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Knowledge Base Design for Control System of Oil- filled Equipment Maintenance

Abstract: The presented paper considers solutions realized in designing the structure of knowledge base of technical diagnostics system. The obtained module-hierarchic structure of the knowledge base provides stability of complex expert system operation, quickness and quality of the adopted solutions, updatability of the knowledge base. The obtained solutions can be used by designers of technical diagnostics expert systems.

Keywords: Expert system, Equipment Diagnostics, Transformer, Knowledge Base.

I. INTRODUCTION

Expert systems appearance in power engineering has been called to life not only by development of information technology but also be growing urgency of precise and timely diagnostics of equipment [1]. The latter was connected with transition from the system of scheduled preventing maintenance to equipment maintenance according to its technical state, growth of amount of diagnostic information, sophistication of diagnostics process, both with shortage of high-qualified specialists.

Work on ES designing in power engineering of Russia began in the end of 80-s. Expert – diagnostic system for electrical equipment technical conditions evaluation “Albatross” worked out by the specialists of the Ural National Technical University and joint-stock company “Sverdlovenergo” was one of the first such systems. At present the system is applied at 25 energetic companies of Russia, Moldavia, Ukraine, and Latvia (79 enterprises).

II. POSSIBILITIES OF EXPERT SYSTEM

Expert-diagnostic and information system of estimation of oil-filled equipment state “Albatross” (EDIS “Albatross”) realizes diagnostics of power transformers, shunt reactors, HV bushings, and instrument transformers on the basis of the following measurements: dissolved gas analysis (DGA), physical and chemical tests of oil, insulating characteristics, ohmic resistance of winding and short circuit impendence, oil volumetric specific resistance, and results of no-load test.

EDIS solves the following problems:

- definition of the character, development degree, possible place of imperfection basing on the results of controllable parameters measuring;
- development and optimization of service measures plan, and monitoring its realization,
- personnel training, by explaining the key points when giving the diagnosis;
- interpretation of the obtained data aiming their meaning finding including new knowledge obtaining goal, that is, automation of scientific research elements;
- analytical examination of content and technical conditions of equipment of the energetic company, and conducted service measures (measurements, maintenance, failure etc.)
- compiling the recommendations to the staff on measures necessary in the further maintenance of the object.

III. KNOWLEDGE BASE CONSTRUCTION PRINCIPLES

Sophistication of problems, solved by the system, growth of its functions, knowledge base (KB) subject area widening, both with gaining the experience by knowledge base designers have brought to evolution of the knowledge base. Along with this, its content and structure changed. Now structure of KB is a hierarchy of modules with division on strata.

Modular structure of KB corresponds to structuring the data entering the expert system and to natural hierarchy of the subject area. Functional strata of KB reflect the steps of situation analysis by the expert. Table 1 demonstrates decomposition of the process of decision-making by the expert on functional strata consisting of the steps of equipment technical state evaluation and service recommendations compiling, and functions of KB modules corresponding to these steps.

IV. FORMALIZED DESCRIPTION OF OBJECT TECHNICAL STATE IN THE FORM OF LOGICAL-MATHEMATICAL MODELS

Operation of all KB modules of the expert-diagnostic system is based on logical-mathematical models (LMM). LMM are formalized descriptions of object state basing on the values of parameters being measured, and factors influencing it. Logical-mathematical model consists of conceptual and functional parts. The functional part builds a vector that describes the object state in the space of diagnostic features the structure of which is given in the conceptual part.

Conceptual part of LMM used for diagnosing (LMMR) is of the form:

$$G_D^{JY}=(K_n,\ P_n, V_n,\ S_e,\ H_z, U_m,\ L_b, T_i) \qquad (1)$$

where J - measurement type;

Y - type of oil-filled equipment;

K_n - group of features characterizing the absolute value of parameter aberration from ultimately admissible/normalized value;

n - number of measured parameters;

P_n - group of diagnosis features characterizing the extent of parameter changing with respect to sampling when putting an object into service;

V_n - group of diagnosis features characterizing parameter-changing dynamics with respect to the previous sampling;

S_e - group of diagnosis features characterizing meeting the relations between parameters of the same sample;

e - number of features relations being considered;

Hz - variable characterizing processes running in the object (prehistory);

z - number of features being considered;

U_m - variable describing events that could influence an object state (maintenance, external influences);

m - number of features taken into account;

L_b - variable describing measuring deficiencies (measuring method, device precision) that could influence measuring results;

b - number of measuring deficiencies taken into account;

T_i - variable characterizing design features of the object (voltage class, type of oil, type, etc.) and its service life.

i - number of design features taken into account.

