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WHY IS NOT THERE A 20 KV ASYNCHRONOUS MOTOR?

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Abstract

The need for high-voltage asynchronous motors is relevant. The most significant problem is the appearance of partial discharge. Reliable methods for discharge parameter measurements have not been fully developed yet. The measurement of partial discharge parameters is the first step towards the realization of these high-voltage asynchronous motors. The suggested measurement works in real time. The entire signal is first cleaned, then tables on the intensity, duration and distance between impulses of partial discharge are generated using a logical algorithm based on signal shape recognition. The *generated* data contain all the information about the partial discharge signal. Sorting of the obtained data is performed in the DSP processor and only the interesting statistical data are forwarded to the PC where the archiving or presentation of the results or further processing are carried out. The AD converters, CPLD and FPGA circuits almost of GHz speed have a commercial price which means there is a possibility for a system which observes shape of partial discharge impulses. The steps presented here constitute the initial phase for the realization of a final system.

Keywords: partial discharge signal, signal shape recognition, real-time monitoring system.

1. Introduction

In fact, why? When a significantly higher voltage level has been achieved, problems arise in the realization of the necessary circuit, i.e.: 20 kV distribution network (or 17.5 kV internal network or higher in power facilities) and synchronous generators, cables, switches, protection, etc. Only the asynchronous motor (hereinafter: AM) is missing from the circuit. Why is this a problem? Because a high-voltage asynchronous motor cannot be connected to the network like a low-voltage one but it is necessary to build a transformer station for voltage accommodation [3].

This fact explains the following questions:

a) Does the high-voltage motor have to be more expensive and how much? It can be as expensive as the transformer station.
b) How efficient is the solution? The efficiency of the asynchronous motor can decrease up to the usefulness of the supplying high-voltage transformer.
c) The reliability of the solution is improved because the transformer station is eliminated and thus the possibility of being damaged.
d) Maintenance is reduced to the high-voltage motor. (The number of spare parts, equipment and professional qualification is reduced).

e) How about the ecological aspect? The space required for the positioning of the transformer is reduced (in an urban environment and in tight factory premises this might be significant).

Several decades of experience [6] in design, production, testing and exploitation of high-voltage motors enabled the detection of weak spots and finding a solution and developing trends [8]. The solutions are complex and only their overall application gives the expected result, as for example:

a. In the design of asynchronous motor magnetic field [1]
b. In solving the production technology of AM [8]
c. In testing insulation systems of high voltage machines

Standard procedures for measuring partial discharges are described in detail in [5], there are numerous publications on the condition of I.S. e.g. [4].

1. The breakdown or degradation of I.S. is a process lasting for some time (ms, hours or years). The reason for defining that I.S state with a number (insulation resistance, absorption factor, tg δ) is that it is a mean value, and critical or weak spots are not detected.
2. Partial discharges are basic elements of breakdown of the short-circuit of the I.S. therefore they should be measured and their parameters defined which is possible with the help of modern computer-supported electronic measuring systems.
3. Testing with alternating voltage is desirable during I.S. testing because during exploitation the AM is loaded with such voltage, thus the measuring results are more significant if the measuring method is as similar to the actual working conditions as possible [7].

It is necessary to pay special attention to the fact that there are two possible approaches to testing the device:

- periodic tests during overhauls with the machine being disconnected from the network. The measuring results are compared with the results of analyses from previous service cycles, and
- permanent measurement during exploitation of the high-voltage machine. Monitoring the trend of change of statistical parameters changes the signal content of the partial discharge in the entire current of the exploited motor.

This paper illustrates the principles of realization of a new digital high-frequency unit for measuring and analysing of the insulation system under real-time conditions based on partial discharge. The system is designed for measuring during periodical overhauls of high-voltage machines when the machine is disconnected from the electrical network.

