SOLVING OF SOME PROBLEMS WITH ON-LINE MODE MEASUREMENT OF PARTIAL DISCHARGES

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Summary This paper deals with the problems discussing the transition from off-line diagnostic methods to on-line ones. Based on the experience with commercial partial discharge measuring equipment a new digital system for the evaluation of partial discharge measurement including software and hardware facilities has been developed at the Czech Technical University in Prague. Two expert systems work in this complex evaluating system: a rule-based expert system performing an amplitude analysis of partial discharge impulses for determining the damage of the insulation system, and a neural network which is used for a phase analysis of partial discharge impulses to determine the kind of partial discharge activity. Problem of the elimination of disturbances is also discussed

I. INTRODUCTION

Diagnostic methods are usually used for the determination of actual state of high voltage insulating systems, for the estimation of their residual lifetime, their behavior estimation and the risk assessment in the future operation ([1] - [9]). Diagnostics of high voltage insulating systems in off-line mode is worked up sufficiently and it is broadly executed. However, both the price and power of the newly installed high voltage equipment in the power engineering branch grow up, and that is why the operator's attention is focussed on the operational reliability of their equipment at first. The tendency of all operators is to monitor the state of their equipment continuously, i.e. using on-line methods.

However, the application of some 'classical' methods for on-line diagnostics is inappropriate, sometimes even impracticable (e.g. direct current methods, loss factor measurement, overvoltage tests). On the other hand, suitable methods for on-line diagnostics are methods for the observation of a discharge activity, which are usually based on the monitoring of secondary effects accompanying partial discharges (PD) in dielectric materials. One of these PD methods, applicable on high voltage grounded objects, is the galvanic method with parallel connection of the high voltage coupling capacitor and the measuring impedance with a lowpass filter. This method is broadly expanded due to its high sensitivity, a good resolution of individual types of PD impulses, and due to the fact that its using is not limited in the capacity of measured object or the quantity of used testing voltage. The advantage of this method is also in the possibility in using it directly during the machine operation by means of permanently installed probes.

2. PROBLEMS WITH ON-LINE MEASUREMENT

In the transition process from off-line diagnostics to on-line one (monitoring) it is not possible to take over original methodologies of the evaluation of diagnostic parameters 'automatically' [10]. Some of diagnostic parameters of off-line diagnostics can not be measured in on-line diagnostics, some lose their sense and, on the other hand, it is necessary to develop new on-line diagnostic methodologies regarding of new conditions. For example, in an off-line PD measurement, the evaluation methodology is based on the dependence of basic diagnostic parameters (apparent charge, PD current, PD frequency) on applied testing voltage. In on-line measurement, the value of voltage is constant, but new dependencies appear, e.g. changes of basic diagnostic parameters in operational time. That is why is necessary to develop new methodologies based on the monitoring of time shift of diagnostic parameters. Recently, some suspects about calibration process accuracy in the case of measurement of large capacity objects have appeared in technical community.

