THE DUAL TIME BASE METHOD FOR RECORDING OF OVERVOLTAGES AND SURGES IN POWER SYSTEMS AND HV ELECTRICAL EQUIPMENT

M. Gavric, Institute Nikola Tesla -Belgrade
Koste Glavinica 8, 11 000
Belgrade Yugoslavia

M. Kotlica, KES Ltd. Intern., Willowdale On. Canada
tel: (905) 707 7762 fax: (905) 707 0846
E-Mail keseng@pathcom.com

Abstract - **This paper presents method of dual time base as an optimal solution for collection of overvoltages in power systems. The method provides solution for recording overvoltages of any kind (surges, switching overvoltages and temporary overvoltages). The data collected by this method is used for statistical analysis of overvoltages, estimation of parameters in transmission lines, post accidental analysis etc. The method can be used for Partial Discharge (PD) testing on HV insulation. For the practical implementation of this method a special autonomous microprocessor based instrumentation was developed with a sampling rates of f_o and $f_o/100$. The main part of the equipment contains three synchronous A/D blocks with 8 - bit 20 MHz flash converters and adjacent memory buffers.**

I. INTRODUCTION

In general, measurements of overvoltages in power systems requires very expensive and complex equipment, as well as the separation and taking from regular operation whole tested section of power system. For exact calculation, it is necessary to know all parameters of the system from the applied mathematical model. The parameters of the system can be estimated based on experience and the response & behavior of the system in the real time. The indicated methods, can be used to test just switching overvoltages ("one time" operation) caused by the manipulation of the tested part of the network.

This paper presents the method of dual time base for continuous recording of overvoltages in the power network, with the purpose of collecting all kind of overvoltages appearing in regular operation. This way it is possible to have the most realistic statistic values of the overvoltages in the power system, since all relevant factors of the real "in service" operation are present during the test (various configurations in the network, atmospheric conditions and other relevant factors). The big advantage of this test method is a presence of overvoltages from lighting discharges, which can not be recorded experimentally. This overvoltages attenuates along the line quickly and the most interesting case is the overvoltage surge next to the station where the lighting discharge occurs. The estimation of the danger to the network from the lightning discharge is, in general, calculated based on parameters of the lightning current (references [1] and [2]), while for lower voltage levels the inducted overvoltages are of significant importance (reference [3]).

II. USE OF STATISTICAL DATA

To estimate the risk of flash over R along the insulation on transmission line, it is necessary to know statistical values for the density of the voltage spread function f(U), and a jump over characteristic of the insulation P(U). In that case there is a following:

$$R = \int_{-\infty}^{\infty} f(U)\left[1 - \prod_{i=1}^{n} \left(1 - P_i(U)\right)\right] dU \qquad (1)$$

where n is the number of insulating chains on the line.

Although P_i (U) in formula (1) is parameter given by integral, R can be calculated using numerical methods as explained in the previous papers (reference [5]). Basic problem, in the calculation for the risk of flash over, is, that formula (1) counts overvoltages along the line. $U_1.....U_n$ are functionally dependent. It means:

$$U_i = g(U_i); \quad i = 2,.....,n \qquad (2)$$

which gives

$$f_1(U_1) = ... = f_n(U_n) \qquad (3)$$

where $f_i(U_i)$ is function of probability of overvoltage density.

Overvoltages, of course, are not functionally dependent, but there is a solid correlation among overvoltages along the line. Considering the profile of overvoltages along the line, it is confirmed using simulations (reference [5]) that overvoltages are equally presumable, and instead of formula (3) can be used following equality.

$$f_1\ (U_1) = ... = f_n(U_n) \qquad (4)$$

where $f_i\ (U_i)$ is function of probability of overvoltage density along the line, which is different from formula $f_i\ (U_i)$ in formula (3). With a condition in formula (4), formula (1) is still applicable and besides the possibilities with numerical integration it allows taking into account a series of other factors for the said estimation of risk on flash over. That is why, beside the experimental measurements, that the information on overvoltages in the power network in real operation is so valuable.