2. Identification of Partial Discharge Impulses

During the permanent operation of high-voltage machines the following signals are present:

1. high-voltage signal current (50 Hz)
2. current signals induced due to the micro-vibrations of the rotor in relation to the stator of the high-voltage machine
3. current signals induced due to the change of the mutual position of the rotor and stator teeth
4. connection signals generated outside the machine, e.g. from frequency converters
5. partial discharge signals

Signal types 2 and 3 are with spectral components up to a few kHz and their shape can be predicted earlier based on the number of teeth in the stator and rotor and on the basis of the measured eccentricity of the rotor. The spectrum of these signals is significantly lower than that of the spectral PD signal components and they could be therefore separated but this is not the subject of this paper. Signals type 4 can be significantly weakened, especially the high-frequency components by filtering, or if the legal conditions on clean power network are satisfied then it is not necessary to eliminate these current components.

In the case when the machine is disconnected and operating on a high-voltage 50 Hz test generator, only signal types 1, 4 and 5 are present. Signal type 1 of the PD impulse is eliminated by filtering, while signal type 4 is eliminated by filtering of the supply voltage of the test generator, shielding the test generator and filtering the outgoing test voltage.

In essence, the character of disturbing signals differs from the partial discharge signals because they do not have the exponentially rising and falling character. The original signal shape of partial discharge is deformed while it is approaching the acquisition system. The non-linear phase feature of these filters decreases somewhat with the phase corrector.

An example of signals after eliminating the high-voltage 50 Hz signal is presented in *Fig. 1*.

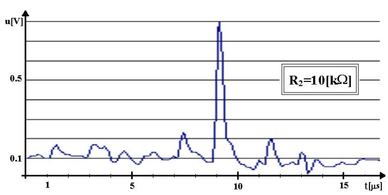

Fig. 1. Partial discharge signals after eliminating the high-voltage 50 Hz signal

While determining the criteria, the experience, the gained knowledge, and signal shape recognition have been applied. The elimination criteria are as follows:

1. number of permitted points of the same value at impulse increase,
2. gradient of impulse at increase,
3. number of permitted points of the same value at the falling impulse edge and
4. steepness of impulse at falling edge,
5. permitted maximum time from the time between impulse increase/fall and fall/increase.

This five-item procedure for the elimination of spurious signals is not perfect and calls for further improvements. Still by developing the system, an algorithm was sought that can be implemented in fast circuits for digital acquisition as CPLD, FPGA or DSP processors.

On the basis of the results of the criteria, we have eliminated the spurious signals, calculated the partial discharge impulse parameters, and generated a final table with compressed data of impulse width of partial discharge, impulse amplitude of partial discharge, time between two partial discharges and impulse polarity of partial discharge.

The possible form of clarified signals is presented in *Fig. 2*. In the third chapter of this paper, for this model of signals, a theoretical background calculation of PD signal parameter is developed.

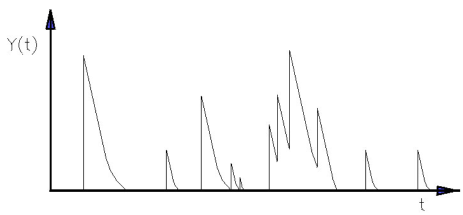

Fig. 2. Model of PD signals

3. Theoretical Basis

A system with an exponential excitation (1) to Dirac's impulse is being observed.

$$h(t) = e^{-\alpha t} \text{ to } t > 0. \tag{1}$$

Let us bring to the input of such a system a series of Dirac's delta impulses with random occurrence time (Poisson's random process) and a random amplitude. The value of the output signal $y(t)$ at moment t will be

$$y(t) = \sum_{i=1}^{N_t} X_i e^{-\alpha(t-t_i)}, \tag{2}$$

where X_i and t_i are amplitude and repetition time of the i-th delta impulse, while N is the total number of the occurred delta impulses in that $(0, t)$ time interval.

The first moment of random signal $y(t)$ e.g. [2]:

$$n_1 = \frac{\lambda}{\alpha}(1 - e^{-\alpha t})m_1, \tag{3}$$

where m_1 is the mathematical expectation (first moment) of the random variable $X(t)$.

In our expressions the second moment of $y(t)$ is:

$$n_2 = \frac{\lambda^2}{\alpha^2}(1 - e^{-\alpha t})^2 m_1^2 + \frac{\lambda}{2\alpha}(1 - e^{-2\alpha t})m_2, \tag{4}$$

where m_2 is the second moment of $X(t)$ and the dispersion of the random variable $y(t)$ is

$$D = n_2 - n_1^2 = \frac{\lambda}{2\alpha}(1 - e^{-2\alpha t})m_2. \tag{5}$$

4. Description of Measuring Equipment

The schematic illustration of the measuring equipment is given in *Fig.*3.