As regards the evaluation of a diagnostic measurement, the quality of the evaluation and the reproducibility of results are stigmatized by relatively complicated methodologies and complicated (frequently artificially made) diagnostic parameters, what leads to the necessity of the consultation of top human experts for the high-quality evaluation. However, the complexity of the decision-making mechanisms (frequently on the edge of the intuitive decision-making) leads very often to the ambiguous or opposite evaluation of the actual state of the tested machine and estimation of its behavior in further operation. This practice is not acceptable for on-line diagnostics and it is one of reasons why it is not so reliable and why the on-line diagnostics is not so wide spread these days. In connection with the on-line methodology development it is necessary to reduce a number of diagnostic parameters to the essential minimum, even at the cost of wasting partial information about the machine actual state. However, this disadvantage is entirely compensated by the fact that the changes in diagnostic parameters in an on-line measurement are indicated at once, and the damage evolution can be monitored permanently. The impossibility of using top human experts for the routine on-line evaluation because their temporary inaccessibility leads to the necessity of developing such an instrument which compensates the human expert view without decreasing the decision-making process quality. Expert systems based on the elements of the artificial intelligence are the best solution of this problem. Their knowledge bases containing experience of the top specialists in the decision-making process are able to solve standard situations reliably. In addition, during an on-line measurement, the expert system indicates a defect of the insulating systems immediately and, at the same time, offers a solution with respect to the safety and reliability of the machine or equipment in further operation. There are different types of expert systems based on production rules (rule-based expert systems, frame-based expert systems), neural networks, genetic algorithms, fuzzy logic, etc., as well as expert systems of a mixed type. At present, the rule-based expert systems and neural networks are used the most often, whereas their application depends on the type of processed information. For the information of the type „assumption-hypothesis", i.e., the „if-then" type of the decision, production rule-based expert systems provide the best solutions. On the other hand, neuron expert systems (neural networks) are usually used for complicated or intuitive decisions, and in cases when the algorithm development of the knowledge base is very complicated, e.g. in PD patterns recognition. For the evaluation of the state of high voltage insulation systems, the rule-based expert systems are very effective as a base of the evaluating or decision-making systems.

The on-line measurements need a high reliability of the measuring apparatus. Unsuitability and complicity of existing measuring PD measurement apparatuses is one of problems, which must be solved by the diagnostic staff. 'Classical' PD measuring apparatuses were developed no only for the data collection, but also for the direct process evaluation of the diagnostic parameters. They are usually based on analog data processing. That is why commercial PD devices have several disadvantages:

- The equipment is too expensive.
- The PD devices are single-purposed and usually they can not be modified according to the specific conditions of a PD measurement, tested equipment, an operational interference and according to the actual state of the research and development in this branch.
- Analog components of PD devices change their quality parameters in time. The calibration of these PD devices must be usually done in the original workplace of the producer, and thus the operational costs increase.
- The commercial PD devices are too complicated and mechanically sensitive and there is no guarantee of their reliable operation during a long-time measurement under the operational conditions.

These disadvantages result from the analog data processing and a stable system conception of the data processing. Both of them have negative influence on data processing quality: time shifts of tolerances and measuring ranges, low frequency ranges of analog amplifiers, displacement of operating points, apparatus sensitivity to disturbances etc. One of the most effective possibilities to reduce the disadvantages mentioned above is the consequent digitization of the PD impulses immediately after their detection at the beginning of the evaluation process (the best, directly after the indication of the PD impulses) and subsequent processing digitized data only. In addition, this data processing system enables to apply an 'arbitrary' data filtration, data processing by the classical computer programs, expert systems etc.

3. Development of PD Equipment

A new principle of PD device has been developed at the Czech Technical University in Prague. The stable-measuring equipment (a stand, a measuring workplace) for the PD measurement and evaluation under the operational conditions in on-line (non-interruptive) mode has been developed, too.

Measuring unit for the measuring, digitizing and processing PD data including a calibration equipment has been developed within. Detected analog PD impulses are digitized in the measuring unit by a special analog-digital converter and they are saved in a special memory block. The connection (via standard serial line RS232) between the measuring unit and the computer enables to transfer digitized PD impulses into a computer for their further processing.

The proper detection and digitization of the input data (measured values of diagnostic PD parameters) is performed in the measuring unit, where the PD impulses enter. These impulses are detected on the classical measuring impedance. Like in case of the classical PD measurement, the surface of the individual current PD impulse is converted into a voltage value in a standard capacitor, which is then discharged in a discharging circuit. In contrast to classical PD devices, the discharging time is set by a built-in digital clock in this case, which is advantageous in exact countdown of the discharging time and in the possibility of its further digital processing. The discharging circuit was developed and set in such a way that the discharging time of the maximal charged standard capacitor (in case of the maximal value of the current impulse in the input amplifier), including resetting, should not take longer time than 50 µs (it is adequate to 256 levels in a digital form). It has a sufficient accuracy for reading the apparent charge value as well as it has a sufficiently high speed for processing PD signals (to the limit 200 signals during the one period of supply voltage, i.e. during 20 ms). A phase shift of the PD impulses is distinguished with the accuracy 1.8 °el., which is sufficient enough. Fig. 1 shows a photograph of the developed measuring unit.

