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AN INTERNATIONAL SURVEY OF THE PRESENT STATUS AND THE PERSPECTIVE OF EXPERT SYSTEMS ON POWER SYSTEM ANALYSIS AND TECHNIQUES

Prepared by members of Working Group 38.02, task Force 07 “Expert systems for power systems analysis and techniques”

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**Prepared by members of Working Group 38.02,
Task Force 07 "Expert systems for power systems analysis and techniques"**

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APPENDICES

1. INTRODUCTION

1.1 General Information

The Stockholm meeting of SC38 held in September, 1985, recognized the strong needs for active research on expert systems as applied to power systems. Subsequently, at the Paris meeting of SC38 in September, 1986, reports were presented on the present status and the perspective of expert systems in power system planning, operation and control in Japan, U.K. and France (see remarks at the end of this section). The SC38 then approved the organization of a new Task Force No.7 (Prof. Y.Tamura as convenor) under WG38.02 (Prof. A. Germond as convenor).

The title and the objective of TF07 are as follows:

Title of TF07 : Expert Systems for Power System Analysis and Techniques

Objective of TF07 : To review the present practice and potential of Artificial Intelligence (AI) techniques, especially Expert Systems, for power system analysis.

The draft of a questionnaire on <u>The Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques</u> was prepared by the convenor and his colleagues; they were sent to the members of TF07 for their suggestions and comments.

The revised questionnaire was then sent to the task force members and the regular members of SC38, who were requested to fill in the FORMAT A and to answer a series of QUESTIONS B, C, D and E. Please refer to <u>Sec.1.3 Inquiry</u> and <u>Appendix <A></u> for details of the questionnaire itself.

Answers to the questionnaire have been received from 15 countries: Canada, Denmark, Finland, France, F.R.G.(West Germany), Ireland, Italy, Japan, Netherlands, Norway, R.S.A., Sweden, Switzerland, U.K. and U.S.A.. Please refer to Table 1-1.

Remarks:

Papers presented at SC38 meeting in September 1986:

(1) Expert System in the Environment of SC38 CIGRE, by Y.Tamura (Waseda Univ., Japan)
(2) A Proposed System Planning Application for Expert Systems, by J. G. P. Scott (CEGB)
(3) R&D in Expert Systems at EDF - An Overview by M. Pavard
(4) A Prototype Expert System for Configuring Technical Systems, by Michael Vitins (Brown Boveri Research Center), The document has been distributed without oral presentation.

1.2 Background and the Objectives of the Questionnaire Survey

The growing needs for supplying vast amounts of electric energy with a high quality have necessitated more sophisticated approaches to power system planning, operation and control.

The above requirements have so far been achieved partly by great efforts of experienced operators and partly by the introduction of partially automated systems which have become possible by the active application of advanced analysis techniques.

Despite the remarkable progress in the extent and quality of the automation technology, much still depends on the judgement of human experts, that is, "experienced operators" capable of making intuitive and yet efficient decisions on the basis of the comprehensive knowledge of the prevailing circumstances that they are faced with.

At present, judgements under ill-conditions in power systems are also left to human experts. Moreover, the anticipated shortage in the

Table 1-1 The Number of Replies for each question in the Questionnaire

Question \ Country	Canada	Denmark	Finland	France	F. R. G.	Ireland	Italy	Japan	Netherlands	Norway	R. S. A.	Sweden	Switzerland	U. K.	U. S. A.	Total	Remarks
(A) Current status of expert system development in power systems	7	1	3	3	1	1	5	18	2	1	1	1	2	4	18	68	Format A
(B) Needs for expert systems as applied to power systems	1		1	2	1	1	0	5	0	1	0	1	0	4	3	20	Format free
(C) Views on future expert systems	1		1	2	1	0	0	5	0	1	1	1	0	4	3	20	
(D) Approaches for the future development of expert systems	1		0	2	1	0	0	3	0	1	1	1	0	4	2	16	
(E) Future environments for expert system development	1		1	1	1	0	0	4	0	1	1	1	0	3	2	16	

supply of sufficient experienced human resources in the near future makes it imperative to further promote advanced automation in power systems.

The tangible outcome sought from AI, especially expert system applications, is the alleviation of the bottlenecks which we are currently facing in system planning, operation and control.

The objectives of the questionnaire survey are summarized below:

(1) To obtain an overview on expert system applications to power systems and to make a comparative study by countries on their concept, application area, function, methodology and the development environment,

(2) To identify the potential areas to which expert systems are to be introduced by reviewing the current problems in power systems, and to identify the problems and limitations of existing expert systems,

(3) To formulate future views of expert systems applications for power systems, and to identify the requirements which expert systems should fullfill.

(4) To identify relevant methodologies and environments necessary for the effective development and implementation of expert systems.

1.3 Inquiry

The questionnaire gathered information on: "The Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques".

The questionnaire consisted of five parts, namely, QUESTION A (FORMAT A), QUESTIONS B, C, D and E.

FORMAT A was arranged in tabular form to gather information on "The Current Status of Expert Systems Development in Power Systems".

The format was divided into four subsections:

1. Project Information
2. Problem Areas and Solution Methods
3. Expert System Information
4. Perspectives for Development.

In QUESTIONS B to E, the respondents were kindly requested to describe their views freestyle on individual subjects as follows:

Question	Subject
B	Recognized Needs for Expert Systems as Applied to the Power System
C	Views on Future Expert Systems
D	Approaches to be Used in Future Expert System Development
E	Future Environments for Expert System Development.

For the complete questionnaire please refer to Appendix <1>.

1.4 Contributors

Replies to the questionnaire were received from the following 13 countries:
(The names of the correspondents and the organisations represented are shown in parenthises.)

Canada (F.D.Galiana, J.A.Findlay)
(McGill Univ., Ontario Hydro)

Denmark (K.Dyre)
(ELKRAFT)

Finland (T.Keränen)
(Imatran Voima Oy, Technical Research Centre of Finland)

France (M.Pavard)
(EDF, CGEE ALSTHOM)

F.R.G. (M.Erche)
(Siemens, Energie-Versorgung Schwaben)

Ireland (R. Curtis)
(Electricity Supply Board, Ireland)

Italy (L.Baggini, G.Manzoni)
(ENEL, CESI, Quinary)

Japan (M.Hayashi, J.Kawakami, M.Kunugi, M.Moriguchi, H.Sasaki,
T.Sawada, H.Suzuki, Y.Tamura, J.Toyoda, R.Yokoyama, M.Yugi)
(Tokyo E.P.Co., Chubu E.P.Co., Kansai E.P.Co., Kyushu E.P.Co.,
Hitachi, Mitsubishi, Toshiba, Hiroshima Univ., Kyoto Univ.,
Tohoku Univ., Tokyo Metropolitan Univ., Waseda Univ.)

Netherlands (H.E.Dijk)
(KEMA)

Norway (N.Flatabø)
(EFI, Norweigian State Power Board, Computas Expert Systems)

R.S.A. (Milje)
(ESCOM)

Sweden (G.Gabricius, K.Wilhelmsson)
(Swedish State Power Board)

Switzerland (A.J.Germond)
(Swiss Federal Institute of Technology, Lausanne)

U.K. (U.G.Knight, J.G.P.Scott)

(CEGB, Imperial College, Univ. of Durham, Queen Mary College)

U.S.A. (I.Dabbaghchi, G.Irisarri, C.C.Liu, D.Lubkeman,
W.Mittelstadt, J.Prince, S.Rahman, D.Tweed)
(EPRI, BPA, AEP, Union Electric, Wisconsin Electric Power,
Energy Systems Reseach Lab., Energy Systems Computer Applications,
CDC, CDC-EMSD, Univ. of California (Berkeley), Univ. of Washington,
North Carolina State Univ., Virginia Tech.)

1.5 Reporting

The work of preparing the report has been shared among the members of task force No. 7.

The Task force members are:

Y.Tamura, Japan (Convenor)
L.Baggini, Italy
W.Bergstrøm, Denmark
H.E.Dijk, Netherlands
F.D.Galiana, Canada
B.Heilbronn, France
C.C.Liu, U.S.A.
J.G.P. Scott, U.K.
H.Suzuki, Japan
J.A.Findlay, Canada (Corresponding member).

The questionnaire has been prepared and the draft and final reports compiled by:

R.Yokoyama, Associate Professor, Tokyo Metropolitan University,
H.Sasaki, Associate Professor, Hiroshima University,
G.Shirai, Professor, Hosei University, Tokyo, JAPAN.

2. CURRENT STATUS OF EXPERT SYSTEM DEVELOPMENT IN POWER SYSTEMS (QUESTION A)

2.1 Overview of Expert Systems

Expert system is one of the key components of Artificial Intelligence.

Artificial Inteligence (AI) originated in the 1950's, as found in the early activities on Mechanical Translation (MT), title of a journal published regularly by the MIT Press, which had an attractive red and white cover.
The success achieved by the Logic Theorist in proving the bulk of theorems in Principia Mathematica using heuristic problem-solving methods made most people at that time believe that higher performance computer would eventually extend the range of general problem-solvers to all of the world's challenging mental activities.

After two decades since then, AI was defined by Barr & Feigenbaum in 1981 as follows:

> "Artificial intelligence (AI) is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behaviour - understanding language, learning, reasoning, solving problems, and so on."

AI includes as three key components,

- Natural Language Understanding

- Image Recognition (or Computer Vision) and

- Knowledge Engineering (Expert System).

The definition of AI above made by Barr & Feigenbaum is rather computer engineering-oriented and somewhat narrow in a sense in the way of covering a wide variety of fields of engineering, behavioral and social sciences.

According to the expression given by Dr. Frederick Hays-Roth, Teknowledge, Inc., in his article on The Knowledge-Based Expert Systems: A Tutorial, in the September 1984 issue of IEEE magazine COMPUTER,

- Knowledge-based expert systems, or knowledge systems for short, employ human knowledge to solve problems that ordinarily require human intelligence.

- Knowledge Engineering (KE) is the subset of AI concerned with applying knowledge to solove problems that ordinarily require human intelligence.

- Most computers today perform tasks according to the decision-making logic of conventional programs, but these programs do not readily accommodate significant amounts of knowledge. Programs consist of two distinct parts, <u>algorithms</u> and <u>data</u>. Algorithms determine how to solve specific kinds of problems, and data characterize parameters in the particular problem at hand. <u>Human knowledge doesn't fit this model, however</u>. Because much human knowledge consists of <u>elementary fragments of know-how</u>, applying a significant amount of knowledge requires new ways to organize decision-making fragments into useful entities.

As experienced in the past 3 to 4 decades in the field of power system analysis and techniques, problems confronting us have been getting larger in size and more complex in goal or objective. Fig.2-1 may indicate, with some subjectivity, the historical transition of our reasoning in the R & D in power system engineering. Expert system is located in the 3rd stage in Fig.2-1.

It may be reasonable to think that expert systems came into existence in the flowing tide of the history as a natural outcome of struggles by operators, planners and researchers for better problem-solving methods in ill-conditioned environments requiring more amount of knowledge-based decision-making.

Intensive efforts are being made in developing expert systems in many fields including engineering. The present survey aims to outline the Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques in the environment of SC-38 CIGRE.

In the 4th stage in Fig.2-1, further promotion is indicated in the R & D of expert systems towards AI.

AI is about the simulation of human behaviour: the discovery of techniques that will allow us to design and program machines which both emulate and extend our mental capabilities. It is thus quite natural to judge that the discipline should be closely related to a wide range of other academic subject areas such as computer science, psychology, philosophy, linguistics and engineering. So traditional interdisciplinary studies are dependable sources of inspiration and new ideas, although AI and interdisciplinary studies may be taken as different domains by nature.

It is to be underlined here that a role, a very important one, of the expert system is to succeed or inherit a treasure of knowledge which has been accumulated in human experts through experiences and heuristic findings. With the recent enhancement of power system reliability, in other words, due to rare occurrence of major faults in recent years, most operators have very little experience with system faults which may lead to emergency states. A training simulator may well provide a dependable means to improve the situation. Expert systems, on the other hand, will be able to give them advice on various aspects of power system planning, operation and control, the advice which can be drawn from knowledge/skills inherited from experienced personnel or experts. However, there could be differences among opinions.

Some of the current Knowledge Engineering (KE) applications other than power system engineering are listed in Table 2-1.

As seen in Table 2-1, KE finds its best application in such domains as involved with,

- decision-making in diagnosis under ill-conditions like incomplete, biased or ambiguous information. Monitoring, alarming & avoidance of MW & MVar instabilities are examples in power system operation and control.

- tasks which handle a large number of combinations of parameters/ elements to achieve a goal. In this category, search in a very large space will be needed for problem-solving, that is, to arrive at the optimum or near-optimum solution. Substation layout, unit commitment and restoration strategies are examples in power system planning.

The definition of the expert system in the environment of Power System engineering can be stated as below by citing from Expert Systems and Energy Management Systems (Mr. G.B.Sheble') in the IEEE paper (Vol.PWR-2, No.4 November, 1987) entitled "Artificial Intelligence Solutions to Power System Operating Problems":

> "An Expert System is a set of computer programs that use current information, a knowledge data base, and inference rules to solve programs that are difficult enough to require siginificant human expertise for their solution. The knowledge data base and the inference rules are the models of the expertise of the best practitioners able to solve the problem."

Key elements such as knowledge data base, inference engine associated with the definition above are laid out in Fig.2-2 (Expert System Building) and Fig.2-3 (Expert System Structure). Fig.2-2 describes the interaction of toolbuilder, domain expert, knowledge engineer, and planner/operator with building tool & expert system. Fig.2-3 is an enlargement of the Expert System, that is, the goal of expert system building.

Table 2-1 Current KE Applications

Application Area	Expert System	Objective
Chemistry	DENDRAL	chemical data interpretation & structural elucidation
	SYNCHEM2	synthesis of organic molecules without human assistance or guidance
Computer	XCON	computer configuration
	YES/MVS	monitoring of the MVS operating system
Electronics	PALLADIO	design & test of new VLSI circuits
	ACE	diagnosis of faults in telephone network
Engineering	REACTOR	diagnosis & treatment of nuclear reactor accidents
	DELTA	identification & correction of malfunctions in locomotives
Geology	DIPMETER ADVISOR	interpretation of dipmeter logs
	PROSPECTOR	evaluation of mineral potential of a region
Medicine	MYCIN	diagnosis & treatment of bacterial infections
	INTERNIST/CADECEUS	multiple & complex diagnosis in general internal medicine
Others	Hearsay	speech recognition
	MACSYMA	algebraic simplification & integration problems

Input information	Type of reasoning	Output information
-unorganised experience -classical control theory -simple reduction of network	1st stage(∿1960) Qualitative Reasoning (classical)	-Xd' model of syn. generator -AFC -equal-area stability criterion
-sensitivity analysis -eigenvalue analysis -energy function method(Liapunov) -Mathematical programming	2nd stage(∿1975) Quantitative Reasoning (classical)	-stability assessment (steady/transient/ long-term dynamics) -security control -state estimation
-controllability & observability -information contained in distorted waveform -probabilistic/ stochastic viwpt. -concept of knowledge engg.	3rd stage(∿present) Quantitative Reasoning assisted by Qualitative Reasoning (both modern)	-state estimation (R & D/implementation) -protective relay designed based on d'Allembert's principle -voltage collapse (analysis/simulation/ control/design) -elementary expert systems
-probabilistic/ stochastic approach -fuzzy set theory -analysis of nonlinear systems -logistics -expert systems -elementary AI	4th stage(near future) Harmony of Quantitative and Qualitative Reasonings (both modern)	-intelligent monitoring & alarming -application of expert systems -harmony of procedural & knowledge-based methods of solving -extension of inter-disciplinary studies
	search for more powerful problem-solvers	

Fig.2-1 Transition of Reasoning in Power System Engineering Field

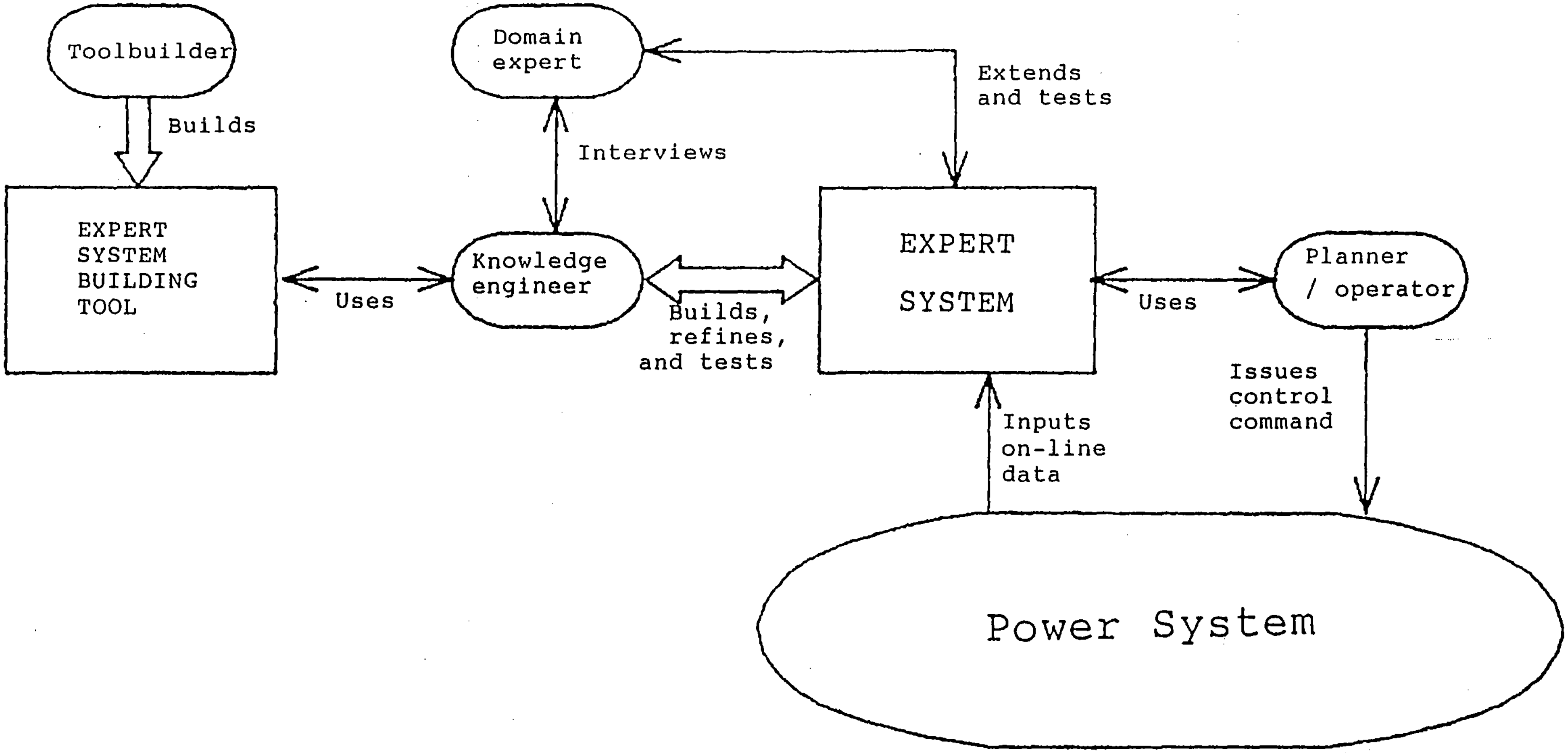

Fig. 2-2 Expert System Building

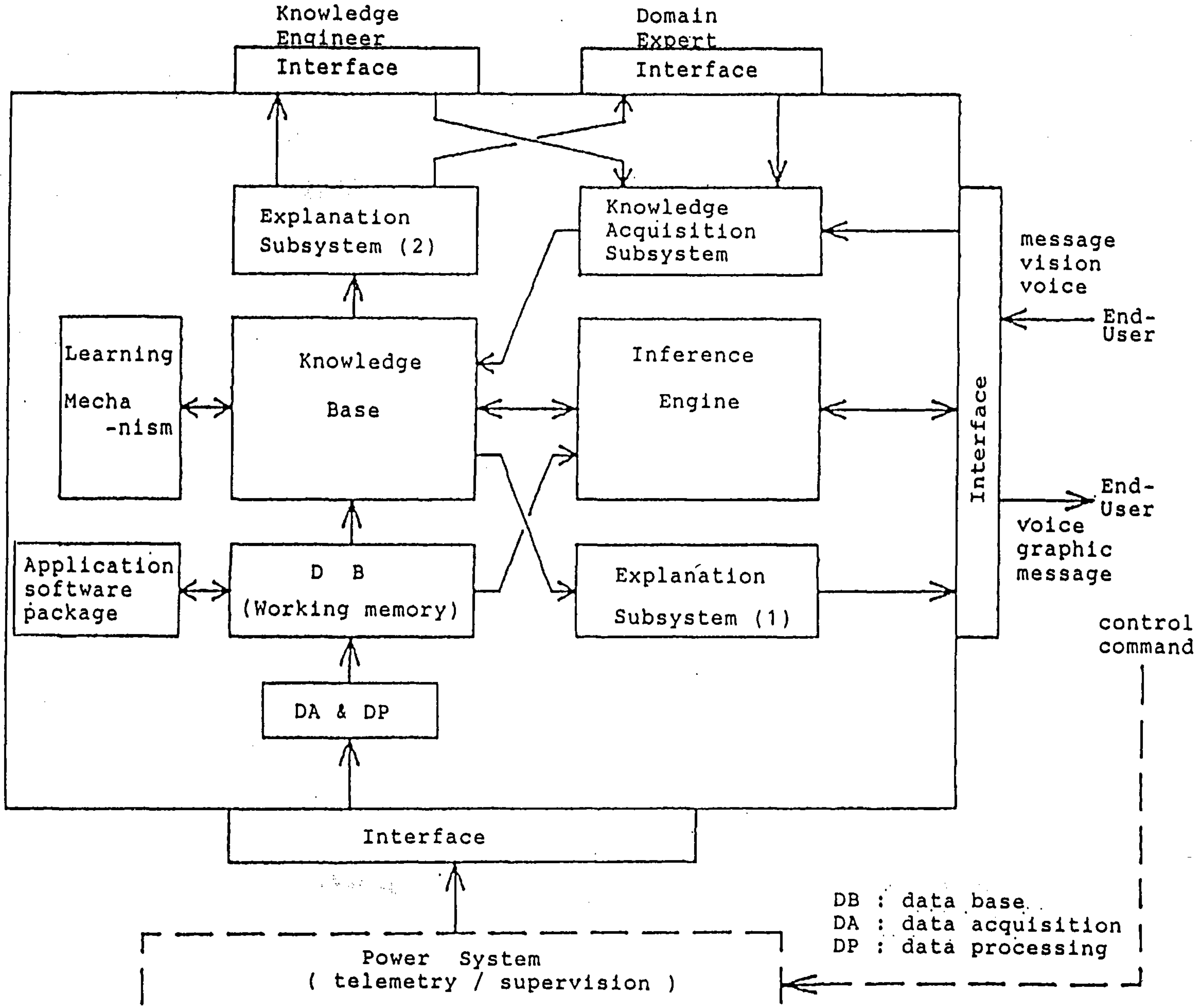

Fig. 2-3 Structure of Expert System

In the following sections in this chapter are described the result of the analysis on the data enumerated from answers responding to Question A of the Questionnaire. The results of the analysis indicate the current status of expert systems development in power systems. The number of responses to Question A reached as many as 68. By countries, they came from Canada, Denmark, Finland, France, F.R.G., Ireland, Italy, Japan, Netherlands, Norway, R.S.A., Sweden, Switzerland, U.K. and U.S.A., and their distribution by country is shown in Fig.2-4. It indicates that a substantial number of institutions in major countries are engaged in the development of expert systems for power systems applications.

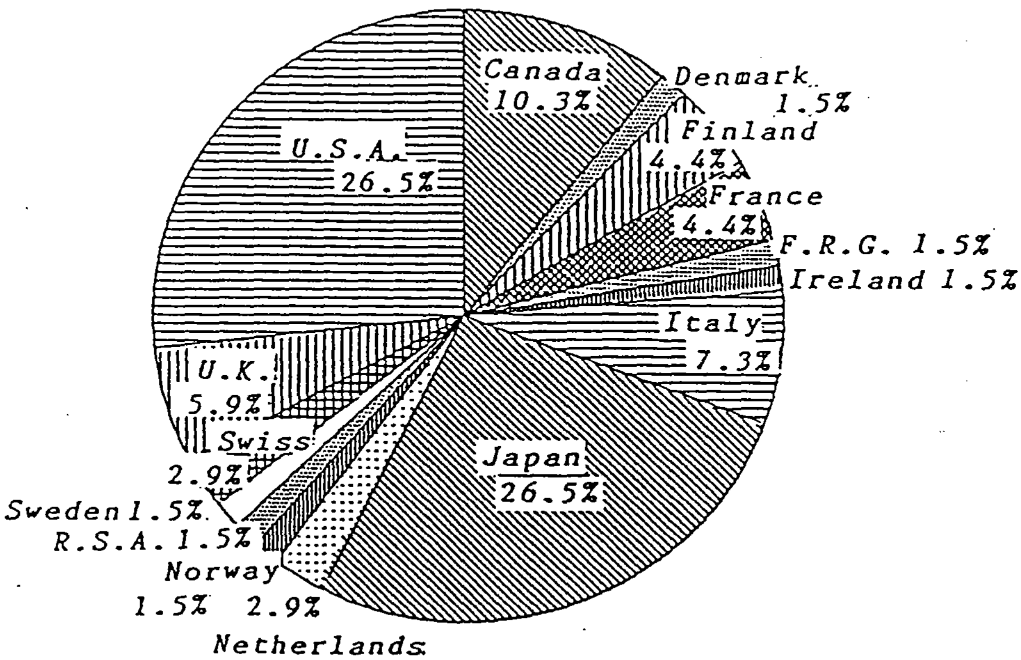

Fig.2-4 The distribution of number of replies by country.

As described in Sec.1.3 Inquiry, the contents of Question A have been divided into the following four topics, namely:

1. Project information
   - Information on expert system projects under development

2. Problem area and solution method
   - Area of application and theoretical background of expert systems

3. Expert system information
   - Software and hardware environments

4. Prospects for development
   - Problem area and necessary improvements/enhancements

The state of the art on the above four topics is summarized in Sections 2.2 to 2.5, respectively.

2.2 Project Information on Expert Systems Development

All the information with respect to the collected responses to Question A of the Questionnaire is tabulated in Tables <B-1> to <B-40> of Appendix <B>. It may be seen that the objectives or intended functions of the expert systems developed in the respective countries are varied, and that development in the power system field is generally in the initial stage. The objectives of the expert systems are classified into six categories, namely, Planning, Monitoring, Control, System Analysis, Education/Simulator, and Others and are further broken down into sub-items or project objectives as shown in Table 2-2 in this section. It is to be noted here that several expert systems have plural objectives, such as, Monitoring and Control. In this case, the project was counted in both categories.

Table 2-2 Statistics of Project objectives of expert systems dévelopment

Category	Project objectives	Number of projects	Total Number(%)
Planning	- Operation planning	10	14 (14.3)
	- Facility design	3	
	- System planning	1	
Monitoring	- Fault diagnosis	13	35 (35.7)
	- Alarm processing	13	
	- Contingency evaluation	9	
Control	- Normal control	11	27 (27.6)
	- Emergency control	4	
	- Restorative control	12	
System analysis	- Static analysis	12	13 (13.3)
	- Dynamic analysis	1	
Education & Simulator	- C.A.I.	1	3 (3.1)
	- Simulator	2	
Others	- Load management - Pollution problem - Expert system shell,etc.	6	6 (6.1)

(Note : Several expert systems have multi objectives)

After reviewing Table 2-2 and the tables of Appendix <B>, several findings were obtained as follows:

(i) Expert systems for monitoring Among the objectives of the expert systems, those classified as monitoring occupied 35.7% of the total response, a major portion of objectives, as shown in Fig.2-5. The reasons for this may arise from the ease of obtaining the necessary facts through measurements, the finite number of conclusions or causes to be determined, the relatively small size of the search space, and the ability to employ well-defined rule-based knowledge or operation manuals.

(ii) Expert systems for control Expert systems classified into the Control category share 27.6% of the total number of objectives cited. One of the major reasons is a greater demand for such systems by the electric utilities. The ease with which conventional algorithmic software can be modified and incorporated into expert system functions also increased the number of objectives cited.

(iii) Expert systems for others A small number of Planning and other applications is reported. This is probably due to a large work burden in acquiring knowledge. The development of deep-knowledge is mandatory to screen out the proper solution from a large search space generated by an infinite number of alternative plans with a limited number of well-defined conditions or specifications in System Planning. However, extensive future development in this area is expected to comply with various demands from system planners. A small number of System analysis and Education/Simulator applications indicates that the development in these fields is still in the initial stage. Indeed, many researchers participating in the expert system building in this area are still more of a theorist than a knowledge engineer. In other words, they are not necessarily familiar wiht circumstances where inductive reasoning or even reasoning of abduction -type plays a more important role than deductive reasoning, and they are not always talented with harmonizing heuristics and interdisciplinary studies. The building of expert systems in a System analysis and Education/Simulator area may flourish in due course of time.

(iv) Institutions engaged in development Utilities amounts to 40.0% of the total number of institutions / organizations engaged in expert systems development, followed by Universities (20.9%) and Research Institutes (20.0%) as shown in Fig.2-6. It indicates a very high demand from the utilities; this is likely to be because they need to develop expert systems to overcome the future lack of experienced operators capable of handling emergencies. Operator experience of such events is becoming increasingly infrequent due to improved system structures and facilities (an opinion from Japan).

(v) Co-operative work in development Co-operative work in expert system projects is frequently observed as shown in Fig.2-7. It is noticeable that utilities are the major partners in conducting co-operative work with manufactures, research institutes and universities. The reason is that they have the expert knowledge source critical to expert systems development. It is observed that many types of cooperative work are common in the U.S.A., while joint projects between utilities and manufactures are predominant in Japan.

(vi) Stage of expert systems development The stages of expert systems development are shown in Fig.2-8. Stages of development are defined by Idea, Prototype, Debugged Program, Field Test, Practical Use and Release (Commercial system). As the figure indicates, most of the expert system projects are in the stages of Prototype (37.0%) and Idea (32.0%). This fact signifies that expert systems development for power systems is just initiated. Some systems (8.0%) are already in the Practical Use stage, indicating a steady transition from fundamental research into practice.

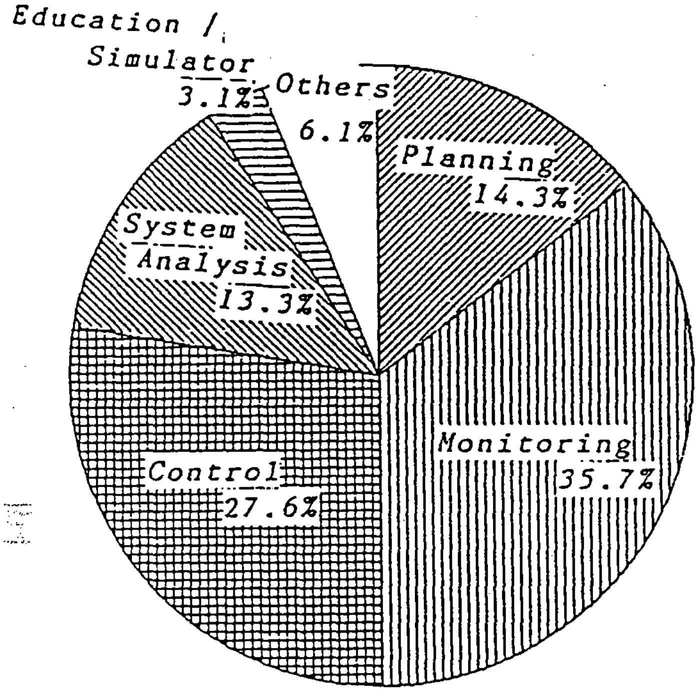

Fig.2-5 Intended functions or project objectives.

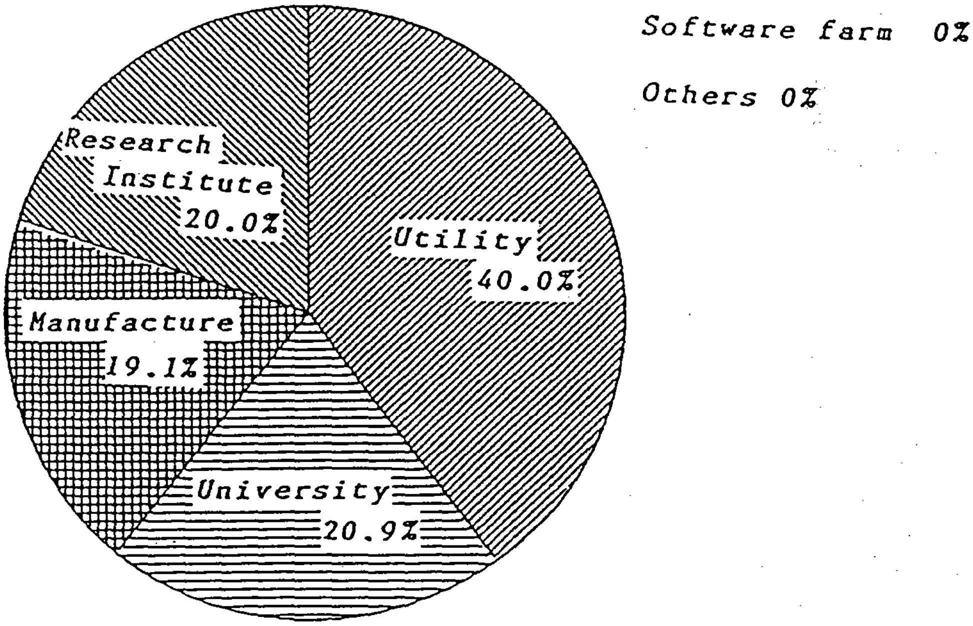

Fig.2-6 Institution/Organizations engaged in development.

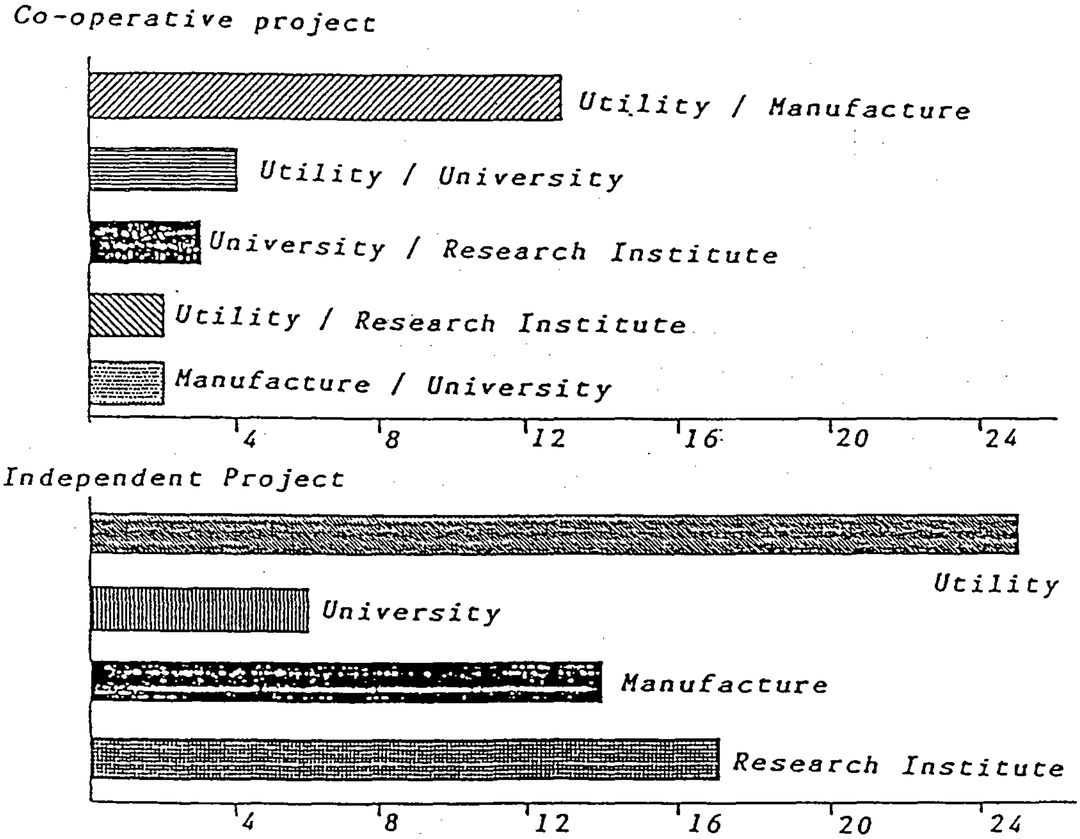

Fig.2-7 Co-operative work of expert system projects among institutions / organizations.

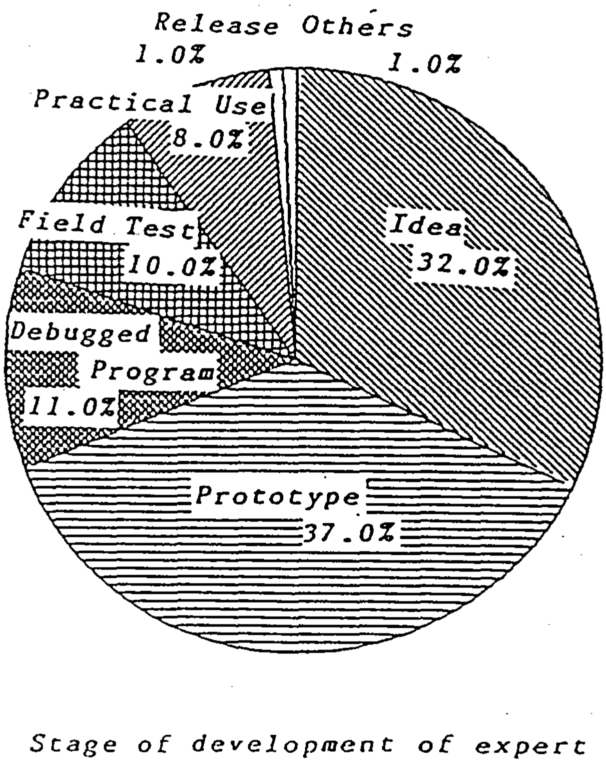

Fig.2-8 Stage of development of expert systems.

2.3 Problem Areas and Solution Methods in Expert Systems Development

In this section, the results of the analysis is given for the area of application and theoretical background of developing or developed expert systems.

Table 2-3 classify 6 major application categories, namely, Planning, Monitoring, Control, System Analysis, Education/ Simulator, and Others, and sub-categories. Detailed information on the project objectives and application area are tabulated in Tables <C-1> to <C-5> of Appendix <C>, together with the corresponding ID no. of the reply for reference.

Table 2-4 shows a summary of the theoretical background in expert systems development in each country according to the same classification of categories and project objectives used in Table 2-3.
Also, detailed information is shown in Tables <D-1> to <D-4> of Appendix <D>.

The identified facts are as follows:

(i) Application to monitoring The monitoring category heads the development of expert systems in this survey. Fault diagnosis and alarm processing among others are dominant in the Monitoring categories. To be noted in the fault diagnosis area are detection and location of faulty section, identification of system behaviour in an emergency state, and diagnosis of equipments. These are being studied in France, Netherlands, F.R.G., Japan, U.S.A., Finland, Italy and Canada. Also to be noted in the alarm processing area are real time monitoring of sequential events, identification of the cause of alarms, and the detection of malfunctions in protective system. These are being studied in Denmark, U.S.A., Japan, U.K., Switzerland, Ireland and R.S.A.

(ii) Application to control Many replies were recieved for the Control category. In particular many applications to control in normal and restorative states are reported. Control in the normal state is being intensively studied in the U.S.A. on such important topics as state estimation, load forecasting, system stability, VQ control, ELD and network topology. The U.S.A. and Japan are very active in control for the restorative state.

(iii) Application to planning Few responses were collected regarding the Planning category, probably because such development requires deep knowledge to be acquired from human experts. Operational planning is being studied in Japan, Finland, the U.K. and Canada for system structure planning, generation and reactive power scheduling, system stabilization, network switching and short-term marketing strategy. Regarding facility design, pioneering expert system projects on automatic configuration of electronic equipment for substations (Italy-2, Italy-3) and design procedures of substation layout (Japan-12) are to be noted.

(iv) Application to system analysis Few answers have been recieved for this area in this survey. In the field of static analysis, reports concerned a Load flow engine (Italy-1, Canada-5), Decision of remedial measures (Japan-10, Canada-3), MVar instability index (Japan-14), Security assessment (Norway-1, Switzerland-1), System model validation (U.K.-4) and user interface of stability program (Canada-7). In the dynamic analysis field, only "MW stability index based on nonlinear oscillation theory" (Japan-14) is reported. Dynamic analysis including nonlinear phenomena and ill-conditioning problems in general are deemed critical in future power system operation and show promise in the application area of expert systems.

(v) Application to education/simulator and others Very few replies in the Education/Simulator category were collected. Interesting applications are the automatic production of training scenarios for training simulators (U.S.A.-8), the evaluation of the actual state and choice of actions (Norway-1) and Training system (Japan-17). Other projects in this category include "cycle water pollution diagnosis" (Italy-4), "Harmonic-related problem" (U.S.A.-1), "Load management" (U.S.A.-7, U.S.A.-18), "Price elasticity" (U.S.A.-9) and "Cause analysis of application program aborts" (Canada-5).

(vi) Stage of development by project objectives Fig.2-9 indicates the cross-correlation between stage of development of expert systems and the project objectives. Though many expert systems are in the stages of "Idea" and "Prototype", some of the Monitoring, Control and System Analysis categories are in the stage of Field Test and Practical Use.

Particularly, examples at the stage of practical use include detection of fault isolation (Monitoring, U.S.A.-16), short term load forecasting (Control, U.S.A.-7), auto-reclosure without electro-mechanical relays (Control, U.S.A.-13), improvement of efficiency of load flow planning (System Analysis, Japan-9), interactive system for system analysis using conventional software (System Analysis, Japan-11) and on-line system security monitoring (Monitoring, Canada-2).

