Using expert systems in evaluation of high voltage insulating systems

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Abstract

Expert systems were used for the evaluation of the actual state and future behavior of insulating systems of high voltage electrical machines and equipment. 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 for this purpose. Developed expert systems evaluate diagnostic measurement data from commonly used diagnostic methods for high voltage insulation systems of rotating machines, non-rotating machines and for insulating oils. Expert systems for evaluation of off-line measurement (CVEX, IZOLEX) also work in practice. Expert systems for on-line measurement (CVEXON, ALTONEX) are in the state of testing and on the basis of requirements of testing workplaces, corrections of their knowledge bases are performed.

Keywords

Dielectric diagnostics, high voltage, insulation, electrical machine, reliability, predictive maintenance, artificial intelligence, expert system

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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 operational reliability of machines and equipment have come to the forefront of experts' attention. The insulation systems are the most exposed parts of high voltage electrical machines and equipment. Special diagnostic methods are used for the detection of defects and anomalies in high voltage insulation systems and for the evaluation of the state of the systems regarding their further operation reliability (Šandrik and Zlatovský, 1998). 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.

For determining the actual state of the insulation system, there is a great number of diagnostic methods available, but none of them solves the problem in all its complexity unambiguously. 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 of the specific work group, by the put-at-risk degree of insulation and by the demands on the 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, e.g. by DC testing methods. The testing method may also stress the insulation system in other parts than it is stressed in operation, e.g., some off-line measurements using external power source. The put-at risk (safety criterion) may be null, e.g., in case of an optical observation or electrical measurement at low voltage, or it may have a high value, as in case of overvoltage proof tests. A risk of damage of 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, i.e. the interruption of normal machine operation in case of the application of the diagnostic method. This criterion would rank differently depending on whether a diagnostic method is presupposed for the purposes of periodic diagnostics or for the 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 the database systems, which were oriented on recording results and storing operational equipment data. In top workplaces, evaluating database systems are also in use for the evaluation. The complexity of its future reliability in service could be, however, solved only by the expert system with elements of artificial intelligence. Such an expert system evaluates individual diagnostic methods, makes correlations between

them, uses knowledge from previous measurements and evaluations and provides expert propositions. 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 expert. By means of a convenient expert system, even an inexperienced user is able to evaluate competently the state of the insulating systems and the equipment's behaviour in further operation. Expert systems can be a very efficient tool for the fast, high-quality decision-making but cannot fully replace humans in their decision-making and cannot solve non-standard situations. Simply stated, the statement of an expert system corresponds with the conclusions and recommendations of a colloquy of top experts in the field, whose advice can either be taken or disregarded. During the 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. 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 (Cimbala, 1994), e.g. for the recognition of patterns of partial discharges (Kolcunová and Kršňák, 1997).

Several expert systems for the diagnostics of high voltage insulation systems have been created at the Czech Technical University (CTU), 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 aim of these expert systems is to increase both the reliability and safety of operation of large power machines (alternators, transformers and apparatuses) working in the Czech Republic National Power System.

The first step in the construction of these expert systems was 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 (Mařík and Vlček, 1991), created at the CTU, Department of Control Engineering) was chosen as a base of all our created rule-based expert systems.

The main sources used for the development of these 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 CTU High Voltage Laboratory cooperates with several Czech top workplaces, including universities (CTU, Prague; TU, Ostrava; TU, Brno; WBU, Pilsen); research institutes and laboratories (EGÚ Research Laboratory, Běchovice; Škoda Research Company, Pilsen; the Temelín Nuclear Power Plant; ZČE);

specialized companies (the Czech Power Company, the ORGREZ Company); and with individual experts worked in this area.

2 THE IZOLEX EXPERT SYSTEM

One of the rule-based expert systems for the evaluating of diagnostic measurement on high voltage machines and apparatus is the IZOLEX expert system (Záliš, 1996). 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.

