USING THE EXPERT SYSTEMS IN THE EVALUATION OF THE STATE OF HIGH VOLTAGE INSULATION SYSTEMS OF ELECTRICAL MACHINES

Karel Záliš

Expert systems are used for evaluating the actual state and future behavior of insulating systems of high voltage electrical machines and equipment. Several rule-based expert systems have been developed in cooperation with top diagnostic workplaces in the Czech Republic for this purpose. The IZOLEX expert system evaluates diagnostic measurement data from commonly used off-line diagnostic methods for the diagnostics of high voltage insulation of rotating machines, non-rotating machines and insulating oils. The CVEX expert system evaluates the discharge activity on high voltage electrical machines and equipment by means of off-line measurement. The CVEXON expert system is for evaluating the discharge activity by on-line measurement, and the ALTONEX expert system is the expert system for on-line monitoring of rotating machines. These developed expert systems are also used for educating students (in bachelor, master and post-graduate studies) and in courses which are organized for practicing engineers and technicians and for specialists in electroenergetics. A complex project has recently been set up to evaluate the measurement of partial discharges. Two parallel expert systems for evaluating partial discharge activity on high voltage electrical machines will work at the same time in this complex evaluating system.

Keywords: expert system, insulation, high voltage, dielectric diagnosis, diagnostics, predictive maintenance, reliability, electric machine, electric equipment, insulating oil, partial discharges, measurement

1 INTRODUCTION

Together with increasing power and cost of new electrical machines and equipment being installed in the electrical power network in the Czech Republic, problems with their operational reliability have come to the forefront of experts’ attention. The insulation systems are the most exposed parts of high voltage (HV) electrical machines and equipment. Special diagnostic methods are used for detecting defects and anomalies in HV insulation systems and for evaluating the state of the systems regarding their further operation reliability. Following the results of these diagnostic methods, it is 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 [1, 2].

For determining the actual state of the insulation system, a great number of diagnostic methods are available but none of them solves the problem unambiguously in all its complexity. Therefore, a complex of diagnostic methods complementing each other is usually used for this purpose and each diagnostic group, workplace, and laboratory uses its own set of diagnostic methods. The choice of the methods for such a set is influenced not only by their declarability but also by the equipment available to specific work group, by the put-at-risk degree of insulation and by the demands on operation interruption. The declarability of the diagnostic method is the ability to quantify the results of these methods with regard to further operation reliability. One of the important aspects is whether by the application of the diagnostic method the insulating system is stressed by the appropriate stress at the appropriate place. In testing, the stress on the insulation could be different than that in operation, eg by DC testing methods. The testing method may also stress the insulation system in other parts than it is stressed in operation, eg in use of some off-line measurements with an external power source. The put-at-risk (safety criterion) may be null, eg in case of an optical observation or electrical measurement at low voltage, or it may have a high value, as in the case of overvoltage proof tests. The risk of damage to certain parts and consequent repair is in some cases accepted in practice as a planned activity to eliminate a high-risk situation. Another criterion is the operation interruption, ie the interruption of normal machine operation in the case of applying of the diagnostic method. This criterion would rank differently depending on whether a diagnostic method is presupposed for the purposes of periodic diagnostics (off-line measurement) or for permanent monitoring of the state of the machine (on-line measurement).

The evaluation of an actual state of the insulation and the estimation of a machine performance in further operation are complicated, and that is why it is necessary to consult experienced experts. Diagnostic measurement data are often gathered in database systems which