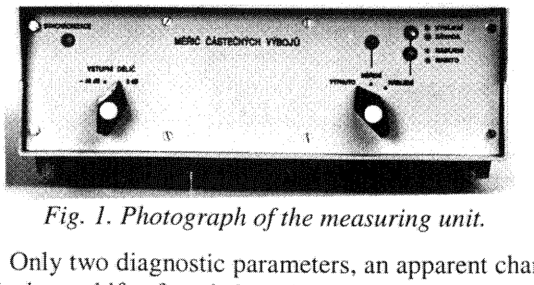

Fig. 1. Photograph of the measuring unit.

Only two diagnostic parameters, an apparent charge and phase shift of each impulse, are processed. These two data (information about every PD impulse) of

10 periods of the supply voltage are saved in the memory data block of the measuring unit and, after the request from the computer, are, with the help of a standard serial RS232 line, transferred into the computer, where a special software processes them further. The central computer automatically controls the gain of the amplifier of the measuring unit, also via RS232 line.

After the value digitization of diagnostic PD parameters, the crux of the further activity lies in the software data processing by a special software [11]. Before a proper evaluation of a PD activity, the statistical processing is applied on measured data for removing both random data and characteristic disturbances (radio interference, thyristor disturbances, etc.). 'Cleaned up' data are further processed and modified for the input into the expert systems.

The evaluation of the diagnostic parameters and monitoring of the insulation system in operation are performed not only by standard classical methods (according to the criteria values and alarm systems), but also by the expert systems with the elements of artificial intelligence, which enable to include the experience of the human experts in this branch as well.

The developed evaluating system also uses two independent expert systems for proceeding measured PD data. These expert systems work simultaneously and special software controls their coordination. The rule-based expert system performs the amplitude analysis of PD impulses to specify the extent of the damage of the insulating system. The neural expert system (a neural network) has better ability of the abstraction, and therefore it is used for the phase analysis of PD impulses (the recognition of PD patterns), which enable not only to specify the kind of PD activity, but even to localize PD resources.

After preliminary processing the data from the central unit is supplied into a small input database. Expert system evaluates this data and the results of the consultation, i.e. the probability of the output hypotheses, are inserted into the small output database, see Fig. 2. After further processing the results of the consultation with the expert system are displayed on the monitor of the computer in the form of the recommendation for further operation.

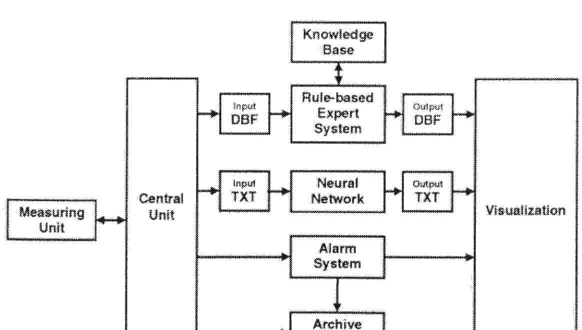

Fig. 2. Data flow in the evaluating system.

A neural expert system (neural network) has better ability of the abstraction and therefore it was used for the phase analysis of PD impulses (the recognition of PD patterns), which enables to specify the kind of PD activity, respectively to localize PD resources. Inputs and outputs of data in these expert systems are similar as in case of a rule-based expert system, i.e. in the form of small input and output text files.