III. CONTINUOUS OVERVOLTAGE MONITORING

1) *History of system development.* The first serious system for "in-service" monitoring of overvoltages was based on tgδ measurements on connecting power transformer bushing. Specially enclosed and protected coaxial cables were used for the transmission of the signals. Registration equipment was a device of limited capabilities (reference [7]).
Similar system was constructed for distribution systems (reference [4]), also with limited capabilities.
Very complex system with all capabilities of registering transient currents and voltages with a voltage dividers, special current transformers and quality registering equipment gives wide possibilities and in reality it is complete measuring station (reference [10]).

2) *The dual time base system.* The optimal system for recording of overvoltages uses HV measuring block consisting of connecting bushing on power transformer, and a optic fiber cable for signal transmission. This system avoids inconveniences of having electrical connection between the transformer and the registration instrument. These devices are not on the same potentials in transient periods and galvanic connections cause various problems and mistakes during the test.
Optic fiber system is constructed using principle of analog modulation with a wide frequency range (10KHz - 10MHz), with very low noise levels. Variation of temperature of the input signal is 1%. This is a

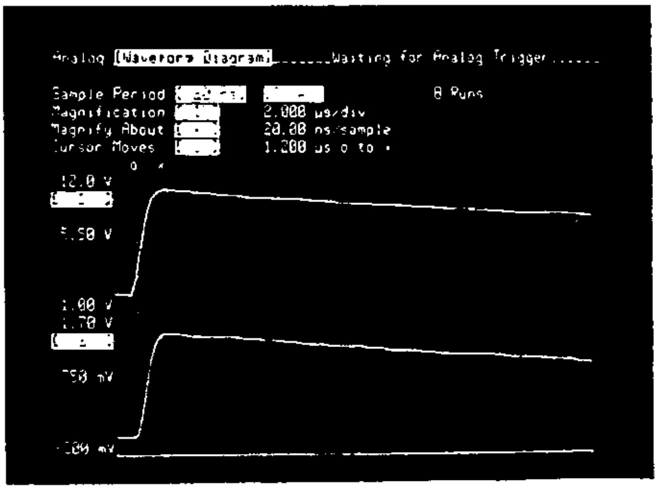

Figure 1. Incoming voltage (upper channel), and outgoing voltage through the optic fiber system (lower channel)

typical for analog transmission of the signal using optical cables. This is well within the tolerances of high voltage measuring system, and it can be also nulled if necessary. This variations are irrelevant, especially considering that overvoltages are expressed in respect to an operating voltage of the transmission line. Figures 1 and 2 are oscilograms of input and output voltages of the optic fiber system for most characteristic cases.

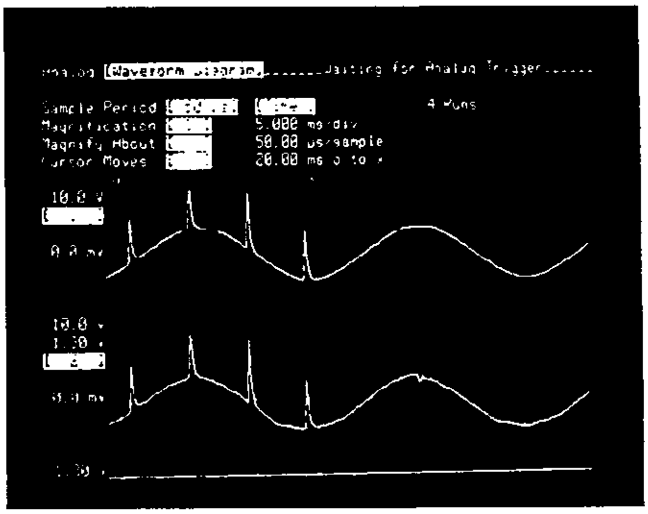

Figure 2. Incoming voltage (upper channel) - imposed on the 50 Hz (lower level) via optic fiber system.

In the figure 2, there is a record of lightning overvoltage superimposed on regular sinus wave.