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Expert systems can be a very efficient tool for fast, high-
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s were oriented on recording results and storing operational
equipment data. In top workplaces, evaluating database
ystems are also in use for evaluation [3, 4]. The com-
plexity of its future reliability in service could, however,
be solved only by an expert system with elements of art-
ficial intelligence. Such an expert system evaluates in-
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them, uses knowledge from previous measurements and
evaluations and provides expert propositions. By means
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tems and the equipment's behavior in further operation.
Expert systems are based on the principle of the trans-
mission of human expert knowledge into the system and
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vice can either be taken or disregarded. During the on-line
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insulating systems immediately and, at the same time,
offers a solution with respect to the safety and reliability
of the 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 algo-
rithms, fuzzy logic, etc., as well as expert systems of
a mixed type. For processing information of the type
"assumption-hypothesis", ie the "if-then" type of deci-
sion, rule-based expert systems provide the best solutions.
On the other hand, neuron expert systems (neural net-
works) are usually used for complicated or intuitive de-
cisions [5, 6], eg for recognizing of patterns of partial dis-
charges [7, 8].

Several expert systems for the diagnostics of HV insu-
lations have been developed at the Czech Technical Un-
iversity (CTU), Faculty of Electrical Engineering (FEE),
Department of Electroenergetics, High Voltage Labora-
tory in collaboration with other top diagnostic workplaces
in the Czech Republic. The aim of these expert systems is
to increase both the reliability and safety of operation of
large power machines (alternators, transformers and ap-
paratuses) working in the Czech Republic National Power
System.

The first step in the construction of the expert sys-
tem is to choose a convenient empty expert system. Sev-
eral empty expert systems were tested and finally the
rule-based SPEL-EXPERT system (a modification of the
FEL-EXPERT system [9], developed at the Department
of Control Technology, CTU) was chosen as a base of
all our developed rule-based expert systems. These rule-
based expert systems are based on knowledge presenta-
tion by production rules in the "if-then" form, and any
uncertainty in the knowledge is represented with the help
of Bayes conditional probability. A weight factor is as-
associated with each rule, representing the degree of cer-
tainty of an expert in a given statement. A part of the
logical structure of the knowledge base is demonstrated
in Fig. 1, where $K_p$ is the coefficient of failure.

The main sources used for developing our expert sys-
tems were first, Czech (CSN) and international (ISO)
standards; second, operational regulations (of the Czech
Power Company and the ORGREZ Company); third, the
results of consultations with experts; and fourth, scien-
tific literature. The quality of expert systems (mainly
of rule-based expert systems) is significantly influenced
by the quality of the knowledge base created by hu-
man experts. For that reason, the staff of the CTU
High Voltage Laboratory cooperates with several lead-
ning Czech workplaces, including universities (TU, Os-
strava; TU, Brno; WBU, Pilsen); research institutes (EGÚ
Research Laboratory, Běchovice); laboratories of pro-
ducers (Skoda Research Company, Pilsen; CKD Com-
pany, Prague) and supply companies (Czech Power Com-
pany; West Bohemian Power Company; Temelín Nuclear
Power Plant; Dukovany Nuclear Power Plant); specialized
electrical power companies (ORGREZ Company, HESIA
Company); and with individual experts working in this
field.

2 THE IZOLEX EXPERT SYSTEM

One of the rule-based expert systems for evaluating
diagnostic measurements on HV machines and apparatus
is the IZOLEX expert system [10]. This expert system
evaluates diagnostic measurements taken by means of
48 commonly used diagnostic off-line methods (with the
device in shut down state, during its maintenance) for
diagnosing HV insulation.
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The IZOLEX expert system was tested in several testing workplaces — the power plants at Chvaletice, Mělník, Dětmarovice, Dukovany, Tisová and Temelín [11]. On the basis of the requirements of the testing workplaces and on the basis of the needs of other users, a further version was worked out and then distributed to all workplaces of the Czech Power Company. This version (IZOLEX 98) is user-friendly and more convenient than the previous ones. 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 main 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 following diagnostic methods are used for evaluating the state of the HV insulation of rotating machines: visual checking methods, apparent insulation resistance, polarization index, time constant of insulation, voltage dependence of conductance, capacitance and loss factor, galvanic (global) PD-measurement, PD-measurement using an inductive coupling probe, PD-measurement using a differential electromagnetic probe, AC (50 Hz) test voltage, DC test voltage, low frequency (0.1 Hz) test voltage, differential thermic analysis, concentration of ozone in the cooling air, frequency analysis of current and magnetic field, and the starting method. For evaluating non-rotating machine insulation the following methods are used: apparent insulation resistance, polarization index, time constant of insulation, capacitance and loss factor, PD-measurement, polarization spectrum analysis, the frequency response characteristic, capacitor bushing methods and the $C_2/C_{50}$ method. Diagnostic methods for insulating oils are a special part of IZOLEX. There are two diagnostic sets in the evaluating system: the gas chromatography (analysis) of gases in insulating oil (methane, ethane, ethylene, propane, propylene, acetylene, hydrogen, carbon dioxide, carbon monoxide, etc.) and physical parameter tests (loss factor, apparent insulation resistance, breakdown strength, water content, acid number, surface tension, etc).

