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DIGITAL TECHNIQUES IN HV TESTS — SUMMARY OF 1989 PANEL SESSION

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Abstract: A panel session on digital techniques in HV tests was held at the IEEE PES Summer Meeting in Long Beach, CA (July 1989). This panel addressed the question of how signal processing can be used to enhance High Voltage Tests and extract more information from them. Part 1 dealt with the evaluation of digitizers and records and Part 2 dealt with the application of digitizers to industrial testing. This paper presents an outline of the Panel Session and lists pertinent reference material.

INTRODUCTION

The first standard covering the application of digitizers to High Voltage Impulse Measurements was published in 1987 (IEEE/ANSI 1122-1987 [1]). This standard states the requirements for an impulse digitizer and the tests necessary to verify that these requirements have been met. When an impulse digitizer is used and maintained in accordance with this standard it will meet or exceed the accuracy requirements presently demanded for surge oscilloscopes. A major difference between an oscillogram and a digital record is that the latter has a non-linear character that is introduced by the acts of sampling and quantization. Imperfections in the practical implementation of sampling and quantization will lead to increased non-linearities. The approach taken in the standard is to limit these non-linearities to values which are sufficiently small that the digitizer can be treated as a quasi-linear device. In addition, resolution and sampling rates are specified to ensure that the resolution of the impulse digitizer is as good as, or better than, that of the best available surge oscilloscopes. Impulse digitizers must meet the accuracy requirements without any signal processing of the raw data. If these requirements are met, then signal processing is permitted in order to enhance the accuracy of the reading.

This paper summarizes the papers that were presented at the Panel Session and does not imply endorsement of any individual's opinions by the PSIM, its Sub-Committees or Working Groups. The full text of these papers were distributed at the meeting and copies can be obtained from:

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CALIBRATION OF IMPULSE DIGITIZERS

T.R. McComb, NRC, Ottawa, Canada

Methods and costs of establishing the voltage and time scale factors of digitizers using "through-the-instrument tests" (in which a known input is applied and the output of the digitizer is read) were discussed. Results from several different digitizers were presented. Further results can be found in the works quoted in part A of the Bibliography.

DYNAMIC TESTS ON DIGITIZERS

J. Kuffel, Ontario Hydro, Toronto, Canada

The differential non-linearity under dc conditions can be calculated from the dc calibration. However, at very high rates of change of input, the DNL may increase drastically and in many digitizers this sudden increase in DNL sets the high frequency limit of the recorder. Rather than attempting to measure the code transition thresholds at high rates of change of the input voltage, the DNL can be inferred from the statistical distribution of a large number of records of any known signal. The signal recommended in [1] is a triangular wave, as this provides a uniform rate of rise which facilitates ensuring that the digitizer under test is capable of measuring the front of an impulse. Results taken with triangular waves were presented. Additional results using sine waves were also presented. Further results can be found in the works quoted in part B of the Bibliography.

ALGORITHMS FOR READING PARAMETERS

E. Gockenback, E. Haefely, Basel, Switzerland
(Now with Schering Institute, Hanover, Germany)

and

ROBUST ESTIMATION IN PARAMETER EXTRACTION

C. Fenimore and Y.X. Zhang, NIST
Gaithersberg, MD, U.S.A. (Y.X. Zhang is now with Hipotronics, Brewster, NY, U.S.A.)

These two papers presented methods of evaluating parameters from digital records. The first paper concentrated on evaluating parameters of full impulses and the particular problems posed by impulses with overshoot and/or oscillations. Simple methods of reducing the scatter in parameters were presented together with test results. The second paper considered the problem of evaluating the parameters of the unit step response of an impulse measuring system. The method used should be robust: that is, the estimates should not be sensitive to noise or small variations in the input. Using cubic splines to fit the waveform provided an objective interpretation of "the mean curve" and "the steepest tangent line" and the derived time parameters of the step response. Direct application of the standard definitions gave estimates which were sensitive to the selected window size of the fitting splines which indicated sensitivity to small changes in the data. Redefining the tangent as the best-fitting straight line along the rising portion of the step gave robust estimates of the parameters. Further results can be found in the works quoted in part C of the Bibliography.

