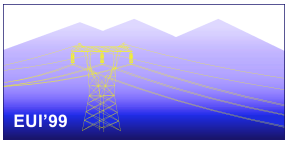

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Karel Záliš*

EVALUATION OF PARTIAL DISCHARGE MEASUREMENT

Abstract: Several rule-based expert systems were developed in the cooperation of top diagnostic workplaces of the Czech Republic for diagnostics of high voltage insulation systems, especially for the evaluation of partial discharge activity. Nowadays, the complex project has been made for the evaluation of partial discharge measurement. Two parallel expert systems for the evaluation of partial discharge activity on high voltage electrical machines will work at the same time in this complex evaluating system.

Keywords: dielectric diagnostics, partial discharges, insulation, artificial intelligence, expert system

1. Introduction

The evaluation of the state of insulating system of large electrical machines and equipment is executed by special diagnostic methods [1]. 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. The complexity of its future reliability in service could be also solved by expert systems with elements of artificial intelligence. These expert systems 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. By means of an expert system, even an inexperienced user is able to evaluate competently the state of the insulating systems and the equipment's behavior 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,

* Czech Technical University in Prague, Faculty of Electrical Engineering, High Voltage Laboratory, Technická 2, CZ – 166 27 Prague 6, Czech Republic; phone: +420 2 2435 23 69, fax: +420 2 311 75 56 e-mail: zalis@fel.cvut.cz

fuzzy logic, etc., as well as expert systems of a mixed type. For the processing of 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 ([2, 3]), e.g. for the recognition of PD patterns ([4, 5, 6, 7]).

Several expert systems for the diagnostics of high voltage (HV) insulations have been created at the Czech Technical University in Prague, Faculty of Electrical Engineering, in the High Voltage Laboratory of the Electrical Power Engineering Department in the collaboration with other top diagnostic workplaces in the Czech Republic.

The first step in the construction of the expert system is to choose a convenient empty expert system. Several empty expert systems were tested and finally the rule-based SPEL-EXPERT system (a modification of the FEL-EXPERT system [8], created at the Czech Technical University in Prague, Department of Control Technology) was chosen as a base of all our created rule-based expert systems. It is based on knowledge presentation by the production rules in the "if-then" form, and any uncertainty in the knowledge is represented with the help of Bayesian conditional probability.

The main sources used for the development of our expert systems became first, Czech (ČSN) and international (ISO) standards; second, operational regulations (in 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, the staff of the High Voltage Laboratory of the Czech Technical University in Prague cooperates with several Czech top workplaces, including universities (Czech Technical University in Prague; Technical University in Ostrava; Technical University in Brno; West Bohemian University in Pilsen); research institutes and laboratories (EGÚ Research Laboratory, Běchovice; Škoda Research Company, Pilsen; the Temelín Nuclear Power Plant; West Bohemian Power Company); specialized companies (the Czech Power Company, the ORGREZ Company, the HESIA Company); and with individual experts worked in this area.

2. Expert systems for electrodiagnostics

One of the rule-based expert systems for the evaluating of diagnostic measurement on HV machines and apparatus is the **IZOLEX expert system**. 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 HV insulation. The IZOLEX expert system was successfully tested in several testing workplaces — power plants at Chvaletice, Mělník, Dětmarovice, Dukovany, Tisová and Temelín. 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. Fig. 1 schematically shows the data flow in this evaluating system. Input data (values of diagnostic parameters) from the set of input forms for individual diagnostic methods (Input Form) are, after preliminary processing, delivered into the small input database (Input DBF). The expert system evaluates these data and saves the results (probabilities of hypotheses) into the small output database (Output DBF). The data are subsequently processed and displayed in the output form. Input data from the input form can be saved in the central database (Database), and the other way round, the data saved in the central database can be filled into the input form, and then evaluated by the expert system.

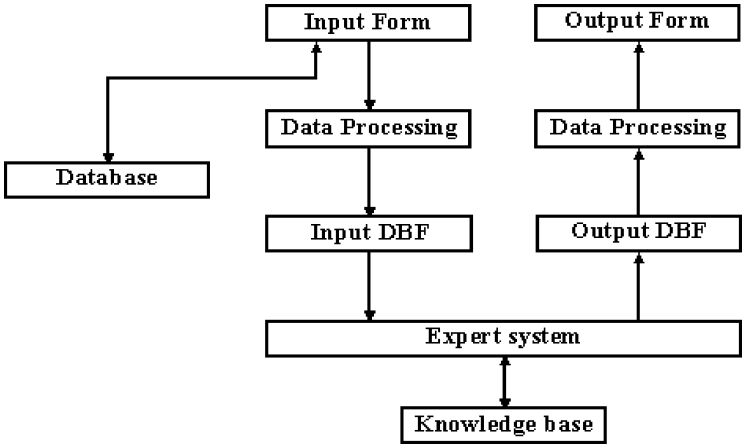

Fig. 1. *Data flow in the IZOLEX expert system*

The **CVEX expert system** is a part of the IZOLEX expert system for the evaluation of partial discharge (PD) activity on HV electrical machines and equipment by an off-line method, e.g. by the galvanic (global) PD method with a serial connection of the measuring impedance and the coupling capacitor. The evaluation of PD activity is based on the measurement of PD parameters on various levels of applied voltage U. The CVEX expert system uses the values of these diagnostic parameters to determine the coefficient of failure and to provide the main statement, as well as to add additional statements. The CVEX expert system provides five main statements (the same as the IZOLEX expert system) and 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 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 $q = f(U)$, $I = f(U)$, and $Q = f(U)$, and changes in the shape of these curves.