The IZOLEX expert system provides five main statements depending on the final coefficient of failure $K_p$. The main statements are associated with intervals of coefficient $K_p$, see Tab. 1. 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 information module has been implanted into our system with respect to the users’ wish. If desired, the system can display information about the current diagnostic method, the technique routine of measurements, measured parameters, limiting values, etc. This information is especially useful for users who are not familiar with the diagnostic method.

The IZOLEX expert system is also equipped with a system of input/output data forms. This system makes the procedure of data inserting more convenient and user-friendly. Figure 2 shows a sample of an input form (input form of physical parameter tests for insulating oils).
3 THE CVEX EXPERT SYSTEM

Measurement of partial discharges (PD), ie measurement of PD-activity, is an important modern non-destructive method for testing HV machines and equipment [12,14]. The discharges destroy the insulating system, which leads ultimately to the breakdown and crash of the equipment. The measurement of the PD-activity is also especially convenient for detecting the loosening of stator bars in rotating electrical machines, which leads to vibration of the bars during operation, to mechanical damage of resin insulation and, eventually, to the breakdown of the insulation. From this point of view the measurement of PD-activity is the most effective method for evaluating the state of modern insulating systems based on resin materials.

The CVEX expert system is a part of the IZOLEX expert system and it is used for evaluating PD-activity on HV electrical machines and equipment only. It is used for off-line measurement, eg by the galvanic PD-method with a serial connection of the measuring impedance and the coupling capacitor. The evaluation of PD-activity is based on measuring PD-parameters on various levels of applied voltage U.

The following diagnostic PD-parameters are usually evaluated as quantifiable parameters:

- \( U_i \) – Initial voltage of PD (kV). The lowest value of supply AC voltage at which the PD-intensity of PD is equal to the standard intensity (eg 1000 pC) while the supply voltage increases.
- \( q \) – Apparent charge (pC). The maximum apparent charge during the period of supply voltage. Also denominated \( q_{\text{max}} \).
- \( I \) – Average current of PD (mA). The sum of the absolute values of apparent charges at the given time interval divided by the duration of this interval.
- \( Q \) – Cumulative charge (pC). The sum of absolute values of apparent charges at the given time interval, usually equal to the period of supplied voltage.
- \( dq \) – Jump on curve \( q = f(U) \) (%). Maximum jump (sudden change in value), expressed by the formula \( dq = \frac{(q_1 - q_2)}{(U_1 - U_2)} \cdot U_n/q_{\max} \), where indices 1 and 2 indicate values obtained in one measurement on curve \( q = f(U) \) and index \( n \) indicates values obtained for nominal voltage.
- \( dI \) – Jump on curve \( I = f(U) \) (%). Maximum jump, expressed by the formula \( dI = \frac{(I_1 - I_2)}{(U_1 - U_2)} \cdot U_n/I_{\max} \), where indices 1 and 2 indicate values obtained in one measurement on curve \( I = f(U) \) and index \( n \) indicates values obtained for nominal voltage.
- \( dQ \) – Jump on curve \( Q = f(U) \) (%). Maximum jump, expressed by the formula \( dQ = \frac{(Q_1 - Q_2)}{(U_1 - U_2)} \cdot U_n/Q_{\max} \), where indices 1 and 2 indicate values of \( Q \) for the same value of \( U \) on curves \( Q = f(U) \) obtained in different measurements.
- \( DI \) – Change in shape of curve \( I = f(U) \) (%). Maximum change in shape of the curve evaluated according to the formula \( DI = \max \left| I_1 - I_2 \right| \cdot 100/\min(I_1, I_2) \), where indices 1 and 2 indicate values of \( I \) for the same value of \( U \) on curves \( I = f(U) \) obtained in different measurements.
- \( DQ \) – Change in shape of curve \( Q = f(U) \) (%). Maximum change in shape of the curve evaluated according to the formula \( DQ = \max \left| Q_1 - Q_2 \right| \cdot 100/\min(Q_1, Q_2) \), where indices 1 and 2 indicate values of \( Q \) for the same value of \( U \) on curves \( Q = f(U) \) obtained in different measurements.