DIGITAL FILTERING OF HV LIGHTNING IMPULSES

K. Schon, PTB, Braunschweig, Germany

The recorded data are approximated in parts, i.e. within a "moving window", by least-squares adjustment to a suitable smooth approximation function which may be a polynomial or a Fourier series. The window covers the samples ranging from number k-N to K+N, where k is the running number of the sample, y_K, to be filtered, and 2N+1 is the window width which must be carefully chosen for effective smoothing. The samples within the window are weighed according to the weight coefficients, w_i. The filtered sample at the time kt, in the center of the window, is then:

$$y_k = \sum_{i=-N}^{N} w_i \cdot y_{k+i}$$

The sample interval is usually uniform and the weight coefficients are symmetrical with respect to i = 0, i.e. $w_i = w_{-i}$. Digital filters can be subdivided into two groups: A) the weight coefficients, w_i, group are exclusively positive; B) some are positive and some are negative. The result of filtering a step is that filter A rounds off the edges of the step while filter B causes an overshoot. Good results were obtained for full impulses but special care was needed when analyzing chopped impulses.

CONVOLUTION/DECONVOLUTION

T.R. McComb, NRC, Ottawa, Canada

There is great interest in the use of numerical correction techniques to extend the range of "state-of-the art" impulse measuring systems. The basis of these techniques is the convolution theorem, in which the output from the measuring system, y(t), is related to the input, x(t), by the impulse response, h(t), of the measuring system by the convolution integral. If y(t) and h(t) were known analytic functions then the convolution equation would have a unique solution for x(t). However, y(t) and h(t) can only be measured with limited resolution and may be contaminated with noise: in this case the problem becomes ill-posed. The frequency response of the system can be divided into 3 regions: (1) low frequencies where the attenuation is constant and no correction is needed, (2) high frequencies where there is more than 40 dB additional attenuation and no correction can be made, and (3) a band of frequencies where correction may be made. Several authors have used deconvolution with some success and their results have been published. However, it is generally agreed that although deconvolution is a useful technique it should not be used to compensate for an unsuitable measuring system in standard impulse measurements.

Recently, a new approach has been applied to calculating the error limits of the reconstructed impulse from assumed errors in the measurements [E7]. To date this work has only been applied to probes whose step response can be measured without modifying the probe: however, it offers a new tool for use in this area.

DIGITAL TECHNIQUE FOR IMPULSE TESTING OF POWER TRANSFORMERS

R. Malewski, IREQ, Montréal, Canada (Now with 2640-0184 Québec, Inc., Montréal)

This paper reviewed techniques of analyzing impulse tests of power transformers and discussed how digitizers can be applied to impulse testing. While digitizers with resolutions of 9 bits or more can provide better records than oscilloscopes for conventional evaluation of test data, the real advantage of digital recording is shown in the new technique of transfer function analysis. The basic elements of this technique were outlined and some illustrative results presented.

A simplistic conceptual winding model is a string of inductors tapped by their parallel capacitance to ground and shunted by the parallel stray capacitance between the winding sections. Such a model is quite adequate for explaining changes in the transfer function caused by a fault in the winding insulation. Breakdown between adjacent turns in an EHV transformer usually excites an oscillation at approximately 2.5 MHz, whereas an interdisc breakdown causes an oscillation at about 0.8-1.2 MHz. In larger winding sections a fault would cause an oscillation at a proportionately lower frequency. Experiments have demonstrated that a local breakdown in the winding results in a frequency shift of one of the transfer function poles. This can best be detected by superimposing the transfer functions obtained at the full and reduced test voltages. Even a minor shift in the pole frequency indicates a local breakdown, since no other mechanism could change the frequency of the local winding resonance with the increase in the applied test voltage. In addition, the frequency of the affected pole may provide an indication of the size of the short-circuited section and, also, of its location in the winding. In this somewhat oversimplified model of the winding insulation, a partial discharge may be perceived as an insertion of a high ohmic resistance (with respect to the nearly zero resistance of a breakdown) between the affected location of the winding and the ground, or between two parts of the winding. As predictable, in a nearly resistance-free network of inductances and capacitances, this results in resonance damping. Consequently, the pole height decreases, although its frequency remains practically unchanged.