Conceptual part of LMM used for staff activity planning (LMMs) is of the form:

$$G_R^{JY}=(D, H_m, T_i, C_q, A_k, U_z) \qquad (2)$$

where J - measurement type;

Y - type of oil-filled equipment /unit;

D - equipment state class recognizable by the system;

H_z - variable characterizing processes running in the object (prehistory);

z - number of features being considered;

T_i - variable characterizing equipment passport characteristics and life time;

i - number of design features taken into account;

C_q - variable describing staff actions during the equipment state control; -

Q - the number of control kinds being considered;

A_k - variable describing staff actions conducted during the equipment repair;

k – repair operations number;

U_m - variable describing external factors that influence the equipment and its maintenance mode;

m - the number of factors taken into account

LMM functional part fulfils information search; selection of necessary parameter evaluation criteria and conditions of variables number code generation from the KB.

Some variable are binary that is, take only two values:
1 – if definite event takes place; or 0 – if this event is absent.

The other variables characterize definite category of the variable with number code. For example, the variable “time of operation” can take the values 1, 2, 3, 4, 0 for categories “burn-in period”, “up to 20 years”, “from 20 to 35 years”, “over 35 years”, “unknown”, correspondingly.

To obtain diagnostics features controllable parameters (for example, reduction according to temperature), their dynamics, relations are calculated and the measured parameters are verified, and only then the features are obtained. As diagnostic features the following ones can be used: warning about:

- parameter deviation from the value being normalized;
- changing measure of the given relations between parameters.

The feature is evaluated in categories: ‘normal maintenance ', ‘a dangerous state’, ' and a band of imperfection ‘,’ and a zone of failure ‘, ‘unreliable parameter’; and is written in LMM as a number code. So, LMM gives us a vector describing an object state in the space of diagnostic features, coordinates of which are given with the number code of the variables.

Every type of measurements has its own diagnostics feature space and LMM describing the object (its system) state from different points of view: electrical, magnetic, chemical, etc. Diagnostic spaces (LMM) of one and the same type of measuring for different kinds of equipment have their peculiarities.

For tactical planning of the staff actions special LMM are constructed, different for different kinds of measurements and types of equipment.

Table I

Expert cognition operations	**The essence of diagnostic features spaces transformation**	**Functions of knowledge base modules**		**Stratum**
		for technical conditions evaluation	**for staff actions planning**	
Search	**Vectors generating in diagnostic features spaces F_1**	**Data preparation for analysis**	**Generation of advises concerning measurements validity checking, working-out the recommendations on repeated measurements R_{pl}**	**1**
Comparison				
Evaluation				
Selection	**Source space partitioning into subspaces correlated with appearance of imperfections of the same character / space convolution with the help of neuron net F_2**			
Generalization				
Abstraction	**Characteristic sensible symptoms projection into the less dimensional subspace F_3**	**The most fundamental features selection**		
Comprehension		**Giving the preliminary diagnosis D_1**	**Working-out the preliminary recommendations on plan-prophylactic R_{pl} or additional R_{add} control**	
Supporting / ruling out, preference	**Projection of alternative space of features existence/absence of which can rule our the hypothesis F_4**	**Preposition testing on consistency D_2**		**2**
Selection	**Space expansion by features addition, composition with projections of various measurement aspects spaces in terms of hypothesis being worked out F_5’, F_5”, F_5”’**	**Selection of necessary data for subsequent analysis**	**Working-out the recommendations on additional R_{add} control in order of diagnosis specification; determination of repair operations R_{rep};**	**3**
Comprehension generalization, (refinement), justification		**Imperfection nature refinement D_3**		
		Determination of the imperfection danger extent D_4	**Specification of recommendation R_{add} , R_{rep} taking into account imperfection danger**	
		Imperfection localization D_5	**Specification of recommendation R_{rep} taking into account imperfection localization**	
Generalization		**Preparing the various measurements data to joint output**	**Making general conclusions R_{pl} , R_{add} , R_{rep} basing on the set of different measurements recommendations**	**4**
Comprehension preference		**Making general conclusion on object states D_0**		

V. DIAGNOSTIC CRITERIA LIBRARY

Every category of diagnostic features estimate (‘normal maintenance ', ‘a dangerous state’, ' a band of imperfection ', ' a zone of failure', ‘unreliable parameter’) is given by numerical values (criteria), which are saved in diagnostic criteria library of KB. Criteria library comprises declarative knowledge divided into modules in terms of measurement aspects and equipment kinds.