(vii) Theoretical background in expert systems development
In Table 2-4 and Tables <D-1> to <D-4> of Appendix <D>, the theoretical backgrounds are analyzed and listed in terms of:

(a) Category
(b) Project Objectives
(c) Approaches related to power system engineering
(d) Concepts and methodologies related to knowledge engineering.

(viii) Approaches related to power system engineering By reviewing the tables of Appendix <D>, approaches related to power system engineering include power system analytical methods, system modelling, optimization approach and others.

The topics (theoretical background) included in each of the above approaches are:

Power system analytical method : Power flow analysis, state estimation, load forecasting, economic dispatch, voltage and reactive power dispatch, stability analysis, security control and SCADA.

System modelling : graph theory, sensitivity, impedance network, linearized model, dynamic differential equation, state space representation and qualitative model.

Optimization approach : linear and nonlinear programming, mixed integer programming, decoupled technique, dual and primal algorithm.

Other approaches : frequency analysis, statistical analysis, filtering and ranking.

(ix) Concept and Methodologies Related to knowledge engineering As shown in Table 2-4,a broad spectrum of the concepts and methodologies are seen in this category. The knowledge representation methods include: production system, frame, blackboard (U.S.A.-2), semantic network (France-2, Japan-16), script - (France-2), triplets (France-3), world model (Norway-1), meta-knowledge (France-2) and so on. It is noticeable that the above methods cover most of the knowledge representation methods proposed so far in the AI wider environment. The use of such a broad spectrum of representation methods is necessitated by the critical importance of expressing equipment characteristics and structures in power system.

(x) Inference mechanism and other methods   Regarding the inference mechanism, forward chaining is most extensively used followed by mixed chaining as shown in Table 2-4.

A multitude of search methods are used such as, hill climbing search (Italy-2), depth first search (U.S.A.-6), logic programming (U.K.-1, Finland-2), object oriented programming (Norway-1) and goal creation (U.S.A.-8). The other problem solving techniques used include pattern recogniton (F.R.G.-1, Japan-15), fuzzy set theory (Netherland-1), first order logic (France-3) and decision analysis (Netherland-2).

Use of a wide variety of approaches employed in such European countries as Finland, France, Italy, Netherlands, Norway and the U.K. are quite noticeable.

Table 2-3 Project Objectives and Application Area of Expert Systems

Category	Project Objectives	Area of Application	Number of Project		
Planning	Operation Planning	Generation scheduling	1	10	14 (14.3%)
		Reactive power scheduling	1		
		System structure planning	3		
		System stabilization	1		
		Security assessment	1		
		Unit commitment	1		
		Power exchange scheduling	1		
		Operation planning (Overall)	1		
	Facility Design	Electronic equipment for substation	1	3	
		Equipment for distribution station	1		
		Substation layout	1		
	System planning	Distribution automation - all aspects	1	1	
Monitoring	Fault Diagnosis	Transformers, machines, substation & control centers	5	13	35 (35.7%)
		Location of faulty section and fault situation	5		
		Sysem behaviour in the emergency state	3		
	Alarm Processing	Identification of breaker and relay status	8	13	
		Identification of malfunction of protective system	2		
		Alarm filtering and ranking	2		
		Recommendation of corrective action	1		
	Contingency Evaluation	Contingency analysis	4	9	
		Advice of remedial action	3		
		Reliability / Stability assessment	2		
Control	Normal State	State estimation	1	11	27 (27.6%)
		Short term load forecasting	2		
		Determination of network topology and operation	2		
		Economic dispatch	2		
		Reactive power and voltage control	2		
		Stability evaluation	1		
		Security assessment	1		
	Emergency State	Corrective action to voltage collapse	2	4	
		Countermeasures to system security	2		
	Restorative State	System restoration of trunk lines	9	12	
		Switching operation in a substation	3		
System Analysis	Static	Intelligent load flow / Load flow engine	3	12	13 (13.3%)
		Assessment and analysis of system security	6		
		Voltage instability index	1		
		Validation and building of system / equipment model	2		
	Dynamic	MW stability index based on parametric resonance	1	1	
Education & Simulator	C.A.I.	Automatic production of training scenarios for operator training simulator	1	1	3 (3.1%)
	Simulator	Evaluation of actual state and choice of actions	1	2	
		Training system for power system operation	1		
Others		On-line monitoring and diagnosis of cycle water pollution in a thermal power plant	1	6	6 (6.1%)
		Identification and prediction of harmonic-related problems	1		
		Consumer reaction to pricing alternatives	1		
		General purpose expert system shell for energy management system applications	1		
		Energy management system applications	1		
		Analysis of the cause of application program aborts	1		

Table 2-4 Theoretical Background in expert systems development in power system

Theoretical Background \ Category and Project Objectives	Planning				Monitoring			Control			System analysis		Education & Simulator	
	Operation planning	Facility design	System planning	Fault diagnosis	Alarm processing	Contingency evaluation	Normal control	Emergency control	Restrative control	Static analysis	Dynamic analysis	C.A.I	Simulator	Others
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Knowledge representation														
Production rule	○	○		○	○		○		◎	○				△
Frame				○						○				
Blackboard			△											
Semantic network				△				○						
Script				△										
First order logic				○	△									
Triplets				△										
Logic rule	○						△							
Meta - knowledge				○			△							
Temporal logic				△										
Inference mechanism														
Forward chaining	△	△	△	◎	△	△	○	△	○	△	△	△	△	○
Backward chaining				△										
Mixed chaining	△			◎	○	○	○	△	○	○			△	○
Procedural chaining														
Search method														
Back tracking	△				○	△	○		△	△				
Hill climbing search		△												
Depth first search				△	△		△							
Logic programming	○													
Goal creation												○		
Heuristic search							△					○		
System / object modelling														
World model						△	△			△			△	
Object-oriented representation						○	△			○		△	△	
Qualitative modelling					△									
Other methodologies														
Incremental qualitative analysis					△									
Pattern recognition				△	△		△			△				
Fuzzy set theory				△										
Decision analysis				△					○					
Feature extraction							△							
Certainty factors								△						
Membership function				△										

Note ◎ :5~ 4 applications, ○ :3~ 2 applications, △ :1 application

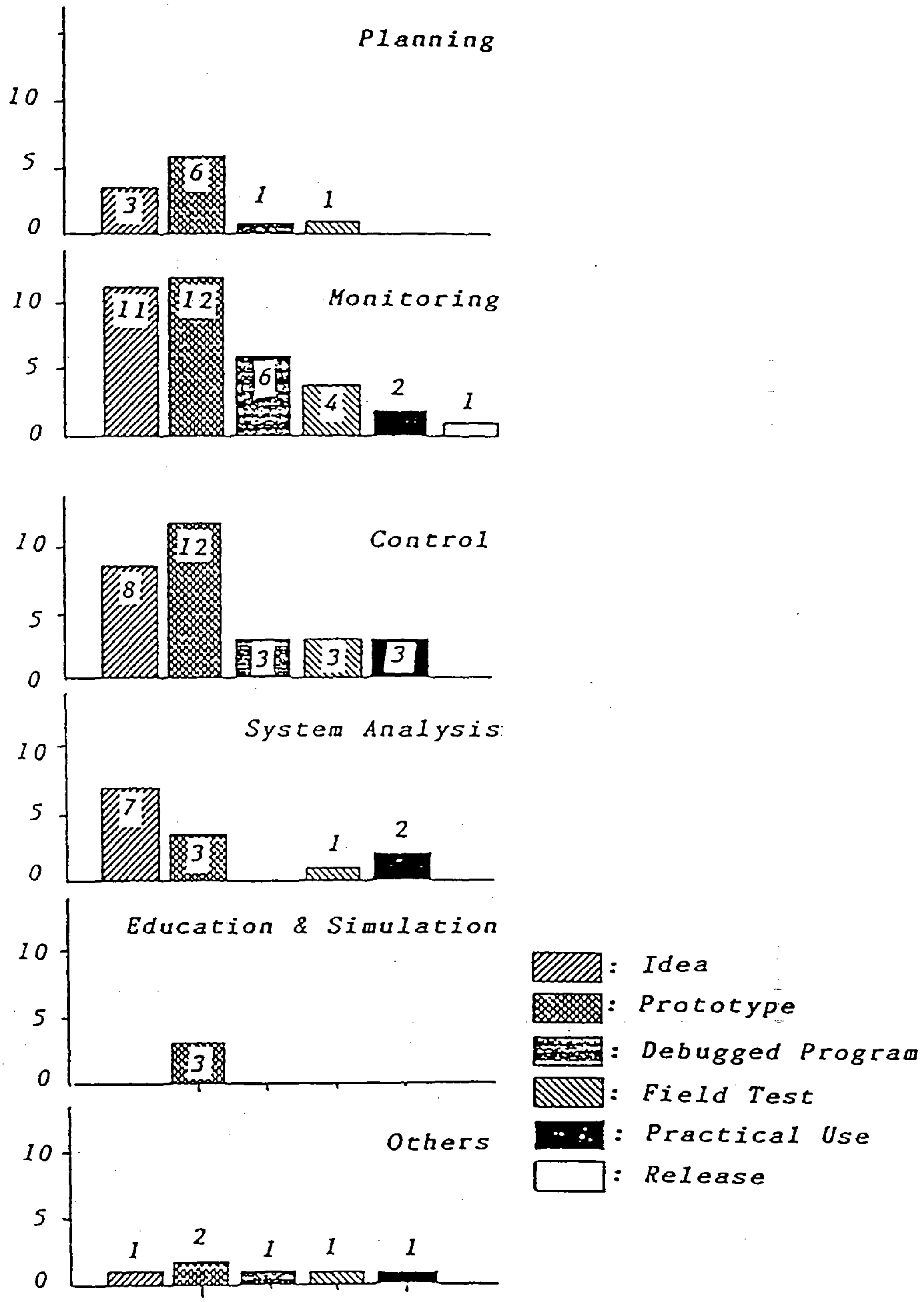

Fig.2-9 Distribution of development stages of expert systems by objectives category.

2.4 Analysis of the Expert Systems Reported

This section reviews the relationship between expert system development stages, project objectives versus the number of rules and the information systems used. Information systems here include such topics as hardware configuration and a system development environment, namely, languages, AI tools and so on.

(i) Function of expert systems   Though expert systems development in power systems is still in the initial stage, Fig.2-10 shows that the intended functions of the expert systems in respective countries are diversified. The functions of the expert systems have been classified into ten items, namely, Interpretation, Diagnosis, Guidance, Monitoring, Education, Prediction, Planning, Design, Control, and the Others. Fig.2-9 indicates that Guidance is 16.0% of total number of functions, followed by Diagnosis (15.4%), Planning (14.9%), Monitoring (12.6%) and Control (9.1%).

(ii) The number of expert system rules   Fig.2-11 shows the distribution of the number of rules of the reported expert systems. It is indicated that the majority of the expert systems developments employ no more than 300 rules. Samples with more than 500 rules are very few. A remarkable application is an expert system for on-line system security monitoring developed by Ontario Hydro, Canada. According to an answer to the Questionaire, this expert system has more than 100,000 rules written in Fortran and has been implemented on UNIVAC 1180.

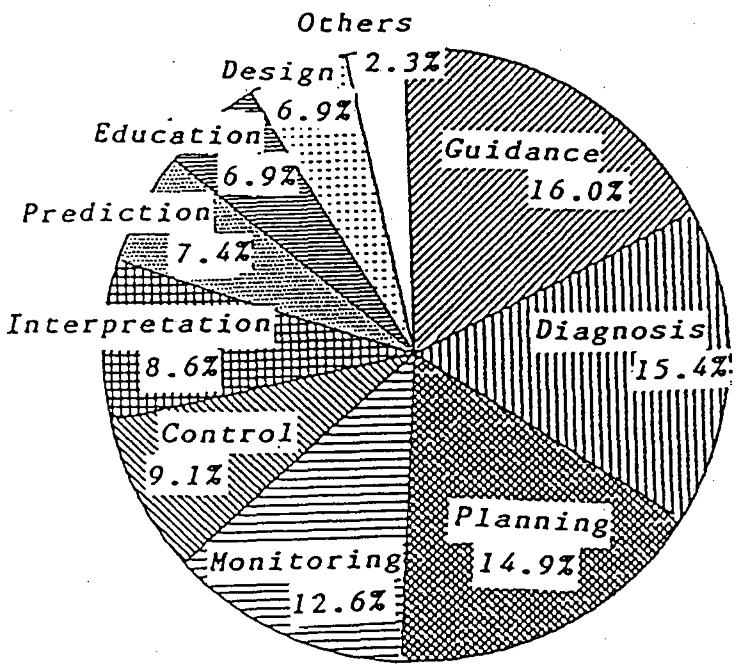

Fig.2-10 Functionality of expert systems in power system.

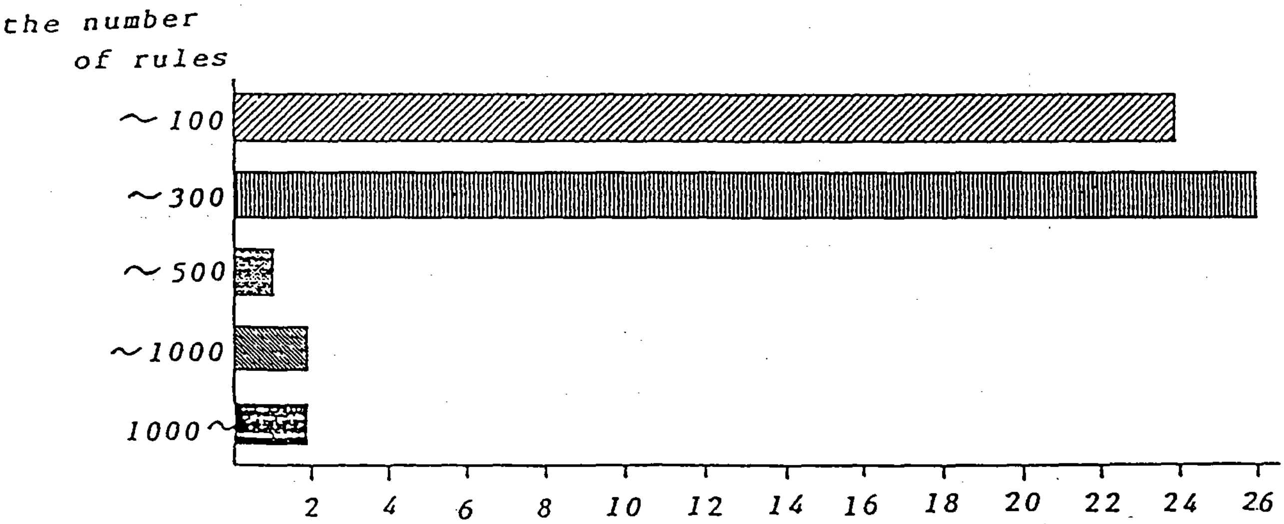

Fig.2-11 Distribution of the number of rules of expert systems.

(iii) Cross-correlation between project objectives and the number of rules Fig.2-12 shows a cross-correlation between the project objectives and the number of rules for the expert systems reported. This figure shows the distribution classified by project objectives. In either planning or monitoring, the number of rules is larger than 200. In other project objectives, namely, Control, System Analysis, Education and Simulator, the number of rules is less than 200.

In the Control category the number of rules is scattered indicating the greater extent of problem complexity associated. A larger number of rules employed in the Planning category is partly due to the necessity of building deep knowledge bases.

(iv) Cross-correlation between development stage and the number of rules Fig.2-13 shows the cross-correlation between development stage and the number of rules. It may be noted that the Prototype systems have 100-5000 rules. The number of rules in the stage of practical use distributes in the ranges of 100300. It may be observed from the figure that the number of rules in the expert systems reduced to some extent as the systems go up to the level of practical use. This observation may be interpreted as follows: In developing a prototype expert system, engineers concerned with the projects are likely to collect as many rules as possible to realize the intended functions of the expert system. This tendency would be accelerated when exploiting knowledge from different experts related to the target fields of the expert system. In the next stage, the collected knowledge base must be scrutinized to make it consistent and transparent for practical use. During these refinement works, duplicated rules may be reduced to one rule and several rules may be combined into one sophisticated form of rule. This must be the main reason to explain the reduction in the number of rules of expert system in practical use. Most of the expert systems reported here are intended to use in real-time processing, and hence short response time is inevitably required. At present it is not appropriate to assert that

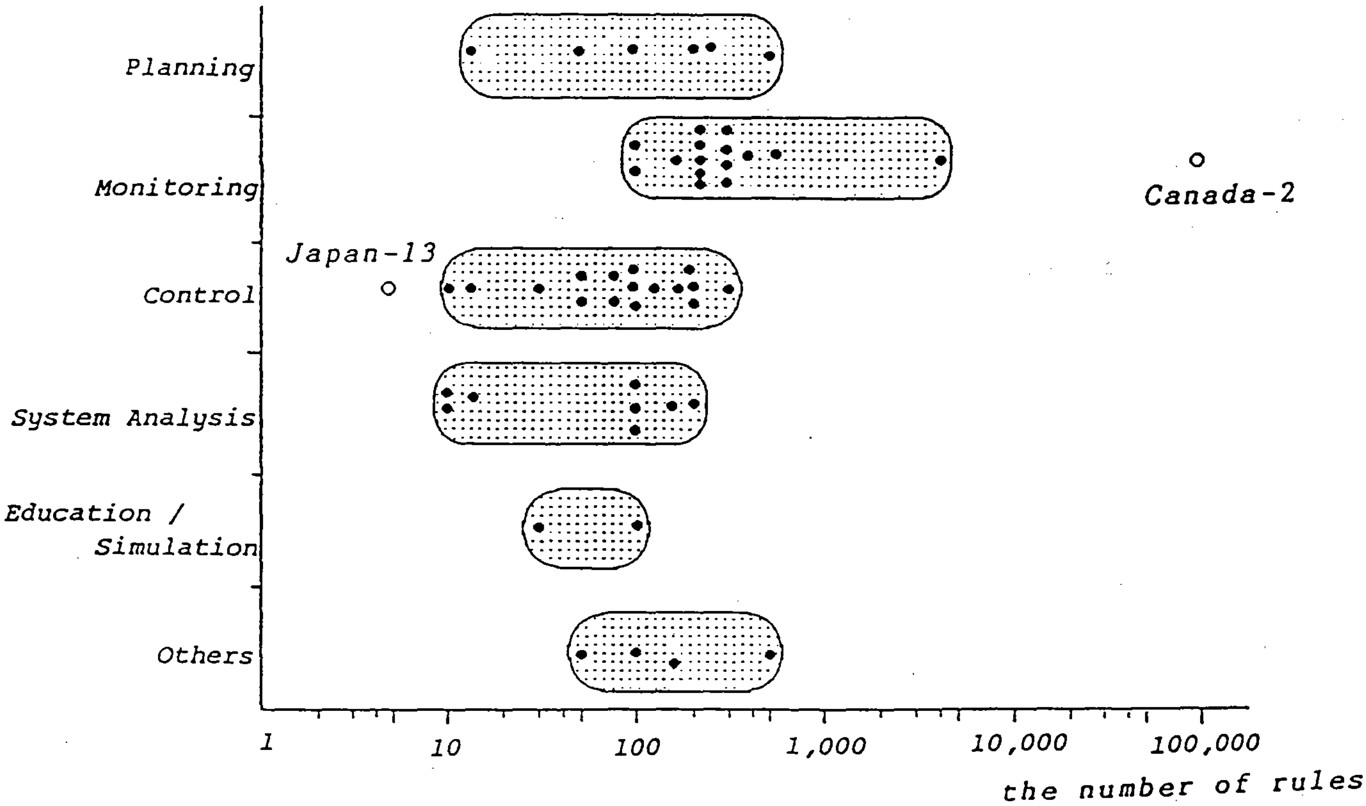

Fig.2-12 Cross-correlation between the project objectives and the number of rules for the systems reported. A black dot within each shaded area corresponds to each system reported.

Note : For the meaning of ○ , refer to Appendix <B>

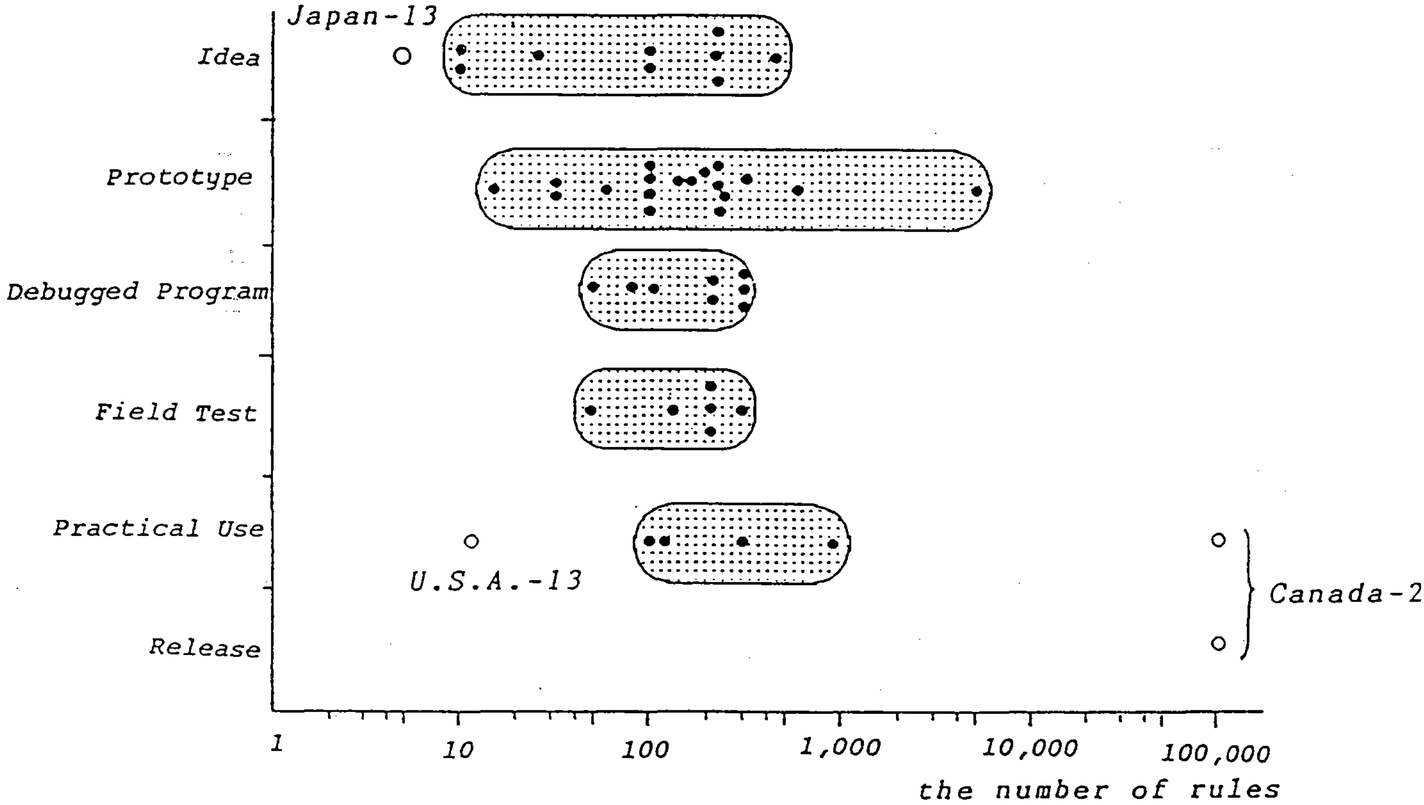

Fig.2-13 Cross-correlation between development stage and the number of rules. A black dot within the shaded area corresponds to each system reported. Note that the abscissa is in a logarithmic scale.

Note : For the meaning of O , refer to Appendix <B>

there is a common size of knowledge for expert system in practical applications. However in consideration of requested short reponse time and the limit of current hardware and software, there may be a certain upper limit in the number of rules of expert system for real-time use.

(v) Hardware environment used for development Fig.2-14 shows the types of hardware used for expert systems development. It may be noted that the super-minicomputers and AI workstations are extensively used for development, as they are convenient due to their stand-alone performance and friendly man-machine interface. Detailed statistics of hardware used for development are shown in Table 2-5 and Tables 2-6(1) to 2-6(3).

(vi) Languages used for development Fig.2-15 shows the languages used for development. It is quite interesting that the major high-level languages, LISP, Prolog, Fortran, C and Pascal are the most used languages. Fortran, C and Pascal are efficiently used for scientific calculation, while LISP and Prolog are for the AI part of the system.

(vii) Software used for development Fig.2-16 shows the use of AI tools for development. KEE, OPS83, ART, ALOUETTE, ESHELL and SAGE are the most extensively used tools for expert systems development. It is indicated that a simple commercial shell may not be suitable for repetitive task likely to encounter in system wide problems.

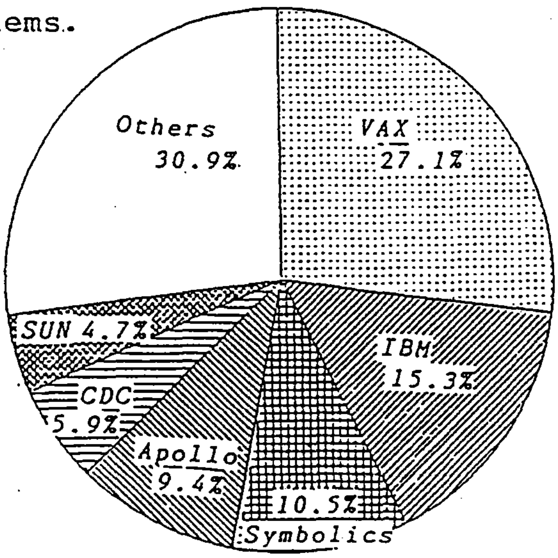

Fig.2-14 Types of hardware used for development.

Table 2-5 Computer Hardware used for Expert system Development

Name of computer	Model name	(Number)	Total number
VAX	·VAX 8600 ·VAX 8800 ·Micro VAX ·Micro VAX Ⅱ ·VAX 11/750 ·VAX 11/780 ·Others	(1) (1) (4) (5) (3) (3) (6)	23 (27.1%)
IBM	·PC Series - AT/XT/RT ·IBM 370 ·IBM 3090 ·IBM 4341	(8) (1) (3) (1)	13 (15.3%)
Symbolics	·3620 ·3640 ·3645 ·Others	(1) (1) (1) (6)	9 (10.5%)
APOLLO	·DN Series ·DN 580 ·DN 660 ·DN 3000	(1) (2) (1) (4)	8 (9.4%)
CDC	·CDC ·CDC CYBER	(1) (4)	5 (5.9%)
SUN	·SUN-2, SUN-3 ·SUN-Workstation	(2) (2)	4 (4.7%)
Others	·TOSBAC DS 600/80 ·MITSUBISHI EWS MN ·XEROX 1108 AI-Workstation ·PDP 11/23 ·HITAC M280H ·MELCOM 70-MX/3000 ·HP-Vectra ·NEC PC-9801 ·FACOM FM16β ·RM 80 ·RA 81 ·TU 77 ·VT 100 ·AYDIN 5217 ·EWS E-330 HITACHI ·FACOM M-780 ·ACOS 1000 ·UX-300FⅡ ·NEC 98XA ·UNIVAC 1180	(2) (1) (1) (1) (1) (2) (1) (2) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1) (1)	23 (27.1%)

For "Hardware vs Application Area", refer to Table 2-6(1)(2)&(3).

Table 2-6 (1) Relation of Computer Hardware and Application Area

Name of Computer	Model name	Area of application (ID. No.)
VAX	VAX 8600	-Load forecasting (U.K.-2)
	VAX 8800	-Different fault tripping (France-3)
	Micro VAX	-Decision-making (security assessment) (U.K.-1) -Distribution automation - all aspects (U.S.A.-2) -Communication system alarm (U.S.A.-4) -Sequential events in major intertie substations (U.S.A.-5)
	Micro VAX II	-Electronic equipment for substations (Italy-2) -Early detection and diagnosis of machine's malfunction (Italy-5) -Advise in real time operation (U.S.A.-11) -Decision-making of voltage/Var control (U.S.A.-15) -Customer restoration procedure (U.S.A.-16)
	VAX 11/750	-Events diagnosis (Finland-2) -Power plant faults (U.K.-3) -Energy management system applications (U.S.A.-18)
	VAX 11/780	-Breaker and relay status in control center (U.S.A.-6) -Contingency analysis and remedial action for security enhancement (U.S.A.-12) -Causes for the alarm and recommendation of corrective action (U.S.A.-14)
	Others	-Planning checking switching operations (Finland-3) -Equipment in high voltage substation (France-2) -Evaluation of system state and determination of remedial measures (Japan-10) -Evaluation of state and choice of actions (Norway-1) -Alarm processor at national control center (Ireland-1) -Restoration from a deenergised power system (Sweden-1)

Table 2-6 (2) Relation of Computer Hardware and Application Area

Name of Computer	Model name	Area of application	(ID. No.)
IBM	PC Series AT/XT/RT	-Analysis of a disturbance information	(Finland-1)
		-Equipment in high voltage substation	(France-2)
		-Load flow engine	(Italy-1)
		-Power transformers	(Netherlands-1)
		-Identification and predicting of harmonic related problems	(U.S.A.-1)
		-Short term load forecast	(U.S.A.-7)
			(U.S.A.-7)
		-Restoration of area load following an outage	(U.S.A.-17)
	IBM 370	-Advice on errors or system weak points	(U.K.-4)
	IBM 3090	-Computer aided decision on network topology	(France-1)
		-Equipment in high voltage substation	(France-2)
		-Different fault tripping	(France-3)
	IBM 4341	-Restoration of area load following an outage	(U.S.A.-17)
Symbolics	3620	-Contingency analysis, Reliability assessment	(Norway-1)
	3640	-Planning	(Japan-3)
	3645	-Events diagnosis	(Finland-2)
	Others	-Switching planning after disturbances	(Finland-3)
		-System restoration	(Japan-4)
		-Identification of faulted section	(Japan-6)
		-Evaluation of system state and determination of remedial measures	(Japan-10)
		-Automatic production of training scenarios	(U.S.A.-8)
		-Restoration from a deenergised power system	(Sweden-1)
APOLLO	DN Series	-Improvement in load flow planning	(Japan-9)
	DN 580	-Faulted equipment detection	(Japan-2)
		-Location of faulted point (section)	(Japan-5)
	DN 660	-Load flow engine	(Italy-1)
	DN 3000	-Network restoration	(Netherlands-2)
		-Contingency analysis and emergency control	(Switzerland-1)
		-Fault identification in a substation	(Switzerland-2)

Table 2-6 (3) Relation of Computer Hardware and Application Area

Name of Computer	Model name	Area of application (ID. No.)
CDC	CDC CDC CYBER	-Relay auto-reclosure in system restoration (U.S.A.-13) -Automatic production of training scenarios (U.S.A.-8) -General purpose expert system shell for EMS applications (U.S.A.-9) -Filtering and ranking of alarms (U.S.A.-10) -Contingency analysis and remedial action for security enhancement (U.S.A.-12)
SUN	SUN-2 SUN-Workstation	-Electronic equipment for substations (Italy-2) -Equipment for distribution centers (Italy-3) -Monitoring and diagnosis of water pollution in thermal power plants (Italy-4)
	SUN-3	-Security assessment and control in alert states (Japan-15)
Others	TOSBAC DS 600/80	-Identification of faulted equipment (Japan-7) -Restoration guidance under emergency status (Japan-8)
	MITSUBISHI EWS MN	-Improvement in load flow planning (Japan-9)
	EWS E-330 HITACHI	-Interactive power system analysis using conventional software (Japan-11)
	XEROX 1108 AI-Workstation	-Power plant faults (U.K.-3)
	PDP 11/23	-Early detection and diagnosis of machine's malfunction (Italy-5)
	HITAC M280H	-MVar and MW Stability indices (Japan-14)
	MELCOM 70-MX/3000	-On-line dynamic ELD for power plants (Japan-13) -MVar and MW Stability indices (Japan-14)
	HP-Vectra	-Alarm processing (Denmark-1)
	NEC PC 9801	-On-line dynamic ELD for power plants (Japan-13) -Security assessment and control in alert states (Japan-15)
	FACOM FM16 β	-Countermeasures to ensure system security (Japan-16)
	RM 80	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)
	RA 81	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)
	TU 77	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)
	VT 100	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)
	AYDIN 5217	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)
	FACOM M-780	-Training system for power system operation (Japan-17)
	ACOS 1000	-Daily planning of unit committment (Japan-18)
	UX-300 FII	-Daily planning of unit committment (Japan-18)
	NEC 98XA	-Daily planning of unit committment (Japan-18)
	UNIVAC 1180	-Monitoring and control of stability constrained power system (Canada-2)

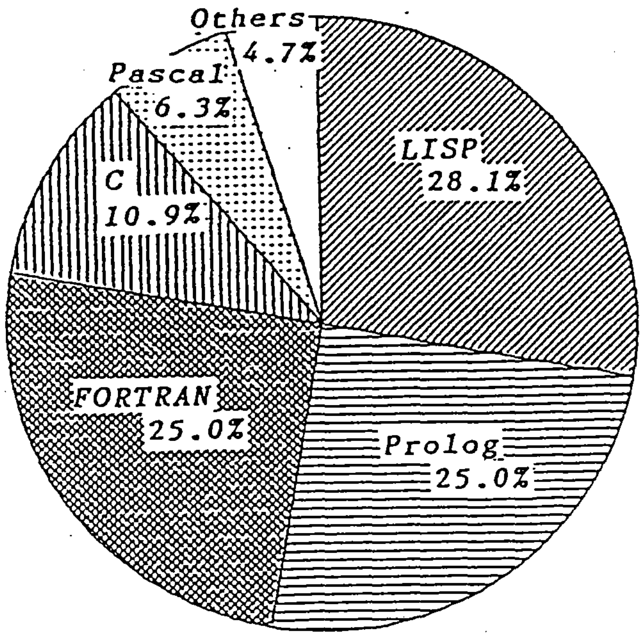

Fig.2-15 Languages used for development.

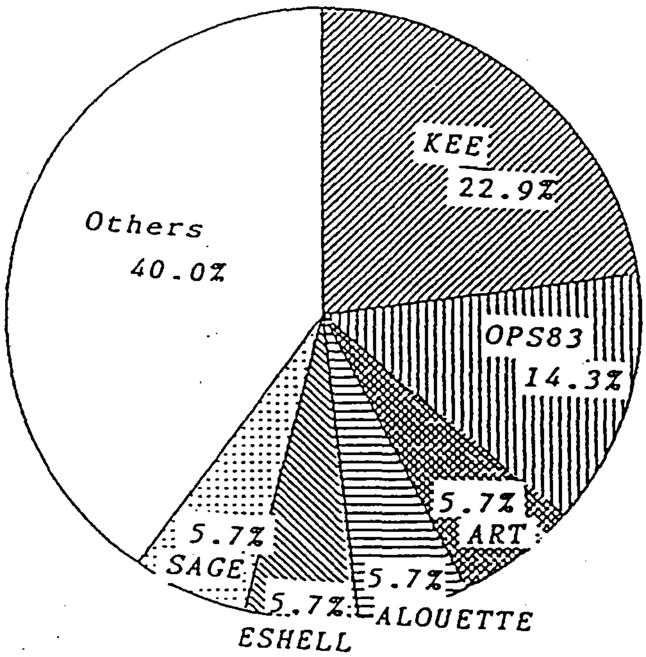

Fig.2-16 Tools used for development.

2.5 Perspective for Development

This section describes perspectives for expert systems development, which include necessary improvements/enhancements of the systems and promising application areas for the future. As expert systems development in the power system field is in the initial stage, the perspectives for development in the respective countries are widely diversified. Reviewing answers to Question A, the perspectives can be divided into 6 items as follows:

(1) Refinement of knowledge base

- To increase the number of rules (Japan- 9)
- To develop deep knowledge base (Japan-14)
- Acquisition of deep knowledge from human experts (Japan-15)
- Extend knowledge to power system models (U.S.A.-10)
- To extend the knowledge base to other operational problems (U.S.A.-15)
- Blackboard approach (U.S.A.- 2)
- Decentralized or structurized knowledge base (Japan-16)

(2) Use of advanced tools and methodologies

- To process unreliable and fuzzy data (Netherland- 1)
- More problem-oriented language (Italy- 3)
- To use more advanced tool (KEE, ART, Knowledge Craft) (Netherlands- 2)
- Qualitative model and control scheme (U.K.- 3)
- To use temporal logic for dynamic behavior (Japan-15)
- To build up proper index for search space confinement (Japan-14)

(3) Enhancement of developed expert systems' function

- To test the function and effectiveness (Japan- 1)

- To improve computation time and memory size (Japan-13)
- To evaluate practicability of the system (Japan-16)
- Assessment of the feasibility of tools (U.S.A.-16)
- To handle very rare case of contingency (Japan-15)

(4) Improvement of man-machine interface

- Man-machine interface for guidance (Japan- 2)
- Visual display for guidance (Japan- 5)
- Advanced man-machine interface (Japan-15)
- To establish front-end using a mouse (Norway- 1)
- User interface used by technicians (U.S.A.- 1)
- User friendly system to operations personnel (U.S.A.- 9)
- Refinement to man-machine interface (U.S.A.-12)

(5) Expansion of application area

- Application to on-line operations (France- 1)
- To support more complex cases of substation configuration (Italy- 3)
- Automatic interpretation of sensor data (Italy- 5)
- Application to practical-scaled system (Japan- 1)
- Application to large and complex system (Japan- 7)
- Application to system including plural generators (Japan- 8)
- Application to many kinds of analysis (Japan-10)
- Application to real system with complex structure (Japan-15)
- To formulate a general computer approach (Netherlands- 1)

(6) Others

- Transport to personal computer (Italy- 4)
- Interface to the EMS database (U.S.A.-11)
- To combine with conventional softwares (U.S.A.-12)
- Extensive data acquisition systems (U.S.A.-17).

3. RECOGNIZED NEEDS FOR EXPERT SYSTEMS AS APPLIED TO POWER SYSTEMS (QUESTION B)

Replies to this question have been received from 20 institutions (laboratories, universities and utilities) in 10 countries: Canada, Finland, France, F.R.G., Ireland, Japan, Norway, Sweden, U.K. and U.S.A.. As the answers cover various aspects in power systems, it is difficult to classify the opinions into appropriate categories.

The original contents are listed in Table 3-1 without omission according to each item of the questionnaire.

3.1 Indicated Needs for Introducing Expert Systems

The main reason for the present AI fever in the power industries lies in that while there are so many tasks which are quite difficult to be handled by the conventional approaches, expert systems have potential capabilities of dealing with such problems very efficiently and precisely.

The strong motivation for introducing expert systems into power system affairs principally comes from the following factors which are likely to occur in the alert state, during contingencies, while load shedding, and during system restoration:

- mass of data
- complexity of network structures
- combinatorial nature of solutions
- incomplete information
- data conflict

Similar situations can arise in off-line tasks such as system planning, substation layout, etc.

In Fig.3-1 are shown the relationship between indicated needs and relevant factors for introducing expert systems.

The following items are recognised as appropriate application areas of expert systems to power systems:

- identifying alert or emergency states
- providing emergency procedures
- restoration control
- analysis of very slow state transition
- load shedding
- system planning
- voltage / Var control
- fault isolation
- distribution automation
- operator training
- advanced man-machine interfaces

3.2 Functions to be Furnished

The original intentions of this question were to ask respondents what kind of functions need to be provided in expert systems for applying them to solve the various power system problems cited in the questionnaire. Expected answers would have been, for instance, to describe inference mechanisms, ideal knowledge base systems, or easy man-machine interfaces. However, due to lack of clarity in the questionnaire, it has brought about unintended answers and comments, which have been found very informative as shown in Tables <E-1> to <E-20> in Appendix <E>. Some respondents mention the realization of more advanced, that is, easy to use man-machine interface. This particular requirement will be a key to establishing expert systems as truly practical for utility jobs since the man-machine interfacing is the only function that appears in front of the system operators/dispatchers who are presumably ignorant of either computers or expert systems.

3.3 Future Project Plans

Answers related to this issue are enumerated by countries in Tables

<E-1> to <E-20>. It is clear that most of the future projects intend to realize effective decision-support capabilities in expert systems. Very informative and valuable comments presented from France are listed in Table 3-1.

3.4 Summary

Tables <E-1> to <E-20> have made clear that there exist strong needs for introducing expert systems in reponse to the inherent difficulties that are associated with the daily operation and future planning of complicated power systems. As power system disturbances which might lead to system collapse are relatively fast, the time available to decide and execute correct countermeasures is very limited. Nevertheless, human beings are incompetent in correctly judging situations within a very short time, based on a large amount of incomplete information. It is strongly hoped that expert systems will be able to fill the gap between human capability and the complications involved in operating power systems.

