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DIGITAL TECHNIQUES FOR PARTIAL DISCHARGE MEASUREMENTS IN UTILITY GENERATORS

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Abstract

In this paper a digital implementation of different partial discharge measuring methods is presented and results of tests on hydroelectric generators are discussed. It is shown that conventional digital oscilloscopes can be used as an interesting alternative for these techniques, instead of using expensive dedicated electronics.

Introduction

Many methods are used for the diagnostics of the insulation of large generators. They are based on the measurement of partial discharges and it is important to identify its origin. They can be internal discharges, surface discharges, corona, etc..
Conventional equipment for partial discharge measurement in large generators, is based on the detection of high frequency pulses and analogue processing. This processing depends on the technique used. In some countries it is a common technique [1] to measure the partial discharge level using narrow pass band filters. The filters are centered on frequencies from 10 kHz to 130 kHz. This technique has some discrimination on the location of the discharges. The higher frequencies are attenuated by the winding impedance while the lower show the general level of the whole winding. The output of the filter is measured by a quadratic mean detector and the results are expressed in dB. This technique does not analyze the types of discharges, or their position related to the phase of the power frequency cycle. Anyway, there exists a wide experience using this procedure and it is possible to implement with digital techniques. The signal is captured with digital oscilloscopes and the filter and the detector can be implemented using computer processing.
Another technique measures the peak value of the pulses detected. The filter used is a broad band filter, and there is a correspondence between the peak pulse and the peak values of the discharges. The implementation using digital techniques is easy taking into account the characteristics of the digitizer and the frequency band analyzed.

On the other hand, digital processing permits to measure new parameters. It is possible to discriminate the quantity of discharges related to the phase position and implement other sophisticated methods. It has been proposed to analyze the accumulated distribution on a Weibull diagram [2]. Internal discharges produce straight lines, while slot discharges present different patterns.
For many years the identification of the pattern of the discharges in the power frequency ellipse was done by eye. The interpretation depends on the experience of experts. The use of digital techniques has given new possibilities for automated diagnostics of the insulation. The equipment used so far is specifically designed for this application [3,4] and they use a peak detection technique. The system captures only the peak magnitude of the discharge signal and converts it to a digital value. Special fast circuits are used for the sample and hold and data converters. Although this type of equipment is commercially available it is very expensive. With new low cost digital oscilloscopes, this technique can be implemented, and the cost of the equipment can be reduced. It is necessary to download the information of the oscilloscope to a personal computer and with the aid of software analyze the data. In this paper we introduce a system developed with a low cost digital oscilloscope connected to a personal computer through IEEE 488.

Proposed System

Measurement System Description

The arrangement for this system includes an analogue sensing circuit, a digital oscilloscope, some interfacing circuit and a computer. The sensing circuit detects the discharges and adapts the signal to the adequate levels for the input circuits of the oscilloscope. The oscilloscope detects the peak values of the discharges and sends the data to the computer through its interface IEEE 488. The details of these are presented in the following sections.

Analogue Sensing Circuit.

The system uses a conventional circuit to detect the partial discharges pulses. The measuring impedance is connected in series with the coupling capacitor. The impedance is formed by an inductor. The coupling capacitor is a 1000 pF, discharge-free, high voltage capacitor with a nominal voltage of 25 kV. The signal picked by the impedance is then fed through a shielded cable to an analog band pass filter. The high cut off frequency of this filter is 300 kHz. The output of this filter is fed into the oscilloscope. The peak value of the pulse is proportional to the electric charge across the insulation of the generator. The frequency response of the system is that of a wideband circuit. The output signal is a pulse with very little oscillation and its length is approximately 30 μs.

Digital Oscilloscope.

With a digital oscilloscope two different techniques can be used. One of them acquires the full waveform of the discharges and after processing the information the peak must be detected. This technique is difficult to implement because of the practical limitations in the

instrumentation. The sampling frequency of the oscilloscope must be high enough to make it possible to reconstruct the waveform of the pulses. This is no problem but as it is necessary to gather information for some time the data records become too large.
In this method the full waveform is acquired and downloaded to the computer. Figure 1 shows the response of the proposed measuring system for the calibration pulse. To assure the capture