There are two libraries in KB. Normative library mainly contains criteria of equipment assignment to the category ‘zone of imperfection’. Knowledge in it is rarely updated, they are of legislative nature, contains norms recommended by the ministry and (or) manufacturing plant. Expert criteria library has a dilated gang of equipment condition evaluation criteria and categories: ‘a dangerous state’, ' a band of imperfection ', ' a zone of failure'. Knowledge in it is often updated, is of recommendation nature and is to contain evaluation criteria of controllable parameters dynamics changes.

The following ways exist to obtain parameters estimates and their dynamics values estimates:

- from experts basing on their understanding of physics of processes running in the equipment and taking into account their rich practical experience;
- from the results of mathematical or full-scale simulations;
- by statistical methods.

Multiple categories and criteria of expert library permits consideration the imperfection growth extent (the object technical condition danger), makes diagnostic more exact. The user can select the library, which is used for analysis, basing on his psychological peculiarities, situation at the moment, and technical politics at the enterprise.

Imitation Steps of Expert Cognition Operations KB for Situation Analysis and Diagnostic Features Spaces Transformation.

VI. TYPES OF KNOWLEDGE PRESENTATION AND DECISION-MAKING

Four strata (table 1) reflect KB decomposition according to steps of object technical conditions decision-making and recommended service measures. As a result an initial hypothesis is set at the first stratum. At the second stratum an attempt is made to reject the proposed hypothesis. At the third one the adopted hypothesis is elaborated. At the last stratum general conclusion is made about equipment condition and recommendations to the staff are worked out basing on the various measurements.

Each stratum includes subject knowledge and metaknowledge on representation and control. Subject knowledge consists of modules of two kinds: object description in LMM form and decision-making. The later are subdivided into modules of equipment conditions class recognition, that is, putting the diagnosis, and service measures planning, the is, working-out the recommendations

Service measures can be divided into checking and repair ones according to the kind of their influence on the equipment. The former service measures include equipment monitoring based on the parameters being measured, the later ones - operations of current and medium maintenance. Maintenance operations Rrep are directed either on renewing the material properties, systems functions, and equipment units (insulation drying, oil degassing, etc), or on their replacement (oil replacement, HV bushing replacement, etc.). In terms of function service measurements have been divided into plan-prophylactic Rpl and additional Radd. The former ones are regulated with norms recommended by the ministry [2], and internal standards of energetic companies. They are prescribed with some frequency depending on the period of equipment exploitation, design philosophy and service measures conducted at the object. Additional checking is prescribed taking into account the state of equipment and events connected with the object and is necessary for the expert system to specify imperfection character, development degree and localization, to make more reasonable decision concerning subsequent usage of the object [3].

Subject knowledge on object description in the form of LMM realizes construction or transformation of the feature space and the vector describing object state and situation it depends [4]. LMM conceptual part describes dimension and structure of diagnostic features space and is defined with declarative knowledge. Diagnostic criteria and variables categories LMM libraries are defined with declarative knowledge too. Using diagnostic criteria library, functional part builds the vector describing object technical state, realizes necessary transformation of the space. In the most cases it is given by procedure knowledge. LMM modules procedure knowledge can be in the form of algorithms, neuron net, and product rules depending on practicability.

There is definite LMM and hence definite starting feature space F1 for each kind of measurements and each type of equipment. Feature space is transformed passing from one KB module to another according to the sequence of situation analysis steps in correspondence with expert cognition operations (Table 1). Herewith, for different types of measurements there are peculiarities both in situation analysis and in feature space usage.

At the preliminary step when transforming space F1 into subspace F2 features can be divided into groups correlating with appearance of imperfection of the same character (selection) or transformed into more general notions (generalization) by diagnostic space convolution with the help of neuron net. Convolution eliminates non-diagnostable situation in the case of contradictions appearance in data being analyzed and tautology of KB rules application. Then abstracting of feature space into space F3 is made by selection of features in F1 with the highest diagnostic value (the most characteristic and sensitive symptoms) for preliminary diagnosis putting. After this the alternative subspace F4 consisting of the features, the existence (or absence) of which can refute the proposed hypothesis is projected from the set of features left out of the subspace F3. Further on new projections F5’, F5”, F5”’ are made from the space F1, taking into account the hypothesis under consideration.

Imperfection character can be refined by the analysis of additional features of the same or (and) of the other kinds of measurement. The deepness of the fault development can be defined also by existence of diagnostic features of less sensitive measurable parameters, correlated with the features F3. The more definite is the imperfection, the greater number of features is considered. For example, when revealing an imperfection connected with the troubles with design, one must take into consideration the type of equipment and special features of the design (oil type, oil protection kind, winding connection network, windings location on rods, etc.).