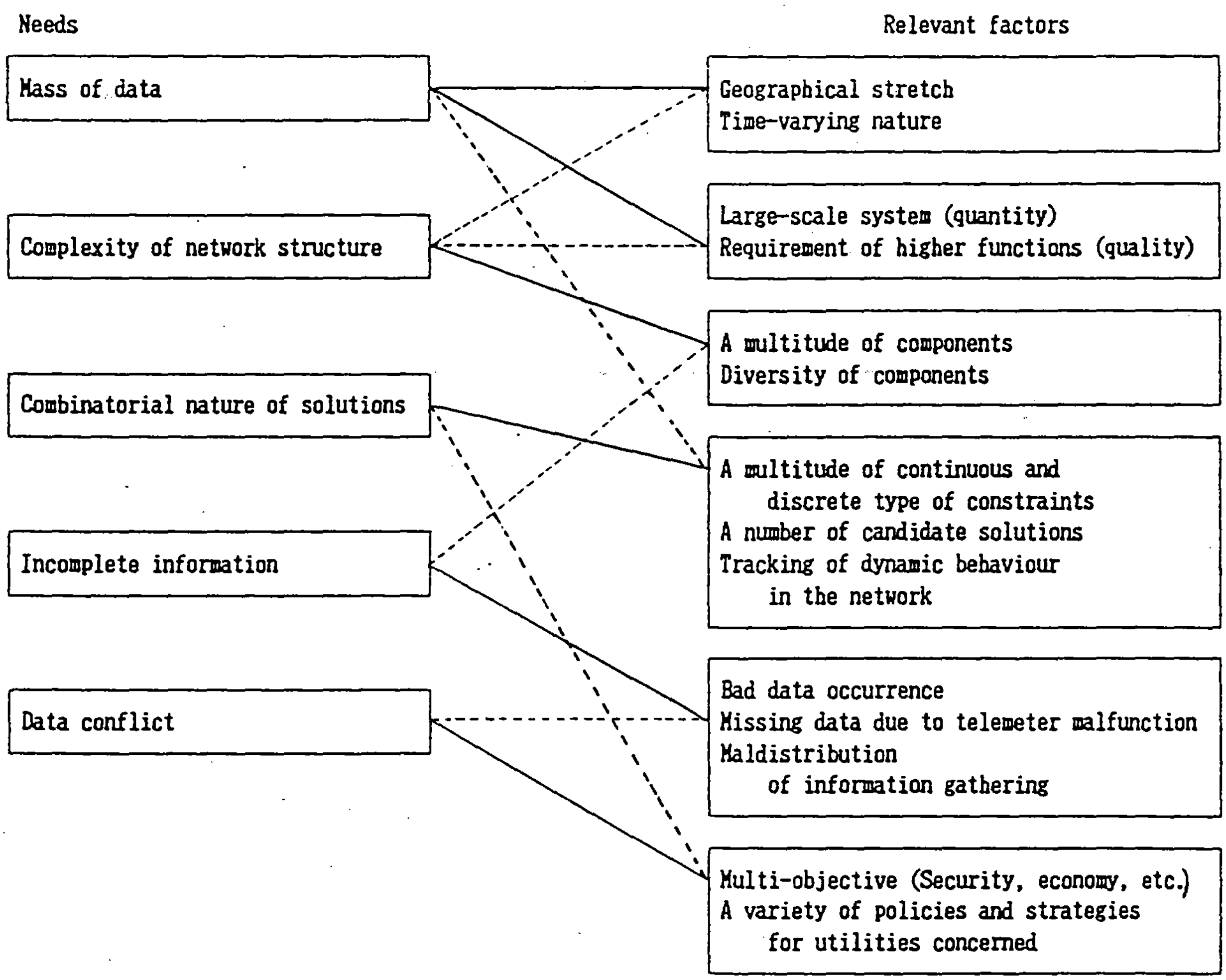

Fig.3-1 Indicated Needs and Relevant Factors for Introducing Expert System

Table 3-1 (1) Recognized Needs for Expert Systems Applied to the Power System

(Country: France)

ITEMS ID.No.of Answers	France-b (EDF & CGEE - ALSTHOM)
Potential Needs	The main problems in power system operation that can be tackled with expert system are : a) Evolution Analysis One major obstacle is to define and to detect a potential alert situation, that is a situation that will lead, in a relatively by short time, to an operation problem. Another obstacle is to define safeguard strategies for alert situations. b) Alarm synthesis The major obstacle is to correlate various alarms in space (alarms coming from different points of the network) and in time (taking into account different transmission delays between substations). c) Load shedding Up to now, load shedding is based on static algorithms. The kind of customers to be interrupted is predefined. The problem is to be able to define dynamically, according to operation constraints, which customers must be shed. d) Restorative strategy The problem is to find the correct sequences of feeders to restore after a fault. The major obstacle is the impossibility of determining effective loading of each feeder. e) Operator training Generally a training simulator allows an operator to simulate actions on an electrical network, and give the consequences. It would be important to simulate defaults, analyze operator actions in this context and then explain the operator default nature and problems resulting from his actions. The obstacles are the number and the nature of functions to implement: all problems relative to a fault itself and to transmissions should be taken into account. f) Man-machine interface: assistance to image design (off line) Image design of electrical network is a field where expert systems could bring important assistance. The problem is to create images, for a given screen resolution. Indeed, an image must contain exhaustively, the description of a significant network area. Moreover, it must be sufficiently understandable by the operator. The major obstacle is to determine a good compromise between: - giving maximum information to minimize operator handlings or requests and - ensuring efficient image resolution to facilitate operator understanding

- continued -

Table 3-1 (2) Recognized Needs for Expert Systems Applied to the Power System

(Country: France)

ITEMS ID.No.of Answers	France-b (EDF & CGEE - ALSTHOM)
	a) Evolution analysis Evolution analysis concerns slow phenomenon supervision. The study can be done by assessing variations of indicators giving a large view of global process evolution. The expert system will implement operation rules of the utility and correlation rules between indicator variations. A function which can supply new data to the expert system during inferences and which can verify data coherence seems important. In other words time varying input must be taken into account. b) Alarm synthesis The number of alarms that can appear when there is a failure on the network can be very important. To establish a diagnosis, a preliminary classification is needed. A sorting out function, using spatial and temporal criteria must be furnished. That must allow the expert system to work with less data. c) Load shedding
Functions to be furnished	To resolve the problem of dynamic load shedding, the function to be implemented must be able to evaluate quickly (according to load shedding delay) feeder supply load in a determined area, and to determine dynamic constraints. Finally, from these constraints and a set of criteria, the expert system will define a list of appropriate feeders to be shed. d) Restorative strategy To restore the power on unsupplied feeders subsequent to an incident, hypothesis must be done on feeder potential loading according to load forecasting and feeder load before the incident. Some functions like storage, load forecasting and load flow and the possibility to define dynamic criteria (restorative strategy) must be implemented with the expert system. After a fault on the network, the expert system can help the operator by giving him the sequence of devices to operate according to: - the diagnosed fault - the operation rules of the utility e) Operator training An incident generator able to simulate faults on electric network and transmission network, with an explicative module, would bring great assistance in operator

- continued -

Table 3-1 (3) Recognized Needs for Expert Systems Applied to the Power System

(Country: France)

ITEMS ID.No.of Answers	France-b (EDF & CGEE - ALSTHOM)
Functions to be furnished	education. The expert system will allow fault generation. f) Man-machine interface: assistance to image design The expert system will implement object representation rules and ergonomic rules. Functions to be furnished with the expert system shall allow image parameter acquisition and modification of final images given by the expert system.
Future Project	1987 - Test of the base of rules 1988 - Response time measurements on the final hardware (VAX 8800) 1989 - Integration of application software 1990 - Acceptance tests on site - Field test in a regional control centre

4. VIEWS ON FUTURE EXPERT SYSTEMS (QUESTION C)

Reflecting the very premature state of current Expert Systems (ES), responses to this question are widely diversified, some are quite positive and some rather negative.

However, the survey provides, in a sense, a useful guide to hardware and software developers on the aspects or directions on which they will have to concentrate to realize truly effective Expert Systems.

4.1 Potential Applications of Expert Systems

Reviewing opinions to question C, the followings can be regarded as potential applications of ES to power systems:

- power system analysis in an on-line situation
- system operation
- system control
- system restoration
- system planning/design
- substation automation
- maintenance scheduling
- alarm processing

4.2 Effectiveness/Practicability of Expert Systems

Opinions on this particular item show sharp contrasts in evaluating the future capability of ES; this presumably stems from the fact that ES have not yet been developed enough to correctly judge their future practicability. Here, the responses obtained are grouped into positive and negative sides and by individual respondents:

Positive side

Canada (Ontario Hydro)

- The expert systems represent an important future tool for the on-line analysis of power systems.
  For expert systems to achieve their potential, the following must be resolved:
  (a) A way to integrate it in an operating EMS (same man-machine, data base, ...).
  (b) A way to overcome the requirements for large memory and CPU.
  (c) A method of acquiring expertise, loading it into the knowledge base and keeping it up-to-date.

Finland (IMATRAN VOIMA OY)

- Artificial intelligence and Expert Systems are considered important development targets in the field of transmission network operation and maintenance.

France (EDF)

- The use of expert systems in power application and in process control applications will be able to be generalized when the major problem of real time inference techniques has been solved, either with the appearance of a new generation computers or the utilization of more powerful machines that can process large knowledge bases.
  One way of solving this problem could be the use of languages such as C or Pascal (as used in our system).

Japan (Chubu Electric Co. / Toshiba Corp.)

- <u>Effectiveness</u>: Expert systems are very promising; They are very effective in some areas, whereas they are not necessarily so in other fields. Therefore, it is anticipated that the expert systems must coexist with systems established by conventional techniques.
  The expert systems will be very effective to:
  * Tasks where there are many conditions to be judged in

drawing a conclusion and yet they are involved with each other.

* Functions which need frequent software maintenance.
* Jobs in which there is a large technical gap between veterans and rookies, and besides the inheritance of techniques owned by veterans is very important.

- Practicability:

  At present - testing and validation by prototype systems
  In 3 years - first appearance of practical systems
  In 5-6 years - wide application of practical systems

Japan (Kyushu Electric Power Co. / Toshiba Corp.)

- Effectiveness: The application of expert systems makes it possible to systematize the judgement mechanism of experienced engineers that is based on their knowledge, and to store the knowledge in a common format. Thus, the following effects can be expected:
  * inheritance of techniques
  * prompt and yet accurate system restoration
  * curtailment of the time for planning and design, and improvement in planning accuracy
  * improvement in fault diagnosis accuracy
  * effective teaching and training system
  * higher reliability in power system operation
- Practicability: Major factors in evaluating expert systems are the accuracy of solutions obtained, response time, easiness in man-machine interfaces and maintenance capability of knowledge base. Especially, both the accuracies and fast reponse time are very important features in on-line expert systems for real-time processing. The response time can be reduced by the usage of advanced hardware equipment and by developing new tools for inference control. On the contrary, it is rather difficult to improve rapidly solution accuracies considering the fact that there are no established techniques of testing the accuracies. In view of the foregoing, it is vital to start practical

applications to relatively easy cases and then gradually proceed to complicated situations.

Sweden (Swedish State Power Board)

- Lisp chips and parallel processing may solve both the effectiveness and practicability problem. Meanwhile, there will be plenty of work needed to develop applications of practical use.

United Kingdom (CEGB)

- Potential needed are seen:
  - (a) in problems involving network topology.
  - (b) where there is a mass of data, some redundant, some possibly conflicting.
  - (c) where, based on (b), there are a considerable range of actions which can be taken , there may be no clear optimal solution and action is needed without delay.

United Kingdom (Imperial College / CEGB)

- Expert systems can be effective and practicable with present technology provided the application areas are well chosen. Their inherently slow execution speed may be alleviated by the inclusion of efficient numerical algorithms. One important area in which further theoretical work is necessary is in the representation of dynamic systems.

United States (University of Washington)

- The user-friendliness of rule-based programming techniques is a major attraction to users. The development, maintenance and expansion tasks can be simplified.

  Expert systems are also a knowledge development tool. An engineer can develop rules for the solution of domain problems. The effectiveness of expert systems depends on two things: the quality of knowledge and the computational efficiency.

<u>Negative Side</u>

France (EDF)

- Several important questions below have to be solved before expert systems techniques can become more widely used in power system applications:
  * bridge gap between algorithms and knowledge based systems,
  * interface with standard data base management systems,
  * use high level representation languages for handling mixed knowledge representation (frames, production rules, scripts, objects) well suited for network applications,
  * reduce CPU time by using more powerful machines,
  * represent time varying processes in a better way,
  * use rule-checking methods (detecting incompleteness, inconsistency, ...).

F.R.G. (Siemens)

- Effectiveness suffers from high effort to update knowledge base and testing for verification. For power system control, a high share of procedural evaluation seems more practical than a huge number of rules and facts.

Japan (Kansai Electric Power Co. / Mitsubishi Electric Corp.)

- Current expert systems are only applicable to prototype machines. The application of expert systems requires longer CPU time and large storage capacity, which are not desirable to on-line systems. Therefore, in realizing on-line expert systems, it is of primal importance to allot an adequate ratio between burdens of expert systems and of conventional analysis tasks.

Norway (EFI)

- Today's tools are not powerful enough to handle the total problem of power system analysis in an on-line situation, but there are hopes that increased capability for computers and more effective software will help solve this problem.

R.S.A. (ESCOM)

- There are many misconceptions about Expert Systems and their application to engineering applications. Most artificially intelligent systems require a lot of compute power, but many are capable of working with limited resources. Before effective Expert Systems can be built, effective knowledge representation methods are needed as well as proficient knowledge engineers. Control and monitoring applications need to operate within real-time and operate with time variant data. Engineering DP functions have been traditionally performed by die-hard FORTRAN programmers who often do not see new methods as holding the key to the solution of problems.

United Kingdom (University of Durham / CEGB)

- Due to limitations of speed, expert systems are not really practical for real time control.

U.S.A. (Wisconsin Electric Power Co.)

- With regard to the effectiveness of Expert Systems when applied to power system dispatching, it appears too early to pass judgement. The areas where we have experience are extremely simple applications of Expert Systems and indeed may not be considered as such at all. The probability exists that as the impementation of Expert Systems become more complex especially in the areas of alarm processing and restorative control that the Expert System will not match the event during an actual disturbances. The knowledge base applied in the implementation on an Expert System is drawn partially from past experience. Analysis of past disturbances to the power system would indicate that each event is relatively unique. As such, the knowledge base will probably be inadequate for the actual occurrence.

4.3 Interactions between Expert Systems and Human Operators

Responses to this issue were limited; most of them assert that ES should supplement human decisions, and never replace the human role. The followings are opinions by country.

Canada (Ontario Hydro)

- We had problems when we tried to introduce expert system type programs that perform some decision making (Remedial Action Analysis). It is also a fact that expert systems will not produce correct results at all times. We expect to have some problems when we try to introduce expert systems to handle tasks that the operator has handled for a long time and still feels that he can handle better than an expert system. The ability of an expert system to provide the rationale for the solution will make them more acceptable.

Finland (IMATRAN VOIMA OY)

- The starting point in the development of expert systems is that even the best system cannot replace a man. For the time being, the target is to make systems which help and criticise a man. The final decision is left to a man.

France (EDF)

- Expert systems should ensure the greatest assistance to an operator.

  Expert systems must be able to provide solutions, explain them on the operator's request, and accept and analyze the operator's interrogations.

  A decision that will influence network configurations must be executed by an operator. It should not be expected that expert systems will act directly on a power system.

Japan (Tokyo Electric Co. / Toshiba Corp.)

- Expert systems will be supporting tools which provide information necessary for the solution of problems or alternative coutermeasures by repeating dialogue with the operators. The expert systems will never replace the human role.

Japan (Kansai Electric Power Co. / Mitsubishi Electric Corp.)

- Expert systems should function as a favourable tool which provides necessary knowledge to the system operators, and hence are suitable as a guidance system.

Japan (Chubu Electric Power Co. / Toshiba Corp.)

- There are many tasks in which human experience plays a key role but conventional techniques can do little. Consequently, it is quite difficult to fully automatize these tasks by means of computers. These areas must be good application targets of expert systems. Another problem lies in that the technique of test and validation for expert systems has not been established so far. Thus, the expert systems and the operators will have to coexist in real applications: This implies the expert systems will act as supporting tools of the system operators (reduction in the burden of the operators).

Japan (Kyushu Electric Power Co. / Toshiba Corp.)

- Areas to be processed only by expert systems:
  * simple tasks to be processed without human participation
  * complex tasks which require conclusions within short time but the conclusions drawn under the ambiguity of the expert systems may not cause serious harm
- Areas to be processed jointly by expert systems and human beings:
  * tasks for which a conclusion should be drawn by the judgement of the human beings in an interactive mode
  * complex tasks which immediately needs exact conclusions based on a high level of judgement of human beings, and final execution command of which should be dispatched by the operators.

Norway (EFI)

- As an assistant to an operator or engineer.

R.S.A. (ESCOM)

- There seems to be a large scope for intelligent assistants rather than expert replacement systems. These systems would help the operator in his work rather than replace him.

Sweden (Swedish State Power Board)

- The likely interactions between the Expert System and the human operator, and the role and functions shared by ..?
  The expert system role will naturally intrude and partly take over the role of the operator. The important issue is that this can be done at the same time as the operator's working environment is made more stimulating.

United Kingdom (Imperial College / CEGB)

- The expert system applications most likely to succeed are those implemented in the framework of a decision-support system.
  This would allow the user to accept or reject the advice offered. The complete automation of particular functions is a long-term goal which can only be realised after such systems have been shown to be robust enough to handle a wide range of possible events.

United Kingdom (CEGB)

- To draw inference, with levels of probability if possible, from available data; conflicting data should be identified.
  To suggest alternative courses of actions, including designs, for consideration by planning and operations engineers.
- Expert systems should be such that the user could have access to adding/modifying rules without the need to involve highly specialised software staff. This closeness of interaction between end-user and software tool could be very powerful for adapting the tools to suit the job in hand.

United Kingdom (University of Durham / CEGB)

- Expert systems will act in an advisory mode to human operators.

U.S.A. (University of Washington)

- Expert systems should serve as system operators' or planners' aids. System operators have a broader view of the system operating condition and therefore should be the final decision-makers.

U.S.A. (Wisconsin Electric Power Co.)

- The greatest fear with regard to the interaction between the expert system and the dispatcher lies in his probable dependence on the ES to function for all situations with the result that he will be less prepared to analyze either the situation itself if the ES is unable to produce a solution or to analyze the correctness of solution proposed by the ES.

4.4 Summary

As stated at the outset, a wide range of answers has been sent back with respect to this question, from quite positive to rather negative. This phenomenon looks confusing but is in fact likely to occur when predicting the future potential of an emerging technology. Furthermore, any technology has both merits and demerits. Hence, if one evaluates more of the former than the latter, it may give a positive answer, and vice versa. This is exactly the case for ES.

It is true that present expert systems have many shortcomings as is pointed out by the negative opinions. However, it is clear that the mere extension of the approaches we have taken so far will not provide a solid remedy to the difficulties that we are now facing. Nevertheless, ES are judged to have the potential capabilities for solving some or hopefully a large part of the present difficulties.

5. APPROACHES TO BE USED IN FUTURE EXPERT SYSTEM DEVELOPMENTS (QUESTION D)

5.1 General Observations

Fifteen institutions in 8 countries responded to this question. As a result of there being few expert systems of practical use for power system operation and planning, answers received are widely diversified in approaches to be used in future developments. The answers are summarized in Table 5-1, from which the following observations may be drawn:

(1) The answers mention a variety of approaches for knowledge processing but few for knowledge acquisition.
(2) There are pros and cons in regard to pattern recognition and fuzzy set theory (see next section).
(3) A wide spectrum of opinions on this question manifests the fact that presently available expert systems have much room for refinement in the realization of really practical expert systems.
(4) Most of the approaches raised in relation to knowledge processing or inference mechanism necessitate great research effort to make them applicable to real world matters.

5.2 Opinions by Countries

This section lists only opinions which may cause some debate.

Canada (Ontario Hydro)

- Pattern recognition was used in one of our Application (on-line security monitoring). The number of rules is quite large (100,000 +). An off-the-shelf shell would not work in such an application. We had to take advantage of the nature of the problem (combine the rules with common test conditions in tables, and order the processing of tables) to reduce the computation time. For power system operations, where only correct answers are acceptable, pattern recognition is the most appropriate technique. To reduce computation time, specialized software that takes advantage of the nature of the problem must be used.

France (EDF, Research and Development Division)

- A second generation of expert system reasoning with heuristics and many aspects of reasoning "in depth":
  * model based reasoning,
  * qualitative physics,
  * multi level/multi model reasoning,
  * causal reasoning,
  * reasoning from structure, behaviour, function

  should provide more adequate tools to treat the complexity of power system monitoring and control.

France (EDF / CGEE ALSTHOM)

- The best method seems to be the use of production rules. Utilization of pattern recognition or fuzzy set theory can lead to heavy computation.

R.S.A. (ESCOM)

- The key to effective Expert Systems appears to be the selection of a knwoledge representation method that closely matches expertise in the problem domain. Pattern matching is useful where knowledge is about entity sets rather than individual entities (eg. about circuit breakers in general rather than about each circuit breaker in the system). During different stages of decisions, different sets of rules are often the most powerful. This would indicate that a method of organising rules using meta-rules would prove a useful and very powerful tool.

Sweden (Swedish State Power Board)

- Existing tools have not matured to the point where the developed applications can be of real practical use. In the future, domain specific tools or semi-complete applications will grow in importance. That would imply a more intense collaboration within utility organisations to develop such systems.

United Kingdom (Imperial College / CEGB)

- For deterministic problems in power systems analysis, effective techniques include generate-and-test, heuristic-guided search with appropriate performance indices and graph theory. Pattern recognition is not recommended due to the need for large numbers of case studies.

U.S.A. (Wisconsin Electric Company)

- It would appear that pattern recognition is the most applicable method to be applied to Expert Systems as they apply to power system operation.

5.3 Summary

The respondents claim a wide variety of approaches for the purpose of developing future expert systems, such systems are seen to be of great help to resolving the difficulties involved in power systems. Of course, there exist clear contradictions among the opinions on some approaches, especially on pattern recognition and fuzzy set theory. Nevertheless, a wide diversity of opinions may lead to sound development of expert systems in the near future by exchanging opinions among interdisciplinary areas and accumulating experiences in applying expert systems.

Table 5-1 Approaches to be Used in Future Expert System Development

Country	Approach	Area
Canada (Ontario Hydro)	-Pattern recognition	-On-line security monitoring
France (EDF / CGEE ALSTHOM)	-Production rule	
France (EDF, Research and Development Division)	-Model based reasoning -Qualitative physics -Multi level/multi model reasoning -Causal reasoning -Reasoning from structure, behaviour, function	-Power system monitoring and control
F.R.G. (Siemens)	-Pattern recognition (in combination with logistics, time behaviour of protection relay and system topology)	-Alarm processing
Japan (Mitsubishi and Kansai E.P.Co.)	-Hypothesis generate and test -Temporal logic -Branch and bound method	-Fault analysis -Restoration
Japan (Mitsubishi)	-Qualitative reasoning technique	-Education and Training
Japan (Chubu E.P.Co. and Toshiba)	-Fuzzy set theory -Fault tree analysis	-Diagnostic
Norway	-Not mentioned	-Operators assistant -Diagnosis of apparatus
R.S.A. (ESCOM)	-Pattern matching -Meta-rules -Forward chaining	-Alarm filtering -Real-time applications with time variant data
U.K. (CEGB)	-All methods mentioned in questionnaire D seem to have potential roles depending on the problem	
U.K. (Imperial College / CEGB)	-Generate-and test -Heuristic-guided search with appropriate performance indices -Graph theory	-For deterministic problems in power systems analysis
U.K. (Univ. of Durham/CEGB)	-Pattern recognition	-Load forecasting
U.K. (CEGB, System Planning Dept.)	-Rule based knowledge -Real-natural language coding -Explanation facilities -Fuzzy reasoning	
U.S.A. (Wisconsin Electric Co.)	-Pattern recognition	-Power system operation
U.S.A. (Univ. of Washington)	-Automatic knowledge acquisition	-Real-time use

6. FUTURE ENVIRONMENT FOR EXPERT SYSTEM DEVELOPMENT (QUESTION E)

This question has proved to be quite difficult to answer at present; in fact there are few clear opinions about desirable hardware/software environments for future expert system development. Most answers emphasize the importance of close links between conventional computer functions and future expert systems.

Opinions by countries in this chapter have been cited as they appear in their original replies.

6.1 Hardware Environment

The responses may be classified by the viewpoint of whether special purpose hardware is required or not.

Recommendation of special hardware

France (EDF)

- Multiprocessor machines seems to be the best hardware environment, taking into account a large volume of data and knowledge to be processed.

Japan (Kansai Electric Power Co. / Mitsubishi Electric Co.)

- Engineering workstations with AI tools which may be adjustable to particular problems.

Norway (EFI)

- LISP machines with full development facilities including an advanced LISP-based expert system development tool like KEE, Knowledge Craft, etc.
- Integration of a LISP-processor in a conventional control center, or the porting of a "finished" expert system to the control center computer.

United Kingdom (Imperial College / CEGB)

- Development can be best carried out in powerful single-user work-stations. An ideal system would be a suitable combination of the existing CAD/CAM workstations which possess adequate number-crunching power and the existing artificial intelligence workstations which can execute AI languages efficiently.

<u>Others</u>

Canada (Ontario Hydro)

- For on-line analysis of the power systems, the expert system must be integrated in the EMS (use same data base and man-machine, ...). It must be capable of initiating the execution of, and receiving data from the other EMS programs (contingency analysis, load flow, ...). The hardware used should be the same as the EMS.

F.R.G. (Siemens)

- The expert system should be an integrated part of the control centre system. No special hardware (e.g. LISP-machine) should be necessary. The man-machine interface (console in the control room) should be the same as for network surervision and control.

Japan (Chubu Electric Power Co. / Toshiba Corp.)

- As the expert systems should coexist with conventional computer systems, it is not advisable to install special purpose CPU and peripheral equipment. Nevertheless, the installation of a back-end processor as an inference engine may be justified for the speedup of inference.

Sweden (Swedish State Power Board)

- For general development of power applications the tools best suited seem to be object oriented hybrid tools with good graphics. The large Lisp-based hybrid tools such as KEE, Goldworks and Knowledge Craft will probably be used to prototype the next generation of domain-specific tools. The applications will then be fielded on PCs or mainframes. There is also a trend to rewrite Lisp-based tools into conventional languages. That would make it possible to implement expert system software into the EMS hardware. One advantage is that the execution speed will get higher. That might give a future solution to efficient real-time expert systems.

6.2 Software / Tools

Strictly speaking, there are responses to this item:

France (EDF)

- An important effort must be made into the research of software tools allowing easier expert system development and implementation, similar to classical programs.

Japan (Chubu Electric Power Co. / Toshiba Corp.)

- Language: When developing a prototype expert system, LISP or Prolog are used. It is anticipated that languages such as C may be used in case of practical applications.

  Supporting tool for constructing expert systems (shell):
  * shell suitable to on-line real time processing
  * easiness in linking programs written in procedure-oriented language (e.g. load flow program, etc.)
  * easy to use shell for layman

  Other tools:
  * graphic support tools
  * editor for knowledge base

R.S.A. (ESCOM)

- Although we have had limited exposure to power system Expert Systems, we have identified useful tools.
  - An environment supporting LISP as well as conventional languages such as PASCAL and FORTRAN.
  - A relational database with a SQL query facility to allow

implementation of intelligent data retrieval.

-Graphics are proving to be a useful method for building man machine interfaces, so suitable hareware would include graphics workstations.

6.3 Desirable Implementation Mode of Expert Systems

Prospective expert systems would never exhibit their true potential without reference to presently utilized computer hardware and software, since current computer systems have carried out an essential role in ensuring the safe and economic operation of power systems. Hence, the perspective of how expert systems should correlate with the conventional computer systems is an important point. None of respondents insist on an independent usage of expert systems when applied to power systems.

Finland (IMATRAN VOIMA OY)

- It is important to combine expert systems with
  * power system control
  * substation automation
  * measurements from the network

  It is also necessary to combine expert systems with graphics, databases and measurements from the system.

F.R.G. (Siemens)

- The expert system should use existing databases, process images and existing software environments as far as possible.

Norway (EFI)

- Networking facilities should be provided between the LISP-machine and traditional number-crunching machines (IBM, VAX, etc.) in order to make efficient use of established software written in FORTRAN, C, or Pascal.

United Kingdom (CEGB)

- Intelligent interfaces require handling of large quantities of data and interaction with existing datasets by other programs. Suitable hardware/software therefore depends, to some extent, on the facilities under which the conventional programs (e.g. load flow) are being run. For mainframe conventional programs, there will be certain advantages in having a mainframe expert systems.

United Kingdom (University of Durham / CEGB)

- Need close integration between expert systems, GKS (Graphical Kernel System), personal databases and number-crunching languages, e.g. FORTRAN 77.

U.S.A. (Wisconsin Electric Power Co.)

- With regard to the future environment for expert system development, it is a concern that there will be sufficient computer resources available to perform expert system analysis, especially during periods of system disturbance or restoration. These periods of time are when present energy management systems are already utilized to the limit of their capability. Expert system development should be prepared to operate in a computer resource which would not be burdened during system disturbances.

6.4 Summary

The opinions are divided on future hardware environments, especially on the necessity of special hardware for ES.

It is almost unanimous that ES should not be implemented independently from the conventional computer hardware and software, which have been accumulated to become valuable assets in the power system planning and operation and will be developed for the foreseeable future.

7. CONCLUDING REMARKS

Expert systems, a major component of Knowledge Engineering, began to attract attention of eager engineers in early 1980's. Technology of expert systems may be considered as a kind of intermediate products brought about after a vast amount of human endeavour which has been made to break through difficulties confronting us such as treatment of a system of immense size and to meet the needs for human-like reasoning.

Since the advent of digital computers of Von Neumann type in 1950's, human labour required for solving extremely large scale systems numerically has rapidly been replaced with computer technology. 30 years later since then, Computer-assisted reasoning became the central concern of researchers in various fields. In other words, human-like judgement under incomplete information, fuzzy environments, etc. has been selected as a key issue to build highly automated yet easy-to-use facilities to be needed in the future society.

Present Status of Expert System in Power Systems

The expert system application to power system problems is a relatively new area. In fact, based on the survey, most of the expert system projects are in the stage of idea and prototype; very few expert systems have arrived at the practically operational stage.

The objectives of the expert systems have been classified in six categories, namely, planning, monitoring, control, system analysis, education/simulator and others. Most of the expert systems are classified as monitoring and control; monitoring is the biggest category. Reason for this is the relative easiness with which monitoring can be tackled - in essence the task of monitoring fits a rule-based approach by nature. Further, the strong needs for expert systems in other application areas such as planning, education, simulator and analysis were recognized in this survey.

Features of environment surrounding expert systems for six categories are summarized in Table 7-1. It can be seen that ill-conditions below make difficult the application of expert systems to planning category:

- An infinite number of conclusions (design alternatives)
- Deep knowledge required to screen out proper solution

Needs and Expectations

The needs in many application areas were indicated in the responses of the survey. One could not help getting the impression, when browsing in Tables<E-1> to <E-20> of "RECOGNIZED NEEDS FOR EXPERT SYSTEMS AS APPLIED TO POWER SYSTEMS", that expert system technology will solve all the unsolved problems in power systems. Obviously, this cannot exactly be predicted, since experiences with this new technology are few and not yet fully evaluated. Nevertheless, Tables<E-1> to <E-20> are very valuable in that it reveals those problems of which some engineers feel that they can hardly be solved with conventional mathematical methods, or that they have ended in a deadlock. Consequently, Tables<E-1> to <E-20> can be used for opening the discussion on how to tackle these problems, going further with the conventional techniques (e.g., by improving mathematical methods), or using more advanced expert system techniques (which by nature are more qualitative).

Future

The assessment of the future approaches to the expert system development varies greatly among the researchers. This is clearly due to the fact that the area is still young and more research would be necessary before a truly convincing assessment to the future can be made. Fig.7-1 shows an idea of foreseeable steps towards future expert system in power system and techniques. It is felt from this survey that expert systems in power system application are midway between phase-2 and phase-3.

Making the best use of all the powerful (numerical) tools that have been developed so far, and the experiences - good and bad ones - obtained from implementations, expert system applications in power systems cannot be successful if further developments in these two are ignored. This means, a bridge must be built between the old and new approaches, that is, between quantitative and qualitative approaches, or in other words, between numerical and symbolic approaches. In the development of future expert systems more attention should be paid to this mixed approach.

In conclusion, it is felt that the survey was very fruitful. It offered an opportunity to assemble an extensive list of existing research programs in the expert system application area. The summary and publication of the responses can facilitate the exchange of information and ideas, leading to greater communication and understanding among the researchers and engineers. It is our hope that the activity of the task force can be continued into the next year in order to follow up on the activities of this fast-growing, high-interest area. The task force can make a contribution to the power engineering community in the future by evaluating benefits and difficulties for possible areas of research and development. Report on the practical experiences of expert system applications in the power system environment would also be a meaningful task. This is presently impossible since few expert systems have reached the practical stage. The state of the art in expert systems on power system analysis and techniques may be grasped from Table 7-2, Summary of Expert System Projects.

Table 7-1 Features of Inference Environment for Individual Functions

Category	Project Objectives	Features of Environment surrounding Expert System's
Monitoring	-Fault diagnosis -Alarm processing -Contingency evaluation	-A large number of facts (data,measurements) -Incomplete information (bad data, missing data), redundancy, priority -A small number of conclusions (cause of faults, malfunctions and inactions) -Relatively small size of search space -Easy to extract well-defined knowledge (rules)
Control	-Normal state -Emergency state -Restorative state	-A medium size of facts (data, measurements) -Modelling, parameter identification -A finite number of conclusions (control and switching operation to be dispatched) -Use of indices to confine search space -Easy to prepare knowledge in off-line calculation
Planning	-Operation planning -Facility design -System planning	-A manageable number of facts (specifications) -Unambiguous specifications given -An infinite number of conclusions (design alternatives) -Deep knowledge required to screen out proper solution
Others	-Education -Simulator	-Typical system model, structure and parameter valves need to be prepared -Typical conclusions (cause, control and switching operation, to be prepared to trainee -Construction of restricted search space using indices, etc. -Knowledge obtained from off-line calculation and practice -Friendly interface is mandatory
	-Analysis	-Supply basis for routine work (Monitoring, Control, Planning) -Analysis of infrequently visited events (phenomena) -Interface with conventional application packages -Large size and complex problem can be treated off-line -A number of case studies

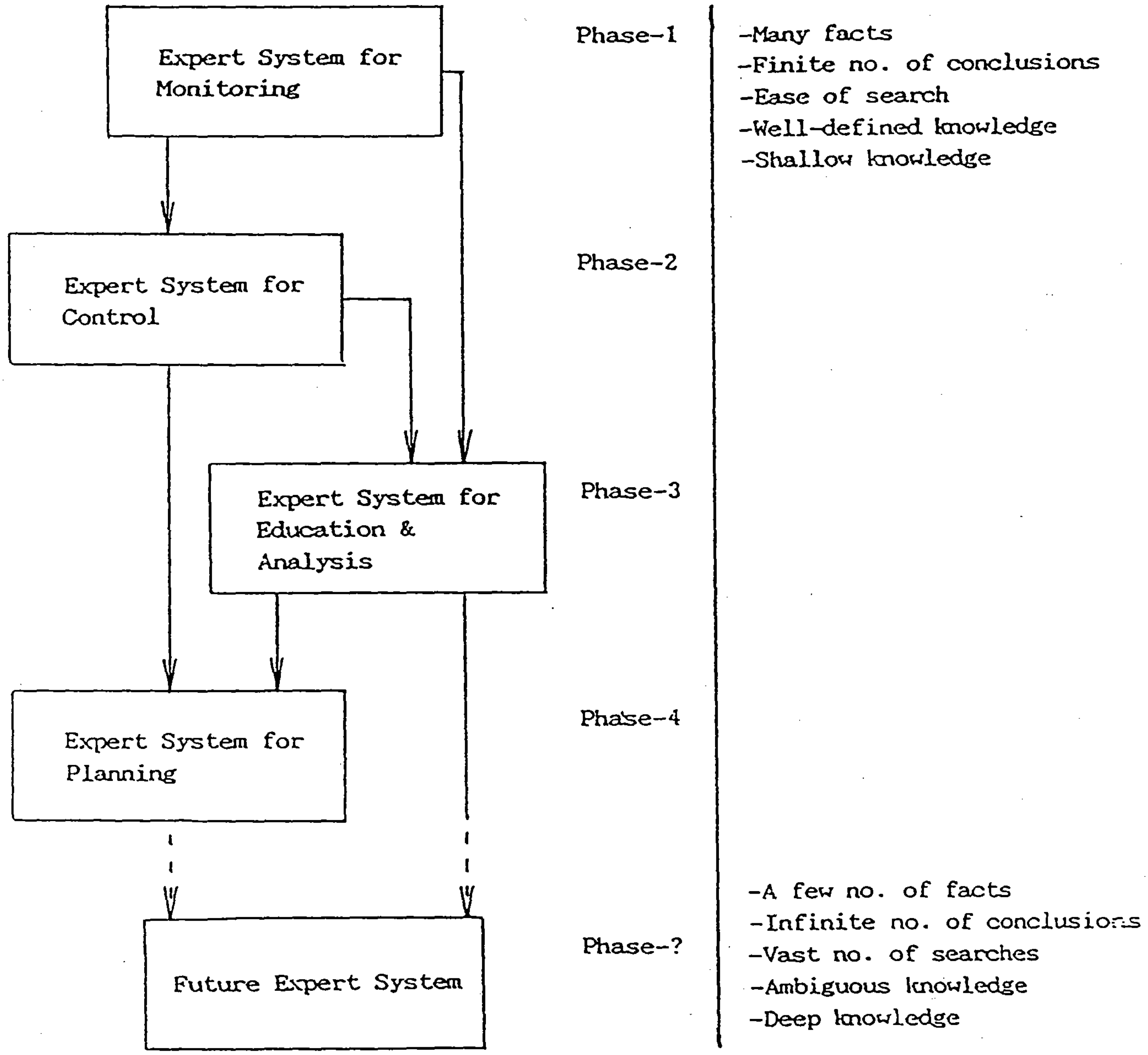

Fig.7-1 Foreseeable steps towards future expert system in power system analysis and techniques

Table 7-2 (1) Summary of Expert System Projects

<Category: Planning (1/1) > (No. 1)

	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoretical Background conventional	AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
	<Operation Planning>										
1	·Bulk power system ·System structure planning ·Generation scheduling ·Reactive power scheduling ·System stabilization (Japan-1)	Util./Manu.	Prototype	-----	·Deep knowledge base with hierarchical structuren system	Planning	forward chaining production rules		LISP	150~ 300	
2	·Decision-making (security assessment) (U.K.-1)	Univ.	Idea	·Numerical algorithms ·AC load flow ·Graph theory	·Logic programming and Logic rules	Guidance Planning	mixed chaining generate-and-test	MICRO VAX/VMS		-----	
3	·Planning checking switching operations (Finland ·Switching planning in normal operation (Finland-3)	Util.	Idea	-----	·Logic programming and Logic rules	Guidance Education Planning Checking	Production rules	VAX or Symbolics	-----	-----	
4	·Daily planning of unit commitment (Japan-18)	Univ.	Prototype	·Monte Carlo approach	-----	Planning	Backtracking	ACOS 1000 UX-300FII NEC 98X	LISP micro-PROLOG + FORTRAN	60	
5	·Short-term marketing strategy (Canada-1)	Util.	Idea	-----	-----	Guidance Planning	-----	undetermined ·likely PC	undetermined -possibly VP-Expert	undetermined	
	<Facility Design>										
6	·Electronic equipment for substations (Italy-2)	Util.	Debugged Program	-----	·Heuristic rules combined with Hill climing search	Design	Heuristic rules Hill climbing search	SUN-2 MICRO VAX II	Common LISP	100	
7	·Equipment for distribution centers (Italy-3)	Util.	Tested on set of meaningful real examples	-----	-----	Design	Forward chaining Production rules	SUN workstation	Franz LISP	200	
8	·Substation layout (Japan-12)	Manu.	Prototype	-----	-----	Design	Production rules	-----	LISP	600	
	<System Planning>										
	·Equipment in high voltage substation (France-2)	Univ.	Idea Prototype	-----	·Blackboard approach integrating both knowledge and algorithmic based functions	Monitoring Control	Forward chaining	MICRO VAX	OPS83		

Table 7-2 (2) Summary of Expert System Projects

<Category: Monitoring (1/3) > (No. 2)

	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background conventional	Theoritical Background AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
	<Fault Diagnosis>										
10	-Equipment in high voltage substation (France-2)	Util.	Prototype	-----	-Semantic Networks -Frames, Scripts, Temporal logic -Meta-knowledges	Interpretation Diagnosis Monotoring	Production rules Forward chaining Meta-knowledge	IBM 3090 VAX IBM PC-AT	ALOUETTE	370	
11	-Different fault tripping (France-3)	Util.	Debugged program	-----	-First order logic -Triplets <object, relation, object>	Diagnosis	Forward chaining Production rules First order logic triplets	VAX 8800 IBM 3090	PASCAL FORTRAN FRENCH	300	
12	-Network incidents in control center (F.R.G.-1)	Util.	Prototype	-----	-Pattern Recog.	Diagnosis	-----	process computer	process computer langage		
13	-Location of faulted point (section) (Japan-5)	Util./Manu.	Idea	-----	-----	Guidance	Production rules	Apollo DN-580	OPS83 FORTRAN	200	
14	-Identification of faulted section (Japan-6)	Util./Manu.	Idea Debugged program	-----	-----	Diagnosis Guidance Control	Forward chaining Frame	SYMBOLICS	LISP KEE	200	
15	-Identification of faulted equipment (Japan-7)	Util./Manu.	Field Test	-----	-----	Diagnosis	Mixed chaining	TOSBAC-DS600/80 super minicomputer	Prolog special purpose shell	200	
16	-Power transformers (Netherlands-1)	Manu.	-----	-----	-Fuzzy set theory -Membership function	-----	Mixed chaining	IBM PC-XT	Sage	100	
17	-Power System Behavior in Emergency states (Netherlands-2)	Manu./Univ.	Some ideas have already been tested.	-----	-Decision analysis and Search method	-----	Inference of Prolog	Apollo DN3000	POPLOG	300	
18	-Trouble shooting of operating conditions (U.S.A.-10)	Manu.	Debugged Program	-----	-Mixed chaining	Interpretation Diagnosis	Mixed chaining	CYBER	LISP PASCAL	300	
19	-Detection of fault isolation (U.S.A.-16)	Univ./Inst.	Being implemented in PSPL	-Breaker/Relay simulation -Voltage & Reactive power dispatch	-Depth first search	Diagnosis Planning	Forward chaining	MICRO VAX II	OPS83	300	
20	-Events diagnosis (Finland-2)	Inst.	Prototype	-Alarm filtering and ranking -Power flow analysis -Load forecasting	-----	Monitoring Planning Control	Mixed chaining	SYMBOLICS 3645 VAX 11/750	Common LISP FORTRAN KEE	5000	

(continued)