The CVEX expert system evaluates all commonly known PD-parameters, ie initial voltage \( U_i \), apparent charge \( q \), average PD-current \( I \), cumulative charge \( Q \), jumps on curves \( q = f(U) \), \( I = f(U) \), and \( Q = f(U) \), and changes in the shape of these curves (see input form in Fig. 5). The CVEX expert system provides five main statements (the same as the IZOLEX expert system) and
interruptive monitoring, continuous checking of the state of the insulation system). In contrast to the CVEX system, the CVEXON expert system evaluates only basic diagnostic parameters (apparent charge, average PD-current) together with their variations with time.

The data flow and the data evaluation are similar to the IZOLEX and CVEX expert systems. The input data are, however, obtained from permanently installed probes (Measuring unit), see Fig. 6. Data is 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 (see Fig. 7).

Table 3.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Limits</th>
<th>$K_p$</th>
<th>Additional statements</th>
</tr>
</thead>
<tbody>
<tr>
<td>$U$</td>
<td>$&lt; U_{i,n}$</td>
<td>0.5</td>
<td>V9</td>
</tr>
<tr>
<td>$q$</td>
<td>$&lt; 10^3$ pC ( (10^3, 2 \times 10^3) ) pC ( (2 \times 10^3, 10^3) ) pC $&gt; 10^3$ pC</td>
<td>0.5</td>
<td>V1, V2 + V5, V3 + V5 + V6</td>
</tr>
<tr>
<td>$I$</td>
<td>$&lt; 10 \mu A$ ( (10, 20) ) $\mu A$ ( (20, 50) ) $\mu A$ ( &gt; 50 \mu A )</td>
<td>0.7</td>
<td>V2 + V6, V3 + V6, V4 + V6</td>
</tr>
<tr>
<td>$Q$</td>
<td>$&lt; 10^3$ pC ( (10^3, 2 \times 10^3) ) pC ( (2 \times 10^3, 5 \times 10^3) ) pC ( &gt; 5 \times 10^3 ) pC</td>
<td>0.7</td>
<td>V3 + V6, V4 + V6</td>
</tr>
<tr>
<td>$dq$</td>
<td>$&lt; 2$ ( (2, 5) ) ( &gt; 5 )</td>
<td>0.7</td>
<td>V1, V2 + V6, V3 + V6, V4 + V6</td>
</tr>
<tr>
<td>$df$</td>
<td>$&lt; 2$ ( (2, 5) ) ( &gt; 5 )</td>
<td>0.7</td>
<td>V1, V2 + V6, V3 + V6</td>
</tr>
<tr>
<td>$dQ$</td>
<td>$&lt; 2$ ( (2, 5) ) ( &gt; 5 )</td>
<td>0.7</td>
<td>V1, V2 + V6, V3 + V6</td>
</tr>
<tr>
<td>$Dq$</td>
<td>$&lt; 10$ % ( (10, 20) ) ( &gt; 20 %)</td>
<td>0.7</td>
<td>V1, V2 + V6, V3 + V6, V4 + V6</td>
</tr>
<tr>
<td>$DI$</td>
<td>$&lt; 10$ % ( (10, 20) ) ( &gt; 20 %)</td>
<td>0.7</td>
<td>V1, V2 + V6, V3 + V6, V4 + V6</td>
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<tr>
<td>$DQ$</td>
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<td>V1, V2 + V6, V3 + V6</td>
</tr>
</tbody>
</table>