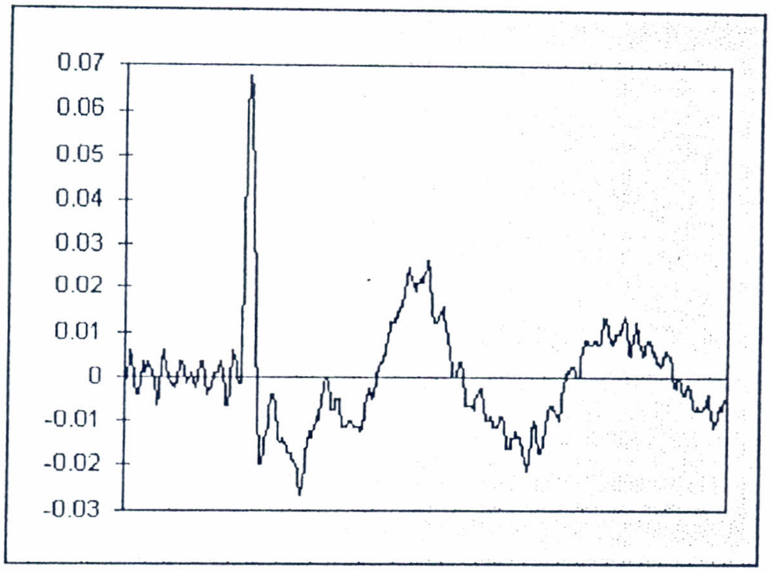

Figure 1
calibration pulse

of the peak value with an error lower than 10%, the sample rate must be, at less, 0.1 μs. With an oscilloscope of 8 kbytes of memory length, the power frequency period must be divided in 800 μs windows. This gives a total of 25 windows to complete the 20 ms period. The trigger of the oscilloscope is delayed each subsequent window. This is automatically done by the computer. The data saved to disk is analyzed to find the peaks and to measure its magnitude. This values are stored in an array to find the amplitude histogram and other calculations. The total time needed to acquire 50 power frequency cycles is about 20 minutes. This is a very long time for this test, and the principal cause of poor performance of this method. Anyway, the method was implemented and evaluated. It has the advantage that it can analyze the behaviour of each pulse, and can discriminate between discharges and noise. On the other hand, this method will be useful as new and powerfull oscilloscopes arrive at the market.
In the second technique, the oscilloscope is used in the peak mode. Lately new oscilloscopes have appeared that have peak detection capabilities. In this acquisition mode the whole record is divided in time windows with adjustable length. The oscilloscope samples at its maximum sampling rate and only keeps the maximum and minimum of the signal in the time window. With this technique the amount of information is small and it can be quickly transferred to the computer. In the oscilloscope used in the proposed system (a very cheap model), the record length is divided in 1250 windows with a time base of 2.5 ms/div. If a whole power frequency cycle is displayed, the window length is 16 μs. However the acquisition is run at maximun sampling rate (1GS/s) This window is in the order of the duration of the pulses. This assures that no pulse will be lost and that only one pulse will be counted. With this acquisition mode

there is no need for the software to find peaks so the code is easier and the processing time is reduced. The total time nedeed to acquire 50 power frequency cycles is less than 2 minutes. Even during this time, the adjust of the tan delta bridge is done. The advantage of this technique is clearly seen.

Interface circuit.

A commercial solution available in the market was used for this circuit, based on the standard IEEE 488. A plug in card for the computer and its drivers were used. Some software was developed to control the oscilloscope and download the data from it. The data is encoded in binary format to reduce the transfer time.

Software

The software was developed under LabWindows ver 2.3a. It controls the IEEE 488 interface of the computer, sends commands to the oscilloscope and saves to hard disk the information received. The user can choose the number of cycles to be acquired. When the test is finished the files are converted to ASCII format. The files contain information on the magnitude and position of the pulses in the power cycle. A Matlab procedure was developed to process automatically these files. It then plots the distribution of the discharge magnitude by analyzing the number of pulses as a function of apparent charge. The observation of these histograms gives important information about the source of the discharges [5]. In figures 2 and 3 examples of magnitude distributions areshown. Clearly each distribution is characterized by its specific shape.