<Category: Monitoring (2/3) > (No. 3)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background: conventional	Theoritical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
21	-Early detection and diagnosis of machine's malfunction (Italy-5)	Util.	Debugged Program	-Frequency analysis of vibration	-----	Diagnosis	Backward chaining	PDP 11/23 MICRO VAX II	Sage	200	
22	-Hardware problems in control system (Canada-4)	Util.	Development was rejected	-----	-----	Diagnosis Guidance	Rule based Frame based	TI Explorer	KEE	-----	
	<Alarm Processing>										
23	-Alarm Processing (Denmark-1)	Util./Univ.	Idea Prototype	-----	-----	Interpretation Diagnosis Guidance Monitoring	Not yet decided	HP-Vectra	Turbo-Prolog Turbo-Pascal	-----	
24	-Alarm Processing (France-3)	Util.	Debugged Program	-----	-----	Diagnosis	Forward chaining Production rules First order logic Triplets	VAX 8800 IBM 3090	PASCAL FORTRAN FRENCH	300	
25	-Faulted equipment detection (Japan-2)	Util./Manu.	Prototype	-Alarm filtering and ranking -Power flow analysis -NL Programming	-----	Guidance	Production rules	Apollo DN-580	OPS83 FORTRAN77	200	
26	-Malfunctions in protective system (Japan-7)	Util./Manu.	Field Test	-----	-----	Diagnosis	Mixed chaining	TOSBAC-DS600/80 super minicomputer	Prolog	200	
27	-Power plant faults (U.K.-3)	Inst.	Prototype	-Plant dynamic difference equation	-Qualitative modelling techniques -Incremental qualitative analysis	Interpretation Diagnosis Monitoring	Dependency-direct tracking	VAX 11-750 XEROX 1108 AI WORKSTATION	Prolog INTERLISP AND LOOPS	160	
28	-Communication system alarm (U.S.A.-4)	Util.	Idea	-----	-----	Diagnosis	-----	MICRO VAX	ART	several hundreds	
29	-Sequential events in major intertie substations (U.S.A.-5)	Util.	Idea	-Sequential events processing	-----	Monitiring	-----	MICRO VAX	-----	-----	
30	-Breaker and relay status in control center (U.S.A.-6)	Inst.	Prototype	-----	-----	Control	Backtracking of Prolog Depth first search	VAX 11/780	Prolog		
31	-Filtering and ranking of alarms (U.S.A.-10)	Manu.	Debugged Program	-----	-----	Interpretation Diagnosis	Mixed chaining	CYBER	LISP PASCAL	300	
32	-Causes for the alarm and recommendation of corrective action (U.S.A.-14)	Util.	Idea Prototype	-----	-----	Interpretation Diagnosis Guidance Monitoring	-----	VAX 11/780	LISP FORTRAN	200	

(continued)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background conventional	AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
33	-Fault identification in a substation (Switzerland-2)	Inst.	Prototype	-Graph search	-----	Diagnosis Guidance Education Design	Backtracking	Apollo DN3000	PROLOG	100	
34	-Alarm processor at national control center (Ireland-1)	Util.	Idea	-----	-----	Monitoring	Not yet developed	VAX	-----	-----	
35	-Alarm filtering and interpretation (R.S.A.-1)	Manu.	Idea	-----	-----	Interpretation Monitoring	Mixed chaining	IBM PC environment	LISP C Unix and lex		
	<Contingency Evaluation>										
35	-Contingency analysis (Denmark-1)	Util./Univ.	Idea (Prototype)	-----	-----	Interpretation Diagnosis Guidance Monitoring	Not yet decided	HP-Vectra	Turbo-Prolog Turbo-Pascal Assembler	-----	
37	-Contingency analysis -Reliability assessment (Norway-1)	Inst.	Prototype	-SCADA System -State Estimation -Optimal power flow -Sensitivity	-World representation -Object-oriented Programming	Education Prediction Planning Design	Mixed chaining World model Object-oriented representation	SYMBOLICS 3620 VAX	Common LISP KEE	-----	
38	-Identification of weak areas / boundaries -Contingency selection (U.K.-1)	Univ.	Idea	-Alarm filtering and ranking -Power flow analysis -Graph theory	-----	Guidance Planning	Mixed chaining Generate-and-test	MICRO VAX/VMS	POPLOG	-----	
39	-Advice on errors or system weak points (U.K.-4)	Util./Inst.	Prototype	-Alarm filtering and ranking -Power flow analysis	-----	Validation	Forward chaining	IBM 370		-----	
40	-Contingency analysis and remedial action for security enhancement (U.S.A.-12)	Inst./Util.	Field Test	-Linear programming -Dual and Primal algorithm -Decoupled power flow technique -ELD	-----	Guidance Prediction Planning Control	State estimation	VAX 11/780 RM80,RA81,TU77, VT100 AYDIN-5217 CYBER 830	Common LISP DCL(Digital Common Language)	-----	
41	-Contingency analysis and emergency control (Switzerland-1)	Inst.	Idea	-----	-Pattern Recog.	Interpretation Monitoring	Backtracking	Apollo DN3000	Prolog	-----	
42	-Monitoring and control of stability constrainted power systems (Canada-2)	Util.	Practical use Release	-----	-Pattern Recog.	Monitoring Control	Forward chaining	UNIVAC 1180	Fortran	100000	

Table 7-2 (3) Summary of Expert System Projects

<Category: Control (1/3) > (No. 6)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background: conventional	Theoritical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
	<Normal Control>										
43	-Computer aided decision on network topology (France-1)	Util.	Prototype	-----	-Meta Knowledge	Guidance	Production rules Forward chaining Meta-knowledge	IBM 3090	ALOUETTE	100	
44	-State Estimation (Norway-1)	Inst.	Prototype	-State estimation -Optimal power flow -Sensitivity -Reactive Power Control	-World representation	Education Prediction Planning Design	Mixed chaining World model Object-oriented representation	SYMBOLICS 3620 VAX	Common LISP KEE	-----	
45	-Short term load forecasting (U.K.-1)	Univ.	Idea	-Optimal power flow -Sensitivity -Reactive power control -Graph theory	-Logic programming and Logic rules	Guigance Planning	Generate-and-test Heuristic-guided search Mixed chaining	MICRO VAX/VMS	POPLOG	100	
46	-Short term load forecasting (U.S.A.-7)	Inst.	Practical Use	-Load forecasting -Statistical analysis	-----	Prediction	Forward chaining	IBM-RT PC IBM-PC AT	Extended Fortran Langage (EFL) C BASIC	100~ 150	
47	-Evaluation of power system stability (U.S.A.-3)	Util.	Idea	-Voltage instability index	-----	Prediction	-----	-----	-----	-----	
48	-Voltage and VAR dispatch (U.S.A.-6)	Inst.	Prototype	-----	-Back tracking -Prolog -Depth first search	Control	Backtracking of Prolog Depth first search	VAX 11/780	Prolog		
49	-Advise in real time operation (U.S.A.-11)	Util.	Prototype	-----	-Procedural chaining	Guidance	Backward chaining Production rules Procedural reasoning	MICRO VAX II/VMS	PASCAL C	-----	
50	-Economic dispatch (U.S.A.-23)	Inst.	Field Test	-ELD -Decoupled power flow technique -LP	-----	Guidance Prediction Planning Control	-----	VAX 11/780 RM80,RA81,TU77, VT100 AYDIN-5217 CYBER 830	FORTRAN DCL(Digital Command Language)	-----	
51	-Decision-making of voltage/Var control (U.S.A.-15)	Univ.	Debugged Program	-Voltage and Reactive power control -Linearized analysis -Sensitivity	-----	Control	Forward chaining	MICRO VAX II	OPS83	75	

(continued)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background: conventional	Theoritical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
52	·On-line dynamic ELD for power plants (Japan-13)	Univ.	Idea	·Equal incremental fuel cost law ·Dynamic ELD ·NLP ·Dual and Primal algorithm ·State space representation of control status	-----	Monitoring Prediction Control	Production rules	MITSUBISHI MX-3000 NEC PC-9801	FORTRAN Prolog-KABA MS-DOS	5	
53	·Security assessment and control in alert states (Japan-15)	Univ.	Prototype	·Mixed integer programming ·Security index	·Pattern Recog. ·Feature extraction	Monitoring Prediction Control	Mixed chaining Criteria frame	NEC PC-9801	COMEX FORTRAN	15 (For each node)	
	<Emergency Control>										
54	·Remedial action (Denmark-1)	Util./Univ.	Idea (Prototype)	-----	-----	Interpretation Diagnosis Guidance Monitoring	Not yet decided	HP-Vectra	Turbo-Prolog Turbo-Pascal Assembler		
55	·Corrective action to prevent voltage collapse (U.S.A.-3)	Util.	Idea	-----	-----	Prediction	-----	-----	-----	-----	
56	·Selection of reactive power devices (U.S.A.-15)	Univ.	Debugged Program	·Voltage and Reactive power control	-----	Control	Forward chaining	MICRIO VAX II	OPS83	75	
57	·Countermeasures to ensure system security (Japan-16)	Univ.	Debugged Program	-----	·Certainty factors ·Semantic network by frame model	Guidance	Mixed chaining Semantic network	FM16β	CC-LISP ESHELL-FM	50	
	<Restorative Control>										
58	·System restoration (Denmark-1)	Util./Univ.	Idea (Prototype)	-----	-----	Interpretation Diagnosis Guidance Monitoring	Not yet decided	HP-Vectra	Turbo-Prolog Turbo-Pascal Assembler	-----	
59	·Restoration of trank lines ·Restoration procedure planning and guidance (Japan-2)	Util./Manu.	Prototype	-----	-----	Guidance	Production rules	Apollo DN-580	OPS83 FORTRAN77	200	
60	·Restorative procedure from overload and blackout (Japan-5)	Util./Manu.	Idea	-----	-----	Guidance	Production rules	Apollo DN-580	OPS83 FORTRAN77	200	

(continued)

	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background conventional	Theoritical Background AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
61	-Retoration guidance under emergency states (Japan-8)	Util./Manu.	Field Test	-----	-----	Guidance	Forward chaining	TOSBAC-DS600/80 super minicomputer	Prolog special purpose shell	200	
62	-Network restoration (Netherlands-2)	Manu./Univ.	Some ideas have already been tested	-----	-Decision analysis and search method	-----	Inference of Prolog	Apollo DN3000	POPLOG	50	
63	-Relay auto-recloser in system restoration (U.S.A.-13)	Util.	Practical Use	-----	-----	Monitoring Control	-----	1787 Mini computer	Assembler-1700	11	
64	-Customer restoration procedure (U.S.A.-16)	Univ./Inst.	Being implemented in PSPL	-----	-Decision analysis and search method	Diagnosis Planning	Forward chaining	MICRO VAX II	OPS83	300	
65	-Restoration of area load following an outage (U.S.A.-17)	Univ.	Prototype	-Group and Zone restoration sequence -Switching actions	-----	Planning	Mixed chaining	IBM 4341 IBM PC	Prolog/VM Turbo Prolog	180	
66	-Switching planning after disturbances (Finland-3)	Util.	Idea	-----	-----	Guidance Education Planning Checking	Production rules	VAX SYMBOLICS	-----	-----	
67	-Switching operation in a substation (Switzerland-2)	Inst.	Idea/ Prototype	-Graph theory	-----	Diagnosis Guidance Education Design	Backtracking	Apollo DM3000	PROLOG	100	
68	-Restoration from a deenergised power system (Sweden-1)	Inst.	Idea Prototype	-combinatorial optimization	-----	Planning Guidance Control	Mixed chaining Production rules	VAX(Epitool) SYMBOLICS(Kee)	Epitool Kee	30	

(continued)

Table 7-2 (4) Summary of Expert System Projects

<Category: System Analysis (1/2) > (No. 8)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background: conventional	Theoritical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
	<Static Analysis>										
69	-Load flow engine (Italy-1)	Util.	Idea	-Load flow analysis	-Load flow engine	Planning	To be selected	PC XT/AT Apollo DN660 DN3000		-----	
70	-Improvement in load flow planning (Japan-9)	Manu.	Practical Use	-Load flow analysis	-Load flow engine	Planning	Mixed chaining	Apollo DN Series MITSUBISHI EVA-MN Series	Prolog	100	
71	-Evaluation of system state and determination of remedial measures (Japan-10)	Manu.	Field Test	-load flow analysis	-----	Planning Design	Mixed chaining Frame	VAX SYMBOLICS	LISP FORTRAN KEE	150	
72	-Interactive power system analysis using conventional software (Japan-11)	Manu.	Practical Use	-----	-----	Planning	Production rules Frame	EWS.(E-33 HITACHI) workstation	Prolog C FORTRAN Eureka II	200~ (MAX 2000)	
73	-MVar and MV stability indices (Japan-14)	Univ.	Idea	-MV stability index -MVar stability index	-----	Monitoring	Production rules	HITACHI HITAC M280H MITSUBISI MELCOM 70 MX-3000	FORTRAN	10 (Major rules)	
74	-On-line Operation and control and security assessment (Norway-1)	Inst.	Prototype	-SCADA system	-load flow engine -World representation -Object-oriented programming	Education Prediction Planning Design	Mixed chaining World model Object-oriented representation	SYMBOLICS 3620 VAX	Common LISP KEE	-----	
75	-Validation of system models (U.K.-4)	Util.	Prototype	-load flow analysis	-----	Validation	Forward chaining	IBM 370	IBM main frame shell ESE/VM	-----	
76	-Analysis of disturbance information (Finland-1)	Util.	Idea	-----	-----	Diagnosis	Frame Production rules	IBM AT/E on clone	-----		
77	-Security analysis based on knowledge acquired from past history of the system (Switzerland-1)	Inst.	Idea	-----	-Pattern Recog.	Interpretation Monitoring	Backtracking	Apollo DN3000	Prolog	-----	
78	-Decision table generation for security monitoring (Canada-3)	Util.	Idea	-Stability analysis -Decision theory	-----	Interpretation	undetermined	undetermined -possibly VAX	undetermined -possibly Prolog and Fortran	undetermined	
79	-Intelligent load flow (Canada-6)	Util.	Idea	-----	-----	Education Planning	-----	-----	-----	≒100	

<Category: System Analysis (2/2) >

(No. 9)

	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoritical Background: conventional	Theoritical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
80	-Relay modelling interface (Canada-7)	Util.	Prototype	-----	-----	Planning Design Control	-----	Prime computer	C	≒15	
	<Dynamic Analysis>										
81	-MV stability index based on parametric resonance (Japan-14)	Univ.	Idea	-----	-----	Monitoring	-----	HITACHI HITAC M280H MITSUBISHI MELCOM 70 MX-3000	FORTRAN	10 (Major rules)	

Table 7-2 (5) Summary of Expert System Projects

<Category: Education & Simulator (1/1) > (No. 10)

No.	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoretical Background: conventional	Theoretical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
	<C.A.I.>										
82	-Automatic production of training scenarios (U.S.A.-8)	Manu.	Prototype	-operator training simulator -Automatic production of training scenarios -power flow analysis -Transient stability analysis	-Heuristic search -Goal creation	Education-Training	Forward chaining Heuristic search Goal creation	SYMBOLICS CYBER	LISP	~100	
	<Simulator>										
83	-Evaluation of state and choice of actions (Norway-1)	Inst.	Prototype	-----	-----	Education Prediction Planning Design	Mixed chaining World model Object-oriented representation	SYMBOLICS 3620 VAX	Common LISP KEE	-----	
84	-Training management system applications (Japan-17)	Univ.	Prototype	-----	-----	Education	Forward chaining Event driven method	FACOM M-780	LISP ESHELL	30	

Table 7-2 (6) Summary of Expert System Projects

<Category: Others (1/1) > (No. 11)

	Area of Application (ID. No.)	Organisations/ Institutions	Stage of Development	Theoretical Background: conventional	Theoretical Background: AI-oriented	Functions	Inference/ Control/Scheme	Hardware Environment	Software Environment	Rule Size	Remarks
85	·Monitoring and diagnosis of water pollution in thermal power plants (Italy-4)	Util.	Field Test	-----	·Representation of procedural knowledge	Interpretation Diagnosis Monitoring Guidance	Forward chaining Production rules Event graphs	SUN-2 workstation	Franz LISP	50	
86	·Identification and predicting of harmonic-related problems (U.S.A.-1)	Inst./Univ.	Prototype	·Impedance network model ·Numerical number crunching algorithm	-----	Diagnosis Prediction	Mixed chaining	IBM PC-AT	Micro Data Base System's GURU	100	
87	·Consumer reaction to pricing alternatives (U.S.A.-7)	Inst.	Practical Use	·Load forecasting ·Statistical analysis	-----	Prediction	Forward chaining	IBM-RT PC IBM-PC AT	Extended Fortran Langage (EFL) C BASIC	100~ 150	
88	·General purpose expert system shell for EMS applications (U.S.A.-9)	Manu.	Debugged Program	·Energy management system	·Mixed chaining		Mixed chaining	CYBER SERIES	LISP PASCAL	-----	
89	·Energy management system applications (U.S.A.-18)	Inst.	Idea	-----	·Object-oriented model	Interpretation Diagnosis Guidance Monitoring Planning Design Control	Forward chaining	VAX-750 Unix BSD 4.3	C++ Objective C	-----	
90	·Analysis of the cause of application programs aborts (Canada-5)	Util.	Prototype	------	-----	Diagnosis Education	Mixed chaining	IBM PC	VP-Expert	150 (estimated)	

Appendix <A>

Questionnaire on the Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques

Appendix <B>

Current Status of Expert Systems Development in Power Systems (Format A)

Appendix <C>

Project Objectives and Application Area of Expert Systems

Appendix <D>

Theoretical Background in Expert System Development in Power System

Appendix <E>

Recognized Needs for Expert Systems Applied to the Power System

Appendix <F>

Outline of Expert System Projects (supplement to Format A)

Appendix <G>

List of References Quoted in Replies to the Questionnaire

Appendix <H>

Glossary of Expert System Terminology

cigré

Appendix <A>

Questionnaire on the Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques

cigré

Appendix <A> Questionnaire on the Present Status and the Perspective of Expert Systems on Power System Analysis and Techniques

Questionnaire
on
The Present Status and the Perspective
of
Expert Systems on Power System Analysis and Techniques

TF07 WG02 SC-38

HOW TO FILL IN FORMAT A

(A) Current Status of Expert Systems Development in Power Systems

Please summarize the expert system(s) applied to the power system, developed or being developed, using the attached Format A. Please use one sheet for each expert system. A detailed description of the inquiry items in Format A is given below:

Note : Though nuclear power plant facility diagnosis is out of the scope of the questionnaire, it may be included if it has relevancy with planning, operation and control of power systems.

1.Project Information

(1)Name of Expert System and/or Project:
- The name of an expert system or a project, or
- An appropriate expression which best represents the system concept where a specific name has not been given.

(2)Intended Functions or Project Objectives
- The subject(s) that the expert system intends to solve, those targeted from among the power system problems.

(3)Name(s) of the Institution(s)/Organization(s) and the Country Name:

- The name(s) of the institutions, laboratories, companies and/or universities which are engaged in the development of the expert system. Specify up to three such major institutions if more than four institutions are engaged.
- The country name where the major part of the system is being developed.

(4)Stage of Development

- Identify the relevant development stage of the expert system from among the choices shown.
- Development time (from idea to present stage), or
- The year the system development was completed,
- The target year the system development is planned to be completed (practical use or release) if it is beyond the year 1987.

2.Problem Area and Solution Method

(1)Application Area:

- System application area(s). Refer, for example, to G.B.Sheble's classification. See the attached paper IEEE 86 SM 335-4, see page Q-7/7.

(2)Theoretical Background:

- Please specify concepts, methodologies, models and/or tools from the viewpoint of the power system, that have been employed to solve the problem.

(3)Outline:

- Give a description of the system in about 700 words. Please refer to the system response time if available.

3.Expert System Information

(1)Function Classification:

- Indicate the relevant function(s) designed or targeted from the multiple choices shown in Format A.

- Please give other function(s) if they do not fall into the choices given.

(2)Inference Mechanism/Control Scheme:

- The inference mechanism and the control scheme that the expert system employs.

(3)Languages/Tools/Shells:

- The languages, tools or shells used in the system development.

(4)Computer Hardware:

- Name(s) of the computer hardware used for the system development. Hardware specification should include model name, indicative performance, main memory size and the computer class (mainframe machine, microcomputer, workstation, superminicomputer, minicomputer).

(5)No. of Rules and Knowledge Base Size:

- The number of rules and the size of knowledge base that the system has.
- The limits the system can handle.
- Knowledge expression method.

(6)Problems in Development and Solution:

- Problems encountered during system development,
- Improvements/enhancements planned for the future.
- Others (e.g. comments on suitability of software).

4.Perspective for Development

(1)Perspective for Development:

- To show which problem area the system is planned for and/or intended to be applied to with the system's growth(expansion),
- Necessary improvements/enhancements.

Documents/References:

- Please cite the names of the relevant reports, papers, manuals and the documents available.

Remarks:

- Please use one format sheet (Format A) per one expert system.
- Please attach copies of available documents cited in the document section in Format A in your return envelope.

*** End of Format A ***

Notes: Please write down your replies (format free) for questions (B) to (E) on separate sheets.

QUESTIONS B

(B) The Recognized Needs for Expert Systems as Applied to the Power System

Please briefly enumerate under the appropriate sub-sections the problems currently identified in all aspects of power system planning, operation, control, analysis and education (training) vis-a-vis potential expert system applications and particular attributes.

B-1 Please indicate generally the recognized problems in all aspects of power system planning, operation, control, analysis and education (training) vis-a-vis identified obstacles that hinder solution.

B-2 To resolve the problems raised in item B-1, please indicate the functions to be furnished with an expert system in the appropriate areas such as,

- power apparatus & equipment diagnosis & repair instruction
- power system monitoring & alarming
- restorative control

- emergency control
- substation layout
- operator training
- others

B-3 Please outline your future project plans and indicate relevant reports, if possible.

QUESTIONS C

(C) Views on Future Expert Systems

Please give views under the appropriate sub-sections on the effectiveness/practicality of expert systems, per se, and on their questions and limitations. What do you foresee as the likely interactions and/or relationships between expert systems and the human operator?

C-1 Views on the effectiveness/practicability of expert systems

C-2 The likely interactions between the expert system and the human operator, and the roles and functions shared by them.

QUESTIONS D

(D) Approaches to be Used in the Future Expert System Development

Please indicate the applicable methods (e.g. Fault Tree Analysis, logistics, pattern recognition, fuzzy set theory) deemed most effective in approaching power system problems. Also indicate recommended approaches and methods applicable to the specific problem areas of power systems.

QUESTIONS E

(E) Future Environment for Expert System Development

Please indicate your views on suitability of software and hardware environments for the future expert system development in power system analysis and techniques.

Also indicate a typical combination of the system software with supporting tools (e.g. graphics, editor, data base management), running on an appropriate hardware configuration, which is deemed most desirable for the expert system development environment.

If you have any questions on this questionnaire, please contact.

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Tokyo 160 Japan.

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FAX : 03-205-2615

Please return your reply to the same address no later than May 15, 1987.

Extracted from G.B.Sheble's Paper(IEEE 86 SM 335-4)

Artificial Intelligence may be the next major enhancement for the functions of an Energy Management System. Some of the potential applications and expected improvements include:

- o Contingency Analysis -- a more robust selection of cases to be studied, an evaluation of the solution accuracy of using a steady state algorithm instead of a dynamic stability algorithm, and a more concise presentation of the solution results.

- o Alarm Processing -- a more concise statement of the problem and to provide a priority to the importance of each alarm.

- o State Estimation -- a more complete method of bad data and of biased data identification, an alternative method of tap estimation, and to adapt the bus section load models of conforming and of nonconforming loads.

- o External Model Estimation -- the buses which should be reduced, the pseudomeasurements which are the best indication of the state of other power systems, and an analysis of the present state of the total power system.

- o Remedial Action -- the controls which should be considered, the control order (generation or tap position changes), and the controls which should be used after the next contingency.

- o Automatic Generation Control -- selection of regulation participation factors for units under control, unit not responding logic, and automatic tuning of unit and system parameters.

- o Economic Dispatch -- generation of energy conversion curves, selection of curves, more complete handling of forbidden unit operating regions and valve points.

- o Unit Commitment -- decision of when to re-execute the algorithm, selection of algorithm (e.g., full, sequential or truncated dynamic programming), selection of constraints to be enforced, and models to be used (e.g., linear, quadratic, or piece-wise linear energy conversion curves).

- o Short Term Load Forecast -- selection of base curve, selection of weather variables, selection of model parameters (e.g., degree of differencing, number of components in a Multiple Autoregressive Moving Average process), and estimation of the impact of exogenous variables (e.g., Nielson ratings).

- o Interchange Evaluation -- selection of possible schedules to be evaluated, pricing of potential schedules, and execution of an evaluation algorithm (e.g., Economy A or B).

- o Dispatcher's Optimal Power Flow -- selection of control variables to use, selection of control variable ordering, and selection of constraints to enforce.

- o Contingency Analysis -- selection of contingencies to be evaluated, selection of equipment loadings to be checked, selection of contingency cases for Remedial Action.

- o System Restoration -- selection of cranking path(s), selection of load restoration, selection of generation restarting schedule.

- o Contingency Relay Arming -- selection of relays to be armed or disarmed, selection of key system parameters (equipment status) to be used as triggers, selection of equipment(s) to be removed for each contingency.

- o Energy Cost Reconstruction — selection of costing algorithm, selection of unit(s) to be used for costing, selection of transaction schedules to be used for costing, and selection of transmission loss model for costing.

- o Load Shedding -- selection of distribution feeders to open which will most likely remedy system overload or voltage violation.

- o Load Management -- selection of load curtailment strategy based upon expected load and weather trends.

- o Trouble Call Analysis -- faster identification of outaged equipment based upon equipment reliability, weather conditions and load demand in addition to customer complaints.

All of the above are interesting topics for future papers. The important issue is why should Artificial Intelligence be used. A primary reason is that a more complete understanding of why we operate as we presently do will cause improvements even if no Expert Systems are built. Another reason is that power systems are becoming more complex and difficult to operate. There is also the need to continually search for improved economic operation.

Appendix <B>

Current Status of Expert Systems Development in Power Systems (Format A)

Table <B-1> ~ <B-40>

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Appendix

Appendix <B> Current Status of Expert Systems Development in Power Systems (Format A)

Table <B-1> Current Status of Expert Systems Development in Power Systems

[Country: Canada] (Format A)

ITEMS / ID. No. of Answers	Canada-1	Canada-2
<1.Project Information>		
(1)Name of Expert System and/or Project	ICQ Short-Term Study Mode	System Security Monitoring
(2)Intended Functions or Project Objectives	Development of short-term marketing strategy for interchange transactions.	To help the Control System Supervisors monitor and control a stability constrained power system.
(3)Organisation / Country	Ontario Hydro / Canada	Ontario Hydro / Canada
(4)Stage of Development	Idea	Practical Use, Release
<2.Problem Area and Solution Method>		
(1)Area of Application	Interchange evaluation (ICQ - Interconnection Cost Quotation)	On-Line Control of Power Systems
(2)Theoretical Background	Interchange marketing staff correlate anticipated domestic and foreign resouces with economic trends to determine profitable marketing strategies. Assessment is largely heuristic.	Off-line studies are used to produce operating limits for different power system conditions. Pattern recognition is used to match the current power system conditions to one of the studied conditions and extract the appropriate limits.
<3.Expert System Information>		
(1)Function Classification	Guidance, Planning(Operation Pranning)	Monitoring, Control
(2)Inference Mechanism Control Scheme	Undetermined	Forward chaining
(3)Languages / Tools / Shells	Undetermined - possibly VP·Expert	Fortran
(4)Computer Hardware	Undetermined - likely PC	UNIVAC 1180
(5)No. of Rules & Knowledge Base Size	Undetermined	100,000 +
(6)Problems in Development and Solution	Undetermined - possibly interface between expert system and conventional software.	Large number of rules
<4.Perspective for Development>		
(1)Perspective for Development	Undetermined	May rewrite it using Lisp or Prolog
<5.Documents & References>		

Table <B-2> Current Status of Expert Systems Development in Power Systems

[Country: Canada] (Format A)

ITEMS / ID. No. of Answers	Canada-3	Canada-4
<1.Project Information>		
(1)Name of Expert System and/or Project	SYSM Decision Table Generation	Bruce LGR Diagnostics
(2)Intended Functions or Project Objectives	Generation of decision tables for use in the Ontario Hydro System Security Monitoring function	Help diagnose hardware problems in the Bruce Load and Generation Rejection Supervisory Control System and recommend alternative actions until the hardware problems are resolved.
(3)Organisation / Country	Ontario Hydro / Canada	Ontario Hydro / Canada
(4)Stage of Development	Idea	Other (Rejected)
<2.Problem Area and Solution Method>		
(1)Area of Application	Power System Security	Operational aid
(2)Theoretical Background	Outputs from power system stability studies are analyzed and interpreted by engineering staff. Software technologists then translate the results into decision tables using conventional software(Fortran).	
<3.Expert System Information>		
(1)Function Classification	Interpretation	Diagnosis, Guidance
(2)Inference Mechanism Control Scheme	Undetermined	- Rule based - Frame based
(3)Languages / Tools / Shells	Undetermined - possibly Prolog	KEE
(4)Computer Hardware	Undetermined - possibly VAX	TI Explorer
(5)No. of Rules & Knowledge Base Size	Undetermined	
(6)Problems in Development and Solution	Cooperation of experts not easily forthcoming	The proposed solution could not handle the volume of data, the Explorer system could not be integrated into the EMS, and insufficient expertise exists to make a useful system.
<4.Perspective for Development>		
(1)Perspective for Development	Undetermined	Development of this expert system was rejected.
<5.Documents & References>		

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Table <B-3>Current Status of Expert Systems Development in Power Systems

[Country: Canada] (Format A)

ITEMS / ID. No. of Answers	Canada-5	Canada-6
<1.Project Information> (1)Name of Expert System and/or Project	Program Dump Analysis Expert System	Intelligent Load Flow
(2)Intended Functions or Project Objectives	Analysis of the cause of power system applications program aborts.	The objective is to provide both an expert and novice user with a friendly working environment
(3)Organisation / Country	Ontario Hydro / Canada	Hydro-Québec,Vice-président Planification des équipements, Direction Transport, Division Systèmes d'analyse de réseaux / Canada, Québec
(4)Stage of Development	Prototype	Idea
<2.Problem Area and Solution Method> (1)Area of Application	Development and maintenance of application programs.	Planning & Network analysis
(2)Theoretical Background		
<3.Expert System Information> (1)Function Classification	Diagnosis, Education	Education, Planning
(2)Inference Mechanism Control Scheme	Forward and backward chaining / rule based	----
(3)Languages / Tools / Shells	VP - Expert	----
(4)Computer Hardware	IBM PC and compatibles	----
(5)No. of Rules & Knowledge Base Size	150 rules (estimated)	≃100
(6)Problems in Development and Solution	N/A	
<4.Perspective for Development> (1)Perspective for Development	A small prototype was developed in August 1987. Full analysis of the problem space and expansion of the prototype is planned for late 1987. Production version and release by September 1988.	
<5.Documents & References>		

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Table <B-4> Current Status of Expert Systems Development in Power Systems

[Country: Canada] (Format A)

ITEMS / ID. No. of Answers	Canada-7	
<1.Project Information>		
(1)Name of Expert System and/or Project	Expert LIKE Relay Modeling Interface	
(2)Intended Functions or Project Objectives	Provide easy way for users of stability program to build new models of Relay	
(3)Organisation / Country	Hydro-Québec, Vice-président Planification des équipements, Direction Transport, Division Systèmes d'analyse de réseaux / Canada, Québec	
(4)Stage of Development	Portotype	
<2.Problem Area and Solution Method> (1)Area of Application	Network Analysis / Planning	
(2)Theoretical Background		
<3.Expert System Information> (1)Function Classification	Planning, Design, Control	
(2)Inference Mechanism Control Scheme		
(3)Languages / Tools / Shells	C	
(4)Computer Hardware	Prime Computer	
(5)No. of Rules & Knowledge Base Size	≃100	
(6)Problems in Development and Solution		
<4.Perspective for Development> (1)Perspective for Development		
<5.Documents & References>		

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Table <B-5> Current Status of Expert Systems Development in Power Systems

Country: Denmark (Format A)

ITEMS / ID. No. of Answers	Denmark-1	
<1.Project Information>		
(1)Name of Expert System and/or Project	Application of KBS to planning and daily operation of Power Utilities	
(2)Intended Functions or Project Objectives	The project will investigate and identify the areas in which it is possible and desireable to use KBS's.	
(3)Organisation / Country	ELKRAFT Power Company Ltd. and Power Dept. of Tech. University of Denmark in cooperation.	
(4)Stage of Development	Idea / (prototype)	
<2.Problem Area and Solution Method>		
(1)Area of Application	Alarm processing, Remedial Action, Contingency Analysis and System Restoration.	
(2)Theoretical Background	The existing set of written instructions and operator experience/knowledge.	
<3.Expert System Information>		
(1)Function Classification	Interpretation / Diagnosis / Guidance / Monitoring	
(2)Inference Mechanism Control Scheme	Not yet decided.	
(3)Languages / Tools / Shells	Turbo-Prolog: Compiler (BORLAND - Danish developed) Turbo-Pascal, assembler	
(4)Computer Hardware	HP-Vectra 640 kb RAM, 80286 and 80287 processors	
(5)No. of Rules & Knowledge Base Size	System(s) not implemented yet.	
(6)Problems in Development and Solution	Using a PC makes testing in the control room difficult because the m.m.i. is limited to the possibilities of the PC, which is very unlike the interface normally used in the control room.	
<4.Perspective for Development>		
(1)Perspective for Development	Running prototype within this summer.	
<5.Documents & References>	de-1, de-2(1987)	

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Table <B-6> Current Status of Expert Systems Development in Power Systems

Country: Finland (Format A)

ITEMS / ID. No. of Answers	Finland-1	Finland-2
<1.Project Information>		
(1)Name of Expert System and/or Project	System for the analysis of disturbance information	An Expert System to Support operators in power system operations
(2)Intended Functions or Project Objectives	To get experience of developing an expert system wholly in microcomputer environment and also get experience of "hybridtools" (knowledge can be represented with frames and rules) for microcomputers	- Event diagnosis - Switching planning in the normal operation and after disturbances
(3)Organisation / Country	Imatran Voima Oy / Finland	Technical Research Centre of Finland (electrical engineering laboratory, Helsinki Energy Board Financing The ministery for trade and Industory)
(4)Stage of Development	Idea	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Alarm processing	- Network operation - Control centre operations
(2)Theoretical Background	Rules to represent the knowledge and heuristics of control-staff and frames to represent the objects of power network.	- computer programs for network operation planning (power flow, load forecast)
<3.Expert System Information>		
(1)Function Classification	Diagnosis	Monitoring / planning / Control
(2)Inference Mechanism Control Scheme	Both frames and rules	forward and backward reasoning
(3)Languages / Tools / Shells	Not selected yet	- Common LISP, FORTRAN - KEE
(4)Computer Hardware	Microcomputer (IBM AT/E on clone)	- Symbolics 3645 - VAX 11/750
(5)No. of Rules & Knowledge Base Size	----	- 5000 rules - LISP - functions (3000 - 5000 program lines)
(6)Problems in Development and Solution	----	- data transmission and interface with external computers - KEE (processor not efficient enough) - the unreliable function of LISP - computer - updating of the operating system (LISP environment)
<4.Perspective for Development>		
(1)Perspective for Development	----	----
<5.Documents & References>	----	----

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Table <B-7>Current Status of Expert Systems Development in Power Systems

Country: Finland (Format A)

ITEMS / ID. No. of Answers	Finland-3	
<1.Project Information>		
(1)Name of Expert System and/or Project	An expert system to support operators in planning and checking of network switching operations.	
(2)Intended Functions or Project Objectives	To get experience about expert systems, training of operators specification of support systems for district control rooms, to improve quality of switching plans.	
(3)Organisation / Country	Imatran Voima Oy / Finland	
(4)Stage of Development	Idea	
<2.Problem Area and Solution Method>		
(1)Area of Application	Operation planning	
(2)Theoretical Background	Logic rules to perform switching sequence in substations (switchings of disconnection and breakers)	
<3.Expert System Information>		
(1)Function Classification	Guaidance / Education / Planning / Checking	
(2)Inference Mechanism Control Scheme	Rules	
(3)Languages / Tools / Shells	Not yet selected	
(4)Computer Hardware	VAX or Symbolics	
(5)No. of Rules & Knowledge Base Size	Not known	
(6)Problems in Development and Solution	----	
<4.Perspective for Development>		
(1)Perspective for Development	----	
<5.Documents & References>	----	

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Table <B-8>Current Status of Expert Systems Development in Power Systems

[Country: France] (Format A)

ITEMS / ID. No. of Answers	France-1	France-2
<1.Project Information>		
(1)Name of Expert System and/or Project	CASTOR	SEPT
(2)Intended Functions or Project Objectives	CASTOR : Conception ASsitee de la TOpologie du Reseau Computer aided decision on network topology	SEPT : Surveillance des Equipments dans un Poste a tres haute Tention Monitoring of equipments in an Electric High voltage substation
(3)Organisation / Country	Electricite de France - DER/SER(FRANCE)	Electricite de France - DER, Service Etudes de Reseaux(FRANCE)
(4)Stage of Development	Prototype	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Short-term planning and real-time operations	Control equipments and relays monitoring
(2)Theoretical Background	Objects and frames	Entities in the substation as objects and semantic networks Relations between entities as frames, scripts and temporal logic.
<3.Expert System Information>		
(1)Function Classification	Guidance	Interpretation, Diagnosis, Monitoring
(2)Inference Mechanism Control Scheme	Production rules Forward chaining, meta knowledges	- Production rules formalism - Forward chaining with strategies and meta-knowledges
(3)Languages / Tools / Shells	ALOUETTE(EDF)	ALOUETTE (EDF product)
(4)Computer Hardware	IBM 3090	mainframe IBM 3090 (VAX and IBM PC-AT in a further stage) memory size : about 700 kB
(5)No. of Rules & Knowledge Base Size	100 rules and Fortran subroutines (2000 lines)	370 rules - about 600 kB for facts and rules.
(6)Problems in Development and Solution	Include algolithmic procedures into a knowledge based system	Although the system has been developed in the production rules formalism, there is an evident need for a mixed formalism.
<4.Perspective for Development>		
(1)Perspective for Development	New tools for short-term planning and on line operations	- Modelisation of a larger variety of equipments and protection systems. - Implementation in all substations. - Integration in the hierarchical structure of the set of substations.
<5.Documents & References>	----	fr-1(1987), fr-2(1988)

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Table <B-9> Current Status of Expert Systems Development in Power Systems

Country:France (Format A)

ITEMS / ID. No. of Answers	France-3
<1.Project Information>	
(1)Name of Expert System and/or Project	ALOUETTE EXPERT SYSTEM IN FRENCH REGIONAL CONTROL CENTRE
(2)Intended Functions or Project Objectives	SUPPLY A DIAGNOSIS IN CASE OF ELECTRICAL NETWORK FAULT
(3)Organisation / Country	ELECTRICITE DE FRANCE - CGEE ALSTHOM / FRANCE (Service des Mouvements d'energie)
(4)Stage of Development	Debugged program - Rule implementation
<2.Problem Area and Solution Method> (1)Area of Application	ALARM PROCESSING
(2)Theoretical Background	METHODOLOGY : ANALYSIS OF DIFFERENT FAULT TRIPPINGS, ACCORDING TO THE PROTECTION SCHEEMS
<3.Expert System Information> (1)Function Classification	DIAGNOSIS
(2)Inference Mechanism Control Scheme	The inference engine works in forward chaining with a knowledge representation based on production rules in first order logic and facts written as triplets (object, relation, object). According to facts in the base, a value is affected to each rule. The first rule to be choosen is the less valued.
(3)Languages / Tools / Shells	Inference language : PASCAL Application language : FORTRAN Production rules : FRENCH TOOL FAULT : SIMULATOR USING THE EXPERT SYSTEM ITSELF FOR KNOWLEDGE BASE TEST
(4)Computer Hardware	Application : VAX 8800 Test of rules : IBM 3090
(5)No. of Rules & Knowledge Base Size	About 300 500 k Bytes
(6)Problems in Development and Solution	1 - Sharing of functions between the application and the expert system 2 - Response time of the expert system (2s expected) 3 - Production of the base of rules Inference engine already debugged at the start of the project
<4.Perspective for Development> (1)Perspective for Development	----
<5.Documents & References>	fr-3, fr-4, fr-5, fr-6

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Table <B-10>Current Status of Expert Systems Development in Power Systems

Country: F.R.G. (Format A)

ITEMS / ID. No. of Answers	F.R.G.-1	
<1.Project Information>		
(1)Name of Expert System and/or Project	Alarm Handling in Control Centre	
(2)Intended Functions or Project Objectives	diagnosing network incidents in control centre*	
(3)Organisation / Country	Energie-Versorgung Schwaben / F.R.G.	
(4)Stage of Development	prototype*	
<2.Problem Area and Solution Method>		
(1)Area of Application	diagnosing network incidents*	
(2)Theoretical Background	----	
<3.Expert System Information>		
(1)Function Classification	Diagnosis*	
(2)Inference Mechanism Control Scheme	pattern recognition*	
(3)Languages / Tools / Shells	process computer language*	
(4)Computer Hardware	process computer*	
(5)No. of Rules & Knowledge Base Size	event pattern 5 *	
(6)Problems in Development and Solution	----	
<4.Perspective for Development>		
(1)Perspective for Development	an evaluation of the extent and the location of an event*	
<5.Documents & References>	g-1(1986), g-2(1987)	

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Table <B-11>Current Status of Expert Systems Development in Power Systems

Country: Ireland (Format A)

ITEMS / ID. No. of Answers	Ireland-1	
<1.Project Information>		
(1)Name of Expert System and/or Project	Alarm Processor at National Control Centre.	
(2)Intended Functions or Project Objectives	Reduction of number of alarms presented to control centre operators and improvement of intelligibility of those presented, particularly at times of alarm flooding.	
(3)Organisation / Country	Electricity Supply Board / Ireland	
(4)Stage of Development	Idea	
<2.Problem Area and Solution Method>		
(1)Area of Application	Alarm Processing	
(2)Theoretical Background	Methodology now under study.	
<3.Expert System Information>		
(1)Function Classification	Monitoring	
(2)Inference Mechanism Control Scheme	Not Yet Developed.	
(3)Languages / Tools / Shells	None yet.	
(4)Computer Hardware	DEC VAX	
(5)No. of Rules & Knowledge Base Size	Not yet known.	
(6)Problems in Development and Solution	----	
<4.Perspective for Development>		
(1)Perspective for Development	Only first stage considered to date.	
<5.Documents & References>	----	

