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DEVELOPMENT OF COMPLEX SYSTEM FOR MEASUREMENT AND EVALUATION OF PD ACTIVITY

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Abstract – Expert systems are used for the evaluation of the actual state and future behaviour of insulating systems of electrical machines and equipment, especially for the evaluation of discharge activity in high voltage insulation by partial discharge (PD) measurement. Several rule-based expert systems were developed in the High Voltage Laboratory of the Czech Technical University in Prague for these purposes in the co-operation with top diagnostic workplaces in the Czech Republic.

Nowadays, the complex system for the evaluation of PD measurement including software and hardware facilities has been developed. Two expert systems for the evaluation of PD activity work in this complex evaluating system: a rule-based expert system performs an amplitude analysis of PD impulses for determining the damage of the insulation system, and a neural network is used for a phase analysis of PD impulses to determine the kind of PD activity. Both expert systems operate simultaneously and special software ensures co-ordination between them.

Keywords: dielectric diagnostics, measurement, partial discharges, artificial intelligence, expert system.

1. INTRODUCTION

Together with the increasing power and cost of new electrical machines and equipment being installed in the electrical power network of the Czech Republic, problems with operational reliability of machines and equipment have come to the forefront of expert's attention. The insulation systems belong to the most exposed parts of high-voltage electrical machines and equipment. Thus special diagnostic methods have been worked out, which are able not only to detect defects and anomalies in high-voltage insulation systems, but also evaluate the state of the systems regarding their further service reliability. Following the results of these diagnostic methods, it is then possible not only to determine the reliability of the equipment in subsequent service but also to prolong the inspection periods, or to reduce the number of inspections.

The evaluation of the state of high voltage insulating system of large electrical machines and equipment is executed by special diagnostic methods. Because the evaluation of an actual state of the insulation and the estimation of a machine performance in further operation are complicated, it is necessary to consult experienced experts or this problem could be solved by expert systems. These expert systems are computing programs with elements of artificial intelligence are based on the principle of the transmission of human expert knowledge into the system and using it with the same results as the consulting human expert. For the processing of information of the type „assumption-hypothesis“, i.e., the „if-then“ type of the decision, rule-based expert system provides the best solutions. On the other hand, neural expert systems (neural networks) are usually used for complicated or intuitive decisions, e.g. for the recognition of partial discharge (PD) patterns.

Several expert systems for the diagnostics of high voltage insulation systems have been created at the Czech Technical University (CTU) in Prague, Faculty of Electrical Engineering, in the High Voltage Laboratory of the Electrical Power Engineering Department. These expert systems are based on the empty rule-based SPEL-EXPERT system (a modification of the FEL-EXPERT system, created at the CTU, Department of Control Technology). The main sources used for the development of our expert systems became first, Czech and international standards; second, operational regulations of the Czech Power Company and the ORGREZ Company; third, the results of consultations with experts; and fourth, scientific literature.

The quality of expert systems (mainly of rule-based expert systems) is significantly influenced by the quality of the knowledge base created by human experts. For that reason, ours research team co-operated with several Czech top workplaces, including universities, research institutes and laboratories, specialised companies and with individual experts worked in this area.

2. DEVELOPED EXPERT SYSTEMS

The IZOLEX expert system is one of the developed rule-based expert systems for the evaluating of diagnostic measurement on high voltage machines and apparatus and was successfully tested in several testing workplaces - power plants at Chvaletice, Mělník, Dětmarovice, Dukovany, Tisová and Temelín. This expert system evaluates diagnostic measurements done by means of 48

commonly used diagnostic off-line methods (with the device in shut down state, during its maintenance) for the diagnostics of high voltage insulation. The IZOLEX expert system provides five main statements depending on the final coefficient of failure. Limit values of diagnostic parameters must be given for each diagnostic method in the expert system corresponding to the coefficients of the failure, including statements. The present inference network of the IZOLEX expert system consists of 628 nodes, 783 rules, 65 context links, 282 priority links, 3 taxonomies and 107 goals. The following taxonomy classes of the IZOLEX expert system were selected according to the respective areas of diagnostics: Rotating electrical machines, non-rotating electrical machines and insulating oils.

The CVEX expert system is a part of the IZOLEX expert system for the evaluation of PD activity on high voltage electrical machines and equipment by an off-line method, e.g. by the galvanic PD method with a serial connection of the measuring impedance and the coupling capacitor. The PD measurement is based on the measurement of PD parameters on various levels of applied voltage U. The CVEX expert system evaluates all common known PD parameters, i.e., initial voltage U_i, basic PD parameters (apparent charge q, average PD current I, cumulative charge Q), jumpings on curves $q = \mathrm{f}(U)$, $I = \mathrm{f}(U)$, and $Q = \mathrm{f}(U)$, and changes in the shape of these curves. The CVEX expert system uses the values of these diagnostic parameters to determine the coefficient of failure and to provide five main statements, as well as to add nine additional statements. The present inference network of the CVEX expert system consists of 65 nodes, 116 rules, 1 context link and 28 priority links.