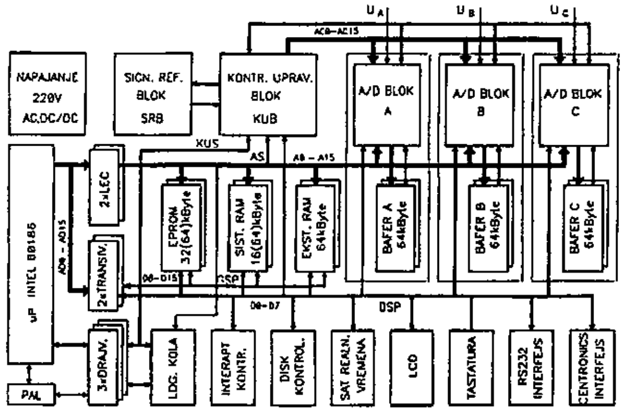

Figure 3. Block schematic diagram of the device

Considering the importance of recording incoming overvoltages, it is necessary to have a sampling time as low as possible (as many samples as possible).

Bandwidth chosen for the implemented A/D converter is 10MHz. To have the necessary length of the record, it is important to have a large memory buffers. Since it is difficult to achieve this opposite requirements, a hybrid construction of A/D block was chosen using double frequency. Before the triggering, and a little after the triggering A/D blocks work on base frequency f_o , and after that with $f_o/100$, in order to have the necessary time frame for the recording. This frequencies have "fast" and "slow" information buffer in sequence.

For A/D conversion it is used 8 bit flash A/D converters. Since overvoltages do not go higher of three times value of the operating voltage, for all types of network 8 bit resolution with an error of 0.5% of incoming voltage, completely satisfy the accuracy.

Every block contains separate 20 MHz A/D converter and a separate memory data buffer of 64KB. Converters work in independent mode using separate control block. All control signals are generated by the control block, not by microcomputer.

Figure 3 gives a block diagram of the device for overvoltage recording. This device have an option of changing frequency in the range 1-20MHz, and a capabilities of changing "fast" and "slow" buffers as well as the size of pre- trigger.

For example, table 1 contains recording times for different frequencies f_o . In the A/D blocks, there is an option of regulating the level of analog trigger. The trigger itself is constructed as a comparator of incoming signals A/D blocks, independent from it's polarity.

Table 1. Recording Time of some typical values for "quick" & "slow" buffer and chosen sampling frequency

Sampling Frequency	"Quick" Buffer	Recording Time	"Slow " Buffer	Recording Time
1	32	32768	32	3.2768
1	64	65536	0	0.0
1	4	4096	60	6.144
10	32	32768	32	0.32768

IV. TEST RESULTS OF THE INSTRUMENT

The results of the test of the constructed instrumentation are given through several characteristic examples. These examples are shown using program for result analysis. All three channels of the instrument work synchronous. Figure 4 shows results from one of the channels, using impulse voltage from figure 1. The sampling frequency is f_o=1MHz and quality of the record is quite adequate for use with the recording of atmospheric overvoltages. Figure 5 gives samples of recorded impulses superimposed on the sinus wave (signal from figure 2). This type of signals are adequate with atmospheric discharges. Multichannel acquisition systems with high frequencies are very rear, and this registration instrument have been successfully used for different site measurements (motor start current, transformer testing, surge recording in rotating machinery etc.).

Special aspect in design, and use of microcomputer systems ensures protection against electromagnetic interference.

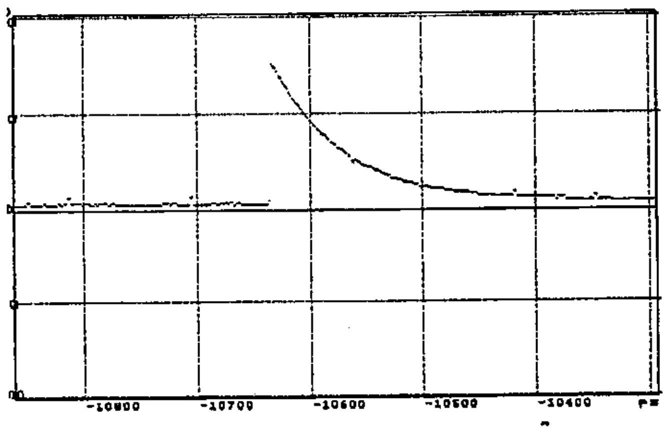

Figure 4. Recorded impulse 1.2/50 μs at 1MHz

Numerous tests were performed on the instrument in HV laboratory in order to make it resistant on corona and other HV effects.