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Table <B-12>Current Status of Expert Systems Development in Power Systems

Country: Italy (Format A)

ITEMS / ID. No. of Answers	Italy-1	Italy-2
<1.Project Information>		
(1)Name of Expert System and/or Project	Computer Aided for Small Load-Flow	TRIAL (Terminal Resources Intelligent Allocator)
(2)Intended Functions or Project Objectives	To perform experiment on load-flow calculation on small electrical model.	Automatic configuration of the remote peripherals (RTU) controlling the substations of a power distribution network.
(3)Organisation / Country	ENEL-CREI / 1987 / ITALY	CESI, ENEL / Italy
(4)Stage of Development	Idea	Debugged Program (to be accomplished within 1987)
<2.Problem Area and Solution Method>		
(1)Area of Application	Load Flow Engine	Optimal Automatic Configuration (no match with Sheble's list)
(2)Theoretical Background	Conventinal Load Flow calculation and optimization techniques.	Representation of problem constraints; representation of heuristics for problem solving.
<3.Expert System Information>		
(1)Function Classification	Planning	Design
(2)Inference Mechanism Control Scheme	To be selected	Heuristic Rules combined with Hill Climbing Search.
(3)Languages / Tools / Shells	To choose among the more convenient Expert System Shell.	Frame-based language implemented in Common Lisp
(4)Computer Hardware	PC XT/AT, Apollo DN660 and DN3000	Sun-2 (development) and MicroVAX II (practical use)
(5)No. of Rules & Knowledge Base Size	To be defined	About 300 objects (frames) and 100 rules
(6)Problems in Development and Solution	----	The reduction of the search space through the heuristics
<4.Perspective for Development> (1)Perspective for Development	----	The system will be used to configure electronic equipment associated to electric power voltage reduction and distribution substations (about 100000 in the country). There exist different models of this equipment, and the knowledge base of the system will cover all of them.
<5.Documents & References>	----	ita-1(1986), ita-2(1984), ita-3(1984)

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Table <B-13>Current Status of Expert Systems Development in Power Systems

Country: Italy

ITEMS / No. of Answers	Italy-3	Italy-4
<1.Project Information>		
(1)Name of Expert System and/or Project	DESYAC (DEvelopment SYstem for Automated Configuring)	PROP
(2)Intended Functions or Project Objectives	Development for the solution of configuration tasks.	Monitoring, diagnosis, and control of pollution phenomena in the water cycle of a thermal power plant
(3)Organisation / Country	CESI, Quinary / Italy	CESI, ENEL / Italy
(4)Stage of Development	tested on set of meaningful real examples	Field test (development time: 4 man/year) (completion date: end 1987)
<2.Problem Area and Solution Method>		
(1)Area of Application	Interactive assistant to the configuration of an electronic equipment for power distribution stations.	Aalarm processing, remedial actions
(2)Theoretical Background	----	a) Representation of procedural knowledge b) Use of deep knowledge
<3.Expert System Information>		
(1)Function Classification	Design	Interpretation, diagnosis, monitoring, guidance
(2)Inference Mechanism Control Scheme	forward production	Forward chaining on production rules controlling chunks of procedural knowledge (Event-graphs)
(3)Languages / Tools / Shells	Franz Lisp	Franz Lisp
(4)Computer Hardware	SUN workstation	Sun-2 workstation (68010 based workstation 2 Mbyte main memory)
(5)No. of Rules & Knowledge Base Size	more than 200 rules	Event-Graph (Petri-net-like-formalism): 70 Production rules: 50 (each Event-Graph corresponds, to, on average 10 production rules).
(6)Problems in Development and Solution	The test results prove so far that allocations produced by DESYAC are as good as those produced by a high livel expert work, and in some cases, better.	Procedural representation of events and actions occurring over time. Representation and use of a model of the chemical behaviour of the water cycle. System validation required the development of a plant simulator.
<4.Perspective for Development>		
(1)Perspective for Development	Development are planned in order to supply the language with more problem oriented language statements and in order to support more complex case.	a) Installation on other fossile fired power plants considered. b) Transport on a personal computer.
<5.Documents & References>	it-4(1983), it-5(1985), it-6(1980), it-7 , it-8(1983) it-9, it-10(1981), it-11(1982), it-12(1984)	ita-13(1987), ita-14(1985), ita-15(1986), ita-16(1987)

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Table <B-14>Current Status of Expert Systems Development in Power Systems

Country: Italy (Formal A)

ITEMS / ID. No. of Answers	Italy-5	
<1.Project Information>		
(1)Name of Expert System and/or Project	TVM (Turbogenerator Vibration Monitor)	
(2)Intended Functions or Project Objectives	Interpretation of vibration, oil pressure and temperature data from the bearings of a turbo generator. Early detection and diagnosis of machine's malfunctions.	
(3)Organisation / Country	CESI / Italy	
(4)Stage of Development	Debugged Program (development time:1 year)	
<2.Problem Area and Solution Method>		
(1)Area of Application	No match	
(2)Theoretical Background	Frequence analysis of vibration	
<3.Expert System Information>		
(1)Function Classification	Diagnosis	
(2)Inference Mechanism Control Scheme	Backward chaining. Knowledge domain separated in differnt areas.	
(3)Languages / Tools / Shells	SAGE	
(4)Computer Hardware	PDP 11/23 (microcomputer, 256Kb main memory), MicroVAX II	
(5)No. of Rules & Knowledge Base Size	Production rules: n. 200	
(6)Problems in Development and Solution	Difficulty of the knowledge domain separated in different areas.	
<4.Perspective for Development>		
(1)Perspective for Development	Automatic interpretation of sensors data.	
<5.Documents & References>	ita-17(1984), ita-18(1987)	

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Table <B-15>Current Status of Expert Systems Development in Power Systems

(Country: Japan) (Format A)

ITEMS / ID. No. of Answers	Japan-1	Japan-2
<1.Project Information>		
(1)Name of Expert System and/or Project	Research and development of a practical expert system for planners of bulk power system operation	System Restoration Support System of Trunk Lines
(2)Intended Functions or Project Objectives	For versatile study including reliability and economy indispensable to system operation planning, R and D has been conducted incorporating AI technology.	Restroration Guidance - Faulted equipment detection - Restoration Planning - Restorative procedure guidance
(3)Organisation / Country	Tokyo Electric Power Co. ,Mitsubishi Electric Corp. / Japan	Tokyo Electric Power Co. ,Mitsubishi Electric Corp. / Japan
(4)Stage of Development	Prototype	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Intelligent Support System for operation planning, e.g. system structure planning, generation scheduling reactive power scheduling, system stabilization.	System restoration of trunk lines
(2)Theoretical Background	In the system operation planning,because comprehensive evaluations considering system reliability, stability and economy etc. must be performed by using many computer softwares repeatedly, it takes much time for the evaluation and judgement of the results. By furnishing guidance functions for judging analysis results, and indicating remedial measures and control actions, more effective system planning will be attained.	Analytical tools(NL programming, load-flow, etc.)
<3.Expert System Information>		
(1)Function Classification	Planning	Guidance
(2)Inference Mechanism Control Scheme	Forward chaining has been used as inference scheme. (Production type is used for knowledge representation.)	Production system
(3)Languages / Tools / Shells	Language for development···LISP	OPS83, FORTRAN77
(4)Computer Hardware	For development····workstation(stand alone) (1 MIPS, 60 MB) For practical use···mainframe machine (30 MIPS)	Apollo DN-580
(5)No. of Rules & Knowledge Base Size	Around 150 - 300 rules for each support subsystem (Prototype system)	Around 200 rules , 0.3 MB
(6)Problems in Development and Solution	Construction of deep knowledge base by building up groups of heuristic knowledge acquired from human experts as hierarchical structure.	Linkage between online data base and OPS 83
<4.Perspective for Development>		
(1)Perspective for Development	Prototype system for each subsystem in the total plan has been developed, application to the practical -scaled system is intended after testing the function and effectiveness of the developed systems.	Improvement of man machine interface (especially how to guide the restorative procedures)
<5.Documents & References>		

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Table <B-16>Current Status of Expert Systems Development in Power Systems

Country: Japan (Format A)

ITEMS / ID. No. of Answers	Japan-3	Japan-4
<1.Project Information>		
(1)Name of Expert System and/or Project	Maintenance Scheduling Support Expert System	Restoration Support Expert System of Trunk Lines
(2)Intended Functions or Project Objectives	Maintenance scheduling considering reliability and security in case of disconnection of system components.	Optimal operation planning / Restoration guidance to restore blackouts of interconnected system including trunk lines.
(3)Organisation / Country	Tokyo Electric Power Co., Toshiba Corp. / Japan	Tokyo Electric Power Co., Toshiba Corp. / Japan
(4)Stage of Development	Idea	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Planning	System Restoration
(2)Theoretical Background	Intelligent man machine interface Power system operation techniques	Power System Analysis and Operation
<3.Expert System Information>		
(1)Function Classification	Planning	Guidance
(2)Inference Mechanism Control Scheme	Combination of forward and backward chaining	- Rule-base - Frame-base - Object-base
(3)Languages / Tools / Shells	KEE	LISP / FORTRAN / KEE
(4)Computer Hardware	Symbolics 3640, Main memory 8 Mb Disc memory 380 Mb	Symbolics
(5)No. of Rules & Knowledge Base Size		400
(6)Problems in Development and Solution		Improvement of processing efficiency is indispensable for applying to large-scale interconnected systems.
<4.Perspective for Development>		
(1)Perspective for Development		A prorotype system for foundamental studies will be completed before Sept.,1987 and Tests of knowledges and algorithmes will be performed next.
<5.Documents & References>	ja-1(1987)	ja-2(1986)

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Table <B-17> Current Status of Expert Systems Development in Power Systems

Country: Japan (Format A)

ITEMS / ID. No. of Answers	Japan-5	Japan-6
<1.Project Information>		
(1)Name of Expert System and/or Project	Guidance System for Restoration in Control Center	Restorative Control Support System for Power System
(2)Intended Functions or Project Objectives	-Restoration guidance -Fault point location -Operation guidance for system restoration -Determination of restorative procedure for overload and blackout	In case of faults in trunk network, faulted section and fault situation are identified and Guidances for restoration control are also indicated.
(3)Organisation / Country	Kansai Electric Power Co., Mitsubishi Electric Corp. / Japan	Chubu Electric Power Corp.,Toshiba Corp. / Japan
(4)Stage of Development	Idea	Idea for restoration Debugged program for fault identification (detection).
<2.Problem Area and Solution Method>		
(1)Area of Application	Restoration in power system	Fault identification / restoration
(2)Theoretical Background		Protective relay technology in power system
<3.Expert System Information>		
(1)Function Classification	Guidance	Diagnosis, Guidance, Control
(2)Inference Mechanism Control Scheme	Production system	Forward chaining / Inference based on Frame structured knowledge base
(3)Languages / Tools / Shells	OPS 83, FORTRAN77	LISP / KEE
(4)Computer Hardware	Apollo DN-580	SYMBOLICS
(5)No. of Rules & Knowledge Base Size	Around 200, 0.3 MB (Guidance system control, operation guidance)	200 roles (Fault identification)
(6)Problems in Development and Solution	Interface between OPS 83 and online data	
<4.Perspective for Development>		
(1)Perspective for Development	Improvement of man machine interface, especially visual display for Guidance.	
<5.Documents & References>		

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Table <B-18>Current Status of Expert Systems Development in Power Systems

(Country: Japan) (Format A)

ITEMS / ID. No. of Answers	Japan-7	Japan-8
<1.Project Information>		
(1)Name of Expert System and/or Project	Power System Fault Locating System	Power System Restoration Support System
(2)Intended Functions or Project Objectives	Identification of faulted equipments, fault situations, and malfunctions of protective system under emergency condition.	Determination of the system restoration guidance under fault (emergency) state
(3)Organisation / Country	Kyushu Electric Power Co., Toshiba Corp.Inc. / Japan	Kyushu Electric Power Co., Toshiba Corp.,Inc. / Japan
(4)Stage of Development	Field Test, completed in 1986 of for 2 year study.	Field Test, completed in 1986 of for 1 year study.
<2.Problem Area and Solution Method>		
(1)Area of Application	Fault Analysis	System Restoration
(2)Theoretical Background	To identify faulted equipments, fault situation, and malfunctions by status of protective relays and circuit breakers which are equipped on power system components.	Procedure for Power System restoration
<3.Expert System Information>		
(1)Function Classification	Diagnosis	Guidance
(2)Inference Mechanism Control Scheme	Combination of forward and backward chaining / Inference based on the knowledge concerning inference control and fault detection	Forward chaining / Inference baced on the knowledge concerning inference control and system restoration
(3)Languages / Tools / Shells	Prolog / Special purpose shell for the system	Prolog / Special purpose shell for the system
(4)Computer Hardware	TOSBAC-DS600/80, 3.7 MIPS, Main memory 6 MB, Super minicomputer (shared with Power System Restoration Support System see Japan-8)	TOSBAC-DS600/80, 3.7 MIPS, Main memory 6 MB, Super minicomputer (shared with Power System Fault Locating System)
(5)No. of Rules & Knowledge Base Size	200 rules / 200 KB	200 rules / 300 KB
(6)Problems in Development and Solution	Knowledge acquisition method and consistency check	Knowledge acquisition method and consistency check. It was inevitable that surface knowledge had high share for enhancing the practicability. The knowledge of system restoration has been grouped for improving the system response.
<4.Perspective for Development> (1)Perspective for Development	Only single generator and radial-structured system has been studied for the system development up to now. This system is planned to be applied to large scale system with plural generators. So it is necessary to add further knowledges and functions for the purpose.	At present Restoration Support System to determine switching operation of power system including plural generators is under developement.
<5.Documents & References>	ja-3(1985), ja-4(1985), ja-5(1986), ja-6(1986), ja-7(1986), ja-8(1986), ja-9(1986), ja-10(1986), ja-11(1986) ja-12(1987), ja-13(1987), ja-14(1986), ja-15(1987), ja-16(1987)	

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Table <B-19>Current Status of Expert Systems Development in Power Systems

[Country: Japan] (Format A)

ITEMS / ID. No. of Answers	Japan-9	Japan-10
<1.Project Information>		
(1)Name of Expert System and/or Project	Advanced Analyzer of Power System	Intelligent Support System for System Analysis
(2)Intended Functions or Project Objectives	To improve efficiency of power system analysis, especially for load flow calculation.	For the task of power system analysis, guidances are displayd to evaluate analysis results and to revise data for improving system week points, which leads to enhancement of analysis efficiency.
(3)Organisation / Country	Mitsubishi Electric Corp. / 1985 / JAPAN	Toshiba corp.,Inc. / Japan
(4)Stage of Development	Practical Use	Field Test
<2.Problem Area and Solution Method>		
(1)Area of Application	Load Flow Engine	Power system analysis
(2)Theoretical Background	Conventional load flow calculation technique.	Approaches for power system analysis.
<3.Expert System Information>		
(1)Function Classification	Planning	Planning / Design
(2)Inference Mechanism Control Scheme	Forward / Backward chaining scheme.	Backward / Forward chaining / FRAME structure
(3)Languages / Tools / Shells	Prolog interpreter.	LISP, FORTRAN / KEE
(4)Computer Hardware	Apollo DN Series / Mitsubishi EWS MN Series. Minimum core size 2MB	VAX, Symbolics
(5)No. of Rules & Knowledge Base Size	100 rules(if-then),up-to-date. There are no limits.	150 rules
(6)Problems in Development and Solution	Because Prolog interpreter was used, it is not convenient to add or modify the rules. Some appropriate tool should be chosen to be applied.	- Improvement of chaining efficiency (for time saving) - Man-Machine interface - Data exchange between numerical analysis software and knowledge base
<4.Perspective for Development>		
(1)Perspective for Development	The number of rules should be increased, in order to be practically used in utilities.	Extensive application to many kinds of analyses
<5.Documents & References>	ja-17(1985), ja-18(1985), ja-19(1986)	----

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Table <B-20>Current Status of Expert Systems Development in Power Systems

[Country: Japan] (Format A)

ITEMS / ID. No. of Answers	Japan-11	Japan-12
<1.Project Information>		
(1)Name of Expert System and/or Project	Expert System for Power System Analysis (Avalo)	Application of knowledge Engineering to Substation Layout Systems
(2)Intended Functions or Project Objectives	Interactive system combining several softwares for analysis and guidance functions	Development of expert system incorporating the design procedure taken by human expert
(3)Organisation / Country	Hitachi Research Laboratory,Hitachi Ltd.(Japan)	Hitachi Ltd. / Japan
(4)Stage of Development	Practical Use	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Power System Analysis, Planning, and Scheduling	Substation layout
(2)Theoretical Background	Usual analytical methods, frame inference and rule-based inference	Based on the knowledge of substation layout by human expert.
<3.Expert System Information>		
(1)Function Classification	Planning	Design
(2)Inference Mechanism Control Scheme	Frame, If-then rule	Mainly forward reasoning
(3)Languages / Tools / Shells	Prolog, C, Fortran, Eureka II	Lisp
(4)Computer Hardware	EWS.(E-33,Hitachi) workstation, main memory min.2 MB.	----
(5)No. of Rules & Knowledge Base Size	200 rules, max 2000 rules(frame,if-then rule)	600 Rules
(6)Problems in Development and Solution	NONE	The substation layout is performed through various intermidiate design stages. However, the design constraints in each stage is often violated. The design results obtainned in the former stage must be changed. There are many feasible solution in each stage.
<4.Perspective for Development>		
(1)Perspective for Development	After further refinementt (or enhancement), it will be released.	----
<5.Documents & References>	ja-20(1987)	

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Table <B-21> Current Status of Expert Systems Development in Power Systems

[Country: Japan (Format A)

ITEMS / ID. No. of Answers	Japan-13	Japan-14
<1.Project Information>		
(1)Name of Expert System and/or Project	On-line ELD for thermal Power Plants	Intelligent Monitoring & Alarming of MW & MVar Stabilities in Power Systems
(2)Intended Functions or Project Objectives	-On-line economic load dispatching including coal fired plants -Dynamic generation rescheduling -Predictive control of power system operation	A MVar stability index VIPI (Voltage Instability Proximity Index) indicates a solid angle made by two vectors, namely, y, (node specification vector in LF calculations) and y(a) (singular vector to be derived from a pair of multiple LF solutions). Two kinds of MW Stability indices (σ & ν) indicate degree of detuning in Parametric Resonace behaviour of waveforms of envelopes, respectively.
(3)Organisation / Country	Waseda University / Japan	Waseda University / Japan
(4)Stage of Development	Prototype	Idea
<2.Problem Area and Solution Method>		
(1)Area of Application	Real time ELD for thermal Power plants	Stability Assesment of power system
(2)Theoretical Background	-state space representation of control states (upper level of hierarchical structure) -equal incremental fuel cost method & Kuhn-Tucker Theorem (lower level of hierarchical structure)	Nonlinear Oscillation Theory (Parametric Resonace) & Theory of Multiple Load Flow Solutions in ill-conditioned power system
<3.Expert System Information>		
(1)Function Classification	Monitoring, Prediction, Control	Monitoring
(2)Inference Mechanism Control Scheme	Combination of traditional methods (<2>,(2)) of this format & a set of IF-THEN rules	To be refined aiming at implementation
(3)Languages / Tools / Shells	FORTRAN Prolog-KABA / MS-DOS	Production type Representation (Fortran)
(4)Computer Hardware	MITSUBISHI MX/3000 (Traditional methods) NEC PC-9801 (Traditional methods, IF-THEN rules)	HITACHI HITAC M280H (For development) MITSUBISHI Super Minicon MELCOM 70 MX/3000 (For practical use)
(5)No. of Rules & Knowledge Base Size	Around 5 major rules	Around 10 major rules
(6)Problems in Development and Solution	Link between knowledge base and numerical algorithms	Index VIPI can efficiently be obtained on-line. Index(σ) is obtained by eigenvalue analysis. Calculation of Index(ν) may be time consuming depending on the system size.
<4.Perspective for Development>		
(1)Perspective for Development	Improvement of processing efficiency (computation speed and memory size)	The Expert System developed here has a deep knowledge base as part of inference mechanism. This type of Expert System seems promissing in the future.
<5.Documents & References>	ja-21(1986), ja-22(1987)	

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Table <B-22>Current Status of Expert Systems Development in Power Systems

[Country: Japan] (Format A)

ITEMS / ID. No. of Answers	Japan-15
<1.Project Information>	
(1)Name of Expert System and/or Project	ESSE : Expert System for Security Evaluation
(2)Intended Functions or Project Objectives	Intelligent aid for identifying vulnerability(weak points) and indicating remedial measures in alert state
(3)Organisation / Country	Tokyo Metropolitan University and Hiroshima University / Japan
(4)Stage of Development	Prototype
<2.Problem Area and Solution Method>	
(1)Area of Application	Decision making of control actions for eliminating overloads and voltage violations by generation and reactive power rescheduling
(2)Theoretical Background	Pattern recognition -feature extraction, -security index selection, -discrimination function Conventional algorithms -State estimation, -Load flow computation, -Sensitivity analysis Optimization approach -N.L. Programming, -Mixed integer Programming
<3.Expert System Information>	
(1)Function Classification	Monitoring, Prediction, Control
(2)Inference Mechanism Control Scheme	Combination of forward and backward chaining Criteria frame Certainty coefficients (C.F. values)
(3)Languages / Tools / Shells	Tool ··· COMEX written by C, ART for implementation Conventional algorithms have been written by Fortran
(4)Computer Hardware	Personal computer PC-9801 / NEC for development Sun-3 for implementation
(5)No. of Rules & Knowledge Base Size	Around 15 rules for each node
(6)Problems in Development and Solution	Linkage between knowledge base and conventional software Expertize for real power system operation
<4.Perspective for Development>	
(1)Perspective for Development	Application to real scale system with complex structrue Acquisition of deep knowledge from human expert Advanced man machine interface
<5.Documents & References>	

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Table <B-23>Current Status of Expert Systems Development in Power Systems

[Country: Japan] (Format A)

ITEMS / ID. No. of Answers	Japan-16	Japan-17
<1.Project Information>		
(1)Name of Expert System and/or Project	Expert Systems Assisting Power System Security Control	Knowledge based training system for power system operation
(2)Intended Functions or Project Objectives	To assist operators to determine an effective countermeasure to ensure a proper level of power security	To develop a training system which can teach how to operate power
(3)Organisation / Country	Hiroshima University, Tokyo Metropolitan University / Japan	Department of Electrical Engineering, Kyoto University / Japan
(4)Stage of Development	Debugged Program	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	In determination of corrective / preventive control of power systems	Generation of restorative process of power system, explanation of the process, and evaluation of the operationa done by trainees
(2)Theoretical Background	Expert knowledge, load flow, contingency analysis, security analysis, voltage / VAR control	Expert system, CAI, Power system simulator
<3.Expert System Information>		
(1)Function Classification	Guidance	Education
(2)Inference Mechanism Control Scheme	Forward and Backward Chaining with certainty factors, Semantic network by frame model	Forward interface / Event driven method
(3)Languages / Tools / Shells	GC Lisp / ESHELL-FM	LISP / ESHELL
(4)Computer Hardware	FM16β (Fujitu Co.)	FACOM M-780 (Main frame)
(5)No. of Rules & Knowledge Base Size	About 50	About 30
(6)Problems in Development and Solution	Link between Lisp and Fortran Slow execution speed	Nothing special
<4.Perspective for Development>		
(1)Perspective for Development	To evaluated the practicability in the near future	The system will be improved so that it can deal with information on protective relays, set more kinds of problems to trainees, carry more kinds of tasks by the trainee's request, and have better explaining function
<5.Documents & References>	ja-23(1987)	ja-24(1987)

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Table <B-24>Current Status of Expert Systems Development in Power Systems

[Country: Japan] (Format A)

ITEMS / ID. No. of Answers	Japan-18	
<1.Project Information>		
(1)Name of Expert System and/or Project	Support system to aid daily planning of unit commitment	
(2)Intended Functions or Project Objectives	To make feasible planning to satisfy the operating restrictions of each unit and some other constraints	
(3)Organisation / Country	Tohoku University, Sendai / Japan	
(4)Stage of Development	Prototype	
<2.Problem Area and Solution Method>		
(1)Area of Application	Sub-optimal planning of daily start-stop operation of generation mix under very complex restrictions	
(2)Theoretical Background	Approximate optimization of planning by Monte Carlo Approach using feasible combination of units to satisfy operating rules	
<3.Expert System Information>		
(1)Function Classification	Planning	
(2)Inference Mechanism Control Scheme	Constraint satisfaction and dependency-directed backtracking	
(3)Languages / Tools / Shells	LISP / micro-PROLOG + FORTRAN	
(4)Computer Hardware	ACOS1000 / UX-300F II / NEC 98XA	
(5)No. of Rules & Knowledge Base Size	About 60 rules in knowledge base	
(6)Problems in Development and Solution	Joint implementation of PROLOG and FORTRAN is very slow	
<4.Perspective for Development>		
(1)Perspective for Development	When the number of units increases, this AI type approximate optimization technique becomes more practical compared with the classical DP approach.	
<5.Documents & References>	ja-25(1987)	

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Table <B-25>Current Status of Expert Systems Development in Power Systems

[Country: The Netherlands]

(Format A)

ITEMS / ID. No. of Answers	Netherlands-1	Netherlands-2
<1.Project Information>		
(1)Name of Expert System and/or Project	Exformer / an Expert System for Transformer Fault Diagnosis	Expert system for Network restoration; interpretation of faulty states
(2)Intended Functions or Project Objectives	Pilot project expert systems in order to - introduce the use of expert systems within KEMA - getting acquainted with methods and techniques used in expert systems - assist in transformer fault diagnosis.	- Operator assistance (advisory system) - Advanced tool for obtaining more insights in the behaviour of power system in emergency states
(3)Organisation / Country	N.V. KEMA / 1986 / The Netherlands	KEMA + Technical University of Delft / 1987 / The Netherlands
(4)Stage of Development	----	some ideas have already been tested
<2.Problem Area and Solution Method>		
(1)Area of Application	Diagnosis of Power Transformers	Power System Monitoring and Control
(2)Theoretical Background	- Diagnosis - Fuzzy Set Theory - Behaviour of Power Transformers	- knowledge of the behaviour of power systems - knowledge of protection systems - decision analysis, search methods, etc.
<3.Expert System Information>		
(1)Function Classification	----	----
(2)Inference Mechanism Control Scheme	Mainly backward chaining. A few possibilities for forward chaining.	inference mechanism of Prolog
(3)Languages / Tools / Shells	Sage (can be considererd as a stripped version of PROSPECTOR)	POPLOG
(4)Computer Hardware	IBM PC-XT	Apollo DN 3000
(5)No. of Rules & Knowledge Base Size	about 100 rules	50 rules for the first version. However, above idea has not yet been fully elaborated.
(6)Problems in Development and Solution	- The performance (response time) is affected badly by the use of the implemented membership function. - A more versatile tool (KEE, Knowledge Craft, Art, etc.) is needed in order to improve the user-friendliness.	- The performance is influenced for a great deal by the number of facts in the database and the applied search algorithms. Blind search methods cause a prohibitively long search process.
<4.Perspective for Development>		
(1)Perspective for Development	Discussion with KEMA's Coordination Commitee of Damages in order to formulate a general computer approach for diagnosis (of faults in electrical devices) and automated reporting.	In the near future a more advantanced tool (KEE, ART, Knowledge Craft, etc.) will be used in order to speed up the conceptual phase.
<5.Documents & References>	nl-1(1985), nl-2(1983), nl-3(1986), nl-4(1987), nl-5(1977), nl-6(1975)	nl-7, nl-8(1986), nl-9(1983)

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Table <B-26> Current Status of Expert Systems Development in Power Systems

[Country: Norway] (Format A)

ITEMS / ID. No. of Answers	Norway-1
<1.Project Information>	
(1)Name of Expert System and/or Project	Intelligent Operator Assistant
(2)Intended Functions or Project Objectives	On-line aid for Operation in Control Center -Intelligent Frontend for Simulation Programs. -Expert advice when evaluating Actual State and in choosing actions
(3)Organisation / Country	The Norwegian Research Institute of Electricity Supply A/S (EFI), Norway, in cooperation with The Norwegian State Power Board and Computas Expert Systems.
(4)Stage of Development	Prototype
<2.Problem Area and Solution Method>	
(1)Area of Application	On-line operation and control. Reliability Assessment Keywords: State Estimation / Contingency Analysis / Remendial Actions / Dispatchers Optimal Power Flow
(2)Theoretical Background	SCADA System / State estimation / Optimal Load Flow / Sensitivity Signals / Reactive Reserve Assessment / Contingency Evaluation.
<3.Expert System Information>	
(1)Function Classification	Education, Prediction, Planning, Design
(2)Inference Mechanism Control Scheme	Forward / Back Chaining / Worlds / Objectoriented Representation
(3)Languages / Tools / Shells	Commonlisp, KEE
(4)Computer Hardware	Symbolics 3620 and Vax communicating - using Decnet
(5)No. of Rules & Knowledge Base Size	-Not decided yet, will be chosen depending on HW/SW limitations.
(6)Problems in Development and Solution	The Knowledge bases might be too large for one LISP-machine. Will use a LISP machine and a μVax in a network. LM for reasoning, Vax for number crunching.
<4.Perspective for Development>	
(1)Perspective for Development	The project is in an early stage, the first goal being to establish frontend using a mouse for selecting and setting up programs for analyzing the actual system state. The prototyp is expected to be runnig by the end of 87. The task od building the expert system to guide the operator will start in the second half of 87.
<5.Documents & References>	no-1(1986), no-2(1985), no-3(1986), no-4(1986), no-5(1986), no-6(1987)

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Table <B-27>Current Status of Expert Systems Development in Power Systems

[Country: R of S.A.-1] (Format A)

ITEMS / ID. No. of Answers	R of S.A.-1	
<1.Project Information>		
(1)Name of Expert System and/or Project	An Experimental Expert System for Alarm Processing	
(2)Intended Functions or Project Objectives	Intended functions are alarm filtering, limited alarm interpretation and an aid during crisis management. Project objectives include the introduction of Expert System technology to engineering DP.	
(3)Organisation / Country	ESCOM / Republic of South Africa	
(4)Stage of Development	Idea	
<2.Problem Area and Solution Method>		
(1)Area of Application	Alarm Processing: To reduce information overload and provide more meanigful alarming.	
(2)Theoretical Background	System not yet implemented.	
<3.Expert System Information>		
(1)Function Classification	Interpretation, Monitoring	
(2)Inference Mechanism Control Scheme	Trigger alarms use forward chaining to select candidate goals for evaluation. Backward chaining then proves/disproves goals. Time variant data is used to update decisions by forward chaining.	
(3)Languages / Tools / Shells	To be written mainly in LISP and C, possibly Objective C. The UNIX utilities yacc and lex would be useful for developing rule compilers and parsers.	
(4)Computer Hardware	IBM PC environment	
(5)No. of Rules & Knowledge Base Size	System not yet implemented	
(6)Problems in Development and Solution	Problem areas identified so far include handling of time variant data and suitable knowledge representation.	
<4.Perspective for Development>		
(1)Perspective for Development	Human operators often miss important events during information overload situations(eg. during a crisis). It is hoped that an Expert System will help to overcome such problems by filtering and interpretation.	
<5.Documents & References>		

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Table <B-28>Current Status of Expert Systems Development in Power Systems

[Country: Sweden] (Format A)

ITEMS / ID. No. of Answers	Sweden-1
<1.Project Information>	
(1)Name of Expert System and/or Project	DUBA
(2)Intended Functions or Project Objectives	Today the expert system performs a restoration from a deenergised power system
(3)Organisation / Country	Electric Power Research Centre / Sweden
(4)Stage of Development	Idea / Prototype
<2.Problem Area and Solution Method>	
(1)Area of Application	Power system restoration area
(2)Theoretical Background	
<3.Expert System Information>	
(1)Function Classification	Planning / Guidance / Control
(2)Inference Mechanism Control Scheme	As inference mechanism, we use a combination of forward and backward chaining to perform a solution. As conflict resolution, we use different rule sets (Epitool), greatest weight on rules (Kee) and different worlds (Kee) to perform a solution.
(3)Languages / Tools / Shells	Epitool / Kee
(4)Computer Hardware	VAX (Epitool) Symbolics (Kee)
(5)No. of Rules & Knowledge Base Size	Until now we have implemented about 30 rules.
(6)Problems in Development and Solution	In our first prototype the major problem has been to understand how the different tools work. We work together with the experts in this area but they have not given any comment and because of that we do not have any feedback.
<4.Perspective for Development>	
(1)Perspective for Development	The plans are to design and implement an automatic system restorating the power system when there has been a disturbance.
<5.Documents & References>	

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Table <B-29>Current Status of Expert Systems Development in Power Systems

[Country: Switzerland] (Format A)

ITEMS / ID. No. of Answers	Switzerland-1	Switzerland-2
<1.Project Information>		
(1)Name of Expert System and/or Project	Artificial intelligence techniques as an aid to security analysis	Expert system in PROLOG for alarm handling in a substation
(2)Intended Functions or Project Objectives	Identification of unsecure system states based on knowledge acquired from past history of the system.	Alarm handling and switching operations
(3)Organisation / Country	Swiss Federal Institure of Technology, Lausanne / Switzerland	Swiss Federal Institute of Technology, Lausanne / Switzerland
(4)Stage of Development	Idea / Research project started in May 1987.	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Contingency analysis	Fault identification and restoration
(2)Theoretical Background	Combination of pattern recognition and expert system techniques	- switching operaitons in power system - graph search
<3.Expert System Information>		
(1)Function Classification	Interpretation / Monitoring	Diagnosis / Guidance / Education / Design
(2)Inference Mechanism Control Scheme	first test in PROLOG, backtracking / to be determined further	PROLOG, backtracking
(3)Languages / Tools / Shells	first test in PROLOG	PROLOG
(4)Computer Hardware	Apollo DN 3000, 4 MB memory graphic workstation	Apollo DN 3000, 4 MB memory graphic workstation
(5)No. of Rules & Knowledge Base Size	unknown yet knowledge structure to be developed	About 500 PROLOG lines code and 100 rules for the test system
(6)Problems in Development and Solution	expected large size of knowledge base	PROLOG IMPLEMENTAITON VERY SLOW
<4.Perspective for Development>		
(1)Perspective for Development	security analysis and emergency control	Use of computation programs to define the goals for the switching operation
<5.Documents & References>	----	swit-1(1987)

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Table <B-30>Current Status of Expert Systems Development in Power Systems

[Country: The United Kingdom] (Format A)

ITEMS / ID. No. of Answers	U.K.-1	U.K.-2
<1.Project Information>		
(1)Name of Expert System and/or Project	An Expert System for Security Assessment in Opprational Planning of Power Systems	O.C.E.P.S(Operational Control of Electric Power Systems)
(2)Intended Functions or Project Objectives	Combine numerical algorithms and LOGIC PROGRAMMING to assist in the decision-making process during the operational planning stage (SECURITY ASSESSMENT) of power systems.	Load forecasting
(3)Organisation / Country	IMPERIAL COLLEGE (SERL)/ENGLAND	School of Engineering & Applied Science, University of Durham/C.E.G.B - United Kingdom
(4)Stage of Development	Idea Target Year of Completion 1989	Idea
<2.Problem Area and Solution Method>		
(1)Area of Application	- Security Assessment - Identifiction of weak areas/boundaries - Contingency selection	Short term load forecast/load management
(2)Theoretical Background	- P.S. AC contingency analysis - Load flow - Graph theory	----
<3.Expert System Information>		
(1)Function Classification	- Guidance - Planning	Prediction
(2)Inference Mechanism Control Scheme	Generate-and-test; Heuristic-guided search Forward and backward chaining	Forward/backward claiming
(3)Languages / Tools / Shells	POPLOG (POPLOG AND PASCAL)	POPLOG
(4)Computer Hardware	MICRO VAX/VMS, 1 MIPS CPU 2 MBYTE RAM	VAX 8600 Mainframe, 4.7 MIPS, 8 MBYTES
(5)No. of Rules & Knowledge Base Size	Not known - Rules and frames	----
(6)Problems in Development and Solution	N/A	OPS5 Evaluated and rejected
<4.Perspective for Development>		
(1)Perspective for Development	- POSSIBLE EXTENSION TO INCLUDE REMEDIAL ACTIONS - SEE R.B.I.JOHNSON AND B.J.CORY (REF 2)	Load forecasting
<5.Documents & References>	uk-1(1984), uk-2(1986)	uk-3(1986), uk-4

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Table <B-31>Current Status of Expert Systems Development in Power Systems

[Country: The United Kingdom] (Format A)

ITEMS / ID. No. of Answers	U.K.-3	U.K.-4
<1.Project Information>		
(1)Name of Expert System and/or Project	Power plant diagnosis using a qualitative model(IQA)	Minder: a.c. loadflow intelligent interface (Demonstrator Project)
(2)Intended Functions or Project Objectives	To assess feasibility of a real-time diagnostic aid for nuclear power plant operators using deep knowledge qualitative modelling techniques	To examine the output from conventional power system analysis loadflow program to validate the system model and advise the engineers on errors or system weak points.
(3)Organisation / Country	Central electricity research laboratories of the CEGB and Queen Mary College,London / UNITED KINGDOM	CEBG System Planning Department*. UK * in conjuction with CEGB computing Dept(CISD) and Research Division(CERL)
(4)Stage of Development	Prototype	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Diagnosis of power plant faults including control system malfunctions and sensor failuers	Intelligent Interface to a conventional program.
(2)Theoretical Background	Qualitative model based on de kleer's incremental qualitative analysis(IQA). Derived from plant dynamic differential equations by formal route.	(still under development) A generalised approach is being adopted that does not require CEGB system-specific knowledge. Rules are being prepared for a 'template' substation, to which analysis result will be 'fitted'.
<3.Expert System Information>		
(1)Function Classification	Interpretation / Diagnosis / Monitoring	Validation
(2)Inference Mechanism Control Scheme	Constraint satisfaction and suspention, dependency-directed backtracking enforced by component scheduler	Under development; probably forward chaining forward chaining; the merits of directing the solution process to particular knowledge areas is being examined.
(3)Languages / Tools / Shells	Two implementations : PROLOG / INTERLISP-D AND LOOPS	The demonstrator system is being developed using the IBM mainframe shell ESE/VM
(4)Computer Hardware	VAX 11/750 / XEROX 1108 AI WORKSTATION	IBM 370 SERIES Mainframe
(5)No. of Rules & Knowledge Base Size	About 160 constraints(confluences) in knowledge base	Not yet known
(6)Problems in Development and Solution	PROLOG implementation very slow, LISP implementation 40 times faster. Recursion limit problem with XEROX 1108,changing to PROLOG on VAX 11-750.	The problems encountered (at this early stage) have been essentially the limitations of ESE/VM for this particular application. For example, ability to handle data objects/records;no generic;not recurrsive.
<4.Perspective for Development>		
(1)Perspective for Development	To be applied to feed and steam system. Qualitative model and control scheme to be enhanced to cope with system with time delays and many possible states.	A production version, rather than demonstrator, would not be capable of making whole system or zoral assessments, and there might be merit in examining loadflow study INPUT as well as OUTPUT data.
<5.Documents & References>	uk-5, uk-6(1985)	

Table <B-32>Current Status of Expert Systems Development in Power Systems

Country: U.S.A. (Format A)

ITEMS / ID. No. of Answers	U.S.A.-1	U.S.A.-2
<1.Project Information>		
(1)Name of Expert System and/or Project	HARMPRO (Harmonic Problem Adviser)	IDMAC (Intelligent Distribution Monitoring and Control)
(2)Intended Functions or Project Objectives	Intelligent aid for identifying and predicting Harmonic-related problems	Software architecture for integrating a mix of Distribution automation functions
(3)Organisation / Country	Electric Power Research Center, North Carolina State University, Raleigh, NC / U.S.A.	North Carolina State University, Raleigh, NC / U.S.A.
(4)Stage of Development	Prototype (Complete by Aug. 1988)	Idea / Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Trouble Call Analysis	Distribution Automation - all aspects
(2)Theoretical Background	Network modeled by impedance matrix. Three phase with ground included	Blackboard approach, which integrates both knowledge-based and algorithmic-based functions
<3.Expert System Information>		
(1)Function Classification	Diagnosis / Prediction	Monitoring / Control
(2)Inference Mechanism Control Scheme	Backward and forward chaining	Forward
(3)Languages / Tools / Shells	Micro Data Base System's GURU	'C' programming language, OPS83
(4)Computer Hardware	IBM PC-AT	DEC Micro-VAX
(5)No. of Rules & Knowledge Base Size	100 Now → 500 - 800 in future	----
(6)Problems in Development and Solution	Interface between knowledge-based representation of network and model used by numerical number crunching algorithms	How to set up database for real-time expert system access. We are currently working on the reconfiguration task, a distribution simulator and the blackboard implementation.
<4.Perspective for Development>		
(1)Perspective for Development	Want a user interface which will allow for use by technicians	The software required for implementing distribution automation is too complex to write in the form of a single program. A distributed problem solving environment, using a blackboard approach, will be more flexible and capable of integrating a large number of related tasks.
<5.Documents & References>	usa-1(1987)	usa-2(1987)

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Table <B-33>Current Status of Expert Systems Development in Power Systems

[Country: U.S.A.] (Format A)

ITEMS / ID. No. of Answers	U.S.A.-3	U.S.A.-4
<1.Project Information>		
(1)Name of Expert System and/or Project	Monitor Power System Stability based on Voltage Phase Angle measurements from important major regional substations and generation plants.	Communications Alarm Processor (CAP) Prototype
(2)Intended Functions or Project Objectives	Power transfers on regional interties, provide information to take corrective action to prevent voltage collapse or further cascading of a power system disturbance.	Analyze communications system alarms
(3)Organisation / Country	Bonneville Power Administration / USA	Bonneville Power Administration / USA
(4)Stage of Development	Idea	Idea
<2.Problem Area and Solution Method> (1)Area of Application	----	Alarm Processing
(2)Theoretical Background	Steady State Stability	Expert System
<3.Expert System Information> (1)Function Classification	Prediction	Diagnosis
(2)Inference Mechanism Control Scheme	----	----
(3)Languages / Tools / Shells	----	ART
(4)Computer Hardware	----	Micro VAX
(5)No. of Rules & Knowledge Base Size	----	Estimate several hundred
(6)Problems in Development and Solution	----	----
<4.Perspective for Development> (1)Perspective for Development	----	----
<5.Documents & References>	usa-3, usa-4, usa-5(1987-88), usa-6, usa-7	----

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Table <B-34>Current Status of Expert Systems Development in Power Systems

Country: U.S.A. (Format A)

ITEMS / ID. No. of Answers	U.S.A.-5	U.S.A.-6
<1.Project Information>		
(1)Name of Expert System and/or Project	Near real-time monitoring of sequential events from major intertie substations.	Development of Knowledge Based Systems for Electric Utility Operation using the PROLOG language
(2)Intended Functions or Project Objectives	Process sequential events to aid the Dispatchers in making important operational decisions associated with power system disturbances.	Operator's assistant / Volt/VAR dispatch
(3)Organisation / Country	Bonneville Power Administration / USA	EPRI , Union Electric / U.S.A.
(4)Stage of Development	Idea	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Alarm and event processing.	Control Center
(2)Theoretical Background	Power system theory and protective relaying.	Breaker/Relay Simulation or Diagnostician Volt/VAR Dispatch
<3.Expert System Information>		
(1)Function Classification	Monitoring	Control
(2)Inference Mechanism Control Scheme	----	PROLOG, backtracking, depth first search
(3)Languages / Tools / Shells	----	PROLOG
(4)Computer Hardware	Micro VAX	VAX 11/780 Unix BSD 4.2
(5)No. of Rules & Knowledge Base Size	----	1100 lines, 630 buses
(6)Problems in Development and Solution	----	Planed to be expended to full seak demonstration as an operator's assistant
<4.Perspective for Development>	----	
(1)Perspective for Development		see 6 above
<5.Documents & References>	----	usa-8(1983), usa-9(1985), usa-10(1985), usa-11(1985) usa-12(1984), usa-13(1986), usa-14(1984), usa-15(1986) usa-16(1986)

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Table <B-35>Current Status of Expert Systems Development in Power Systems

Country: U.S.A. (Format A)

ITEMS / ID. No. of Answers	U.S.A.-7	U.S.A.-8
<1.Project Information>		
(1)Name of Expert System and/or Project	Application of Expert Systems for Short Term Load Forecasting	EPRI OTS HEURISTIC SCENARIO BUILDER
(2)Intended Functions or Project Objectives	Develop an accurate short term load forecasting technique that is sensitive to demand side management, other operational practices, and consumer reaction to pricing alternatives.	Automatic production of training scenarios to be used within the OTS (Operator Training Simulator) environment
(3)Organisation / Country	Energy Systems Research Laboratory Virginia Tech / U.S.A.	Control Data Corp. / U.S.A.
(4)Stage of Development	Practical Use	Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Short Term Load Forecast	Operator training using an Operator Training Simulator (OTS)
(2)Theoretical Background	Statistical analysis to develop relationships between load and the forcing functions.	Scenario building is usually done manually by the instructor. Scenarios are validated using the simulator, the dispatcher's power flow + a transient stability program
<3.Expert System Information>		
(1)Function Classification	Prediction	Education - Training
(2)Inference Mechanism Control Scheme	Forwarding chaining	Heuristic search. Uses rules for goal creation and for base case creation. Mainly used in forward chaining mode.
(3)Languages / Tools / Shells	Extended Fortran Language (EFL), C and BASIC. No shells	LISP. All tools developed in-houseaa
(4)Computer Hardware	IBM-RT PC and IBM-PC AT.	SYMBOLICS, CYBER
(5)No. of Rules & Knowledge Base Size	100-150 rules. Offline database-2 years' of hourly load and weather data. On-line data base-2 weeks' of hourly load and weather data.	~100
(6)Problems in Development and Solution	The historical relationship between electrical load and weather variables ourselves for one year to document certain idiosyncracies and benefit from the system operator's experience and intuition.	Major problem is coupling LISP based environments with FORTRAN based environments.
<4.Perspective for Development> (1)Perspective for Development	To develop a one-to-twenty four hour load forecast that would be sensitive to direct load control actions taken by large consumers of an electric utility. The information on the load forecast would be used by the wholesale consumer to stay away from the utility's system peak and therefore reduce the demand charges.	To be used within OTS. First stage applies to DC model. Second stage to DC/AC and third to dynamic models as well.
<5.Documents & References>	usa-17(1987), usa-18(1986)	EPRI documents: not available yet.