5 THE ALTONEX EXPERT SYSTEM

The ALTONEX expert system [15] is a system for on-line evaluation of the actual state of rotating machine insulation. It has been developed on the basis of our experience obtained during the construction of previous expert systems.

4 THE CVEXON EXPERT SYSTEM

The CVEXON expert system is a modification of the CVEX expert system for on-line measurement (non-

![Fig. 5. Input form in of CVEX expert system](image)

nine additional statements, see Tab. 2. 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 uses the values of these diagnostic parameters to determine the coefficient of failure $K_p$ and to provide the main statement, as well as to add extra statements according to Tab. 3.

Table 2.

| V1 | Diagnostic measurement of discharge activity (partial discharges) to be carried out in current intervals (2-3 years), if not any other recommendations. |
| V2 | Diagnostic measurement of discharge activity (partial discharges) to be carried out in reduced intervals (approx. 1 year), if not any other recommendations. |
| V3 | Diagnostic measurement of discharge activity (partial discharges) to be carried out in intervals of 1/2 year’s duration approximately, if not any other recommendations. |
| V4 | Dangerous discharge activity occurs. |
| V5 | Some of localization method is recommended for locating the source of partial discharges (acoustic probe, differential electromagnetic probe, inductive coupling probe, ...). |
| V6 | Visual checking of winding is recommended at the next opportunity. |
| V7 | The change of the insulation state. |
| V8 | Vibration of bars. |
| V9 | Partial discharges occur during operation of the device. |
systems. This system evaluates diagnostic measurements done by means of several on-line methods for rotating machines: PD-measurement, bearing temperature monitoring, evaluation of temperature stresses and local overheating in insulation, frequency analysis of current and magnetic fields, and the indication of ozone in cooling air (see Fig. 8).

Our aim is to interconnect this expert system with the expert system for vibrodiagnostics of large rotating machines developed by Škoda Pilsen. This complex expert system could be able to monitor the whole turbine-alternator unit.

6 THE COMPLEX SYSTEM FOR THE EVALUATION OF PD–ACTIVITY

At present, a complex system for evaluating of PD-measurement is being developed in the High Voltage Laboratory of the CTU [16]. Two parallel expert systems for evaluating PD-activity on HV electrical machines and equipment will work in this complex evaluating system: a rule-based expert system performs amplitude analysis for determining the damage to the insulation system, and a neuron network will be used for recognizing PD-patterns (a phase analysis of PD-impulses) to determine the kind of PD-activity and the location of the resource of PD-activity according to Tab. 4 [17]. The two expert systems, including the unit for standard evaluation of the discharge activity, will operate simultaneously, and special software will ensure coordination between them. The construction of each expert system requires the construction of a “bank of experts” as well as the determination of limit values of diagnostic parameters and the development of a suitable training set.

The whole project can be divided into several basic parts:

- Analog PD-impulses collection:
  - The design and development of the input unit and the processing of analog PD-impulses.
  - The measuring of dynamic characteristics of the measuring unit under operational conditions (e.g. by interference, the cooperation of systems).
  - Remote control of the measuring unit from the controlling PC.
  - Design and development of the calibration generator (10–20000 pC).

- Data digitalization and transmission. A special unit for data processing, including operating software, will be designed and developed in cooperation with the Development Laboratory of the CTU FEE.

- PC data processing, which contains software development for the following activities:
  - Data and PD-measurement information saving within the database system.
  - Conventional evaluation of the discharge activity, including graphs, histograms and developmental diagrams (flow charts) of diagnostic parameters.
  - Statistical data processing for eliminating interference and random data, data preprocessing for expert systems.
Table 4.