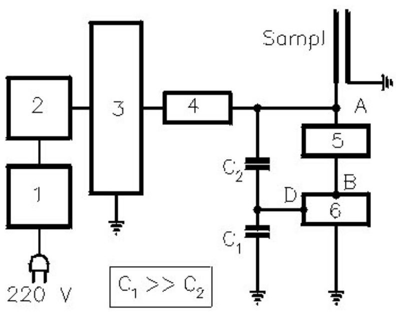

Fig. 3. The schematic illustration of the measuring equipment

The measuring equipment in *Fig.* 3 consists of a coupled energetic filter **(1)**, a voltage regulator (range of 0–270 V) **(2)**, a high-voltage transformer (maximal output voltage 80 kV) **(3)**, protective resistance **(4)**, high voltage adjusting element to the acquisition **(5)** which is in detail shown separately in *Fig.* 4 and a data acquisition unit **(6)**. Capacities C_1 and C_2 are filtering and C_2 gives a trigger signal. In *Fig.* 4 the illustrated circuits serve for adopting the signal to the acquisition system. Resistances R1 and R2 make the voltage divider. HF is the high pass filter which is a phase corrector and removes 50 Hz and its harmonics at the same time.

The HF filter has been realized as a bridged-T network. NF is a low pass filter and has a double role: it is an antialiasing filter and a phase corrector. The NF filter is also realized as a bridged-T network. The filter for eliminating the 50 Hz component has the role to increase the resolution during digitalization.

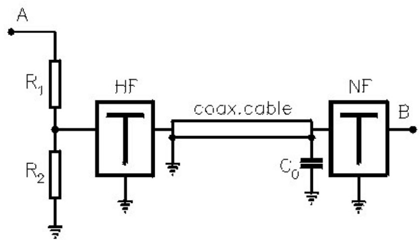

Fig. 4. High-voltage adjusting element to the acquisition

The acquisition equipment comprising HARDWARE and SOFTWARE in *Figs.* 5 and 6 has been developed by the authors of this paper.

Here the two measuring acquisition devices are compared. The first, shown in *Fig.* 5, is old and till now it has been used for measurements and there is a new one which is in the phase of completion and presented in *Fig.* 6.

4.1. Old Acquisition Unit

The acquisition unit has several parts. The A/D converter digitises the signal with a 10 bit resolution. The static memory positions the digitised signal that is the upper eight. The fast PLD circuit controls the accepting and discharge process of data in the static memory. The zero transition detector is required because with this device we can identify the position correctly in the digitized signal in relation to the 50Hz current.

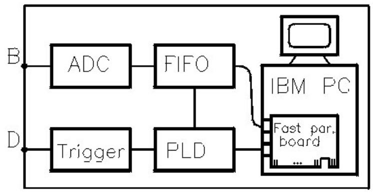

Fig. 5. Old acquisition unit

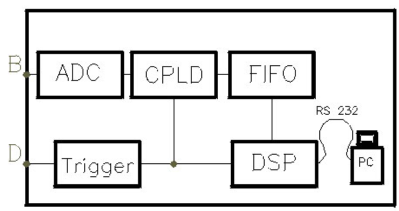

Fig. 6. The acquisition part in phase of development

The antialiasing filter is made with one half of the operational amplifier AD812 with a current feedback connection, and the other half is used for realizing the zero transition detector. The A/D converter is of AD821 type. The FIFO memory is D42280V-30 and has a 256 kByte capacity. This memory quantity is required because we consider a 50 Hz (20 ms) period and it will be filled up with a sampling rate of 12 MHz. The data from the FIFO memory are read into the memory space of the PC unprocessed with the help of a fast parallel board. The parallel board speed during data reading is 300 kByte/s, thus with this system in the optimum case it is possible to take data from each 41st period of a 50 Hz current signal which is considered a handicap of this equipment. This deficiency led the authors of this paper to the idea to design a new equipment which can continually process data of partial discharge practically without stopping and period skipping (of 50 Hz current).

Data are first compressed in the PC (chapter 2) and then statistically processed by the programs STATISTIKA or MATLAB.