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Table <B-36> Current Status of Expert Systems Development in Power Systems

Country: U.S.A. (Format A)

ITEMS / ID. No. of Answers	U.S.A.-9	U.S.A.-10
<1.Project Information>		
(1)Name of Expert System and/or Project	General purpose expert system shell for EMS applications	IAP - Intelligent Alarm Processor
(2)Intended Functions or Project Objectives	To be used within CDC's EMS system to develop expert system applications	Smart filtering and ranking of power system alarms and intelligent trouble shooting of power system operating conditions
(3)Organisation / Country	Control Data Corp. -EMSD / U.S.A.	Control Data Corp. -EMSD / U.S.A.
(4)Stage of Development	Debugged Program	Debugged Program
<2.Problem Area and Solution Method>		
(1)Area of Application	This is a shell and thus can be used to support expert system development in many areas	Alarm processing
(2)Theoretical Background	Coupled to MMI + DB as well as other software of CDC's EMS product.	Volume of alarms in power system energy control center is large. Some alarms are important, other are routine other are noise. Alarm filtering and ranking is very important to operator actions.
<3.Expert System Information>		
(1)Function Classification	As a shell it applies to all of above	Interpretation / Diagnosis
(2)Inference Mechanism Control Scheme	Supports: - forward chaining - backward chaining - mixed	Uses expert system shell with forward chaining, backward chaining and mixed chaining.
(3)Languages / Tools / Shells	Prototype in LISP Implementation in PASCAL	Prototype in LISP. Implementation in PASCAL. Uses special purpose shell developed at CDC.
(4)Computer Hardware	CDC CYBER SERIES	CYBER
(5)No. of Rules & Knowledge Base Size	N/A	~300
(6)Problems in Development and Solution	Must be <u>very</u> user friendly since it is intended for use by operations personnel of electric utilites.	Requires the combination of rule-based knowledge and procedural knowledge
<4.Perspective for Development>		
(1)Perspective for Development	First prototype is available within CDC. First implementations within EMS systems scheduled for 1988 + 1989. More developments and enhancements expected.	A full implementation in a utility's control center is under way. More enhancements planned. Final system will extend knowledge to power system model.
<5.Documents & References>	----	See papers by B.Wollenberg et al on IEEE publications

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Table <B-37>Current Status of Expert Systems Development in Power Systems

Country: U.S.A. (Format A)

ITEMS / ID. No. of Answers	U.S.A.-11	U.S.A.-12
<1.Project Information>		
(1)Name of Expert System and/or Project	SWAD	EPRI Project RP-1712
(2)Intended Functions or Project Objectives	To provide advice to station dispatchers in operation of their facilities, in a real-time environment.	To develop engineering grade Digital computer programs superior to currently implenented techniques for real-time equivalents, contingency analysis, and security enhancement.
(3)Organisation / Country	American Electric Power Service Corporation / U.S.A.	Electric Power Research Institute, Wisconsin Electric Power Co., Energy Systems Computer Applications / U.S.A.
(4)Stage of Development	Prototype	Field Test
<2.Problem Area and Solution Method>		
(1)Area of Application	Real-time operation of stations / planning	Contingency Analysis, Remedial Action, Economic Dispatch
(2)Theoretical Background	See (2) below.	Decoupled Power Flow Techniques, Linear Programming, Dual and Primal Algorithms for feasibility and optimality.
<3.Expert System Information>		
(1)Function Classification	Guidance	Guidance / Prediction / Planning / Control
(2)Inference Mechanism Control Scheme	Backward chaining production systems coupled with procedural reasoning.	State Estimation
(3)Languages / Tools / Shells	Pascal and C	Fortran DCL - Digital Command Language
(4)Computer Hardware	DEC MicroVAX II running MicroVMS operating system	Digital Equipment Corp - VAX 11/780, RM80, RM81, TU77 and VT100 AYDIN - 5217 CDC - CYBER 830 (6000 series)
(5)No. of Rules & Knowledge Base Size	Yet to be determined	----
(6)Problems in Development and Solution	Primarily, knowledge acquisition and knowledge representation bottlenecks.	Development of sensitivity vs. cost models to provide logical and correct recommendations for known solutions to problems.
<4.Perspective for Development>		
(1)Perspective for Development	Once the stand-alone prototype is completed, it will be interfaced to the EMS database.	Refinement of techniques / man-machine / combine these applications with the Optimal Power Flow to account for system losses.
<5.Documents & References>	----	usa-19

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Table <B-38>Current Status of Expert Systems Development in Power Systems

[Country: U.S.A.] (Format A)

ITEMS / ID. No. of Answers	U.S.A.-13	U.S.A.-14
<1.Project Information>		
(1)Name of Expert System and/or Project	Transmission Auto-Reclosure	Intelligent Alarm Processor
(2)Intended Functions or Project Objectives	To provide greater system reliability and flexibility without the problems associated with electro-mechanical type reclosing relay schemes.	For a single substation, analyze all incoming alarms and user input to conclude a cause for the alarm and present such cause to the operator. Corrective action may also be recommended.
(3)Organisation / Country	Wisconsin Electric Power Company / U.S.A.	Wisconsin Electric Power Company / U.S.A.
(4)Stage of Development	Practical Use	Idea / Prototype
<2.Problem Area and Solution Method>		
(1)Area of Application	Remedial Action / System Restoration	Alarm Processing
(2)Theoretical Background	Principles and practice of system protection schemes along with operational constraints and procedures.	N/A
<3.Expert System Information>		
(1)Function Classification	Monitoring / Control	Interpretation / Diagnosis / Guidance / Monitoring
(2)Inference Mechanism Control Scheme	System control and data acquisition (SCADA) system and alarming functions.	Inference Engine
(3)Languages / Tools / Shells	Assembler - 1700	LISP and FORTRAN
(4)Computer Hardware	1784 Mini Computer - CDC (Drivers)	VAX 11/780
(5)No. of Rules & Knowledge Base Size	11 Rules - 2 Terminal Line (Non-Radial) Simultaneous action of 16 circuit breaker pairs.	Approximately 200 rules.
(6)Problems in Development and Solution	Identifying the appropriate rules and the ramifications of those rules.	N/A
<4.Perspective for Development>		
(1)Perspective for Development	1) Expansion of system to other divisions. 2) Distribution reclosing.	Initial knowledge base is in very early stages of development. Therefore, it is too early to judge possibilities of success or failure.
<5.Documents & References>	----	----

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Table <B-39> Current Status of Expert Systems Development in Power Systems

[Country: U.S.A.] (Format A)

ITEMS / ID. No. of Answers	U.S.A.-15	U.S.A.-16
<1.Project Information>		
(1)Name of Expert System and/or Project	VCES(Voltage Control Expert system)	CRAFT (Customer Restoration And fault Testing)
(2)Intended Functions or Project Objectives	To assist in the decision-making of reactive power/voltage control.	To assist dispatchers in control centers in fault isolation and customer restoration
(3)Organisation / Country	University of Washington / U.S.A.	University of Washington, Electric Power Research Institute, Puget Sound Power & Light / U.S.A.
(4)Stage of Development	Debugged Program	Being implemented in PSPL
<2.Problem Area and Solution Method> (1)Area of Application	Selection of reactive power devices to resolve violations of voltage limits.	Fault Isolation and Planning Switching Actions: Between power circuit breakers at the ends of a transmission line, automatic switches have been installed in utility systems to sectionalize the line in case of a fault. Often the auto-switches are not able to isolate the fault exactly.
(2)Theoretical Background	1. Power systems are modeled by the steady-state power flow model. 2. The selection of control devices is based on empirical rules. 3. The empirical rules can be justified by linearized analysis (sensitivity concepts).	This expert system incorporates logic rules for the isolation of the faulted section in a transmission line, rules that dispatchers use to test the line, and the problem solving procedures that dispatchers use.
<3.Expert System Information> (1)Function Classification	Control	Diagnosis / Planning
(2)Inference Mechanism Control Scheme	Forward chaining.	Forward chaining
(3)Languages / Tools / Shells	OPS83	OPS83
(4)Computer Hardware	MicroVAX II	MicroVAX II
(5)No. of Rules & Knowledge Base Size	75 rules	About 300 rules
(6)Problems in Development and Solution	We started with the OPS5 language and found that the interface with Fortran programs was nontrivial. By using OPS83, the computational speed was increased and the OPS83/FORTRAN interface was simplified.	The project team is implementing CRAFT in the Puget Sound Power & Light Control Center. The interface software programs are being developed. The customized nature of control center computers makes the development more involved. We expect the experimental implementation to be completed in about one year.
<4.Perspective for Development> (1)Perspective for Development	The VCES is integrated with a load flow and a linear programming packages. All programs reside in the MicroVAX II. The system provides an excellent test bed for our investigations on expert systems.	The implementation of expert systems in the control center environment is viewed as a critical step for the assessment of the feasibility of such tools. Once the experimental implementation is complete, we plan to perform a thorough evaluation of the performance and extend the expert system knowledge base to other operation problems.
<5.Documents & References>	usa-20(1986), usa-21(1987)	usa-22(1986), usa-23(in preparation)

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Table <B-40> Current Status of Expert Systems Development in Power Systems

(Country: U.S.A.) (Format A)

ITEMS / ID. No. of Answers	U.S.A.-17	U.S.A.-18
<1.Project Information>		
(1)Name of Expert System and/or Project	DFSR (Distribution Feeder System Restoration)	An Object Oriented Expert System for EMS Applications
(2)Intended Functions or Project Objectives	To determine the necessary switching actions which will restore as many load zones as possible.	· integration of ES and standard EMS functions into a single system · high level programming tool for EMS applications
(3)Organisation / Country	University of Washington / U.S.A.	Electronics Research Laboratory, University of California, Berkeley / U.S.A.
(4)Stage of Development	Prototype	Idea
<2.Problem Area and Solution Method>		
(1)Area of Application	To restore load zones through neighboring primary feeders following an outage.	The system is an implementation tool for all high level power system applications and therefore applicable to most applications listed on pages A8.
(2)Theoretical Background	The restoration follows the sequence of group restoration, zone restoration, load transfer and determination of the switching actions.	A common object oriented data model is defined; objects correspond to the elements of the power system, "messages" correspond to the local processing steps, structured rule based system.
<3.Expert System Information>		
(1)Function Classification	Planning	Interpretation / Diagnosis / Guidance / Monitoring / Planning / Design / Control
(2)Inference Mechanism Control Scheme	Backward chaining / forward chaining	· object oriented message passing · data directed (forward) chaining exploiting the object structure
(3)Languages / Tools / Shells	Prolog/VM and Turbo Prolog	implementation in C++ or Objective C
(4)Computer Hardware	IBM 4341 and IBM PC	VAX-750 / Unix BSD 4.3
(5)No. of Rules & Knowledge Base Size	180 rules	----
(6)Problems in Development and Solution	The IBM PC version does not handle the approximate load flow that is incorporated in the system. The IBM 4341 version performs satisfactorily.	----
<4.Perspective for Development> (1)Perspective for Development	The distribution system restoration problem is quite involved. The system is usually unbalanced. Different loads may have different priorities in the restoration. Normally, distribution systems do not have extensive data acquisition systems. All the above issues will be investigated in the extension of this work.	----
<5.Documents & References>	usa-24(1987)	usa-25(1987)

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Appendix <C>

Project Objectives
and
Application Area of Expert Systems

Table <C-1> ~ <C-5>

Appendix <C> Project Objectives and Application Area of Expert Systems

Table <C-1> Project Objective and Application Area of Expert Systems

Category	Project Objectives	Area of Application	(ID. No. of Reply)
Planning	Operation Planning	Bulk power system operation planning	(Japan-1)
		System structure planning	(Japan-1)
		Generation scheduling	(Japan-1)
		Reactive power scheduling	(Japan-1)
		System stabilization	(Japan-1)
		Decision-making during the operational planning (security assessment)	(U.K.-1)
		Planning and checking of network switching operations	(Finland-3)
		Switching planning in normal operation	(Finland-3)
		Daily planning of unit commitment	(Japan-18)
		Short-term marketing strategy for interchange transactions	(Canada-1)
	Facility Design	Optimal automatic configuration of electronic equipment for substation	(Italy-2)
		Configuration of an equipment for power distribution station	(Italy-3)
		Design procedure of substation layout	(Japan-12)
	System Planning	Distribution automation - all aspects	(U.S.A.-2)

Table <C-2> Project Objective and Application Area of Expert Systems

Category	Project Objectives	Area of Application	(ID. No. of Reply)
Monitoring	Fault Diagnosis	Equipment in high voltage substation	(France-2)
		Different fault tripping according to the protection schemes	(France-3)
		Network incidents in control center	(F.R.G.-1)
		Location of faulted point (sectionalization)	(Japan-5)
		Identification of faulted section under fault situation	(Japan-6)
		Identification of faulted equipment and fault situation	(Japan-7)
		Power transformers	(Netherlands-1)
		Behaviour of power system in emergency states	(Netherlands-2)
		Trouble shooting of power system operating conditions	(U.S.A.-10)
		Detection of fault isolation	(U.S.A.-16)
		Events diagnosis	(Finland-2)
		Early detection and diagnosis of machine's malfunction	(Italy-5)
		Diagnosis and recommendation for hardware problems in supervisary control system	(Canada-4)
	Alarm Processing	Alarm processing	(Denmark-1)
		Different fault tripping according to the protection schemes	(France-3)
		Faulted equipment detection	(Japan-2)
		Identification of malfunctions in protective system	(Japan-7)
		Power plant faults including control system malfunctions and sensor failures	(U.K.-3)
		Communication system alarm	(U.S.A.-4)
		Real-time monitoring of sequential events from major intertie substations	(U.S.A.-5)
		Breaker and relay status in control center	(U.S.A.-6)
		Filtering and ranking of power system alarms	(U.S.A.-10)
		Identification of a cause for the alarm and recommendation of corrective action	(U.S.A.-14)
		Fault identification in a substation	(Switzerland-2)
		Alarm processor at national control center	(Ireland-1)
		Alarm filtering and limited alarm interpretation	(R.S.A.-1)
	Contingency Evaluation	Contingency analysis	(Denmark-1)
		Contingency analysis	(Norway-1)
		Reliability assessment	(Norway-1)
		Identification of weak areas /boundaries	(U.K.-1)
		Contingency selection	(U.K.-1)
		Advice for the engineers on errors or system weak points	(U.K.-4)
		Contingency analysis and remedial action for security enhancement	(U.S.A.-12)
		Contingency analysis and emergency control	(Switerland-1)
		Supervisors monitoring and control a stability constrained power system	(Canada-2)

Table <C-3> Project Objective and Application Area of Expert Systems

Category	Project Objectives	Area of Application	(ID. No. of Reply)
Control	Normal	Computer aided decision on network topology	(France-1)
		State estimation	(Norway-1)
		Short term load forecasting	(U.K.-1, U.S.A.-7)
		Evaluation of power system stability	(U.S.A.-3)
		Voltage and VAR dispatch	(U.S.A.-6)
		Advise to station dispatchers in real time operation of their facilities	(U.S.A.-11)
		Economic dispatch	(U.S.A.-12)
		Decision-making of reactive power and voltage control	(U.S.A.-15)
		On-line dynamic ELD for power plants	(Japan-13)
		Security assessment and control in alert state	(Japan-15)
	Emergency	Remedial action	(Denmark-1)
		Corrective action to prevent voltage collapse	(U.S.A.-3)
		Selection of reactive power devices to resolve violations of voltage limits	(U.S.A.-15)
		Determination of countermeasure to ensure a proper level of system security	(Japan-16)
	Restorative	System restoration	(Denmark-1)
		System restoration of trunk lines	(Japan-2)
		Restorative procedure planning and guidance	(Japan-2)
		Restorative procedure for over load and blackout	(Japan-5)
		Restoration guidance under emergency state	(Japan-8)
		Network restoration	(Netherlands-2)
		Auto-reclosure of electro-mechanical relay in system restoration	(U.S.A.-13)
		Customer restoration procedure	(U.S.A.-16)
		Restoration of load zones through neighboring primary feeders following an outage	(U.S.A.-17)
		Switching planning after disturbances	(Finland-3)
		Switching operation in a substation	(Switzerland-2)
		Restoration from a deenergised power system	(Sweden-1)

Table <C-4> Project Objective and Application Area of Expert Systems

Category	Project Objectives	Area of Application	(ID. No. of Reply)
System Analysis	Static	Load flow engine	(Italy-1)
		Improvement in efficiency of load flow planning	(Japan-9)
		Evaluation of system state and determination of remedial measures	(Japan-10)
		Interactive system for power system analysis using conventional software	(Japan-11)
		MVar stability index VIPI(Voltage Instability Proximity Index) for voltage stability assessment	(Japan-14)
		On-line operation and control and security assessment	(Norway-1)
		Validation of system models	(U.K.-4)
		Disturbance information analysis in microcomputer environment	(Finland-1)
		Security analysis based on knowledge acquired from past history of the system	(Switzerland-1)
		Generation of decision tables for security monitoring function	(Canada-3)
		Intelligent load flow for planning and network analysis	(Canada-6)
		User interface of stability program to build new models of relay	(Canada-7)
	Dynamic	MW stability index based on parametric resonance	(Japan-14)

Table <C-5> Project Objective and Application Area of Expert Systems

Category	Project Objectives	Area of Application	(ID. No. of Reply)
Education & Simulator	C.A.I.	Automatic production of training scenarios to be used within the operator training simulator	(U.S.A.-8)
	Simulator	Evaluation of actual state and choice of actions	(Norway-1)
		Training system for power system operation	(Japan-17)
Others		On-line monitoring and diagnosis of cycle water pollution in a thermal power plant	(Italy-4)
		Identification and predicting of harmonic-related problems	(U.S.A.-1)
		Consumer reaction to pricing alternatives	(U.S.A.-7)
		General purpose expert system shell for energy management system applications	(U.S.A.-9)
		Energy management system applications	(U.S.A.-18)
		Analysis of the cause of application program aborts	(Canada-5)

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Appendix <D>

Theoretical Background in Expert System Development in Power System

Table <D-1> ~ <D-4>

Appendix <D> Theoretical Background in Expert System Development in power system

Table <D-1> Theoretical Background in expert systems development in power system

Category	**Project objective**	**Approaches related to power system engineering**	Concepts and methodologies related to knowledge engineering
Planning	- Operation planning	- Numerical algorithms (U.K.-1)	- Forward and backward chaining - Production system and Frame system
	- Facility design	- AC load flow (U.K.-1)	- Deep knowledge base with hierarchical structure (Japan-1)
	- System planning	- Graph theory (U.K.-1)	- Logic programming and logic rules (U.K.-1, Finland)
		- Monte Carlo approach (Japan-18)	- Heuristic rules combined with hill climing search (Italy-2)
			- Blackboard approach integrating both knowledge and algorithmic based functions (U.S.A.-2)

Table <D-2> Theoretical Background in expert systems development in power system

Category	**Project objective**	**Approaches related to power system engineering**	Concepts and methodologies related to knowledge engineering
Monitoring	- Fault diagnosis - Alarm processing - Contingency evaluation	- Alarm filtering and ranking - Power flow analysis (Finland-2, Japan-2, U.K.-1, U.K.-4) - Load forecasting (Finland-2) - Frequency analysis of vibration (Italy-5) - NL programming (Japan-2) - Plant dynamic differential equation (U.K.-3) - Sequential events processing (U.S.A.-5) - Breaker/Relay simulation (U.S.A.-6) - Voltage and Reactive power dispatch (U.S.A.-6) - SCADA System (Norway-1) - State estimation (Norway-1) - Optimal power flow (Norway-1) - Sensitivity (Norway-1) - Graph theory (U.K.-1) - Linear programming (U.S.A.-12) - Dual and Primal algorithm (U.S.A.-12) - Decoupled P.F. technique (U.S.A.-12) - Economic dispatch (U.S.A.-12) - Graph search (Switzerland-2)	- Forward and backward chaining - Production system and frame system - Semantic networks (France-2) - Frames, scripts, temporal logic (France-2) - Meta-knowledges (France-2) - First order logic (France-3) - Triplets <object.relation.object> (France-3) - Pattern recognition (F.R.G.-1, Switzerland-1) - Fuzzy set theory (Netherlands-1) - Membership function (Netherlands-1) - Decision analysis and search method (Netherlands-2) - Mixed chaining (U.S.A.-10) - Qualitative modelling techniques (U.K.-3) - Incremental qualitative analysis (U.K.-3) - Depth first search (U.S.A.-6) - World representation (Norway-1) - Object-oriented representation (Norway-1)

Table ‹D-3› Theoretical Background in expert systems development in power system

Category	Project objective	Approaches related to power system engineering	Concepts and methodologies related to nowleddge engineering
Control	- Normal control	- State estimation (Norway-1)	- Forward and backward chaining
	- Emergency control	- Optimal power flow (Norway-1, U.K.-1)	- Production system and frame system
			- Meta knowledge (France-1)
	- Restorative control	- Sensitivity (Norway-1, U.K.-1)	- World representation (Norway-1)
		- Reactive power control (Norway-1, U.K.-1)	- Object-oriented representation (Norway-1)
		- Graph theory (Switzerland-2, U.K.-1)	- Logic programming and logic rules (U.K.-1)
		- Voltage instability index (U.S.A.-3)	- Back tracking - Prolog (U.S.A.-6)
		- Voltage and Reactive power control (U.S.A.-15)	- Depth first search U.S.A.-6)
			- Procedural chaining (U.S.A.-11)
		- Load forecasting (U.S.A.-7)	- Pattern recognition (Japan-15)
		- Statistical analysis (U.S.A.-7)	- Feature extraction (Japan-15)
		- Dynamic ELD (Japan-13)	- Decision analysis and search method (Netherlands-2, U.S.A.-16)
		- Economic dispatch (U.S.A.-12)	
		- Equal incremental fuel cost law (Japan-13)	- Certainty factors (Japan-16)
			- Semantic network by frame model (Japan-16)
		- Decoupled P.F. technique (U.S.A.-12)	
		- Linear programming (U.S.A.-12)	
		- Nonlinear programming (Japan-13)	
		- Dual and primal algorithm (Japan-13)	
		- Mixed integer programming (Japan-15)	
		- Linearized analysis - sensitivity (U.S.A.-15)	
		- State space representation of control states (Japan-13)	
		- Security index (Japan-15)	
		- Group and zone restoration sequence (U.S.A.-17)	
		- Switching actions (U.S.A.-17)	
		- Combinatorial optimization (Sweden-1)	

Table <D-4> Theoretical Background in expert systems development in power system

Category	Project objective	Approaches related to power system engineering	Concepts and methodologies related to knowledge engineering
System analysis	- Static analysis - Dynamic analysis	- Load flow analysis (Italy-1, Japan-9, U.K.-4, Japan-10) - SCADA system (Norway-1) - MW stability index (Japan-14) - MVar stability index (Japan-14)	- Forward and backward chaining - Production system and frame system - Load flow engine (Italy-1, Japan-9) - World representation (Norway-1) - Object-oriented representation (Norway-1) - Pattern recognition (Switzerland-1)
Education and Simulator	- C.A.I. - Simulator	- operator training simulator (U.S.A.-8) - Automatic production of training scenarios (U.S.A.-8) - Power flow analysis (U.S.A.-8) - Transient stability analysis (U.S.A.-8)	- Forward and backward chaining - Production system and frame system - Heuristic search (U.S.A.-8) - Goal creation (U.S.A.-8)
Others	- Load management - Water pollution - Harmonic contents - Expert system shell - Price elasticity	- Impedance network model (U.S.A.-1) - Numerical number crunching algorithm (U.S.A.-1) - Load forecasting (U.S.A.-7) - Statistical analysis (U.S.A.-7) - Energy management system (U.S.A.-9)	- Forward and backward chaining - Production system and frame system - Representation of procedural knowledge (Italy-4) - Mixed chaining (U.S.A.-9) - Object oriented model (U.S.A.-18)

Appendix <E>

Recognized Needs for Expert Systems Applied to the Power System

Table <E-1> ~ <E-20>

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Table <E-1> Recognized Needs for Expert systems Applied to the power system

(Country: Canada)

(No. 1)

ITEMS ID.No.of Answers	Canada (Ontario Hydro)
Potential Needs	To assess the security of the power system, a large number of contingencies must be simulated. In practice, only a few of these contingencies are critical and thus worth studying. The set of critical contingencies are dependent on the operating system conditions. An expert system that identifies the critical contingencies will result in a considerable reduction in computation time. One task related to the application of the energy method for on-line transient stability is the identification of the unstable machines for each contingency. Mathematical techniques used to identify these machines are time consuming. An expert system to identify these unstable machines for each contingency for the current system conditions will reduce the computation effort.
Functions to be furnished	These expert systems must be integrated in the Ontario Hydro EMS. There are problems related to the integration process, and amount of CPU and memory required.
Future Project	A joint project with EPRI is currently in the feasibility stage.

Table <E-2> Recognized Needs for Expert systems Applied to the power system

(Country: Finland) (No. 2)

ITEMS ID.No.of Answers	Finland (IMATRAN, VOIMA OY)
Potential Needs	Expert Systems are useful tools in the network operation planning, the analysis of disturbances and equipment diagnosis. The problems are the great amount of handled information and complex systems. Individuals have different abilities to handle information and the Expert Systems are used to guarantee the quality of functions in all circumstances.
Functions to be furnished	
Future Project	

Table <E-3> Recognized Needs for Expert systems Applied to the power system

(Country: France) (No. 3)

ITEMS ID.No.of Answers	France-a (EDF RESEARCH & DEVELOPMENT DIV.)
Potential Needs	a) <u>Identifying alert emergency states</u> The problem is to determine reliable indicators taking into account the dynamics of the system. This problem is connected with alarm handling and needs an ability to interpret, in terms of security, the state changes. b) <u>Providing emergency procedures</u> Emergency procedures are elaborated off line and are not always well suited for a given situation. By storing specialized knowledge, it could become possible to have prompt and more reliable decision-making. c) <u>Restorative control</u> When loads are being supplied and after the system has reached a steady state, an expert system would be helpful to take action to restore supply.
Functions to be furnished	
Future Project	<u>Prototypes are being developed on the following subjects</u> - Events synthesis in EHV substations. - Main grid topology design. - Restorative control after a local disturbance. - False data elimination(state estimation). The objectives are to define knowledge representation and tools well suited to work with efficiency on large scale problems. First on-line applications are planned for 1994.

Table <E-4> Recognized Needs for Expert systems Applied to the power system

Country: France) (No. 4)

ITEMS ID.No.of Answers	France-b (EDF & CGEE - ALSTHOM)
Potential Needs	The main problems in power system operation that can be tackled with expert system are : a) Evolution Analysis One major obstacle is to define and to detect a potential alert situation, that is a situation that will lead, in a relative short time, to an operation problem. Another obstacle is to define safeguard strategies for alert situations. b) Alarm synthesis The major obstacle is to correlate various alarms in space (alarms coming from different points of the network) and in time (taking into account different transmission delays between substations). c) Load shedding Up to now, load shedding is based on static algorithms. The kind of customers to be interrupted is predefined. The problem is to be able to define dynamically, according to operation constraints, which customers must be shed. d) Restorative strategy The problem is to find the correct sequences of feeders to restore after a fault. The major obstacle is the impossibility to determine effective load solicitation of each feeder. e) Operator training Generally a training simulator allows an operator to simulate actions on an electrical network, and give the consequences. It would be important to simulate defaults, analyze operator actions in this context and then explain the operator default nature and problems lifted up by his actions. The obstacles are the number and the nature of functions to implement: all problems relative to a fault itself and to transmissions should be taken into account. f) Man-machine interface: assistance to image design (off line) Image design of electrical network is a field where expert systems could bring important assistance. The problem is to create images, for a given screen resolution. Indeed, an image must contain exhaustively, the description of a significant network area. Moreover, it must be sufficiently understandable by operator. The major obstacle is that is very difficult to determine a good compromise between the fact of: - giving maximum information to minimize operator handlings or requests and - ensuring efficient image resolution to facilitate operator understanding

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ITEMS ID.No.of Answers	France－b (EDF & CGEE - ALSTHOM)
Functions to be furnished	a) Evolution analysis Evolution analysis concerns slow phenomenon supervision. The study can be done by assessing variations of indicators giving a large view of global process evolution. The expert system will implement operation rules of the utility and correlation rules between indicator variations. A function which can supply new data to the expert system during inferences and which can verify data coherence seems important. In other words time varying input must be taken into account. b) Alarm synthesis The number of alarms that can appear when there is a failure on the network can be very important. To establish a diagnosis, a preliminary classification is needed. A sorting out function, using spatial and temporal criteria must be furnished. That must allow the expert system to work with less data. c) Load shedding To resolve the problem of dynamic load shedding, the function to be implemented must be able to evaluate quickly (according to load shedding delay) feeder supply load in a determined area, and to determine dynamic constraints. Finally, from these constraints and a set of criteria, the expert system will define a list of appropriate feeders to be shed. d) Restorative strategy To restore the power on unsupplied feeders subsequent to an incident, hypothesis must be done on feeder potential loading according to load forecasting and feeder load before the incident. Some functions like storage, load forecasting and load flow and the possibility to define dynamic criteria (restorative strategy) must be implemented with the expert system. After a fault on the network, the expert system can help the operator by giving him the sequence of devices to operate according to: - the diagnosed fault - the operation rules of the utility e) Operator training An incident generator able to simulate faults on electric network and transmission network, with an explicative module, would bring great assistance in operator

- continued -

(Country: France)

(No. 6)

ITEMS ID.No.of Answers	France－b (EDF & CGEE - ALSTHOM)
Functions to be furnished	education. The expert system will allow fault generation. f) Man-machine interface: assistance to image design The expert system will implement object representation rules and ergonomic rules. Functions to be furnished with the expert system shall allow image parameter acquisition and modification of final images given by the expert system.
Future Project	1987 - Test of the base of rules 1988 - Response time measurements on the final hardware (VAX 8800) 1989 - Integration of application software 1990 - Acceptance tests on site - Field test in a regional control centre

Table <E-5> Recognized Needs for Expert systems Applied to the power system

(Country: F.R.G.) (No. 7)

ITEMS ID.No.of Answers	F. R. G. (Siemens)
Potential Needs	In power system operation (SCADA, State Estimation , Contingency Analysis, Energy Management, Short Circuit Computation and Simulation) in general the following problems are observed: - In case of a severe trouble in the network showers of detailed alarms arise and it is difficult and time consuming for the operator to detect the important alarms, identify the event and find out the real cause of the trouble. - bad data identification in state estimation - definition of critical equipment outages for contingency analysis (contingency selection) - updating neighbouring network equivalents - indicating level of vulnerability or trend to risky system states (voltages collapse, stability) - emergency and restorative control - fault locating in medium voltage distribution networks
Functions to be furnished	An expert system application seems to be useful for - alarm reduction (intelligent filter, pattern recognition) - post mortem analysis of events e.g. to detect correct and faulty relay function - restorative control - fault location in medium voltage systems
Future Project	

Table <E-6> Recognized Needs for Expert systems Applied to the power system

(Country: Ireland) (No. 8)

ITEMS ID.No.of Answers	Ireland-a (Electricity Supply Board)
Potential Needs	Alarm handling in modern computer based control system is recognised as a problem where conventional software solutions are seen to be inflexible and difficult to implement.
Functions to be furnished	Power system monitoring and alarming expert system are to be flexible in regard to addition to rules and presentation of output and preferably portable. In the longer term additional output by way of guidance and suggestions for operators may be added.
Future Project	No future project plans.

Table <E-7> Recognized Needs for Expert systems Applied to the power system

(Country: Japan) (No. 9)

ITEMS / ID.No.of Answers	Japan-a (Kansai E. P. Co., Mitsubishi)
Potential Needs	Planning ; • Too many judgement factors • Ambiguous evaluation criteria • Design of data base for planning Operation ; • Switching operation unable to be standardized Control ; • Var control Analysis ; • Design of data base for analysis Education ; (Training) • Automatic curriculum (text) generation
Functions to be furnished	• Alarm processing • Guidance for system restoration (normal and restorative) • Substation design • Automatic curriculum generation system for operator training • System operation planning system • System planning
Future Project	

Table <E-8> Recognized Needs for Expert systems Applied to the power system

(Country: Japan) (No.10)

ID.No.of Answers ITEMS	Japan－b (Chubu E. P. Co., Toshiba)
Potential Needs	((Problem)) (1) Not smooth inheritance of empirical know-how accumulated (2) Inadequate man-machine interface (3) Lack of flexibility for system maintenance (4) Limitation of automatization/improvement based on continued technology ((Background)) (a) Need for advanced system operation strategies due to power system's complexity (b) Necessity for large scale SCADA systems (c) Two-tier composition of operations staff into younger and older generation
Functions to be furnished	(1) System operation planning (2) Unit commitment (Maintenance scheduling) (3) Load forecasting (4) Outflow forecasting (5) Power system analysis support (6) Normal- / emergency-state switching operation (7) Reservoir system operation (8) Alarm processing (9) Reliability supervision (10) Fault detection and location (11) Faulted equipment diagnosis (12) Operator training
Future Project	

Table <E-9> Recognized Needs for Expert systems Applied to the power system

(Country: Japan) (No.11)

ID.No.of Answers ITEMS	Japan-c (Kyushu E.P.Co., Toshiba)
Potential Needs	(1) System planning In power system planning, various kinds of constraints such as economy efficiency, reliability, and future trend (promising) must be taken into account. This type of study usually takes much time and labour. (2) System operation a. Demand-supply scheduling Before optimal operation can be achieved economic examination of Hydro, Thermal (e.g. coal, oil, nuclear, LNG, LPG, etc.) and pumped-storage hydro power plants is required. Comprehensive studies are needed to consider many factors such as weather, temperature, and fuel supply conditions. This task takes much time and labour to make up long-term, short-term, and daily operation plans. b. Switching operation If the system structure is changed for scheduled maintenance and some system fault is foreseen owing to bad weather, operators check the system state to identify problems of stability, overload, system isolation, and lack of running reserve capacity etc. and determine the remedial measures such as a change in system structure and generation rescheduling to resolve the problems. However because operational constraints vary depending on the system state, only experienced operators can make decisions quickly and accurately. (3) Maintenance scheduling Appropriate planning for maintenance scheduling (time schedule and smooth flow of work) is necessary including evaluation of system reliability, economy efficiency and ease. Much time and labour is needed for the planning, as many constraints have to be checked in the maintenance scheduling. (4) Analysis For preventing system faults, it is necessary to diagnose failure of equipment and cause of the failure using various data obtained from off-line analysis. In evaluating these data, many factors must be taken into account concerning established criteria for judgement, experience for failure and contingencies occured in the past, characteristics of system equipments, weather and seasonal condition and so on, then it takes much time and labour if it is done by human operator's judgement only. (5) Education In the field of system planning, operation and analysis etc., experienced engineers (human experts) who have been playing a central role are getting close to the age of retirement and operators in the next (younger) generation must inherit the tasks. However by the reinforcement of power systems and the improvement of facilities, opportunities to encounter real faults have decreased, which leads to less chance to

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(Country: Japan) (No.12)

ID.No.of Answers / ITEMS	Japan-c
Potential Needs	obtain sufficient experience for the operators. As a means for education of young operators and inheritance of technical knowledge,introduction of expert systems is indispensable.
Functions to be furnished	· Design of substation layout · Operation planning of demand and supply · Monitoring and preventive control in power system · Restorative control · Maintenance scheduling · Diagnosis of equipments and facilities · Education and training for system planning,operation and diagnosis
Future Project	In Kyushu Electric Co., expert system aid for monitoring in normal state, fault restoration and system configuration planning are planned to be used in dispatching centers. Functions of each system are as follows but detail plans are now under study. (1) Monitoring in normal state By simulating contingencies for the present system state, emergencies and content of emergencies are displayed and guidance for suitable remedial measure is also produced by the expert system. (2) Fault restoration Proper restorative procedures are indicated for faults in the real system. (3) System configuration is decided when the system configuration is changed under heavy load in summer period and during system maintenance.

Table <E-10> Recognized Needs for Expert systems Applied to the power system

(Country: Japan) (No.13)

ID.No.of Answers / ITEMS	Japan-d (Mitsubishi)
Potential Needs	Power system planning, operation and control are out side the scope of this project. The recognized problems in power system analysis are described separately in the reply to question A. The training on skill based schemes are realized by using a training simulator which has similar functions and mimetic performance as the real control center. Education and training on rule based schemes could not be realized by training simulator but could be carried out by using expert system technology.
Functions to be furnished	To resolve the above problem, the functions such as operator training and simulation must be furnished.
Future project	Advanced simulator is now under study.

Table <E-11> Recognized Needs for Expert systems Applied to the power system

(Country: Japan) (No.14)

ID.No.of Answers / ITEMS	Japan-e (Tokyo E.P.Co., Toshiba)
Potential Needs	Expert systems will never take the place of human operators, but are expected to be a tool to assist operators by presenting information for problem solving and remedial measures by iterative dialogue.
Functions to be furnished	Application areas of expert systems expected in power systems are as follows : · System analysis · Restorative control in faulted system · Maintenance scheduling However expert systems are still in the stage of fundamental research and development, the next step is to produce more practical systems after evaluating functions and effectiveness of the developed prototypes.
Future Project	Improvement of man-machine interfaces supporting inferences process such as graphical representation of results, explanation of inference process, applied rules and representation and retrieval of knowledges are an important issue to be solved in the near future. Construction of well-structured knowledge base comprised of deep knowledge acquired from human experts is also indispensable in the next development.

Table <E-12> Recognized Needs for Expert systems Applied to the power system

(Country: Norway) (No.15)

ITEMS ID.No.of Answers	Norway-a (EFI)
Potential Needs	The main problems both in the planning and the control stage in putting advanced programs to use are : - complicated setup of program - cryptic and non-filtered presentation of results This means analysis using programs needs expertise both in the field of study and in setting up of programs/ interpreting their results. This means that it takes time to produce skilled users and that they often are rare. In other words a threshold that is too high for the tools to be widely used.
Functions to be furnished	Three keys to lower the threshold : - include coded expert knowledge to guide an inexperienced user - provide a simple "intelligent " interface - integrate expert systems, databases and numerical programs
Future Project	Our project plans are to further develop and test the concept of the Operators Assistant, and to run a pilot project on diagnosis of foreign particles in a SF_6-insulated substation using acoustic measuring techniques.