The **CVEXON expert system** is a modification of the CVEX expert system for the on-line measurement (non-interruptive monitoring, continuous checking of the state of the insulation system) 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 data flow and their evaluation are similar to the IZOLEX and CVEX expert systems. The input data are, however, obtained from permanently installed probes (Measuring unit), see Fig. 2. They are further processed by analog-digital (A/D) converters and displayed in an accessible form for the user, usually in the form of the front panel of the standard measuring instrument.

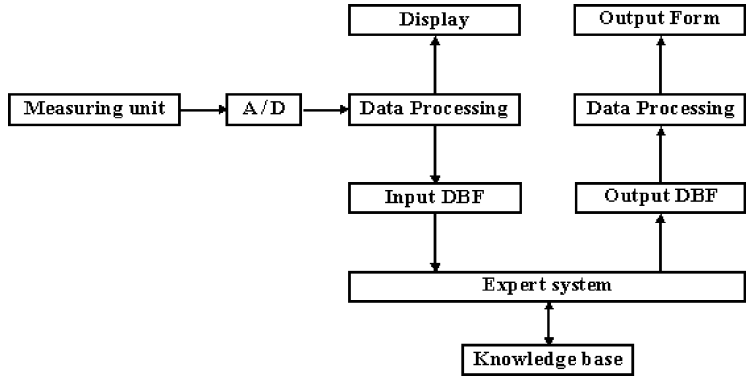

Fig. 2. *Data flow in the CVEXON expert system*

The **ALTONEX expert system** is the system for the on-line evaluation of the actual state of the rotating machine insulation. It has been created on the base of our experience obtained during the constructions of the previous expert systems. 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. In September 1997 the first trial run was implemented successfully in practice (in the Štěchovice power plant).

3. Stand 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, a tested machine or 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 device must be done in the original foreign 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.

In the period of 1994–99, the new principle of PD device has been developed at the Czech Technical University in Prague in the collaboration with the Development Laboratory of the Czech Technical University in Podbrady. In these days, the stable-measuring stand (measuring workplace) for PD measurement under operational conditions in on-line (non-interruptive) mode is created. Within this project, a measuring unit for the measuring, digitizing and processing of PD data, including calibration equipment, has been created. Based on our experience with commercial measuring units, the measuring unit has been made in cooperation with the Development Laboratory of the Czech Technical University in the town of Poděbrady. This unit enables quick and non-distort scanning of PD impulses and digitizes these data by a special A/D converter. A standard serial line connection (RS232) between the computer and measuring unit enable a direct access of the measured data into the computer. This procedure enables to evaluate diagnostic parameters immediately and to use this diagnostic method as an on-line measuring (monitoring) method. The whole project can be divided into several basic parts:

- The collection and digitizing of analog PD impulses.
  - The design and development of the measuring unit for the analog PD-impulse processing and digitizing.
  - The evaluation of the measuring unit reliability under the operational conditions (e.g. interference and cooperation of both systems).
  - The remote control of the measuring unit from the PC.
- The data transmission into the computer. A special unit for data processing, their digitizing and transfer into the computer, including operating software, was designed and created.
- Data processing including software development.
  - The archiving of data and information from PD measurement within the database system.
  - The conventional evaluation of the discharge activity (values of diagnostic parameters).
  - The development of alarm systems and system of limit levels.
  - The statistical processing of data for interference and random data elimination, data pre-processing for expert systems.
  - The development of a rule-based expert system for the amplitude analysis of PD impulses.

- The development of a neural expert system for the PD pattern recognition.
- The development of a command system for controlling the measuring unit and the A/D converter.
- The development of a central and coordinating software, including an evaluating unit.
- The visualization of the evaluated data and expert system recommendations.

A rule-based expert system performs an amplitude analysis of PD impulses for determining the damage the insulation system, and a neuron expert system (neural network) is used for the recognition of PD patterns (a phase analysis of PD impulses) for determining the kind of PD activity and the location of the source of PD activity. Both expert systems operate simultaneously and a special software ensures the coordination between them. The rule-based expert system for the amplitude analysis of PD data is based on the proven CVEXON expert system. After preliminary processing, the data from the central unit are delivered, into a small input database. The expert system evaluates this data and saves the results of the consultation (probabilities of hypotheses) into a small output database. After subsequent processing, the results are displayed on the screen of the monitor of the computer. A neural network has input and output of the data are practically similar, as in case of the rule-based expert system. The data flow in this evaluating system is schematically shown in Fig. 3.