4.2. Calculation of the Necessary Effective Time and Required Memory Capacity for Continuous Operation of the Acquisition System

The typical scope in the 50 Hz signal where the PD signals appear is shown in *Fig. 6*.

The conclusions in this chapter are drawn on the basis of data given in chapter 5 of this paper. According to *Table 1* the minimum average distance between PD impulses for the discussed IS is $2.0 - 2.5\ \mu$s, so on the basis of *Fig.6* we can expect the max. of about 250000 impulses per second (5000 PD impulses in a period). If there is an elimination of disturbing signals, compression and generation of table in CPLD, the number of generated data in a second is 750000 based on the above. If we wish to perform a real-time data sorting into statistical tables, we have to use an additional CPLD+SRAM or FPGA circuit or a DSP processor. We have chosen a DSP processor. For data acceptance and sorting in the inner SRAM of processor, max. 15–20 instruction cycles are required. Therefore, the max. required speed of operation of the DSP is 15 Minst./s. These requirements can be easily met with a DSP processors from Texas Instruments TMS320C5x at 50 MHz with 25 Minst./s or TMS320C54x with 50 Minst./s or more.

Such a system enables a further increase of speed in sampling in real-time operation. This system is described in chapter 4.3 of this paper.

4.3. The Acquisition Part under Development

In the case of equipment shown in *Fig. 6*, the role of the PC is minimized. The PC serves only for illustrating the results and saving the measurement results. In the case of the acquisition unit, an AD converter is used which has a maximum sampling rate of 60 Msampl/s and the bottleneck of the previous system is eliminated with the incorporation of a CPLD circuit (in our case CYPRESS 7C374). This CPLD is placed in front of the FIFO memory. The CPLD circuit eliminates the spurious impulse and performs data compression which was previously done by the PC. In the first acquisition system (*Fig. 5*) the average speed of the whole system is significantly limited. Using the new system, the data arriving into the FIFO memory are of the same type as those used in the same way as in the previous acquisition part. Data speed is also significantly decreased according to the experience of the authors.

The effective data speed has significantly decreased but not so much as to enable their real-time processing with a fast PC, so if real-time processing is required it is necessary to implement a DSP processor in the system sorting out parameter of signals into the corresponding boxes, in order to create density functions of PD signal parameters. The internal memory of DSP processor is used for sorting out. These calculated primary statistical parameters are sent for further processing in a PC. The task of the PC is only to accept these data, position them into the memory space and process them on the screen. The speed of transport between the DSP processor and the PC is several bytes per second which can be realized through a standard serial RS232 port.

This equipment (*Fig. 6*) is in the phase of revival and currently the DSP circuit serves as an addition to the FIFO buffer in the communication between the measuring head and the PC.

5. Presentation of Measurement Results

The results quoted below serve primarily for analyses demonstrated in chapter 4.2.

The main purpose of this paper is not to analyze the results but to demonstrate a real-time acquisition system, thus the authors are only providing an interesting example. For measuring, two samples (A1 and B1 schematically presented in *Fig. 7a*) are used both of which are copper conductors (2 mm × 6 mm) with LGGL insulation (lacquer, double glass layer, lacquer) with a length of 30 cm. After five completed measurements, a mechanical deformation is performed on the samples. Bending sample A1 gives sample A2 and bending sample B1 provides sample B2 (schematically presented in *Fig. 7b*), whose further bending gives B3 (*Fig. 7c*) and finally B4 (*Fig. 7d*). The measurements are made at a voltage of 2 kV.

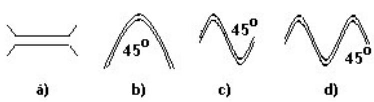

Fig. 7. Schematic presentation of samples to experiment

The mean value and the standard deviation of the PD impulse duration are the values DA and DST in *Table 1* for the data group A1....B4. In the same table, the mean value and the standard duration of the PD impulse intensity are given for a data group marked by AA and AST, respectively. TA and TST are mean values and standard deviations of distances between PD impulses. The time unit in this table is 83.3 ns and the voltage unit is 50 mV.