Table <E-13> Recognized Needs for Expert systems Applied to the power system

(Country: Sweden) (No.16)

ITEMS ID.No.of Answers	Sweden-a (Swedish State Power Board)
Potecial Needs	Indication of recognized problems : - Power system planning ; Prediction of load and expecially production are based on simplified models of complex and poorly understood processes. A combination of the current technique with heuristics and pattern recognition should become more powerful. Possibly induction system could be of use find hidden relationships. - computer programs used in planning, operation and control often have unfriendly user interfaces. The procedure of setting up input data, running the program and analyzing the output is complex and time consuming. Explain facilities and graphical, object oriented knowledge base editor connected to, or integrated in programs would be better. - During normal system operation, operators in dispatch centers are not enough stimulated which leads to stress. Furthermore he has not been supported from good enough tools to optimize the operation of the system. During emergency and restorative states, he will on the other hand get much and irrelevant information, at the same time as fast and correct decisions must be made. Mr. Shelbe's paper (see page A8) gives a good summary of potential applications in this field.
Functions to be furnished	Recognized obstacles that hinder an expert system solution - Execution times of large expert system are high. - Expert system does not handle real time problems. - There is no extra capacity left in the currently used hardware in dispatch centers. - Expert system hardware has poor data input and output interfaces. - The portability problem for developed applications have so far not been solved. - Knowledge aquisition is difficult and takes long time. - Verification and test of developed applications are complicated.
Future Project	Projects plans : At The Swedish State Power Board a number of potential electric power applications have been examined. Out of the applications a minor number is recommended as prototype and demonstration projects. The strategy is to work with small and "fast" prototypes in the beginning to get to know the technique and the problems. With small and different projects it is possible to make a broader evaluation of differnt expert system tools and hardware. Currently a small prototype for power system restoration is developed. Other recommended projects will include : - Alarm handling - Planning of short term hydro power production - reactive power control - Diagnosis of control equipment hardware

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(Country: Sweden) (No.17)

ITEMS ID.No.of Answers	Sweden－a (Swedish State Power Board)
Future Project	A project to investigate the real time problems when expert systems are used in the power system area is to be started probably in the beginning of 1988. The intention for the projects in the EMS area is that they together should lead to an integration of conventional and expert system programs into a complete user interface.

Table <E-14> Recognized Needs for Expert systems Applied to the power system

(Country: U.K.) (No.18)

ITEMS ID.No.of Answers	U. K. - a (Imperial College)
Potential Needs	(a) In problems involving network topology. (b) Where there is a mass of data, some redundant and some possibly conflicting. (c) Where, based on (b), there is a considerable range of actions which can be taken, there may be no clear optimal solution and action is needed without delay.
Functions to be furnished	(1) Alarm analysis (2) Restorative control (3) Emergency control (4) Operator training
Future Project	It is hoped to continue work on (1) & (2) and in due course to start work on (a) & (b).

Table <E-15> Recognized Needs for Expert systems Applied to the power system

(Country: U.K.) (No.19)

ITEMS ID.No.of Answers	U. K. - b (Imperial College (SRCE))
Potential Needs	We have focussed on problems in power systems analysis for which deterministic solutions are possible but for which existing algorithms require excessive computing time and/or storage. Two types of algorithms which fall under this class are; (i) problems which cannot be solved efficiently due to their combinatorial nature (e.g. alarm analysis and evaluation of second contigencies). (ii) problems which require a lot of number crunching (e.g. numerical optimisation). The first may be tackled by heuristic-directed search whereas the second may be solved by approximate methods and/or models.In the case of approximate solutions, an expert system should be able to determine whether the results are good enough, or whether a more accurate method is required.
Functions to be furnished	Functions which will be implemented via expert system technology would be in the area of operational planning. Some such functions include; Type I : Contingency selection; second contingencies; weak boundary and weak area identification; corrective network switching; Type II : Unit comittment; economic and secure rescheduling;
Future Project	Future projects will concentrate on the areas outlined above. The objective is the development of an expert decision-support package for operational planning (Ref. 2).

Table <E-16> Recognized Needs for Expert systems Applied to the power system

(Country: U. K.) (No.20)

ITEMS / ID.No.of Answers	U. K. -c (University of Durham/CEGB)
Potential Needs	(a) Generation, Operation, Protection and Control : Modelling and simulation, Load forecasting, Data acquisition and display, State estimation, Optimal load flow, Marginal costs/Avoided costs, Economic dispatch, Load frequency control, Interchange scheduling, Reactive power control, Generator exicitation control, Adaptive and distributed control, New energy technologies and their control, Energy control center developments and experiences, Microprocessor-based protection, Training simulators. (b) Generation and Transmission Planning : Long-term energy forecasting, Impact of qualifying facilities, Generation and network planning, Reliability, Electric fields : Biological effects and electromagnetic interference. (c) Distribution Planning and Operation : Data acquisition and bases, Subtransmission planning, Distribution planning, Load management, Distribution system SCADA, Distribution automation, Distribution capacitor placement, Distribution network optimization. (d) Transmission and Substations : Switching and lightning overvoltages, Insulation coordination, Electrical grounding system analysis, HVAC and DC lines, Reactive compensation, Gas insulated equipment. (e) Communication : Carrier systems, Digital microwaves, Satellite communication, Fibre-optics. (f) Power Electronics : Power thyristor technology, Phase-controlled rectifiers, Choppers, Inverters, Control of electrical machinery, Converters/cycloconverters.
Functions to be furnished	Expert systems : Network reconfiguration, Alarm processing, Rotating equipment diagnosis, Robotics, Relay coordination and operation, Control.
Future Project	On-line operator advice using expert systems.

Table <E-17> Recognized Needs for Expert systems Applied to the power system

(Country: U.K.) (No.21)

ITEMS ID.No.of Answers	U. K. -d (CEGB)
Potential Needs	In power systems analysis, one problem that exists with conventional programs is their lack of adaptability. This is partly due to the nature of large organisations with data processing / software departments separate from power engineering departments. Problems and new program requirements continually arise. The perfect specification has never been written at the first attempt and there is always a need for program development.
Functions to be furnished	One solution for the above might lie in the structure of the expert systems approach, whereby the users could have access to adding / modifying rules without need to involve highly specialised software staff. There are two ES attributes that are attractive for this (a) Rules written in near natural language. (b) Changing or adding rules should not have a high risk of introducing program bugs and need for major re-validation of the software.

Table <E-18> Recognized Needs for Expert systems Applied to the power system

(Country: U.S.A.) (No.22)

ITEMS / ID.No.of Answers	U. S. A. - a (Wisconsin Electric Power Company)
Potential Needs	The following areas are identified as appropriate for Expert System application to the power system. No details are furnished concerning these areas. 1. Contingency Analysis Preprocessing. Based on the results of the previous Contingency Analysis executions and on the current "movement" of the power system, use an Expert System to select which contingencies need to be examined in the current Contingency Analysis execution. 2. Voltage or VAR Control Post-Processing. Current Voltage/VAR optimization algorithms tend to recommend the movement of large numbers of controllers in each execution. Use an Expert System to determine a subset of the recommended movements as a cost effective set which is of practical size. 3. Alarm Processing. Use an Expert System to reduce the number of alarms generated during a disterbance to those indicating the problem instead of the results (information versus data). 4. Fault Isolation With information such as relay targets, alarms, etc., use an expert system to isolate the fault condition. 5. Distribution Automation Disturbance Analysis. With information such as voltage monitoring and distribution switch status, use an Expert System to make decisions regarding system restoration and Voltage/ART Analysis.
Functions to be furnished	
Future Project	

Table <E-19> Recognized Needs for Expert systems Applied to the power system

(Country: U.S.A.) (No.23)

ITEMS / ID.No.of Answers	U. S. A. - b (University of Washington)
Potential Needs	1. Many power system planning and operation tasks are logic-reasoning in nature. These tasks do not fall into conventional mathematical programming approaches. The expert system techniques provide natural tools for the automation. 2. In control centers. a lot of measurements and data are gathered. It appears that expert systems can serve to acquire knowledge automatically to some extent. An expert system to "learn" from past experiences would meaningful. The areas of emergency control and system restoration have significant "empirical" components. They would be good application areas. 3. A well-designed expert sytem would improve the efficiency of the restoration functions.
Functions to be furnished	
Future Project	

Table <E-20> Recognized Needs for Expert systems Applied to the power system

(Country: U.S.A.) (No.24)

ITEMS ID.No.of Answers	U. S. A. − c (Bonneville Power Administration)
Potential Needs	The Expert System development will require a number of iterations. Initially, the analysis will focus on the most critical stability controls, identify the type of fault (10 30, etc.), breaker operating sequence, consider critical equipment alarms, and apply the appropriate Standing Orders.
Functions to be furnished	Power system monitoring, restorative control, emergency control, and operator training, are important functions to be included with an expert system.
Future Project	A small prototype effort or a co-operative EPRI/university project is being considered for the 1987-88 period.

Appendix <F>

Outline of Expert System Projects
(supplement to Format A)

cigré

Format A

Appendix <F> Outline of Expert System Projects (supplement to Format A)

Outline of Expert System Projects (Denmark-1)

Outline Application of KBS to planning and daily operation of Power Utilities

KNOWLEDGE BASED APPLICATIONS

At ELKRAFT Power Company Ltd., an industrial research project in coorporation with the Power Department of the Technical University of Denmark is in progress. The project will investigate the possibilities of using AI-techniques in the power system planning, control and crisis management.

ANALYSIS

The planning, control and crisis management as it is performed at the ELKRAFT energy control centre today have been analysed in general.

This analysis is based on discussions with planners and operators and by studying the existing written instructions. The result of this analysis is an identification of the domains in wich it is desirable to have computerised assistants to enhance the performance compared to applications based on conventional dp-techniques.

The analysis shows that it is not desirable to use knowledge-based applications in the power plant and grid maintenance scheduling, because there are only few rules, if any, that are valid from one planning session to the next. An application which could check these two plans for contradictions could be very usefull to the planners.

The use of knowledge-based applications in the unit commitment and in the dispatch of power plants makes an extended and autometed use of rules-of-thumb and common cence possible. Further, a knowledge-based application can be useful in guiding and speeding up the analytical algorithm by limiting the space in which the algorithms have to search for solutions. Perhaps, the optimal concept is an embedded application consisting of a "conventional" analytical dispatch algorithm and a knowledge-based application.

The last domain detected in the analysis to which knowledge-based application could be applied profitably is in the area of surveillance. If the knowledge and experince of the operators and the designers are combined in a knowledge-base it is possible to make an application which can identify critical power system states earlier than it is possible today and perhaps even give guidelines for the operator on what actions to take. With such a system it would be possible to reduce the number of emergencies.

The analysis showed that the existing set of written instructions are not a "reference guide" to instruct the operator on what to do in a normal situations and what to do in a selection of abnormal situations. The number of written instructions is limited, and they deal only with a very few normal situations. The emergency situations that are delt with are either common situations or very specific singular situations which are unlikely to happen again.

The reason is that the human mind is limitde and as it is any operators duty to be familiar with any instruction; consequently, the number of instructions must be limited.

TOOLS

Turbo-Prolog with a "tool box" on an IBM AT-3 size PC has been chosen for the development of the prototype.

At a lated date it is expected that the concepts, the architecture and the implemented prototype will be presented.

Format A

Outline of Expert System Projects
(Finland-1)

Outline System for the analysis of disturbance informationt

The system will help controll-staff to analyse network disturbances in dstrict control centres.
Data will be collected from disturbance recorders and asked from the user.
The system will tell the user:

- -beginning time of the fault
- -nominal voltage
- -object (line, busbar, ...)
- -type of fault (line-to-line, line-to-ground, ...) and phases
- -tripping specifications:
    - +voltage
    - +relay indications
    - +rapid auto-reclosing
    - +delayed auto-reclosing
- -fault currents
- -fault voltages
- -fault duration
- -rough estimation of the fault place
- -misfunctions of relays and circuit breakers

It will also compare the fault with previous faults and find out if there has been similar faults.

Format A

Outline of Expert System Projects
(Finland-3)

Outline An expert system to support operators in planning and checking of network switching operations

The primary goal is to develop an expert system which can be used to support power system operators in district control centers to plan and check switching sequences in order to change connections in 110 kV network.
Such a system will be used for those substations where it is not local substation automation system.
The idea is to build model of the substation (disconnectors, circuit breakers, etc.) and add rules to this model.
The events are for example; open the disconnectors close the breaker, give warning to worker, ask permission from the national control center and so on.
The idea is that the operator plans the switching sequence and the expert system checks the validity of the suggested operations.
If the suggested operations will cause troubles, the system tells it to the operator.
However the final checking and acceptance of the switching operations is done by other person. It is expected that the expert system will not improve the capabilities of best operators. But we wish that it could support the most unexperienced operators and to improve the quality of their plans.
The expert system will be used in district control centers as a part of operators support system.

Format A

Outline of Expert System Projects (France-1)

Outline CASTOR

For contingency analysis and "corrective switching", different switch positions in various substations must be studied. In practice, the combinatorial variety of states of a busbar-switching station is restricted by operational constraints presenting situations such as load shedding or tieline overload. Thus, with respect to applications, feasible states are of interest.

The system being developed includes two main parts.

1 - A KNOWLEDGE BASED EXPERT SYSTEM

It fills up the next functions :

- operator interface,
- determination of feasible switching states taking into account local constraints : unavailability of busbar or circuit breakers, obligatory or prohibited configurations on specific sets of tie-lines,
- monitoring models.

2 - ANALYTICAL TECHNIQUES

Standard application programs are used (DC, AC, OPF models), interfaced with the knowledge based system.

They allow to analyse each topology given by the expert system.

The objective is not to optimize a precise aspect but to compare the robustness of each feasible state, dealing with several criteria. These criteria are defined by the operator and can be, for example, the operating cost, loads on lines in normal state, overload or load shedding consequences upon single line outages or common mode faults.

Format A

Outline of Expert System Projects (France-2)

Outline SEPT

When a fault occurs, many signals from protective relays and high voltage components (circuit breakers) are recorded in EHV substations, such as start-up, direction, zone for a relay or changes of state for circuit breakers.

The expert system has a dual aim. Firstly, it must provide a synthesis of the events which have occured during a session by a single message indicating possible misoperations of equipments and the location of the fault. Secondly, it must be able to explain its reasoning on a request. The topology of the substation with its different sections, and the different equipments of each section are taken into account.

The prototype which has been realized operates in the following way ; it first checks :

(1) the consistency of the information coming form each equipment : a finite number of frames have been defined to represent the acceptable states and the unacceptable ones. The temporal characteristics of the information (synchronism, duration, phase shift between two signals,...) are checked within the frame ;

(2) the coherence of the information coming from several equipments, located on the same feeder ;

(3) a higher level of coherence, for all the feeders connected to the same bus-bar.

Then it performs :

(4) a fault localization, using a vote technique from all the localization elements given by the different relays ;

(5) monitoring of equipments : the equipments having worked in an abnormal way are listed ;

(6) explanation of the expert-system reasoning : on a request, it is possible to know the reason why an equipment has been found out of order. At this level, the prototype knows where is the fault, and what should be the correct answer of each equipment.

Format A

Outline of Expert System Projects
(France-3)

Outline ALOUTTE EXPERT SYSTEM IN FRENCH REGIONAL CONTROL CENTRE

ALARM HANDLING

1 - INTRODUCTION

In many computerized control centres, the problem of presentation of the alarms to the operators is one of the most critical one. So in the project of the new Regional Control Centres, EDF made a particular effort on the problem of alarm handling.

Our aims are the following :

- Limit the number of alarms presented to the operator, first to avoid on overflow of information especially during a fault on the electrical network, and secondly to keep all the sense of the alarm. In other words, one alarm is effective only if it alerts usefully the operator which is not the case if the alarms are too numerous or if they are linked together and presented simultaneously.
- Integrate in the displays (substations displays, area displays ...) the representation of the events (elementary alarms) that caused the alarm presented to the operator.
- Give to the operator (automatically if possible) the only useful information to solve the problem caused by the occurence of the alarm.

2 - THE PRINCIPLES

To reach these targets, the following principles have been adopted :

- No alarm on operators' actions (for example a change of status of a breaker due to an operator's telecontrol does not give an alarm)
- No alarm on changes of status due to maintenance actions in the substations
- No alarm on fugitive faults. In other words, if an automatic reclosure has been successful, no alarm will be presented to the operator
- One single alarm (if possible) for a fault on the network causing many changes of status
- Dynamic alarm categorization according to the circumstances under which appears the alarm. Each elementary alarm is assigned a level of severity to which corresponds a way of presenting the alarm, and this level can be changed automatically according to the circumstances.

Each specific software elaborates elementary alarms and makes a first level of filtering, these "filters" being specific to the type of information treated. (For example, a change of status of a device due to an operator's telecontrol will be filtered by the telecontrol software, and no elementary alarm will be transmitted to the next treatment).

Each elementary alarm is then assigned with a level of severity out of four possible.

They are then transmitted to a switching software which switches the alarms towards the automatic analysis software or the delay software according to the type of the alarms.

The automatic analysis software which is detailed further in the document, gives a diagnosis and an ideal list of alarms according to the type of diagnosis.

The comparison software compares the list of the received alarms and the ideal list, and gives the difference to the next treatment.

The final alarm constitution software, treats the diagnosis, the difference mentionned above and the alarms stored during the automatic analysis and constitutes one final alarm with one level of severity that will be presented to the operator.

Format A

Outline of Expert System Projects (France-3)

Outline

3 - THE AUTOMATIC ANALYSIS TREATMENTS

The aim of these treatments is :

- to give a diagnosis when there is a fault on the network (bus bar fault, for example),
- to give the elements to eliminate from the list of the received alarms those that are a direct consequence of this fault.

When a fault occurs on the electrical network, this causes many changes of status (essentially breakers and orders given by the protection devices), that are as many elementary alarms. It is not possible to analyse these alarms progressively.

To make a diagnosis when a fault occurs, it is not necessary to take into account the whole network. So as soon as the storage begins, the topology software extracts a part of the network and gives the topology of this part before the first change of status.

At the end of the storage (30 s), the base of facts is constituted with :

- the topology of the network before the fault,
- the changes of status stored during 30 s.

This base of facts is given to an expert system that works with this dynamic base of facts and a base of rules that may be edited during the whole life of the system.

If the expert systems manages to make a diagnosis, it gives this diagnosis, and an ideal list constituted with the changes of status that should have been occured if the fault had been correctly eliminated according to the diagnosis made and the protection schema of the substations involved.

If the expert system does not manage to give a diagnosis, it gives the reason why it does not, and an ideal list without any change of status. Consequently, the alarms presented to the operator will be :

- the reasons why the expert system has not managed to give a diagnosis,
- the elementary alarms, each one assigned with its static level of severity.

4 - THE EXPERT SYSTEM

4.1 - The information used by the expert system

The expert system will be in a first stage used to give a diagnosis when a fault occurs on the network. So the informations used are the following :

- The changes of status of the breakers
- The orders given by the protections
- Some maintenance alarms that may explain a misoperation
- The voltage indications of the bus bars (out/under)
- The topology of the part of the network before the fault.

The base of rules will work on this base of facts and the reasoning is made on :

- the status of the network before the fault
- the status of the network after the fault

Format A

Outline of Expert System Projects (France-3)

Outline

The expert system does not try to explain how the fault has been eliminated nor to examine the correct or bad operations of the protections. Its targets is to give the localization of the initial fault.

The diagnosis are of these types :

1) Fault on the line AB
2) Fault on the line CD
   Non opening of breaker C causing a false bus bar fault in substation C

So the expert system does not use the date and time (with a resolution of 10 ms) given by the RTU within the change of status message.

4.2 - The characteristics of the expert system

The expert system used has been developped by EDF's Research Department.

It is an inference engine working in forward chaining with a knowledge representation based on production rules in first order logic and facts written as triplets <object, relation, object>.

The expert system has been written in Pascal, because LISP and PROLOG are both programming language that may be used :

- to represent the knowledge

- to write the inference engine that will use this knowledge.

So they are a compromise to reach these two objectives and they are not optimal on each of them. This is why many manufacturers of Expert Systems are now translating their own programs in classical programming languages such as Pascal and C language.

4.3 - The response time expected

When EDF envisaged to use an expert system for alarm handling, one of the main concern was the response time of the system. How much time would it take to give a diagnosis ?

A mock-up has been made on a IBM 30.90 (28 MIPS) with a base of rules and a base of facts considered as representative of the future system, and the response time was 100 ms to give a diagnosis.

According to the available power on the computers that will be used in the new control centres, we may say that the response time of the expert system will never exceed two seconds.

Format A

Outline of Expert System Projects (Ireland-1)

Outline Alarm Processor at National Control Centre

The newly commissioned National Control Centre has a greatly increased number of alarm possibilities over its predecessor. A particular problem exists with voltage alarms which are of individual interest under normal conditions but at time of system disturbance are widespread but of little immediate interest to operators. The problem arises because of the isolation of the Irish power system and the relatively low density of load in the predominantly rural environment.

The priority of other alarm and event indications should also vary depending on system conditions.

No decisions have yet been made as to how these problems will be dealt with, but an expert system is seen as a likely system.

Similar problems have been encountered in our modern power stations and development of a system which is portable is being considered.

Format A

Outline of Expert System Projects
(Italy-1)

Outline Computer Aided for Small Load-Flow

The purpose of the project is to analyze the possibility to develope an Expert System to be used by planning engineers to manage load-flow calculations.
The first step will consist in the selection of a convenient Expert System Shell to be choosen among those available respecting the costraints of portability on PC XT/AT, Apollo and connection with Fortran routines.
The Expert System Selected will firstly be applied at a very small network model consisting of only two busses; a sending end with a generation transmission and a receiving end with load connected with a line.
We expect that this very simple network model will be very useful to develop an experimental expert system and we think to obtain useful responses about benefits and costs.
On the otherside this simple model it's sufficient in our opinion, to generate a complex logic tree with all the constraints and rules, generally applied in planning studies to reach an optimal solution. In case of positive results in this first step we plan to expand the model to a bigger and more realistic one.

Format A

Outline of Expert System Projects (Italy-2)

Outline TRIAL (Terminal Resources Intelligent Allocator)

The electricity distribution network of Italy is currently being equipped with a distributed telecontrol system allowing full control over the net operation by a small number of district centers. In the frame of a multiannual development plan, many thousands of primary substations, performing high (130 KV) to mean (15 KV) voltage transformation and routing, have to be equipped with a Remote Terminal Unit (RTU), in charge of sampling signals relevant to substation state, transmitting the state to a Central Control Unit (CCU), located in the district centre, and actuating the commands transmitted by the CCU.
Prior to installation, the RTU is configured according to the substation composition, using a definite set of electronic printed boards, each one featuring a different number of input and output connectors. The substation is composed of a variable number of elementary components (e.g. voltage transforming, bus-bars, translation lines, etc.), each one featuring a fixed number of state on-off signals, measurements, and oontrol signals, to be connected to the RTU. All the signals coming from a given substation component have to be connected to a single RTU input or output connector.
The RTU configuration problem consists in determining the minimum set of boards able to interface all the signals provided by a given substation configuration. Configuration of an RTU is quite a long and cumbersome task, when performed by a human operator. It involves a combination of natural problem solving skill, heuristics, and a great deal of compiled knowledge derived from experience. Invention of an automated solution to the problem at hand clearly brings about many benefits, ranging from a sensible saving of human resources to standardization of the solutions.
Configuration problems, as well as many other problems investigated by Artificial Intelligence (AI), typically generate very large search spaces. AI has provided many different approaches for effectively performing search in a large state space, like problem decomposition, pruning, backtracking, heuristic search, etc.
In particular, heuristic search methods of AI (Pearl, 1984) are a formal approach to search problems, which guarantee, under certain conditions, an optimal search for an optimal solution.
Operational Research branch-and-bound methods provide, from a different perspective, basically the same properties. Both methods were considered in a first attempt to solve the RTU configuration problem; the A* heuristic search algorithm resulted however, under the admissibility condition, inadequate to solving the problem at hand due to the very high computational resources required (Antoniotti, 1986). A* heuristic search algorithms require to embody the problem solving heuristics into a function that provides an estimate of the overall cost of every alternative path; the approach chosen in TRIAL (Terminal Resources Intelligent Allocator), differs from the ones mentioned above in that heuristics is expressed by a set of rules instead of being more formally identified by means of a numeric function. TRIAL approach does not grant neither the optimality of the search nor the optimality of the solution; on the other hand, it provides some well known benefits of expert systems. In fact, as heuristic knowledge is expressed in a symbolic, declarative language, it is easy to understand, to maintain and modify, and may provide explanations to the solutions found.
The resulting search strategy adopted by TRIAL can be assimilated to hierarchical constraint directed search (Fox and Smith, 1984): the overall oonfiguration problem is partitioned into two levels; heuristics, once applied, provide a partial high level solution which bounds the search space of the bottom level, where a hill-climbing search strategy is adopted.
In addition to the problem solver above summarized, TRIAL features a user interface structuring the dialogue for describing the substation to be controlled. The substation is represented as a set of interconnected components. Every component is an instance of an abstract data type, which describes any relevant attribute of a component class, like voltage transformers, bus-bars, etc. The user interface checks the user provided system description, basing on a set of consistency rules that are expressed with the same formalism used for providing the heuristics that partition the search space. In fact, components of given types, and of given attribute values, constrain other component types and attributes.
Summarizing, both the substation structure, which is described using a taxonomy of component types, and the problem solving strategy, which is based on a partitioning of the problem into hierarchical levels, were posing similar requirements on the representation language. This should allow to represent the hierarchical dependency between subproblem levels (hence the relevant problem solving heuristics), as well as to describe the substation components as instances of predefined classes of objects, and each class as an instance of a parent class, with specific attributes possibly overriding the parent class attributes.
The solution adopted in TRIAL is a simple frame-based language similar to XRL proposed by Charniak, Riesbeck and Mc Dermott (1980).
TRIAL has been developed in Kyoto Common Lisp on a Sun-2 workstation. Its knowledge base, containing a taxonomy of about 300 objects and 100 consistency and configuration heuristic rules, has been fully validated by experts on a meaningful set of test cases for one RTU type, the TIC-1000/2.
Full development of TRIAL, prior to introduction of the system to its intended end users, involves construction and validation of version for the other four RTU types which are operated by ENEL, and transportation on the target hardware, a DEC MicroVax-II.
This development is currently in progress, and is provided to be accomplished within 1987.

Format A

Outline of Expert System Projects (Italy-4)

Outline PROP

The cycle water of a power plant must comply to strict chemical specifications, in order to preserve the materials constituting some critical subsystem (e.g., the tubes of the boiler, the rotating parts of the turbine, etc.). The chemical specifications of the cycle water may be affected by different kinds of polluntants that can enter into the cycle:

- salts, carried by the cooling water (marine or river water) entering from leaks in the condenser;
- oxygen and carbonic dioxide, contained in the air infiltrating in the low pressure parts of the cycle;
- the prefilter and the powdex, containing cellulose and pulverized resins, coming from the filters included in the chemical treatment subsystem;

Pollution phenomena are controlled by continuous measurements of several chemical parameters (total conductivity, cation conductivity, oxygen concentration, etc.) at several points of the cycle.
To clean the cycle water whenever it is affected by pollutants, a chemical treatment system is included in the plant. It is constituted by three kind of filters; the mixed bed, containing ion exchanging resin, the prefilter, using cellulose, and to the powdex, using pulverized resin. The filters must be inserted when a pollution phenomena affects cycle water. The detection of pollution phenomena and the managing of the chemical treatment system in order to face the anomaly require, in addition to the competency of the plant operator, the availability of specific chemical expert knowledge.
This is led CISE to develop PROP, an expert system that, exploiting the competencies of a chemical expert, gives advice to the operator of a power plant in the early detection and proper managing of cycle water pollution phenomena. PROP provides the following functions:

- monitoring of the cycle water chemical characteristics, acquiring the chemical parameters values directly from the sensors;
- detection of abnormal situations and diagnosis of the malfunction(s) causing the anomaly. If the information available do not allow to insulate a single cause, PROP presents to the operator a set of hypotheses that can explain the malfunction;
- suggestion on the proper interventions to be undertaken when an abnormal situation is present. The interventions are suggested taking into account the overall plan status, the chemical treatment system status, and the pollution diagnosed by PROP.

PROP is a real-time, on-line expert system, and its diagnostic activity is largely based upon observation of the temporal evolution of the system. PROP knowledge base refers to a 320 MW production group, with fossile drum steam system.
PROP has been implemented in Franz Lisp (a Lisp dialect) on a SUN-2 workstation. Its architecture integrates three different representation formalisms:

a) a language centered around the concept of component, for describing the model of the physical system (the water cycle) under consideration;

b) a procedural language based on event-graphs, a Petri-net-like formalism specially suited for dealing with time varying situations where sequences of events must be represented;

c) a production rule language, for representing declarative and fragmentary knowledge.

After an extended evaluation in a simulated environment, the system reached the field test phase that is performed on the group n. 4 of Fusina power station, where a PROP prototype has been working since January 1987.
There are currently over 10 plant malfunction classes that can be diagnosed by PROP. PROP is also able to deal with a number of sensor malfunctions (e.g. exhausted resin of the cation conductivity sensors, sensor decalibration, etc.).

Format A

Outline of Expert System Projects (Italy-5)

Outline TVM (Turbogenerator Vivration Monitor)

The turbogenerator is one of the most complex and critical subsystems of a thermal production plant; it is composed of 3-5 coaxial stages (low, medium, and high pressure turbines, and generator), each one supported by a couple of oil film bearings. Almost all known turbogenerator malfunctions result in an alteration of the vibrational state of the machine during operation. Since mid-sixties techniques for an early diagnosis of turbogenerator have become available. They are based on vibration analysis and require monitoring a large number (over fifty) of variables. Some of them concern the overall state of the machine (rotational speed, power produced, bearing alignment); other are relevant to the single bearing and provide detailed information about the shaft vibration (amplitude of the overall vibration; amplitude and phase of the first and second harmonics), as well as about the oil film state (temperature and pressure of the oil film). Once the sensors are installed, the machine is periodically inspected during measurement campaigns performed by means of a data logging and processing system; this system performs, on-line, a spectral analysis of the vibration; sampled and computed data remain available on a mass storage for the diagnostic analysis, usually performed by comparison of plots (against time or rotational speed) of many different variables.
At present, the task of analysing these data is carried out by a diagnostic technician, who, however can be present on the plant only for short periods, normally during periodic plant inspections. Diagnostic technicians require a long and expensive training, mainly based on first hand, in-field experience. Scarce availability and long training required by human experts also provides a motivation for a knowledge-based approach to the design of turbogenerator diagnostic equipment.
This lead CISE to develop TVM (Turbogenerator Vibration Monitor), an expert system for the early diagnosis of turbogenerator's malfunctions. TVM, that has reached the stage of a complete prototype, has been developed under commitment of ENEA, the Italian National Committee for Nuclear and Alternative Energies. The system is based upon a commercial expert system shell, SAGE, developed by Systems Designers (UK).
TVM has been designed as an intelligent aid for the apprentice diagnostic technician; it drives the apprentice through the process of analyzing the data base acquired during a measurement campaign, selecting the diagrams to be consulted, and the symptoms to be evaluated on each plot, in order to ascertain a given malfunction hypothesis, like mass unbalance of the rotor, shaft bending; cracks, rubbing due to bearing displacement or misalignment.
TVM is a pure consultation system. The data interpretation process, i.e. the extraction of significant qualitative features from numerical data is left to the user. This clarifies the main limitation of our prototype system: it does not embody one of the most significant expert's capabilities, that is singling out and evaluating symptoms. TVM performance can be summarized as such:

1) it can be consulted either about baseline drafting or diagnosis.

2) In the latter case, data relevant either to a transient condition, or to the stationary operating condition, can be analyzed. Generally speaking, the former are used to confirm and refine a diagnosis referred to a stationary condition.

3) The diagnosis process always starts asking the user to single out the main malfunction symptoms (i.e., whose vibrations, temperatures, or oil pressures are out of the limits of the standard operating condition). This allows TVM to focus on a set of malfunction hypotheses. On this set, a backward chaining search process is performed: further facts (e.g.; analysis of the 1st and 2nd harmonics amplitude and phase trends, presence of subharmonics, machine stage mainly affected by the anomaly, bearings alignment, etc.) are asked to the user, until either a single hypothesis is given a credibility value beyond a prefixed threshold or the set of remaining facts to ascertain is empty.

Current TVM version contains a body of diagnostic knowledge which refers to about twenty different malfunction causes. This knwoledge can be considered as completely settled and unambiguous, in the sense that it is agreed upon by all the expertise sources known to the authors; a number of known pathologies, with a poor experiential support, has been purposely excluded from the TVM knowledge base. TVM knowledge base consists of about 200 rules; the system runs on DEC Vax and PDP-11 machines.

Format A

Outline of Expert System Projects
(Japan-1)

Outline R & D of a practical expert system for planners of bulk power system operation

Power system operation planning is decided by executing many computations repeatedly using various types of analytical application software for short circuit analysis, power flow computation, stability analysis, etc. and by overall evaluation of the system reliability and economy on the basis of experience from studies in the past.
Then, the objective of this project is to improve the efficiency and accuracy of the power system operation planning by applying the knowledge engineering to the following tasks: tasks which need many complicated steps for evaluating the planning alternatives by using a set of software, and tasks which need empirical and heuristic knowledge of human experts accumulated in the past.
The prototype system shown in the figure consists of several subsystems as follows:

- System structure planning
  - Reduction of short circuit capacity and heavy overloads in the emergency state.
- Active power scheduling
  - Countermeasures against single circuit fault.
- Reactive power scheduling
  - Proper voltage control in the normal and emergency states
- System stabilizing planning
  - Stability check and its improvement.

The knowledge-based system stores the empirical knowledge of human experts in the form of production rules and the inference engine calls up application software depending on the contents of the rules in the knowledge base. After executing several computations and checking problems revealed by the result, the system infers an operation planning alternative to offer a conclusion to the expert planner. The system planner evaluates the alternative in the light of his long experience and makes his decision on the final operation plan.
Presently, the prototype system has been constructed and is being tested for its function and effectiveness. Based on the result, a practical system will be developed in the near future.

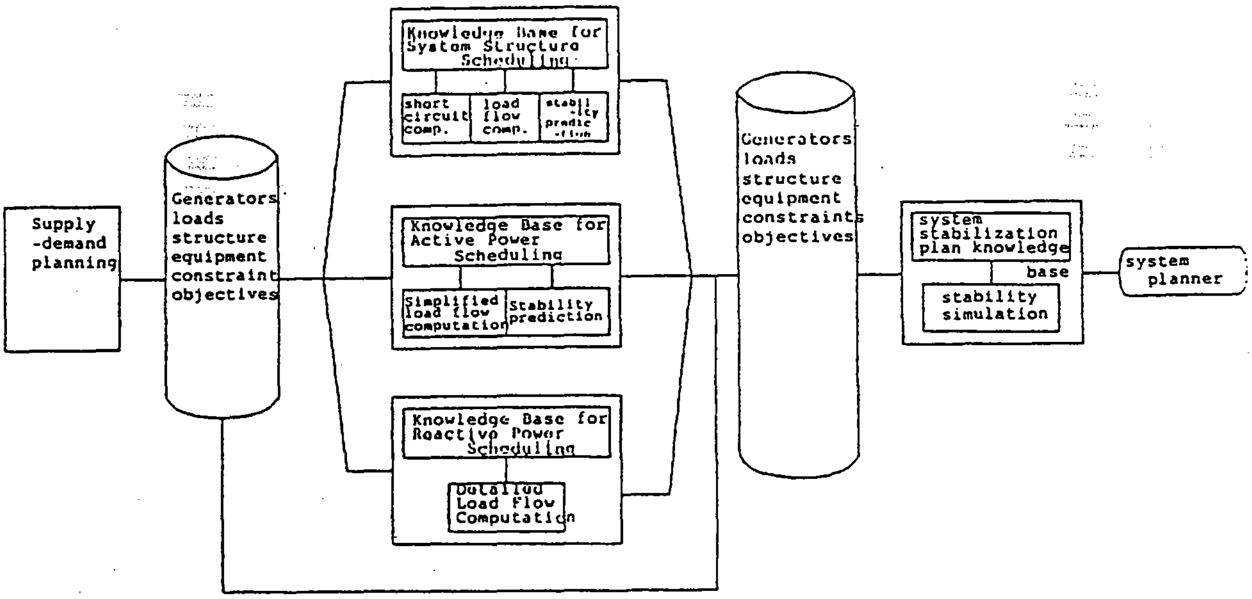


Fig. Expert system assisting system operation planning in large scale power system (Prototype system)

Format A

Outline of Expert System Projects
(Japan-3)

Outline Maintenance Scheduling Support Expert System

1. Introduction
With the enlargement of power system size and the enhancement required of system funstions, system operation personnel is concentrating his effort on the maintenance of system reliability and the improvement of system operational efficiency by utilizing knowledge about the system and heuristic knowledge obtained from the system operation. Above all, operation planning tasks have been bothering system operation personnel because of their difficulty in uniquely making decisions of a system plan, which is related to a variety of tasks in relevant departments. In this project, an expert system has been proposed for assisting the system planner in checking the feasibility of the maintenance scheduling as a decision support tool.

2. System configuration
The system configuration is shown in Fig.1. Emphasis has been put on the improvement of interface with system planner in an interaction mode, because an intelligent & friendly interface encourages the planner to use the system. To equip the workstation with an intelligent interface, interactive communication function (i.e., special feature of a workstation), image representation function and editing function enabling the operator to write memorandam are scheduled to be assembled into the interface module. Through the interface, the following three functions will be at the disposal of the user:

(1) Scheduling support function for maintenance scheduling
(2) System data base function
(3) Simulator function.

System data base and simulator are usually called up by the scheduling funciton, but can be used directly by the user. The system has been developed on a Symbolics 3600.

3. Inference mechanism for maintenance scheduling
The inferencr for maintenance scheduling is triggered by the input of a maintenance scheduling plan and the inference engine offers coarce scheduling plans for the unit commitment as output. Next, by checking the system reliability, and identifying bottlenecks, plural possible maintenance scheduling plans are presented by the proposed system. These plural plans are filtered out to select a candidate plan to be evaluated by the system planner for the final decision. If the result is not feasible, return to the first step (Fig.2).
Information exchange in the inference cycle is made through the blackboard. In Fig.3 is shown the unit commitment scheduling. System structure is expressed in the form of the frame representation in the system data base as in Fig.4.

4. Remarks
Presently, analysis of the maintenance scheduling tasks, listing-up of necessary functions and conceptual design of the system are underway. The next step is to implement the system on the Symbolics 3600. The intelligent interface should be friendly to the user rather than convenient to the system developer.

Format A

Outline of Expert System Projects
(Japan-3)

Outline

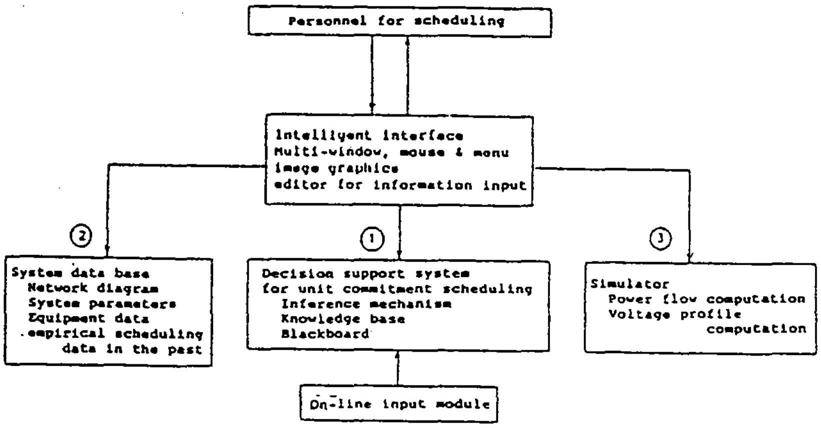


Fig. 1 System configuration

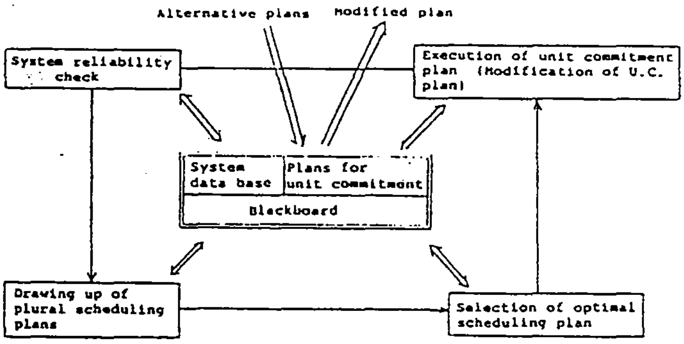


Fig.2 Inference cycle for unit commitment scheduling

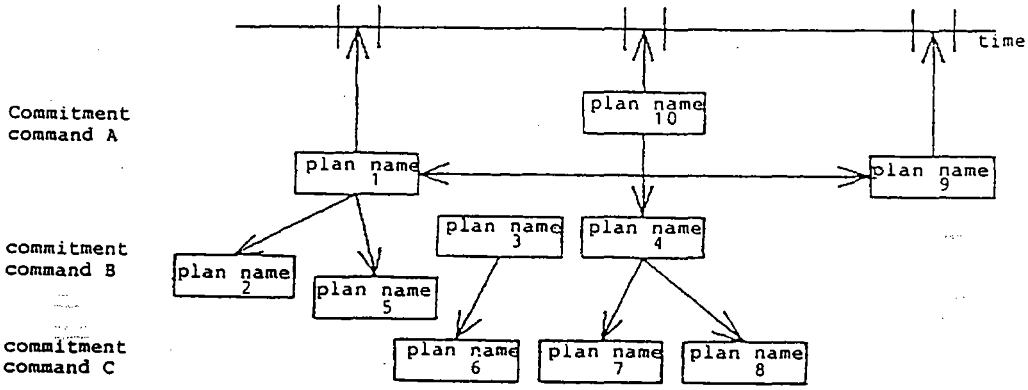


Fig. 3 Unit commitment scheduling

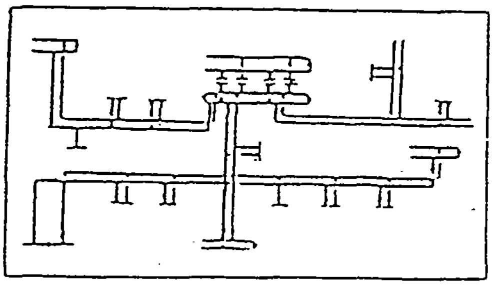


Fig.4 An example of system data base

Format A

Outline of Expert System Projects
(Japan-5)

Outline Guidance System for Restoration in Control Center

Features of Restoration Guidance System

1. Restoration guidance system which can be applied to all kinds of outages (from local outage and overload to a large scale blackout)

2. Exert system which is capable of using many analytical tools (nonlinear programming, advanced load flow calculation, etc.) on request depending on the power system situation.