In 1996 the IZOLEX expert system was tested in several testing workplaces - power plants at Chvaletice, Mělník, Dětmárovice, Dukovany, Tisová and Temelín (Záliš, 1997). On the basis of requirements of the testing workplaces, and on the basis of needs of other users, the further version has been worked out and then distributed. This version is more user-friendly and comfortably 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 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. Following diagnostic methods are used for the evaluation of the state of high voltage insulation of rotating machines: Visual checking method, apparent insulation resistance, polarization index, time constant of insulation, voltage dependence of conductance, capacitance and loss factor, global (galvanic) partial discharges measurement, partial discharges measurement using the inductive coupling probe, partial discharges measurement using the differential electromagnetic probe, AC voltage test (50 Hz), DC voltage test, low frequency voltage test (0.1 Hz), differential thermic analysis, concentration of ozone in the cooling air, frequency analysis of current and magnetic field and starting method. For the evaluation of non-rotating machine insulation following methods are used: Apparent insulation resistance, polarization index, time constant of insulation, capacitance and loss factor, partial discharges measurement, polarization spectrum analysis, frequency response characteristic, capacitor bushing methods, C_2/C_{50} method and ultrasonic emission measurement. Diagnostic methods for insulating oils are the special part of the 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 and a lot of additional statements, which depend on evaluated diagnostic methods.

The information module has been implanted into the system on the users' wish. If desired, the system can display information about the current diagnostic method,

including the technique routines of measurements, measured parameters, limiting values, etc. This information is especially useful for the users not familiar with the diagnostic method.

The IZOLEX expert system is equipped with the system of input/output data forms. This system makes the procedure of data inserting more comfortable and user-friendly. Figure 1 shows a sample of an input form (input form of physical parameter tests for insulating oils). Figure 2 illustrates a sample of an output form (output form for partial discharges measurement on rotating machines).

Rozbor izolačního oleje

Datum měření: 21.12.97 Měřený objekt: Transformátor T401, Chrást u Plzně Číslo měření: 1

☒ transformátor vni - v provozu ☐ první měření oleje
☐ transformátor vni - před provozem ☐ stroj je hermetizovaný
☐ transformátor vvn - v provozu
☐ transformátor vvn - před provozem

Obsah antioxidantu (pouze u inhib. olejů)
obsah inhibitoru: 0,56825 % [0..1]

Izolační stav: Provozní stáří:

odrazné napětí: 25,5 kV/2,5 mm [0..1] povrchové napětí: 1 mN/m [0..1]
 variační koeficient: 5,2 % [0..1] ztr. čísel při SE: 21 x10² [0..1]
 obsah vody: 0,5 g/l [0..1] číslo kyvlosti: 0,5 mg KOH/g [0..1]
 celkový obsah plynu: 0,8 % [0..1] vnitř. rezist. Z₂: 1,6 Ohm.cm.10⁻²² [0..1]
 propustnost světla: 0,5 % [0..1]

☐ v olej jsou vypálené kaly

Pozn.: Vzorok oleje pro vyhodnocování musí být odebrán při teplotě 20 - 25°

Info Delší Zastávka Zpět

Figure 1 Input form of the IZOLEX expert system.

Výroky expertního systému

Celkem ze všech metod Jednotlivé metody

Globální metoda měření částečných výbojů

Hlavní výrok metody

Doporučuji opravu stroje v nejbližším možném termínu. Kp = 0,899

Vedlejší výroky metody

- Výskyt nebezpečné výbojové činnosti. Diagnostická měření výbojové činnosti (částečných výbojů) provádět v co nejkratších intervalech (max. 1/2 roku).
- Pro zjištění zdroje částečných výbojů použít některou z lokalizačních metod (akustická sonda, diferenciální elektromagnetická sonda, induktivně vázaná sonda, ...).
- Při nejbližší revizi stroje provést vizuální kontrolu vinutí.
- Změna izolačního stavu.
- Uvolnění tyčí.
- Výskyt částečných výbojů během provozu stroje.

Předchozí Následující

✓ Ano Tisk

Figure 2 Output form of the IZOLEX expert system.

Input data (measured 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), see Figure 3. 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.