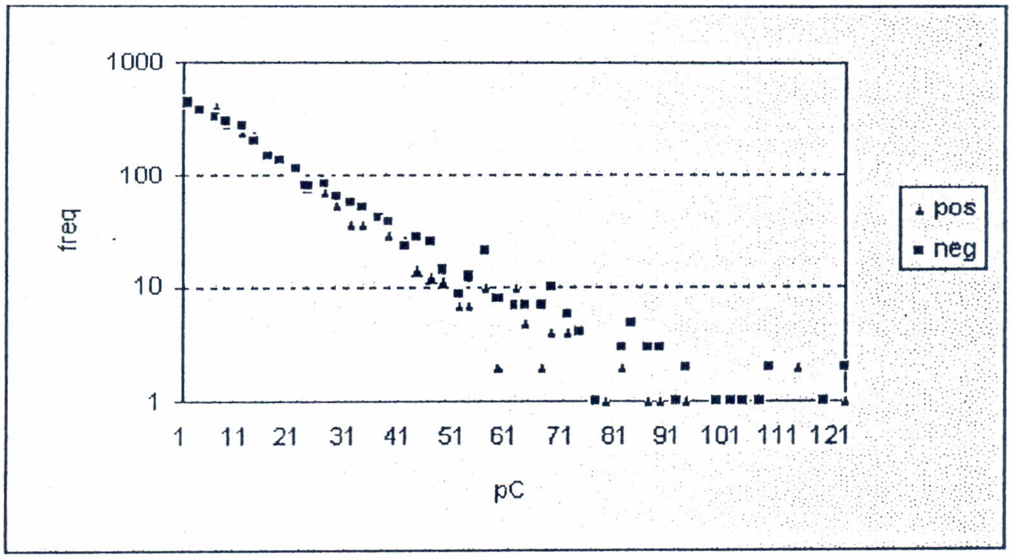

Figure 2
Histogram of discharges in bars

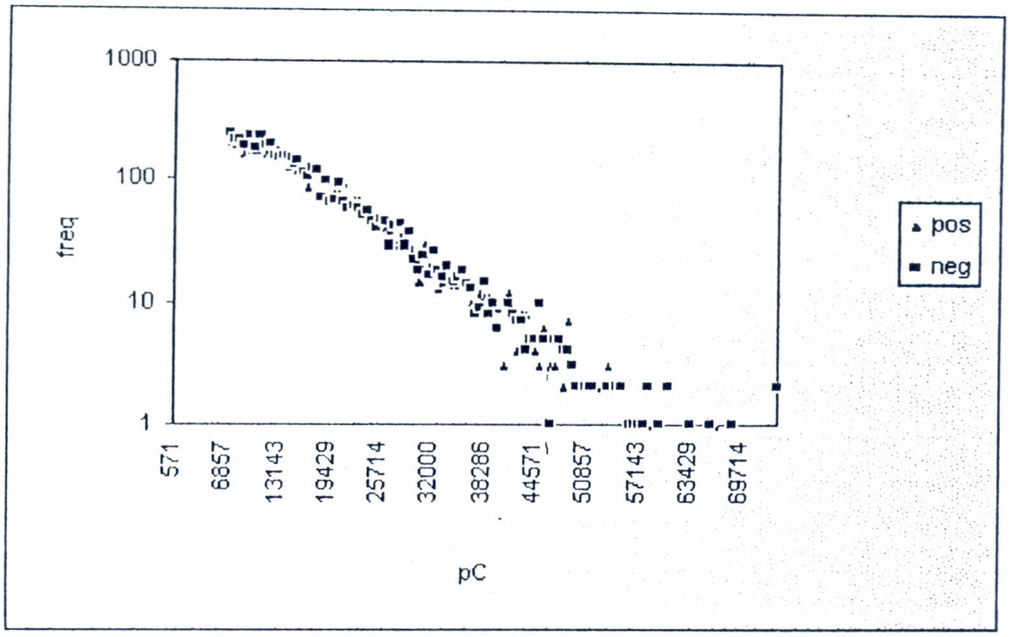

Figure 3
Histogram of discharges in machine

Another analysis done by the software is to plot the cumulative distribution on a Weibull graph[2]. This plot gives additional information for the diagnosis. It has been said that the Weibull plot generally fits the cumulaiive distributions when there is only one source of discharges. That is the case of new single bars. When the insulation deteriorates, deviations from the Weibull distribution appear.

Experimental results

The proposed method has been tested in field tests on generators and in our laboratory on old and new stator bars.

In figures 4 and 5 results from different tests are shown. Figure 4 corresponds to a single bar tested at 0.8 Un. The step like form of the graph is due to the few cycles acquired. The bar was taken from a hydrogenerator under repair. Figure 5 shows the distribution for a hydrogenerator. Both distributions for positive and negative pulses are shown together with theoretical Weibull lines for single source defect. Clearly their shapes depend on the condition of the insulation.