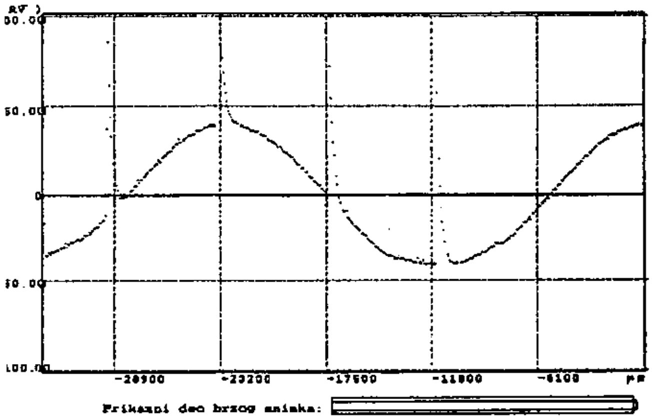

Figure 5. Recorded 10/200μs surge on sinus wave

V. PARTIAL DISCHARGE (PDA) RECORDING

This electrical system is used for recording surges and sparks within or adjacent to a high voltage insulation. Integrity of different HV insulations can be tested at any time even with electrical equipment being in normal operation. The partial discharge sparks (surges), riding on the sinus wave are shown on the figure 7.

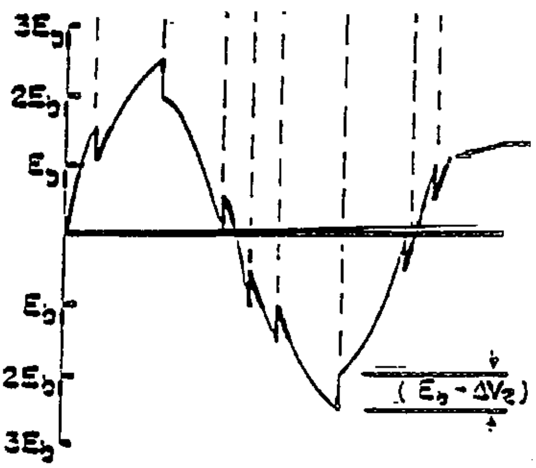

Figure 7. PD surges imposed on sinus wave

The PDA testing on High Voltage insulation has been widely used to have a quick "on-line" assessment of electrical insulation quality, for generators, motors, transformers, HV cables and other electrical machinery.

Partial Discharges are surges caused by the flow of ions and electrons within the air gaps inside or adjacent to a solid HV insulation. There are different monitoring techniquès of partial discharges on HV machinery. The PDA can be monitored from the line end (HV end) or from the low voltage end (neutral side) of the electrical equipment.

There are also different PDA sensors for different applications. For HV (line end) monitoring the most common used sensors are capacitive type sensors. For neutral type monitoring there is a coil type sensors mounted on neutral. There are also antenna type sensors used for either of this applications. The line end monitoring does have advantage, since mounted sensors are very close to the real Partial Discharge site and attenuation of PDA signals is minimal.

Two different techniques were mostly used for line end type of sensor mounting. In case of application on generator/motor, as shown below, there are two typical sensor configuration: Differential and Directional.

1) *Differential PDA test setup*: In differential configuration PD sensors are mounted inside the generator on winding jumpers.

Both methods use the same logic of operation and the same "common mode noise rejection" technique.

Coaxial cables connect sensor to PDA terminal box located outside the generator housing. The terminal box is easily accessible and plant engineers can take a PDA test at any time during the regular generator operation by connecting portable instrument to the terminal box. The surges from the generator insulation are recorded and test results analyzed, giving the information on the condition of the generator HV insulation.