Figure 3 Data flow in the IZOLEX expert system.

3 THE CVEX EXPERT SYSTEM

The partial discharges measurement, i.e. the measurement of discharge activity, is an important modern non-destructive method for testing of high voltage machines and equipment. The discharges destroy the insulating system, which leads to the breakdown and crash of the equipment in the end. The measurement of the discharge activity is also especially convenient for detecting the loosening of stator bars in rotating electrical machines, which leads to the vibration of the bars during the operation, to the mechanical damage of resin insulation and, eventually to the electrical breakdown of the insulation. From this point of view the measurement of discharge activity is the most effective method for evaluating the state of modern insulating systems of rotating machines based on resin materials.

The CVEX expert system is a part of the IZOLEX expert system for the evaluation of discharge activity on high voltage electrical machines and equipment by an off-line method, e.g. by the global (galvanic) partial discharges method with a serial connection of the measuring impedance and the coupling capacitor. The evaluation of partial discharges activity is based on the measurement of partial discharges parameters on various levels of applied voltage U . The CVEX expert system evaluates all common known partial discharges parameters, i.e., initial

voltage U_i , basic partial discharges parameters (apparent charge q , average partial discharges 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. 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.

4 THE CVEXON EXPERT SYSTEM

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 partial discharges activity. In contrast of the CVEX, the CVEXON expert system evaluates basic diagnostic parameters (apparent charge, average partial discharges current) only, together with their variations with time.

Figure 4 Data flow in the CVEXON expert system.

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 Figure 4. 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 (see Figure 5).

Figure 5 Virtual front panel of the measuring instrument.

5 THE ALTONEX EXPERT SYSTEM

The ALTONEX expert system (Brázdil, Bernat and Záliš, 1997) 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 partial discharges measurement, the bearing temperature monitoring, the evaluation of temperature stresses and local overheating of insulation, the frequency analysis of the current and magnetic fields and the indication of ozone in an cooling air (see Figure 6). In September 1997 the first trial run was implemented successfully in practice (in the Štěchovice power plant).

Our aim is to interconnect this expert system with the expert system for the vibrodiagnostics of large rotating machines created in Škoda Pilsen. This complex expert system would be able to monitor the whole turbine-alternator unit. In these days a joint project is preparing on the base of the cooperation of both expert systems, for electrodiagnostics and for vibrodiagnostics.

Figure 6 The view of the ALTONEX expert system.

6 CONCLUSIONS

The problems with the evaluation of diagnostic measurements on high voltage machines and equipment used in the Czech Power Network System are being solved in the CTU High Voltage Laboratory. Several expert systems for the dielectric diagnosis were developed in cooperation with top diagnostic workplaces in the Czech Republic. Rule-based expert systems for the evaluation of off-line measurement (the CVEX expert system for the evaluation of partial discharges measurement on rotating machines and the IZOLEX expert system for electrodiagnostics of high voltage insulation systems) also work in practice. The expert systems for on-line measurement (the CVEXON expert system for the evaluation of partial discharges measurement of rotating machines and the ALTONEX expert system for the complex electrodiagnostics of rotating machines) are in the state of testing.

All these developed expert systems are regularly updated with regards to the latest knowledge of science and practice; the main core can be found in the evaluation of individual diagnostic methods. 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 can be found in incorporating the diagnostics of

other electric components like capacitors, insulators, cables together with other kinds of diagnostics including mechanical vibrations and heat stress.

The biggest advantage of these expert systems lies in the fact that the expert systems enable even to a non-expert user to determine the risks of further operation of the device without the necessity of consulting the matter with top experts.

The expert systems are also very good and effective tools for the education of maintenance men and specialists in the electrical power engineering branch. Although classical expert systems are not developed as basic teaching tools (specialized education software serves for this purpose), it is possible to use it in this way and it seems to be very effective. Particularly the IZOLEX expert system is frequently used for the self-study and for the acquisition of experiences and skills in the area of the evaluation of the insulating system state above all.

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8 BIOGRAPHY

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