DIGITAL TECHNIQUES FOR PARTIAL DISCHARGE MEASUREMENTS

A report on the activities of the working group on digital analysis of partial discharges

B. Ward, Biddle Instruments, Blue Bell, PA, U.S.A.

The working group is addressing the subject of digital analysis of partial discharges (PD) in power apparatus. Included in its activities is a worldwide survey of ongoing research and a review of previous work in this area. A paper is being prepared with emphasis on the post-measurement processing, analysis, and meaningful presentation of the PD signals, and the significance of the presentation as it relates to insulation degradation. The paper describes currently-accepted techniques using analog type instrumentation for detection and display, presents a critical review of these techniques for assessment of the qualification of power apparatus, and shows the inadequacies of these methods in light of the new techniques using digital technology. An expanded version of the material presented at the Panel Session has since been published [2].

DIGITAL ANALYSIS OF CALIBRATION PULSES

K. Schon, PTB, Braunschweig, Germany

According to the standards, the calibration of partial discharge (p.d.) instruments measuring the apparent charge q is carried out by injecting short-current pulses into the terminals of the instrument (or measuring impedance) and into the test object. Advances since the standard was written allow digital recorders to be used to measure fast impulses and computer-aided data processing to analyze them. In these investigations, the calibration pulses i(t) of a commercially available, battery-operated pulse generator were fed into a measuring resistor R_m = 50 , and the voltage drop recorded by a scan recorder. The calibration charge was computed with a numerical integration.In one example, the calibration charge calculated was q_o = 48 pC which agreed with the nominal charge (50 pC) within the measurement uncertainty. To summarize the results of these investigations, it has been found that the calculated charges agree with the nominal values (5pC ... 5000 pC) within 10%, and that variations of the test circuit influence q_o by less than 5%.

DIGITAL TECHNIQUES IN HIGH POWER LABORATORIES

L. Van der Sluis, KEMA, Arnheim

During a test in a High-Power Laboratory both high-voltage and high currents are present in the test area. The strong electromagnetic fields make a disturbance free and accurate measurement difficult, especially when the object under test has a failure. Testing in accordance with ANSI- and IEC-standards makes it necessary to perform short-circuit tests within a fixed time interval of three minutes between tests. In this three minute time interval the test data need to be analysed and evaluated, records have to be printed and the measuring equipment must be armed for the next test.

The introduction of fiber-optic links makes it easier to use sensitive measuring equipment such as digital recorders in High-Power tests, by providing isolation between transducers in its test area and digital recorders in the control room. Both hardware and software have to be sufficiently fast to allow tests to be completed and analysed in the allocated time.

Digital recorders with high resolution and sampling speed are now available (for example, 12 bits at 10 million samples/second). This is suitable for nearly all the measurements during short-circuit testing. Memory sizes of 256 kb are large enough to store the test results at the highest sampling speed. The fiber-optic links, are (from the accuracy point of view) the weakest link in the data-acquisition system. Due to the test sequences it is practically impossible to calibrate the fiber-optic links just before or just after the test. The (battery powered) equipment must be stable and reliable. For this reason mainly analog links with frequency modulated transmission are used. It is possible to build these links with an inaccuracy of less than 1% for frequencies between 0 and 50 kHz and for frequencies up to 600 kHz with an inaccuracy of less than 5%. The signal to noise level limits the overall accuracy of the system.

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