Subject knowledge both on object state class recognition (RM) and on maintenance recommendations prescribing (PM) includes procedure knowledge represented basically by product rules. Graphical recognition on proximity measure and frame-classification is additionally used in recognition module. In this case recognition modules include also declarative knowledge (typical imperfection image description, diagnostic features sensitivity coefficients, etc.).

Modules of decision-making consist of clusters unifying production rules basing on the definite principle: on analysis form, measurement type, equipment type, refinement character, imperfection danger level. For example, the same claster contains production rules describing disabled state of definite type of equipment according to definite type of measurements. Product rules of one measurement kind the same for several types of equipment are unified in one cluster Subject knowledge division into modules and clusters reduces needed product rule search time and hence reduces time for obtaining the general solution over KB.

RM functions on equipment technical conditions evaluation with division on strata are as follows:

Stratum 1- reliability of measurements are estimated and the initial hypothesis of imperfection D1 character is proposed;

Stratum 2 - operations of rejection by a critic are imitated, an alternative conclusion D2 is tried to be proposed;

Stratum 3 - imperfection character D3, its development degree D4 and its localization D5 are clarified;

Stratum 4 - general conclusion D0 on equipment conditions are made basing on diagnosis put on the basis of various measurements.

Planning the service measures (PM) consists of several steps and is based on estimation of equipment technical conditions:

Stratum 1- advises concerning measurements invalidity cause checking and working-out the recommendations on repeated measurements Rpl are provided if needed;

Stratum 2 - depending on the given diagnosis more frequent control Rpl and (or) widened set of the parameters to be measured Radd are prescribed. As most failures are revealed by several kinds of control, the additional kinds of measurements allow confirming and refining the supposed imperfectness. For perfect state equipment a plan of prophylactic measures are prescribed;

Stratum 3 - the recommendations on additional Radd control for diagnosis specification are worked out or operations of current or intermediate repair Rrep are defined taking into account character of imperfection D3, recommendations Radd, Rrep are refined taking into account danger of imperfection D4, recommendations Rrep are refined taking into account localization of imperfection D5.

There are definite modules of subject knowledge (LMM, RM, and PM) for each kind of measurements and each type of equipment (its unit). Selection of necessary module and cluster in it is realized by controlling focusing metaknowledge. And at the same time activation of the needed module/cluster is conducted depending on the solutions adopted at the previous step of the analysis (depending on the considered hypothesis). Controlling focusing metaknowledge in strata are divided into modules and represented with metarules.

Decision-making strategy is realized by controlling decision-making metaknowledge (CDM) which are presented by metarules and divided into modules according to steps of situation analysis. CDM module of the second stratum selects the most likely hypothesis of two alternative D1 and D2 ones, that is, realizes preference operation. At that correlatively dependent features are tested on refutation (justification) of the proposed hypothesis or contradictive features reducing due to their less reliability or sensitivity. CDM module of the third stratum accumulates decisions from recognition modules D3, D4, D5, and recommendations on service measures Radd, Rrep, eliminating tautology, synonymy and contradictions. If when analyzing one and the same kind of measurement (e.g., DGA) different methods of object technical state are used then CDM module gives general conclusion reducing synonymy and contradictions. At the final step CDM module of the stratum 4 gives general evaluation of the object technical state basing on the diagnosis given by recognition modules of different kinds of measurements

Expert system makes general decision about equipment state through taking up one partial (in terms of measurement kinds) statement by more general one (elimination of tautology) or by their unifying, or by making the third conclusion, which couldn't be made basing on the partial ones. For this aim voting procedure is used that takes into account that imperfections can accompany one another, be the cause or condition of each other. When comprising the general recommendations Rpl, Radd, Rrep for the staff, the CDM module brings all partial (on measurement kinds) recommendations together: tautology, synonymy and contradictions are-e reduced.

VII. CONCLUSIONS

The application of elaborated LMM to KB bring to:

- more general description of the situation being analyzed in the selected content area;
- integration of dissimilar information describing object state and factors influencing it;
- ensuring information "noise-protection";
- formalization of object state description for application of KB product rules.

KB organization in the form of interconnected modules imitating the corresponding operations of expert's cognition brings to:

- reducing the dimension of semantic space;
- greater flexibility of decision-making process;
- optimization of the way of decision-making and selection of necessary knowledge cluster;
- more convenient modification of KB and debugging of its operation;
- minimal number of repetitions, redundancy, synonymy, reducing KB volume;
- more reliable, rapid, and stable operation of EDIS.

Development of KB of the expert system is accompanied with the increasing of information generalization, the extent of importance of the problems being solved, the performance of expert system promoting and influence on the enterprise operation as a whole.

VIII. REFERENCES

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