Table 1. Presentation of relevant PD parameters

	DA	DST	AA	AST	TA	TST
***A*1**	9.95	0.67	39.58	8.42	487	73.3
A2	10.4	1.51	28.81	8.90	292	83.6
B1	9.56	0.18	72.37	0.87	1420	124
B2	10.7	0.68	49.84	3.61	863	95.0
B3	10.9	0.47	54.44	3.16	800	87.0
B4	11.6	0.41	49.98	6.09	583	98.0

If we now observe how certain data for samples A and B change (their state before and after the deformation), it can be concluded that the impulse duration has increased and the standard deviation of impulse duration also increases with the deformation, i.e. the range in which these values are found widens with respect to the state prior to the appearance of deformation. If we now observe how the basic statistic parameters of the impulse amplitudes change, we can conclude (in both cases, A and B) that the average amplitude decreases with the appearance of the first deformation while the standard deviation of the amplitude value increases with the appearance of the first deformation. It can be said that the time between the two PD impulses significantly decreases with the appearance of the first deformation. The authors could not define the significant trend with regard to the standard deviation of time between two PD-s.

The same conclusions have been drawn when other repeated measurements were made with some more independent samples.

6. Conclusion

In this paper a principle for measuring PD parameter signals has been presented. The principle is based on the recognition of PD signal shapes. The entire current signal is first cleaned from the 50 Hz signal with a high-pass filter which performs the signal phase correction and accommodation towards the coaxial cable at the same time. Following this, a spectrum width limitation is performed by means of a low-pass filter in order to avoid the antialiasing effect during signal sampling. The tendency is to keep the shape of the PD signal as much as possible to the point of AD conversion, thus such filters are used that can act as phase correctors at the same time. Following the AD conversion from the analogically processed signal, the PD signals are digitally selected from the other signal components by recognizing the shape, and the relevant PD signal parameters are measured and transferred into the FIFO memory. Then the primary real-time statistical data generation of PD signals is performed in the DSP processor.

The value of the first moment (3) for the signal used for modeling the cleaned PD signal based on [2] is given in this paper. The authors of this paper have deducted the values of the second moment and the dissipation of the given signal that are shown in (4) and (5), respectively. With only a simple change in the system's architecture a system can be obtained that is able to follow in real time the system's parameters where partial discharge occurs.

During the measurements it must be observed that the appearance of the first deformation on the sample causes great changes with regard to the deformation value of the standard PD parameter which means that when deformation occurs on the sample, the significant PD parameters take their values from a larger range of values than before deformation.

Some future research in this field: with a possible application of digital deconvolution, the signal identification of the original signal would be of higher quality (the FPGA circuit performing the deconvolution in the chain from the AD). The increase of sampling rate is present in numerous commercial AD converters today. There are AD converters and high speed logical networks with several hundred MHz available.

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References

[1] DJUROVIC, M. – JOKSIMOVIC, G. – VEREB, L., Effect of the Magnetic Shunt in the Teeth of Stator of Inductions Machines, 9^{th} *Symposium on High Voltage Engineering*, Graz, 1997, pp. 83–90.

[2] KARLIN, S. – TAYLOR, M. H., *Sztohasztikus folyamatok*, Gondolat, Budapest, 1985, pp. 135–138.

[3] LEILON, M., POWERFORMER – Ein grundlegend neuer Generator verbessert Gesamtwirtschaftlichkeit von Kraftwerken, *ABB Technik* **2** (1998), p. 21.

[4] 4.I.C.D.I. *Proceedings 'Poster Session 5'*, Budapest, 1997.

[5] IEC STANDARD 'Publication 270'.

[6] MEYER, H., *Die Isolierung grosser elektrischer Maschinen*, Springer-Verlag, Berlin, 1962.

[7] VEREB, L., Sensing and Evaluation of Partial Discharge on Single Insulated Conductor Samples of High-Voltage Rotating Machines Using Oscilloscope and/or Counter, *International Conference – on the Reliability and Lifetime of Electrical Machines*, Budapest, 1987.

[8] VEREB, L. – KARTALOVIC, N. – OSMOKROVOVIC, P., The Influence of the State of Inter-Winding Insulation on the Tendency of Nominal Voltage Increase in High-Voltage Asynchronous Machines, 9^{th} *Symposium on High Voltage Engineering*, Graz, 1997, p. 1092.