The CVEXON expert system is a modification of the CVEX expert system for the on-line measurement (non-interruptive monitoring, continuous checking) of the PD activity. In contrast of the CVEX, the CVEXON expert system evaluates basic diagnostic parameters (apparent charge, average PD current) only, together with their variations with time. The input data are obtained from permanently installed probes and they are further processed by analogue-digital (A/D) converters and finally there are displayed in an accessible form for the user, usually in the form of the front panel of the standard measuring instrument.

The ALTONEX expert system is the system for the on-line evaluation of the actual state of the rotating machine insulation. This system evaluates diagnostic measurements done by means of several on-line methods for rotating machines: The PD measurement, the bearing temperature monitoring, the evaluation of temperature stresses and local overheating in insulation, the frequency analysis of the current and magnetic fields and the indication of ozone in an cooling air.

3. COMPLEX SYSTEM FOR PD MEASUREMENT

The PD activity is usually measured by commercial PD devices, which have several disadvantages:

- The equipment is too expensive.
- The PD device is single-purposed and usually it is not possible to modify it according to specific conditions of a PD measurement.
- Analogue 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 PD device is too complicated and mechanically sensitive and that it does not guarantee the reliable operation during a long-time measurement under the operational conditions.

What is the reason of these problems? Mainly it is the fact, that these commercial devices are based on the principle of analog signal processing, which has 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 for 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.

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

In the frame of this project, a measuring unit for the measuring, digitizing and processing of PD data, including calibration equipment, has been developed. Detected analog PD impulses are digitized in the measuring unit by a special analog-digital converter and there are saved in 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.

3.1. Measuring unit

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 the voltage value on 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 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 maximal value of current impulse in the input amplifier), including resetting, should not take a

longer time than 50 μs (it is adequate to 256 levels in a digital form). It is a sufficient accuracy for the reading of the apparent charge value as well as sufficiently high speed for processing of PD signals (to the limit 200 signals during the one period of supply voltage, i.e. during 20 ms). A phase shift of PD impulses is distinguished with accuracy 1.8 °el., which is sufficient.

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

3.2. Software superstructure

After the value digitization of diagnostic PD parameters, the crux of the further activity lies in the software processing of data by special software. Before a proper evaluation of a PD activity, the statistical processing with the aim to remove random data and characteristic disturbances (radio interference, thyristor disturbances, etc.) treats measured data. '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 enables to include the experience of the human experts in this branch as well.

Developed evaluating system also uses two independent expert systems for the proceeding of measured PD data. These expert systems work simultaneously and special software controls their coordination. Rule-based expert system performs the amplitude analysis of PD impulses to specify the extent of the damage of the insulating system. After preliminary processing the data from the central unit are supplied into a small input database. Expert system evaluates these 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.

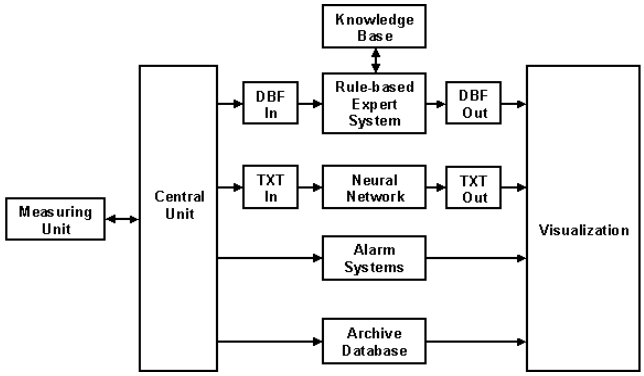

Fig. 2. Data flow in the MCV system

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 complex system has also its own archive database. It is possible to determine the different period of data saving for the different state of an operating system – a normal operation, enhanced PD activity, overfullfilment of alarm levels, important decisions of expert systems, etc. These records of PD data are very important for the consequent analysis of the defect state of the observed machine.

The visualisation of all results is done in an accessible form for the user; i.e. all results are shown on the virtual front panel of the measuring instruments, see Fig. 3. Besides a standard visualisation of PD data impulses during the period of the supply network, the results of expert systems evaluation, modes of filtering, level alarms and the results of statistical processing are also continuously displayed on the monitor screen.

