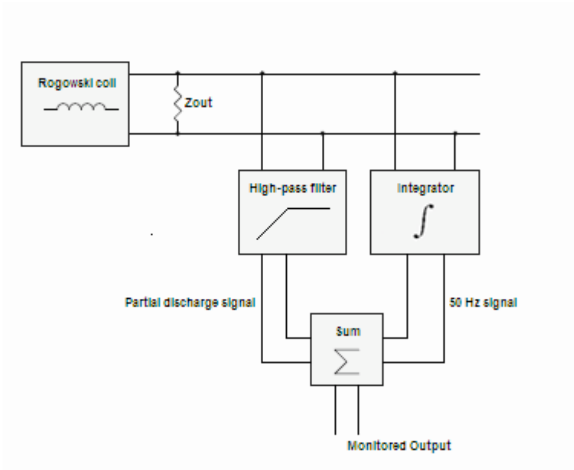

Figure 6. Current transducer block diagram

Therefore it is necessary to increase the inductance of the coil, L, and it can be achieved by two ways: increasing geometric parameters or increasing the number of turns. It is preferred the second option, as the first one would involve to make a huge and expensive coil.

The number of turns needed to achieve the desired response is very high so the solution adopted in this project is to design a multi-layer Rogowski coil. It is important that each layer may have the same number of turns and the total number of layers must not be pair so then the returned loop inside the toroid and all the layers will avoid induced voltages due to external magnetic fluxes.

It is also recommended to build the winding as uniform as possible to have a constant density of turns. Thus, the voltage induced will be independent of the position of the current within the loop.

RESULTS AND CONCLUSIONS

In this paper, the early stages of the development of a low-cost online monitoring system in medium voltage underground cables were described. The system has been assembled in a portable enclosure as show in figure 7.

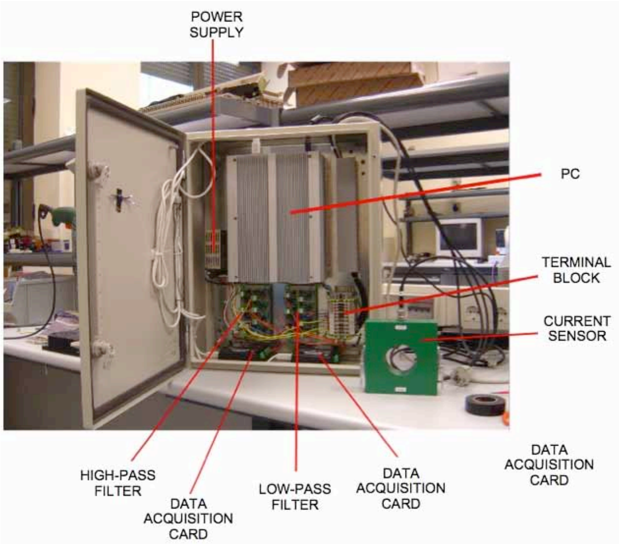

Figure 7. Data acquisition system layout

In addition to the laboratory testing where PD activity in MT cable joints was successfully detected, an on-site trial has been set up to develop and verify the system performance. Tests are being carried out on several 24 kV underground cables in which a previous commercial offline PD measurement has been conducted.

Figure 8. Data acquisition system installed in a MT substation

Thus far it has not been possible to detect any activity related to partial discharges, results also confirmed by the commercial offline equipment. Future works will be aimed to test the system in different MT substations.

The current transducer was tested imposing a sinusoidal voltage between resistor terminals using a low power function generator. The wire used to connect the resistor to the generator was passed through the loop of the coil several times to simulate the current of a medium voltage cable.

Figure 9 shows the signal from the output of the electronic sensor designed. A constant sensitivity with zero phase angle has been achieved from 50 Hz to 1 kHz at low frequencies and from 100kHz to 1MHz at high frequencies. At frequencies up to 2 MHz, the coil presents unexpected resonances probably due to the multi-layer structure that may increase coil capacitance.

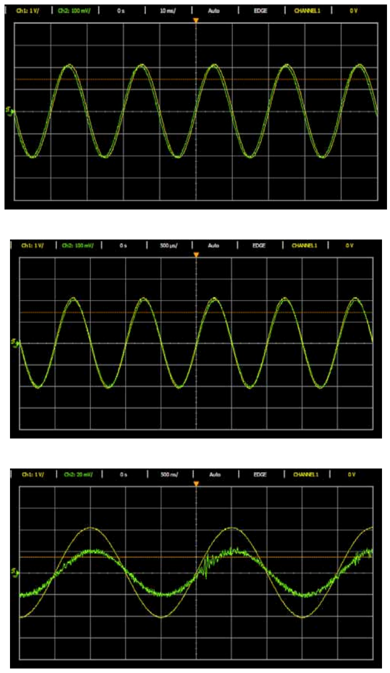

Figure 9. Current transducer response. 50 Hz (up), 1kHz (middle) and 500 kHz (down).

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