The outputs and visualization are performed user-friendly, i.e. all results are displayed on a virtual panel of a standard measuring device. Except of the classical visualization of PD impulses within one period of the supply voltage (the visualization of PD impulses on a sine curve, an ellipse or on an abscissa), the results of evaluations the by expert systems, the mode of data filtering, and the results of statistical processing, the actual levels of diagnostic parameters, levels and the alarm state activity are also continuously displayed on the monitor screen.

The great problems in the evaluations of PD data are in various sorts of interferences. We can divide disturbing signals into internal disturbing signals and external ones. The internal interferences are dependent on the actual voltage of the measured subject; external interferences are not dependent on it. We developed several algorithms for the elimination of disturbing signals of digitized PD data. Mainly, we can eliminate randomize signals and thyristor disturbances. A new way in the evaluation of PD signals is the mathematical analysis, which makes possible a better data processing. According to the frequency spectrum of the signal we can recognize steady signals and unsteady signals. In case of steady signals (stochastic immediate broadband signals) we are interested in the frequency spectrum only. The Fourier Transform is the best solution for these purposes by reason that it transforms a view of the signal from time-based region to a frequency-based one. In the case of the unsteady signals, the frequency is variable. We must adapt the Fourier Transform to analyze signal in the small section of the time only. This technique is called the Short Time Fourier Transform by way of the windowing of the signal. The Wavelet Transform does not process of signal in the time-frequency region as the Short Time Fourier Transform, but it processes it in the time-scale region. One of the main advantages of this processing is the fact, that it is possible to perform a local analysis and to analyze a localized area of a larger signal.

4. CONCLUSIONS

The on-line measurements need a high reliability of the measuring apparatus. Unsuitability and complicity of existing measuring PD measurement apparatuses is one of problems, which must be solved by the diagnostic staff. 'Classical' PD measuring apparatuses were developed no only for the data collection, but also for the direct process evaluation of the diagnostic parameters. The disadvantages of 'classical' PD meters result from the analog data processing and a stable system conception of the data processing.

One of the most effective possibilities to reduce the disadvantages mentioned above is the consequent digitization of the PD impulses immediately after their detection at the beginning of the evaluation process (the best, directly after the indication of the PD impulses) and subsequent processing digitized data only.

The impossibility of using top human experts for the routine on-line evaluation because their temporary inaccessibility leads to the necessity of developing such an instrument which compensates the human expert view without decreasing the decision-making process quality. Expert systems based on the elements of the artificial intelligence are the best solution of this problem.

On the basis of experience with PD measurement a new principle of PD device has been developed at the Czech Technical University in Prague. The developed evaluating system for the PD measurement has several advantages (in comparison with commercially produced PD devices based on analog data processing only):

- The digitization of PD data directly in the measuring unit, the transfer of the digitized data into the computer via a standard serial line and the processing of digitized data enabling to minimize the impulse interference.
- The possibility of software modification with respect to specific conditions of the tested equipment.
- Low price in comparison with commercially produced PD devices.
- The improvement of mechanical resistance and the operational reliability of the PD device considering the fact that the new PD equipment has minimum of mechanical and analog parts.

At present, the developed equipment is tested in the High Voltage Laboratory of the Czech Technical University in Prague. After successful testing under the laboratory conditions, this equipment will be tested in the operation, at several workplaces in the Czech National Network System. Considering all advantages of a new principle of the measurement and evaluation of the diagnostic PD parameters, this diagnostic method is expected to expand in power engineering plants and in the future these systems are expected to be installed in the majority of medium and large power machines and equipments in the power engineering system in the Czech Republic. This system could also be used in nuclear power plants ensuring the safety and reliability of the important electrical machines and equipment.

Acknowledgments

I would like to thank very much to students of the Department of Electrical Power Engineering of the Czech Technical University in Prague, Faculty of Electrical Engineering for the cooperation at the measurement tests.

The Department of Electrical Power Engineering of the Czech Technical University in Prague and the Czech Republic Grant Agency (grant No. 102/02/0105) financially supported this project.

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