<table>
<thead>
<tr>
<th>Type</th>
<th>Oscilloscopic picture</th>
<th>Description</th>
<th>Type of discharges</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td><img src="image" alt="Image" /></td>
<td>Pulses of equal amplitude in one half-cycle, symmetrical about the voltage maximum. With increased voltage, number increases, but not amplitude. Pulses on other half-cycle only at higher voltage.</td>
<td>Sharp point against large opposite electrode in gas. Charge pulses in negative half-cycle; sharp point at high voltage potential. Charge pulses in positive half-cycle; sharp point at earth potential.</td>
</tr>
<tr>
<td>B</td>
<td><img src="image" alt="Image" /></td>
<td>Pulses in both half-cycles symmetrical about the voltage maximum; smaller pulses of same amplitude. Increases in number with increased voltage.</td>
<td>Sharp point against large opposite electrode in liquids. Large pulses in positive half-cycle; sharp point at low voltage potential. Charge pulses in negative half-cycle; sharp point at high voltage potential.</td>
</tr>
<tr>
<td>C</td>
<td><img src="image" alt="Image" /></td>
<td>Pulses between zero-crossings and peaks of both half-cycles. On an average, pulses of the same amplitude in both half-cycles.</td>
<td>Voids in solid insulating materials. Gas bubbles in liquid materials. Insulated conductors in contact. Discharges on surface without metallic contact Ungrounded metallic parts.</td>
</tr>
<tr>
<td>D</td>
<td><img src="image" alt="Image" /></td>
<td>Pulses between zero-crossings and peaks of both half-cycles. On an average, pulse amplitude in one of the half-cycles larger.</td>
<td>Voids in solid insulating materials at the electrodes. Discharges on surface at the electrode. Large pulses in positive half-cycle; discharge on the high voltage side. Large pulses in negative half-cycle; discharge on the earth side.</td>
</tr>
<tr>
<td>E</td>
<td><img src="image" alt="Image" /></td>
<td>Pulses symmetrical about both the zero-crossings.</td>
<td>Poor contact between metallic parts or between semiconducting layers.</td>
</tr>
</tbody>
</table>

In the first period of the work on this research project the measuring unit and rule-based expert system were developed. Based on our experience with commercial measuring units, the special measuring unit, including calibration equipment, was made in cooperation with the Development Laboratory of the CTU FEE in Poděbrady. This unit allows quick and distortionless scanning of PD-impulses. A connection between a computer and the measuring unit enables us to load the measurement data directly into the computer. The detected analog pulses are digitized by special A/D conversion units and then applied to the computer unit. This procedure enables us to evaluate the diagnostic parameters immediately and to use this diagnostic method as an on-line measuring method. Basic software for collecting and evaluating the results from the diagnostic measurement has also been developed. Our work was also focused on increasing the efficiency of the data flow in the system, developing the central database for the measured data, and designing and producing a better, multipurpose measuring unit including a new type of a calibration equipment. A further stage of our research activity involves developing a neuron network for the recognition of PD-patterns (a phase analysis of PD-impulses). The construction of this expert system requires the development of a suitable training set. We decided to teach the neural network in three steps: the first, from artificial data gained from scientific literature, the second, from the commonly known simple real...
PD-arrangements, and the third, from real devices with known defects.