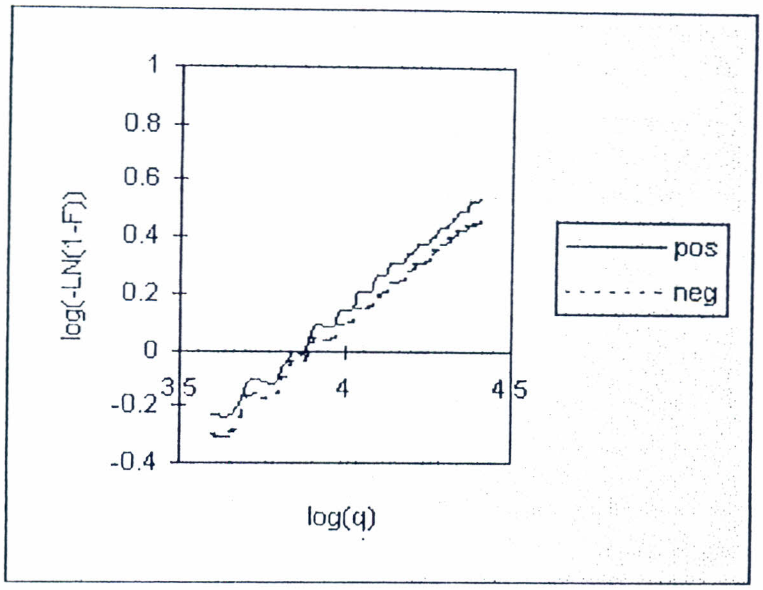

Figure 4
Weibull graph for single bar

During field tests we found that many aspects should be considered. In new bars, the noise present can be important compared to the discharges. It is necessary to mask the pulses caused by noise so that they do not affect the count of pulses. One solution could be to determine a noise level by eye during the test and then disregarding all pulses below that level. For noise that appears in fixed places, it is possible to mark their phase angle, and disregard them in the digital processing of the data.
It is also important that other noise sources are identified. Noise due to electrical equipment is easy to identify. The software can ignore those pulses that are of the same shape.

Conclusions

In this paper different digital techniques were discussed. Two different methods using digital oscilloscopes were compared. It is shown that the requirements in data storage are too much if one is going to acquire the full waveform. Newer low cost oscilloscopes have appeared with peak detection capabilities. Using this equipment gives the opportunity to develop a partial discharge measuring system. The development of software for control and analysis is described. Results obtained from field measurements are shown.

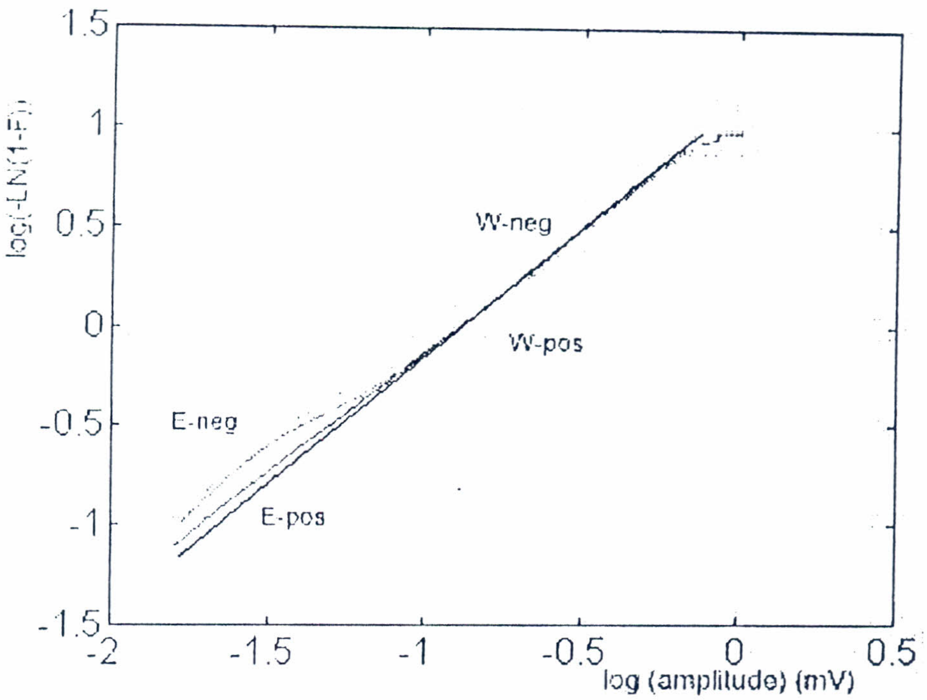

Figure 5
Weibull graph for machine

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