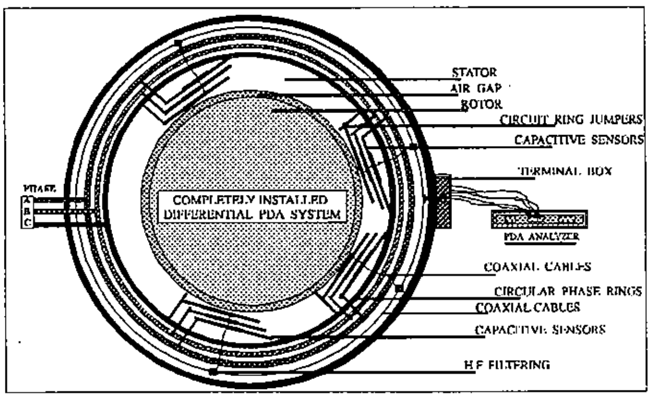

Figure 8. Differential PDA system for surge recording

2) *Directional PDA test setup*: In directional PDA installation, sensors are mounted on the generator phase bus, outside of the generator / motor housing as shown on figure 9.

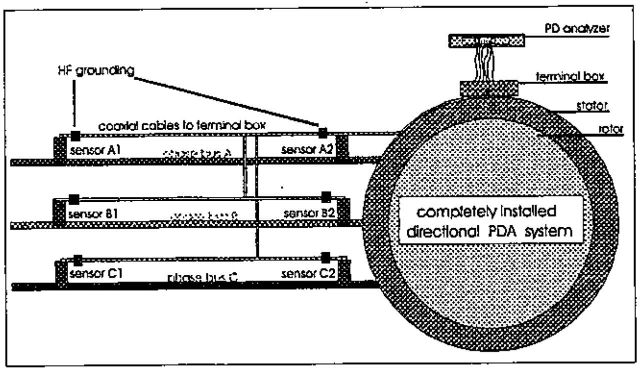

Figure 9. Directional PDA system for surge recording

There are 6 sensors in total (2 per phase) and they are, same as for differential test setup, connected to the terminal box located outside the generator. The surges from the generator insulation are transmitted via coaxial cables and recorded for PDA analysis, and assessment of the HV insulation. Noise, similar to PDA, from other sources, interfering real PDA activity from the winding are rejected using "common mode noise rejection technique" and known "time of flight" formula.

3) Neutral mounted sensors: When neutral mounted sensor is used, it is not possible to have noise from other sources rejected as when sensors are mounted on the line end. In that case, additional antenna sensors are used to record noises from different sources and separate them from real PDA activity coming from generator winding. Gating technique can be also applied for the same purpose of noise separation.

Instruments for line mounted sensors and neutral monitoring sensors are slightly different, since bandwidth of discharges and data acquisition techniques are different. The frequency range of the recording vary and when line mounted sensors are used, frequency range of the surge recording equipment is significantly higher.

Lately PDA test has been used for stator bar testing, subsequent to mounting them in the stator core. It allows power utilities to have information on quality of every bar without destroying them. It helps to allocate bars of different quality for different parts of the winding. The PDA technology can be used for monitoring of partial discharges on generators, motors, transformers, HV switchgears, SF6 equipment, transmission lines and any kind of High Voltage equipment. This type of on-line testing is convenient way of having information on the quality of HV electrical equipment without taking it out of regular operation. The maintenance can be scheduled when necessary, and avoid catastrophic in service failures, expensive repairs and a high cost of unplanned outages. Several different instruments were developed for the purpose of partial discharge recording.

VI. CONCLUSION

The constructed device is optimal combination in economical and technical aspect. Implementation of optic fiber transmission and a special overvoltage recorder is essential improvements over the existing systems. With the new approach using dual time base, all kind of surges and overvoltages can be recorded. The device itself is very convenient for site testing. Special advantage of the system is synchronous work (sampling of the A/D blocks in the same time frame). The newest generation of flash A/D converters (with higher resolution) allow much wider applications of the device.

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