7 EXPERT SYSTEM AS AN EDUCATIONAL TOOL

Although classical expert systems have not been developed as basic teaching tools (specialized educational software serves for this purpose), it is possible to use it in this way and it seems to be very efficient. The IZOLEX expert system is used for self-study and acquisition of experience and skills within the area of evaluating the state of insulating systems, above all. This expert system was modified for this purpose on the request of operational specialists. There are two fundamental ways of using it for teaching and for self-access of both students and operational workers in electroenergetics:

- Obtaining information about electrodiagnostics and diagnostic methods. For this activity the IZOLEX expert system was equipped with a wide informative component part which contains all necessary information about individual diagnostic methods, including connection descriptions, operating procedures for the measurement, the necessary device equipment, advantages and disadvantages of the methods for the operational measurement, measured diagnostic parameters, input data processing, data evaluation and interpretation of results, and contacts with specialized diagnostic workplaces.
- Knowledge testing, practical skills and experience of operational workers in evaluating the state of the HV insulating system. In a routine mode of expert system operation the central database of measured data is used mainly for saving measured values of diagnostic parameters. It is possible to transfer the saved values from the central database back into an input form of the expert system and then to evaluate them repeatedly by the expert system. Just in the case of testing of experience of the operational staff, this central database of measured values is substituted by the specially developed training database. This training database was developed by specialists in electrodiagnostics. Individual elements of the training set (records of database) contain not only standard but even extreme and border (ambiguous) situations close to the evaluation of the state of the insulating system. A tested user selects the elements from the test database according to its degree of difficulty (see Figure 9), does his own evaluation of "measured" values of diagnostic parameters and, after evaluating these input data by the expert system, he confronts his interpretation with the statements of the expert system.

This educational system has already been used successfully at operational diagnostics workplaces for training new workers and for increasing the skills of the current staff. Students at the CTU, Department of Electroenergetics get familiar with these expert systems both in their bachelor studies in the course in Applied Programming in Electroenergetics. Later on, in the master's program, these expert systems are used as teaching media for education in the specialization in insulating system diagnostics and in courses in Database and Expert Systems in Electroenergetics and Diagnostics of Insulating Systems. Students complete stepwise simple expert systems (usually for several diagnostic methods or several flows of input data) in their term presentations. The goal is to teach them general rules for the choice of diagnostic methods (or other sorts of input parameters) for expert system, for choosing a convenient empty expert system and for creating a knowledge base to be able to develop their own simple purposeful expert system for solving various common problems in electroenergetics (not only in electrodiagnostics). In postgraduate programs students develop knowledge bases for solving special problems in electroenergetics, and they also incorporate developed expert systems into more complex evaluating systems.

8 CONCLUSIONS

The problems in evaluating diagnostic measurements on HV machines and equipment used in the Czech Power Network System are being studied in the CTU High Voltage Laboratory. Several expert systems for dielectric diagnostics have been developed in cooperation with top diagnostic workplaces in the Czech Republic. Rule based expert systems for evaluating off-line measurement (the CVEX expert system for evaluating PD-measurement on rotating machines and the IZOLEX expert system for electrodiagnostics of HV insulation of electrical machines and equipment) also work in practice. On the basis of the requirements of testing workplaces, corrections to the knowledge bases of these expert systems have been performed. The expert systems for on-line measurement (the CVEXON expert system for evaluating PD-measurement of rotating machines and the ALTONEX expert system for the complex electrodiagnostics of rotating machines) are undergoing testing. The development of a complex system for evaluating PD-measurement is at the center of current activity. The project for complex evaluation of PD-measurement is now being developed. Two parallel expert systems for evaluating PD-activity on HV electrical machines will work at the same time in this complex evaluating system.

The biggest advantage of expert systems lies in the fact that expert systems enable us to determine the risks of further operation of the device without the necessity of consulting the matter with top experts, even if there is a non-expert user. Expert systems are also very good and effective tools for educating maintenance men and specialists in electroenergetics. It helps them to get experience and skills in evaluating HV insulation. The Department of Electroenergetics at the CTU uses these expert systems for educating students in bachelor, master and post-graduate studies. Programs are also organized for practicing technicians.
All these developed expert systems are regularly updated with regard to the latest results of scientific research and practice. The evaluation of individual diagnostic methods is mainly stressed. The possibilities of developing them further lie in the automation of measuring processes together with mutual linking of the 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, eg capacitors, insulators, cables together with other kinds of diagnostics, eg with mechanical vibrations and heat stress.

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References


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