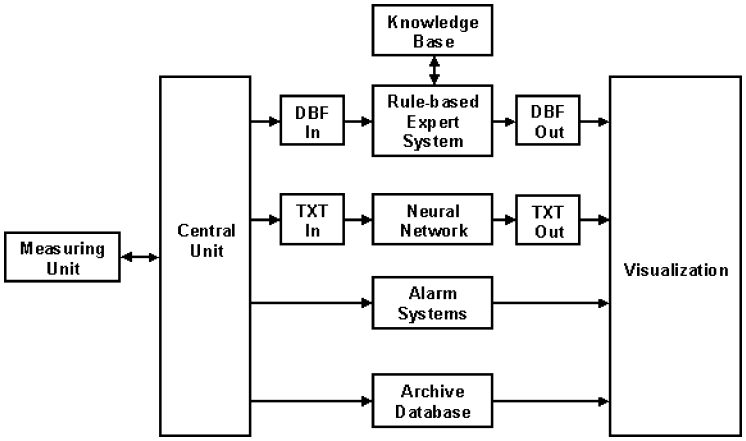

Fig. 3. *The data flow in the MCV system*

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 visualization 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. 4).

Besides a standard visualization of PD data impulses during the period of the supply network, the results of expert systems evaluation, modes of filtering and the results of statistical processing are also continuously displayed. The level alarms are visualized as well.

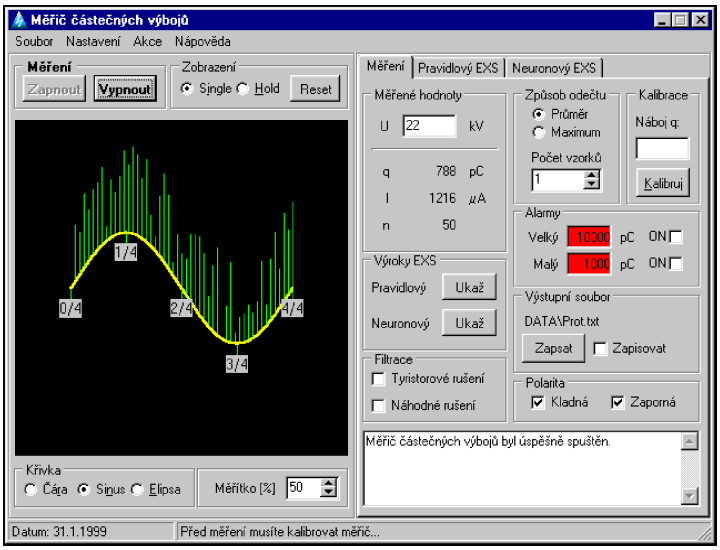

Fig. 4. *Virtual front panel of the MCV evaluating system*

4. Conclusions

Several rule-based expert systems were developed in the High Voltage Laboratory of the Czech Technical University in Prague in the cooperation of top diagnostic workplaces of the Czech Republic. These expert systems are used for diagnostics of HV insulation systems, especially for the evaluation of PD activity. Expert systems for the evaluation of an off-line measurement (CVEX, IZOLEX) are also in regular practice, while expert systems for an on-line measurement (CVEXON, ALTONEX) are under 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. The possibilities of their further development lie in the automation of measuring processes together with the mutual linking of individual sources of knowledge (databases, computer programs, etc.) in such a way that the expert systems can provide the user with a broader overview of the past and present states of the device and its grading according to other experts' criteria. Another possible area for the development can be found in incorporating the diagnostics of other electric components like capacitors, insulators, cables together with other kinds of diagnostics, e.g. with mechanical vibrations and heat stress.

In these days, the complex system for the evaluation of PD measurement has been developed. 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 neuron network is used for the recognition of PD patterns (a phase analysis of PD impulses) to determine the kind of PD activity and location of the resource of PD activity. Both expert systems, including the unit for a standard evaluation of the PD activity, operate simultaneously, and special software ensures coordination between them. The connection between a computer and a measuring unit enables to load the digitized measurement data directly into the computer. This procedure enables to evaluate diagnostic parameters immediately and enables to use this diagnostic method as an on-line measuring method.

In the frame of this research the special calibration generator (5–20000 pC, selectable apparent charge and PD current) has also been designed, developed and realized.

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

- 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 make possible to minimize the impulse interference.
- The possibility of SW modification according to the specific conditions of the tested equipment.
- Low price of this 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 analog parts.

At present, the created stand is tested in the High Voltage Laboratory of the Czech Technical University in Prague. After successful testing under the laboratory conditions, this stand will be tested in the operation, at several workplaces in the Czech National Network System.

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Ocena pomiaru wyładowań niezupełnych

W referacie zaprezentowano systemy ekspertowe, stosowane przy diagnostyce izolacji wysokonapięciowej (szczególnie dla oceny wyładowań niezupełnych) skonstruowane w Laboratorium Wysokich Napięć Czeskiego Uniwersytetu Technicznego w Pradze.