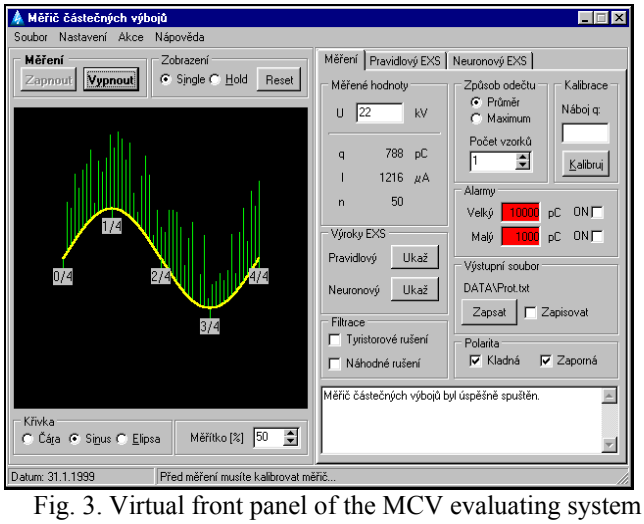

Fig. 3. Virtual front panel of the MCV evaluating system

3.3. Charge Calibrator

Within the project the PD calibrator (equipment for the generation PD impulses for the calibration of the measuring circuit) was developed. This device has top worldwide PD parameters, its calibration charge is switchable in the range

of 10 pC – 25000 pC and the frequency of these calibration pulses can be switched in ranges 50 Hz, 100 Hz, 1 kHz and 5 kHz. A photograph of this calibrator is in Fig. 4.

Fig. 4. Photograph of the charge calibrator

3.4. Data Generator

For the testing of the developed system and for teaching of neural network, it was necessary to develop the special data generator, which produces required testing data. Data generator is the special software product, which emulates the function of the measurement unit. It can be applied as an input of data into the diagnostics system, instead of the digital measurement device. This conception makes possible large variability, which is very advantageous for the training of neural network for recognition PD patterns.

The data generator generates ten periods with the combination of several types of disturbances: Random disturbances (from one to ten pulses in ten periods); thyristor disturbances (three or six pulses in period); PD patterns and background impulses. PD impulses during from the one period are displayed in the window, see Fig. 5.

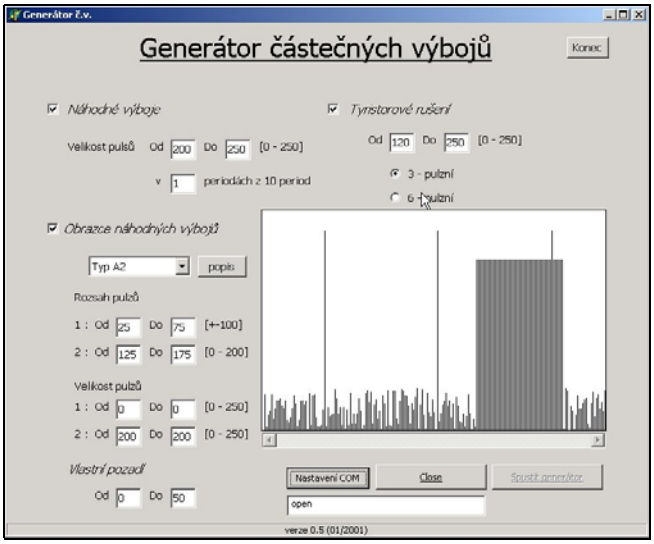

Fig. 5.Virtual panel of data generator

4. CONCLUSIONS

Several expert systems were developed in the High Voltage Laboratory of the CTU in the co-operation of top diagnostic workplaces of the Czech Republic. These expert systems are used for diagnostics of high voltage insulation systems, especially for the evaluation of PD activity. Expert systems for the evaluation of off-line measurements (CVEX, IZOLEX) are also in regular practice, while expert systems for on-line measurements (CVEXON, ALTONEX) are under operational testing, and on the basis of requirements of testing workplaces, corrections of their knowledge bases are being performed. All these developed expert systems are regularly updated with regards to the latest results of scientific research and practice.

In these days, the complex system for the evaluation of PD measurement has been developed. The connection between a computer and a measuring unit enables to load the digitised measurement data directly into the computer. Two parallel expert systems work in this complex evaluating system: a rule-based expert system performs an amplitude analysis of PD impulses for determining the damage of the insulation system, and a neural network is used for the phase analysis of PD impulses to determine the kind of PD activity and location of the resource of PD activity.

The developed evaluating PD stand has several advantages in comparison with commercially produced PD devices:

- The digitisation of PD data directly in the measuring unit, the transfer of the digitised data into the computer via a standard serial line and the processing of digitised data make possible to minimise the impulse interference.
- The possibility of SW modification according to the specific conditions of the tested equipment.
- Low price of this measuring stand in comparison with commercially produced PD devices.
- The improvement of the mechanical resistance and the operational reliability of the PD device considering the fact that the new PD stand has minimum of mechanical and analogue parts.

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