3. High speed processing capability

Procedure for Restoration Planning

Step 1. Selection of buses to switch off

Step 2. Selection of a generator with maximum capacity available for restoration

Step 3. If the capacity of the generator is sufficient, restore the bus which had been switched off. Go to step 1.

Step 4. If the capacity of the generator is not sufficient, several loads connected to the bus which had been switched off are shed to avoid generator overloading, and then the bus is switched on for restoration. Go to step 1.

Procedure for Restorative Operation Guidance

Step 1. Identify set of CB's which need the restorative operation based on comparison between a restoration plan and an actual system situation.

Step 2. Select those CB's which are allowed to be operated in the light of system situation out of the selected CB's.

Step 3. Determine a set of CB's to be used for actual restorative operations according to the priority of individual CB's.

Step 4. Display the restorative operation guidance by presenting information on reactive power requirement and load capacity which can be restored.

Format A

Outline of Expert System Projects
(Japan-6)

Outline Restorative Control Support System for Power System

System Outage Location Module

A decision support system for the restorative control has been constructed to be incorporated into an automated dispatching system in the central dispatching offece.

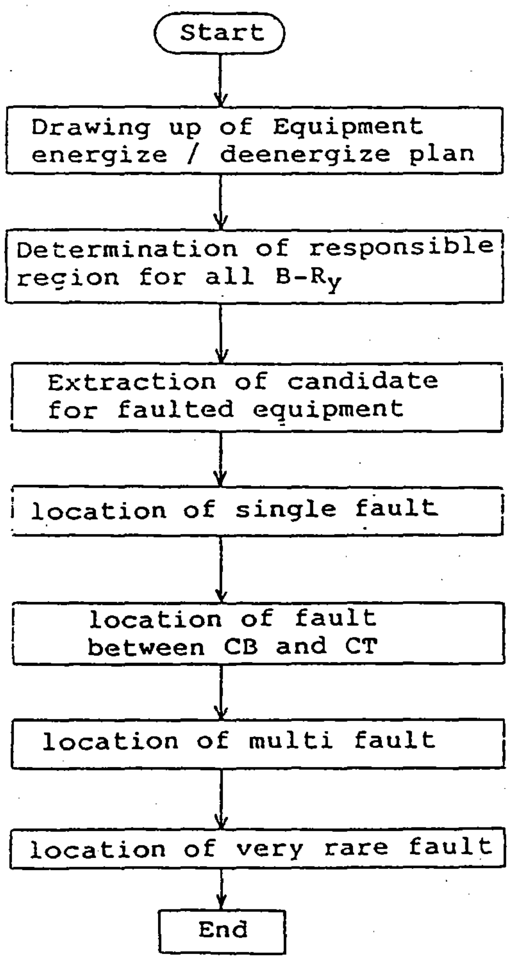
The system comprises two algorithms: one algorithm for discriminating the faulted section and fault situation on the basis of the information on a set of CB's and protective relays following the system fault occurrence, and the other algorithm for determining optimal restorative strategy suitable for the system fault under consideration. Presently, a prototype system based on the former algorithm for the fault location has been completed.

Conceptual flow of the system's processing is depicted in the figure below and features of the system can be summarized as follows:

(1)The proposed system is inteded to be applied to 500KV/275KV-level trunk systems, and the system has been designed to use the information including the protective relay (main protection, back-up protection) scheme which is responsible for bus-, line- and bank levels, status of reclosing, etc..

(2)The algorithm is also capable of treating CB failure, malfunction and inaction of protective relays.

(3)Very rare failure such as a failure between CB and CT and a short circuit by flash-over between CB poles can also be discriminated in the system.



Format A

Outline of Expert System Projects
(Japan-8)

Outline Power System Restoration Support System

1.Outline of the System

Power system fault location system described here and power system restoration support system are combined on a TOSBAC-DS 600 so as to work an integrated system (which is referred to as power system fault location and restoration support system hereafter) capable of locating the system fault and presenting a system restoration procedure continuously to the operator.

The integrated system assists the judgment of operators in the restorative state by identifying the fault situation and presenting a list of the restoration procedures by using on-line information on the fault and empirical knowledge of veteran operators accumulated in a computer.

The on-line information comprises the status of those circuit breakers and protective relays which have been operated, and the telemetry on voltages and line flows. Expertise and empirical knowledge on system equipments, protective units and system operations have already been collected and stored in the computer.

The inference mechanism infers using both the information and the knowledge, and presents a list of the restoration procedures based on the information on faulty equipment and fault situation, followed by the conclusion of the inference.

2.System configuration

2-1 Hardware configuration

Hardware configuration of the system is shown in Fig.1. The on-line information is taken in through a Tele-Control (TC) unit.

2-2 Software configuration

As shown in Fig.2, I/O module which processes the on-line data obtained from a power system and extracts the facility's data to be used in the inference cycle, has been written in Fortran in order to attain fast response in processing. And the inference module which infers using a set of knowledge stored in the knowledge base, has been written in Prolog. By selecting suitable software configuration for bringing each software's function into full play, the proposed system has attained fast processing and flexibility in case of change in opreration rules and system components.

The inference module consists of two parts: fault location system and restoration support system. Each part has been written in different types of language suitable for the inference, and the functions in respective parts are independent of each other.

Inference time is 20-50 seconds for the fault location system and 3 minutes for the restoration guidance system even for a single fault case (single circuit fault in a double circuit line).

3.Processing of Power System Fault Location System

The fault location system consists of a knowledge base for fault location and an inference mechanism. Input data are information on operated circuit breakers and protective relays. The system is triggered by intaking both of two data, and the system outputs the status of faulty components and fault situation following the inference. In the inference cycle, the possibility of malfunction and inaction of relays is also identified.

4.Processing of Power System Restoration Support System

The restoration support system consists of a knowledge base for system restoration and an associated inference mechanism. Knowledge for restoration is expressed in the form of production rules written in Prolog because IF-THEN form is convenient for the knowledge representation. Input data at the system initialization include conclusion of the inference on the fault location and status of circuit breakers and protective relays. Based on the initial data, the restoration support system infers by identifying the system state changing with the lapse of time, and presents a list of the restoration procedures.

Format A

Outline of Expert System Projects
(Japan-8)

Outline

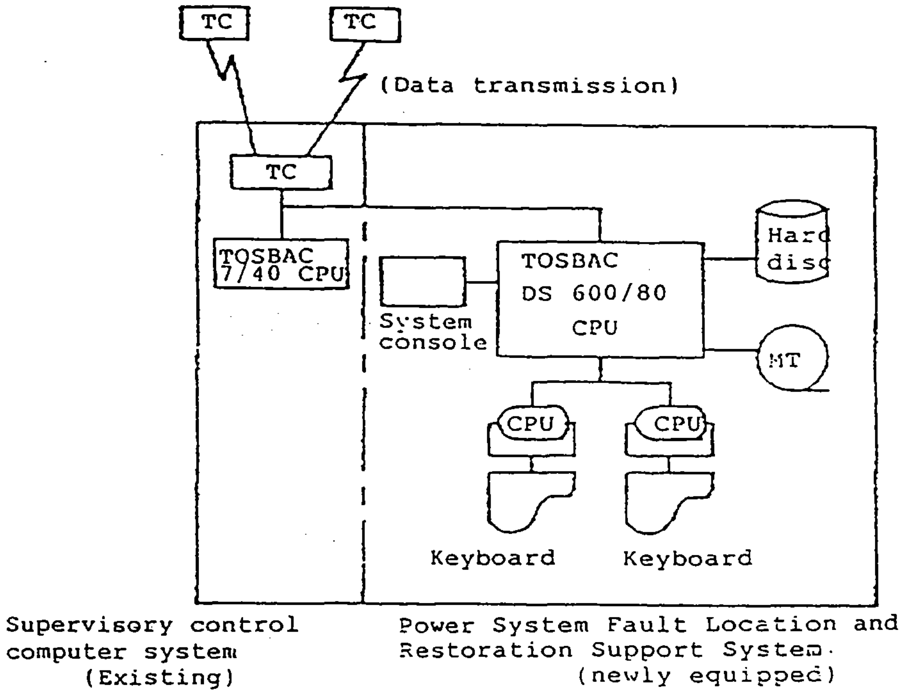


Fig. 1 Hardware Configuration

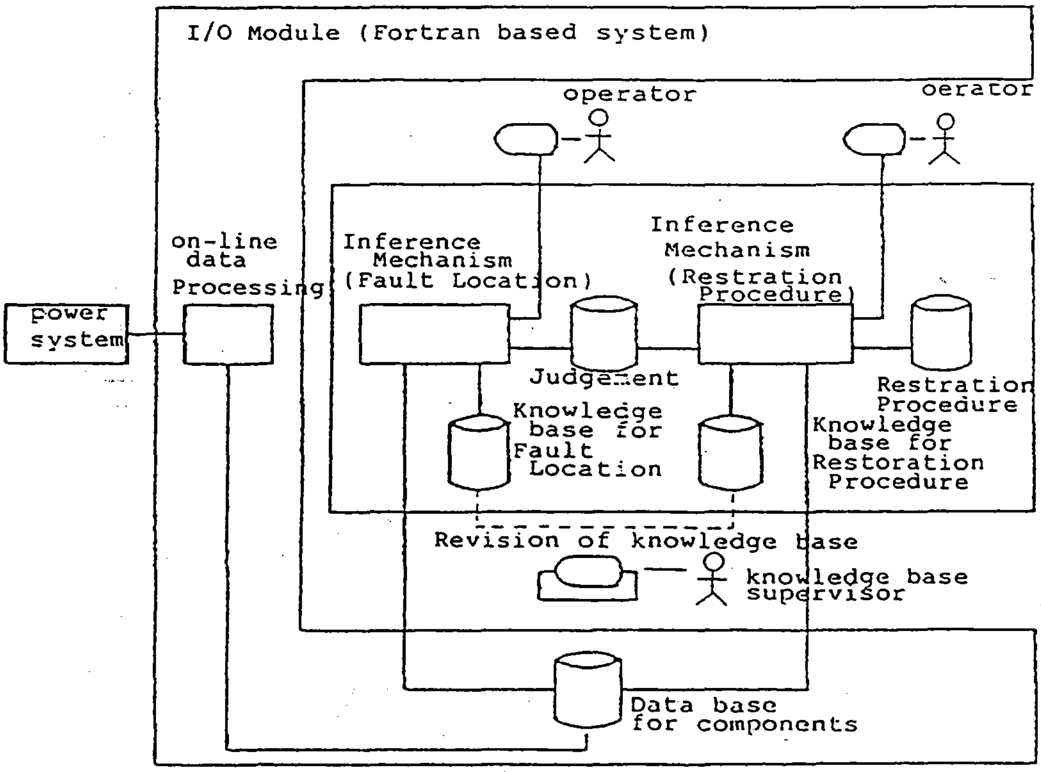


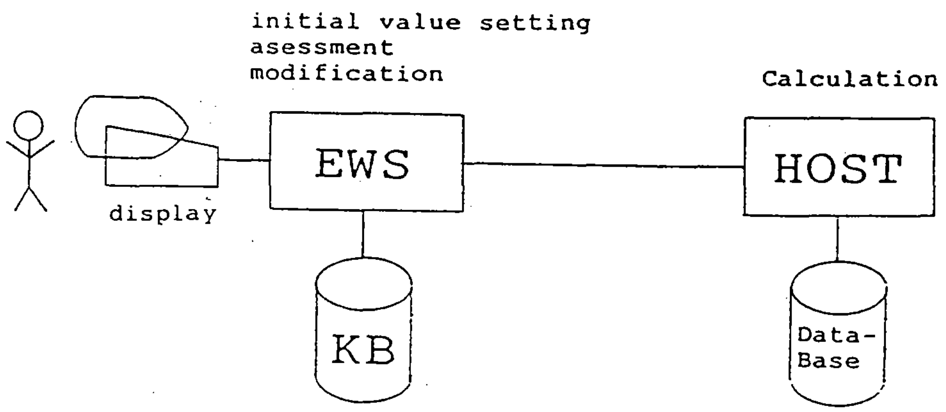
Fig.2 Software configuration

Format A

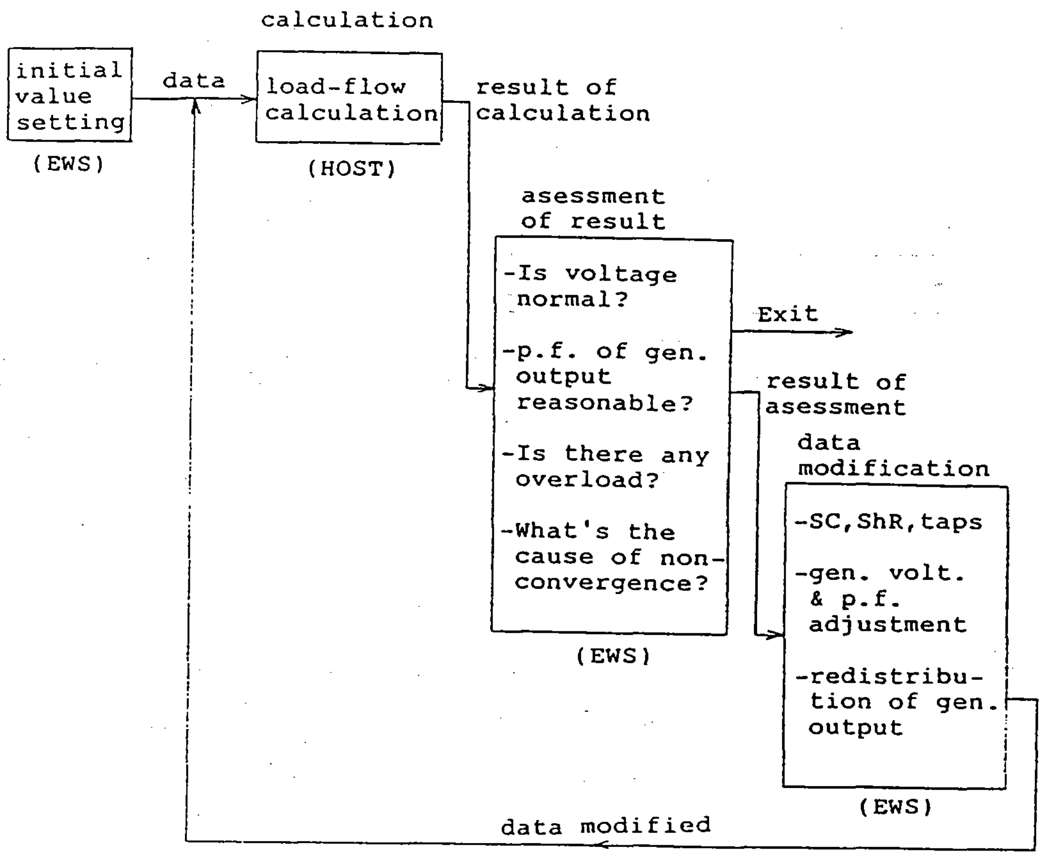
Outline of Expert System Projects (Japan-9)

Outline Support System to Aid Daily Planning of Unit Commitment

Schematic Diagram of System Structure



Flow of Information Processing



Format A

Outline of Expert System Projects
(Japan-10)

Outline Advanced Analyzer of Power System

Advanced Analyzer of Power System

No. 1053 (IEEJ National Convention Records 1987)

Intelligent, Man-Machine Interaction Based Software Package For Power System Analysis

By T.Fukui and J.Kawakami
(Hitachi Research Institute, Hitachi Works, Japan)

1. Introduction

With the recent development of engineering work stations equipped with flexible icons and mouse, interactive-type analysis systems have been developed intensively. This paper is reporting an intelligent, man-machine interaction based power system analysis system with knowledge base, which have been implemented on an UNIX-EWS (Hitachi ES-330) equiped with multi-window and multi-task functions.

2. Outline of System

Power system analyses often put a heavy burden on the back of inexperienced analysts and in some cases on experienced analysts, since an extensive knowledge of electric circuits and know-hows as well as experiences on power systems to be studied and required. This analysis system is aimed at guidance to be needed for power system analysis and advice on the asessment of analysis results.

3. System Structure

The analysis system comprises two parts, namely, Analysis and Inference Engine as shown in Fig.1. These parts ususally work independently of each other and they communicate with each other when required. The analysis part serves in a highly efficient interactive environment using (i) the pop-up menue & icons, (ii) output tables, (iii) windows for message output, (iv) mouse/keyboards, etc.

The editing of power system structure is based on the object-oriented concept as shown in Fig.2. The editing proceeds by generating bus or generator as an instance of the object, and by operating on them. Fig.3 is an example of system structure editing under way.

The numerical analysis part supports engineers in such calculations as short-circuit capacity, load-flow of dc & ac types, frequency response, and dynamic stability. Analysis programs can easily be added to extend functions.

4. Inference Engine

Inference engine has been written in Prolog and it is executed as a UNIX process. The inference engine exchanges information with the analysis part using such communication links as pipes and signals, thus enabling us to monitor how far the analysis has progressed. Further, the inference engine can control the flow of analysis by asking the analysis part to execute specific functions, as if the user is controlling the flow of analysis by selecting specific icons.

Format A

Outline of Expert System Projects
(Japan-10)

Outline

The features mentioned above may be summarized as follows:

(1) Capable of guiding the user in selecting analysis methods,
(2) Assesment of calculation results and guidance in obtaining improved results,
(3) Automated execution of a pre-fixed sequence of analyses.

5. Conclusion

Upgrading of the I/O interface is under way to make use of the function of the EMTP program. A Knowledge base is also being developed which can support plural kinds of analyses. A scheme of knowledge acquisition is planned which is capable of automatic learning of analytical techniques involving a lot of know-hows.

6. Reference

[1] Kono et al: "Development of expert system which supports power system analysis"(in Japanese), IEEJ paper B-105, p.705, August 1985.

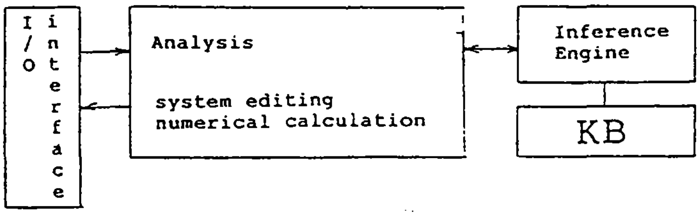


Fig.1 System Structure

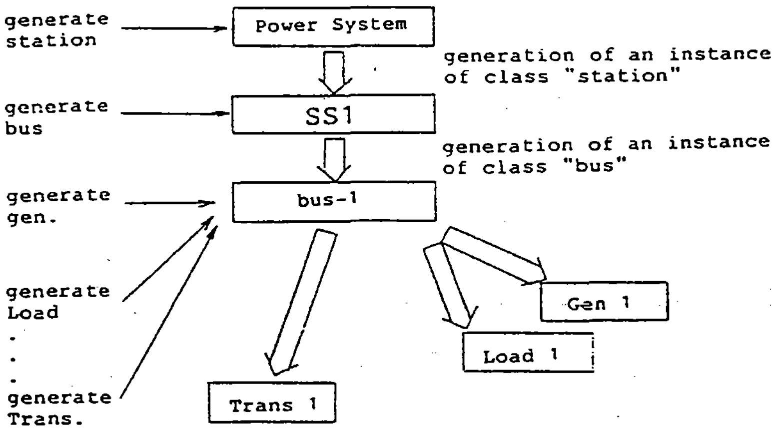


Fig.2 Outline of generation of instances to represent object

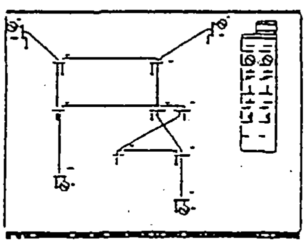


Fig.3 CRT display of system structure editing under way

Format A

Outline of Expert System Projects
(Japan-11)

Outline Expert System for Power System Analysis (Avalo)

Newly developped load flow engine is an expert system that is embedded in the personal workstation and intended to be used for consultation of load flow planning. The objective is to provide both an expert and novice user with a friendly planning environment,aiming at enhancing a user's creativity. We believe that cognitive science and artificial intelligence play a central role to realize such an environment.
Cognitive science tells us what in the planning process should be assisted and artificial intelligence provides us with the better tools to implement.

Task Analysis of Planning Work

Fodor explains human cognitive process with the concept of input modules and central system. Hearing,sight,touch,taste,smell and language modules act as an input to the central system. Based on the abstract data from input module,the central system solves a problem. Many previous works on interactive software and hardware have contributed mainly to the input modules. What is needed,however,is to assist the problem solving process of the human central system.

Expert System for Intelligent Load Flow Engine

The knowledge which an expert uses in the reasoning process is represented as a set of rule and fact. An expert system makes inference reasoning just like an expert does using the rules and facts in its knowledge base.
The intelligent load flow engine has been developped to assist the load flow planning. The functions of the engine are to edit data,run the load flow program,graphically draw output of the load flow and give a consultation to a user.
Load flow planning is usually divided into two phases of load allocation and var compensation. Two problems arise here that are over-loading and voltage violation. Basic idea to get around an over-loading is to increase generation at the outflow side of the line and decrease generation at the in-flow side. For over-voltage is a countermeasure to increase nearby shunt reactor. These ideas are stored in the knowledge base in the form of rule together with many other heuristic rules and facts.
An example of consultation to relieve the over-loading is to be explained. A line that is over-loaded is enclosed with the dotted line, and bus whose voltage goes beyond the voltage limit is indicated with a large reversed bus symbol. A recommendation is shown on the map with up/down arrows and the amount of bus injection. Arrows are used to show that the generation should be increased/decreased by the specified amount to prevent the over-load.
If a user wishes to know how to get the recommendation,he can touch a menu of 'How'. Then the engine will tell a user all rules step by step that were used along the reasoning process.

Conclusions

Cognitive science and artificial intelligence provide the power system engineers with a new engineering methodology. The intelligent load flow engine is a good example to demonstrate the possibility of an expert system.
It contributes to increasing the productivity and creativity of power system planners.

Time Consumption

It takes about five minutes to get final pattern of load flow for 300-bus system.

Format A

Outline of Expert System Projects

(Japan-13)

Outline On-line ELD for thermal Power Plants

Abstract: Nowadays, owing to the increase of the share of nuclear power plants in power systems, thermal units are asked to play a more important role in load following capabilities satisfying various operating conditions. A new ELD scheme with a 2-level structure is proposed.

A: The on-line ELD for thermal units, especially coal-fired units, have to satisfy operating constraints such as:

(1) Upper & Lower bounds of output zones ($\bar{P}$,$\underline{P}$) in a unit,

(2) Maximum change-rate of output (dP/dt),

(3) Preparation time required for changing the no. of coal-mills and burners corresponding to the output level,

(4) The time required for switching of output zones,

(5) Minimum time required for a unit to stay within a specific output zone due to the constraints of operational conditions and auxiliaries.

B: Further, in order to implement a (semi-)automated ELD for thermal units, the following functions are required from the viewpoint of man-machine interface:

(1) Improvement of man-machine interface (CRT display) which gives operators a bird's-eye-view type information,

(2) Considerations for acquiring the confidence of operators in automated ELD.

This paper presents a new algorithm of the ELD which can deal with all the functions mentioned above, by adopting a 2-level structure, the upper level and the lower level.

Upper level The upper level gives operators a bird's-eye-view type information concerning the ELD by adopting the phase plane (P,dP/dt). See B.(1) above.

Lower level On the lower level, based on the commands coming from the upper level, the ELD solutions including the optimization along the time scale, are calculated in detail.

The lower level can deal with the following functions:

(1) The mismatch between prediction of total system demand $\hat{P}$ and total output of thermal units, is made as small as possible,

(2) Overlapping or gap between output zones of a thermal unit can be dealt with,

(3) Knowledge engineering based on the experience of operators can also be incorporated into the switching of output zones of a generating unit.

The proposed 2-level structure ELD method requires a small amount of calculation time, and is suited for on-line use. This proposed method is under study as a key function of R & D aiming at the advanced automated operation in a utility.

Format A

Outline of Expert System Projects

(Japan-14)

Outline Intelligent Monitoring & Alarming of MW & MVar Stabilities in Power Systems

Abstract: This paper presents the following two types of intelligent monitoring & alarming (intelligent M & A) schemes.

Scheme 1: M & A of MW instability Power systems have originally many kinds of nonlinearities. It is very useful for judging power system stability to monitor the real parts α_k of a set of eigenvalues($\alpha_k+j\omega_k$) at each time point along the daily load curve. Nevertheless, the transmission characteristic $P=V_iV_jY_{ij}\sin(\delta_i-\delta_j)$ can not be ignored, which is unique to the functions of a.c. networks. When a specific relation between the imaginary parts ($\omega_1,\omega_2,\cdots$) holds, auto-parametric resonance can occur after a transient fault, which is a kind of nonlinear renonance, which causes energy exchange among some dominant modes, leading to unstable phenomena. Based on the confirmation of the auto-parametric resonace in theory, simulation & laboratory experiment, it is proposed to use the following criterion for montoring MW stability:

If $|\sigma|>\sigma_{crit}$, then the system is in the normal state;

If $|\sigma|\leq\sigma_{crit}$, then the system is in the alert state,

where $\omega_k=\omega_l+\omega_m+\sigma$: resonance condition, σ_{crit}: critical value of σ, $\omega_k,\omega_l,\omega_m$: dominant natural frequencies, σ: detuning parameter.

Scheme 2: M & A of MVar instability (voltage instability) Voltage instability is a dynamic phenomenon by nature. It has been confirmed by simulations that this type of instability is triggered by ill-conditioned load flows (static problem) which usually appear during heavy load period. Ill-conditioned load flow patterns are closely related to multiple load flow solutions from the analytical viewpoint. During a heavy load period, only a pair of multiple solution vectors exist. A solid angle θ made by these two vectors, singular vector $y_{singular}$ and specification vector y_{spec}, are defined Voltage Instability Proximity Index as a quantitative measure of the proximity of voltage instability. Based on the above, it is proposed to use the following criterion for monitoring MVar stability:

If $\theta>\theta_{crit}$, then the system is in the normal state;

If $\theta\leq\theta_{crit}$, then the system is in the alert state,

where $\text{VIPI} \triangleq \theta = \cos^{-1}\dfrac{(y_{spec})^T(y_{singular})}{\|y_{spec}\|\cdot\|y_{singular}\|}$, θ_{crit}=critical value of θ

y_{spec} : specification vector in load flow calculation,
$y_{singular}$: singular vector in load flow calculation.

These two types of M & A of MW and MVar instabilities to be carried out at each time point along the daily load curve are proposed as intelligent M & A.

Format A

Outline of Expert System Projects (Japan-15)

Outline ESSE : Expert System for Security Evaluation

When a power system is adjusted likely to shift an emergency state on account of some outage arising in it, it is necessary to carry out some countermeassures of before the outage takes place in order to improve the existing system state to a safer condition. Such system security evaluations should be undertaken by contingency evaluation in which power flow computations are repeated many times and by computer simulations of transient system stability computations. By such means control must be performed so that secure system operation will be possible regardless of the outage that might arise. However, dealing with massive quantity of data makes overall grasp of the results difficult, and this requires high-level knowledge of experts and their accurate appraisal of the situation. But at such a time, much depends on the knowledge and judgment of an individual, and since there is a limit to personnel accommodation under the emergency state, accurate appraisal becomes difficult. In this study security index for indicating the state and action of the system will be taken into account, and looking into the method of achieving overall discernment of security on the basis thereof, its applicability to the expert system will be discussed.

The system proposed herein will be a system of security evaluation feasible to parallel use of a large number of evaluation techniques, including pattern recognition approach.

These evaluation function patterns will be combined with the expert system in order to make possible high-speed security evaluation and optimal on-line control. This knowledge enginnering approach is a new technology aimed at automating the inference of experts having domain-specific knowledge, and it is attracting attention in recent years. If it should become possible to process expert knowledge with a computer, outstanding efficiency and speed upgrading will be achieved, and while making possible power supply service of high economic feasibility and reliability, it will also give rise to hopes for high-order system operation.

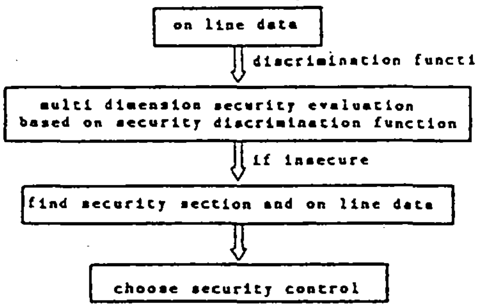


Fig. A flow chart of forward reasoning

In present study, basic inquiry for processing security evaluation procedures by logical programming has been undertaken. The classification functions identify instability factors and furnish information useful to security improvement. Incorporation of multiple security indices into the system leads to accurate grasp of the system state, and adoption of the classification functions under pattern recognition make possible high-speed and optimal security control by backward reasoning. In the present study, system security evaluation based on the classification functions have been shown to be computations of various kinds are to be further promoted, introduction of pattern classification function is to be undertaken and case study simulations of this system and the how and why functions are to be replaced. Incidentally, the software SOOTFW developed at the University of Hirosima has been used for power flow computations.

The proposed system is capable of performing the detection of voltage problems and the application of empirical knowledge to come up with appropriate control actions. The pattern recognition of techniques have been applied to be system security analysis. Artificial Intelligence (AI) has been an active area of research in recent years. Significant progress has been made in the development of the expert or knowledge-based systems.

Format A

Outline of Expert System Projects

(Japan-17)

Outline Knowledge based training system for power system operation

This system has three modes as follows;

(1)Simulation mode
(2)Tutorial mode
(3)Inquiry mode

In the simulation mode, the system carries out any command in the same way as the actual 1:N centralized supervisory controller does. Namely, if a command given by a trainee is feasible, then the system carries out it, and reports the result of the command to the trainee. In this mode, the trainee operates the network by himself without any guidance.

The tutorial mode is the central part of the system, and is the closest to the actual training process. The system asks a trainee to restore the network for one of faults prepared in advance. If the trainee could complete the restoration, the system evaluates the operations done by him. If not, the system generates a model restrative process, and show it to the trainee. By the trainee's request, the system explain the reason why each operation is necessary. Thus the trainee can train in the same environment as the simulator practice under the guidance of a skilled operator.

In the inquiry mode, the trainee requests the system to do some task, then the system generates a series of operations to do it, and presents them to the trainee. The system explains each operation by the trainee's request, again. The trainee can learn many processes for shifting the network from one state to any other one, and he can get much knowledge on ordinary switch operations as well as restorative ones

Format A

Outline of Expert System Projects
(Japan-18)

Outline Intelligent Support System for System Analysis

(1) A trial of expert system application to operation planning of generation

The objective of (Daily) Operation planning is to assign an appropriate no. of generating units to a daily load curve predicted one day ahead. Guidance system for a feasible operation planing should be so designed as to improve the economy of system operation while satisfying various constraints. Major constraints, which are centered around the start & stop of generators, may include:

(i) Min duration time of unit operation after paraleling with the network,
(ii) Min duration time of unit being out of service
(iii) Max load pick-up rate, etc.

In some cases, special constraints such as indicated below have to be taken into account:

(iv) Limits to the water flow to be used at hydro plants,
(v) Availability of operating personnel,
(vi) Constraints on the amount of fuel to be fired, etc.

Concerning inprovement of the economy, following items need be considered:

(i) Order of priority of unit to be put in service.
(ii) economic load sharing amoung units participating
(iii) start-up and shut-down costs, etc.

Furter, Maintenance of security level is required such as balance between supply and demand, supply of reliable electric energy to the customer.

To the type of problems mentioned above, the Dynamic Programming and other traditional numerical methods have been applied. Successful and practicable algorithms are not available yet due to the difficulty of handling the constraints. Our research group is developing a system which finds out feasible solutions using LISP and PROLOG. In an approach based on LISP, items are being studied such as setting of generator data, representation of operation rules, tree structure representation of unit combination, time-wise backtrack search.

A program written in PROLOG has been developed for the same type of problem as above, and it was applied to a small sample power system having one nuclear, three thermal and two hydro units. Example of feasible solutions is listed below. The research group is investigating an algorithm which determines operation planning policy with the combined use of knowledge engineering based processing and the traditional procedural processing.

Outline of Expert System Projects
(Japan-18)

Outline

```
2 load 1800
2 parallel(thermal2 nuclear1)
2 standing-by()
2 start(termal3)
2 stop(hydro1 hydro2 thermal1)
2 state(nuclear1 parallel -110)(thermal1 stop2)(thermal2 parallel -1)
       (thermal3 start -3)(hydro1 stop 0)(hydro2 stop 0)
RULE 21 SELECTED
RULE 42 SELECTED
RULE 51 SELECTED
RULE 61 SELECTED
2 load 1800
2 parallel(hydro2 hydro1 thermal2 nuclear1)
2 standing-by(thermal1)
2 start(thermal3)
2 stop()
2 state(nuclear1 parallel -110)(thermal1 stop 2)(thermal2 parallel -1)
       (thermal3 start -3)(hydro1 parallel 2)(hydro2 parallel 2)
CHECK 1 OK
CHECK 2 OK
```

(2) Application to Optimal Unit Commitment
of a Group of Generatiors

Unit commitment of a generator comprises 4 actions, namely,

(i) synchronuzation,
(ii) stop,
(iii) start &
(iv) stand-by.

Following each action, the generator has to stay in that particular state for a minimum amount of time to be specified in advance. An additional cost will be incurred in case of the start & stop operation of a unit. Each unit after synchronization is asked to supply such an amount of electric energy that results in the most economical dispatch of the total system operation.
Procedural & numerical selection of the optimization problem mentioned above requires a prohibitive no. of descriptions of constraints on the unit commitment, thus leading to a lower efficiency of the software. An alternative way of solution may be the design of a program called "generator" of unit combinations to be put in service. The program will be written with a declarative language such as PROLOG. A proposed set of combinations will be tested against a coarse check of economy, thus producing only a limited no. of candidates, followed by optimization to be carried out by the procedural processing using FORTRAN. A research work is going on along this line.

Format A

Outline of Expert System Projects
(Netherlands-1)

Outline Exformer / an Expert System for Transformer Fault Diagnosis

In a recent report of the Electrotechnical Research Department of the N.V. KEMA [1] the need to get acquainted with developments in Artificial Intelligence (AI), was expressed. Particularly, it was mentioned that expert systems, being one of the most promising products of AI, will play a significant role in the fiel· of electrical engineering. Actually, some papers on this subject have proven the applicability of expert systems in the field of analysis of power systems [2, 3]. As a result, a pilot project has been started: one of its main objects is to gain insight into the methods and techniques used in expert systems. In particular, the strategy of rapid system development has been chosen for a specific domain, namely diagnosis of transformer faults or malfunctions from observables. It was thought that this problem is relatively simple or, at least, can be narrowly defined.

In electrical power systems, power transformers belong to a class of very expensive and vital components. Recognize for example, that the outage of a large power transformer may cost a company 100 millions of dollars. Therefore, it is of great importance to minimize these outages by as many means as possible. In practice, this is realized for instance, by the well-known transformer protection on which much effort has been expended in reaching a high degree of reliability. Oil-filled transformers in service are also monitored by applying oildissolved gas analysis for the detection of incipient faults. Based on this analysis, the transformer can be suspected enough to suggest a close inspection. Close inspection may also be inferred from other data such as strange transformer noises and other irregular transformer behaviour; in the worst cases, inspection of an exploded transformer is required. In general, all possible steps for improving the availability of power transformers are worth being considered, even in the worst case of the transformer bein· irrepairably damaged. In this case the cause of the damage can be important as far as the serviceability of other transformers is concerned. Obvisiously, a system containing knowledge of this domain would be of great importance to an electrical engineer.

This paper presents an expert system, called Exformer, to assist the engineer in judging faulty transformer conditions. Exformer infers deficiencies in large power transformers and their underlying causes based on specific transformer knowledge and data which is potentially noisy. For this purpose the specific knowledge domain is sub-divided into the following main areas:

- gases dissolved in oil
- external investigation
- internal investigation.

The knowledge of these three areas has been mainly elicited from the transformer experts within N.V. KEMA. The analysis of gases dissolved in transformer oil is generally accepted and experienced as a sufficiently reliable method for the detection of incipient faults in transformers. In Exformer, three methods of interpretation of the ratios of gas contents have been implemented [4-6]. Special attention is paid to the processing of the uncertainty in these ratios. Specifically, ideas adopted from the fuzzy set theory are used in the reasoning algorithm. In so doing, a margin of uncertainty can be built in the answers given by Exformer.

Like the gases-dissolved-in-oil-area, the two remaining areas allow for the inclusion of vague statements. These are concerned with the detection of the most likely fault and its underlying cause. In most cases, the track set by outcomes of the gases-dissolved-in-oil-area is followed in the fault-finding process.

Evaluation

The prototype of Exformer has shown that expert systems can be of great help in transformer diagnosis, in particular, when the electrical engineer wants to consult the chemical engineer for the gas analysis (and vice versa). Moreover it is realized that expert systems provides the means of improving the quality of diagnosis (of standard cases), since the line of reasoning can be made visible.

Fine tuning of diagnosis rules will be more aesier with an expert system approach if in this approach a data base is used in which records of transformers are being kept. These records must contain all data needed for transformer diagnosis and must continuously be updated whenever a transformer is being investigated. Having access to these records, diagnosis rules can relatively be easily improved, or even new rules can be generated - for instance, by using existing methods for classification.

Finally, it is realized that in practice the success of these kinds of consulting systems depends on their userfriendliness and in this case also on the ability of automated reporting. In discusions with the experts (and users) all these aspects will be worked out.

Format A

Outline of Expert System Projects
(Netherlands-2)

Outline: Expert system for Network restoration: interpretation of faulty states

An expert system is developed which task is to assist operators in the interpretation of power systems in faulty states, especially when the system has entered the emergency state due to great disturbances. Under these circumstances the answer to the most simple and obvious question "what has happened?" is not straightforward. Great disturbances are often initiated by simple faults: when for some reasons these simple faults cause directly or indirectly the outages of a considerable number of system components - mostly this has to do with failure of the primary protection -, one may speak of a serious disturbance. One of the first things an operator will do in these cases is trying to get an understanding of what has happened by trying to give satisfactory, i.e., consistent, explanations of the available information. In particular, he will try to reconstruct and explain the sequence of component outages, reasoning about a very broad range of subjects such as for instance alarms, data of the protection system, status of circuitbreakers, the topology of the network, etc. It is obvious that an expert system assisting the operator in his inferrings about the system would be a valuable support. An expert system is being developed which gives interpretations of power system in faulty states using information of the protection system. The expert system will also propose suitable actions to restore the black out area.

Outline

The promising developments in the field of artificial intelligence (AI), especially expert systems, have also been recognized by electrical engineers. One of the main characteristics of expert systems is their ability to reason about a process or a system. To do so, an expert system uses knowledge - mostly elicitated from experts - which is stored in what is called a knowledge base. This outstanding characteristic, its inference mechanism, makes expert systems very powerful tools to study the behaviour of complex systems (or systems in complex situations), especially when this means reasoning about the system.

As expert systems and other AI-offsprings are now coming to maturity, there has been a renewed and growing interest in problems which did not or hardly lent theirselves to a conventional computer approach. On of these problems in the electrical world is the comoputerization of a restoration plan.

It is the wish of every operator to have in emergency and restorative states of the power system computer assistant which is as reliable as computer monitoring and control are in the normal state. Knowing that emergency control is hard to deal with - to prevent further outages, islanding and load shedding are used as last resort -, the problem of network restoration will be attacked. It should be noted however, that due to the abundance and variety of the data on the basis of which decisions have to be made, computerization of network restoration plans still is an immense but challenging problem.

It was not until the emerging of new methods and techniques from the AI-field that engineers really feel that the restoration problem, or generally speaking, problems for which no general or satisfactory algortihms exist, can adequately be attacked by the computer. Briefly stated, the AI-products (expert systems) are sufficiently flexible to cope with several tasks such as diagnosis, interpretation, prediction, planning, design, monitoring and control [1]. Notice, that when restoring a power system somehow and somewhere in this proces these tasks must be fulfilled.

When a system disturbance is serious enough to cause a considerable blackout area, one of the first things an operator does is trying not to feel inconvenience with this unusual and undesired state of the system by looking for a suitable and consistent explanation of what has happened. If he can deduct the cause of the outages of the system components he is confronted with, he can decide which restoration scenario should be operative. He will also know how to adapt the actions of this scenario to the actual situation.

As already mentioned, actions during the restoration process are based on information of diverse nature. Generally speaking, the operator bases his conclusions and actions on information from an EMS system and human observations. Notice at this point, that carrying out a restoration plan basically implies, taking components into service without violating any (system) constraints due to this action. It is not unconceivable that under the stress imposed by the circumstances operators sometimes make wrong decisions. Expert systems for power system restoration can make the work of operators under these circumstances easier.

Two main tasks of an expert system for power system restoration will be focussed on. One task of the expert system is trying to understand the state of the power system at any time in the restoration process. Like the operator the expert system uses information of the power system to interprete a certain state. In the expert system being developed information of the protections system and circuit breakers is mainly used for the interpretation. Actually, the work that is being done, is an extension of Fukui and Kawakami [2] in that more type of relays are being considered, while the knowledge base will be richer. The other task naturally follows from the essence of restoration. This task of the expert system consists of proposing a sequence of system components (being members of a blackout area) to be re-energized, or a sequence of control actions (power and voltage control) to be taken.

The actions related to these proposals will be checked by the expert system: none of them will cause a violaton of constraints. The first knowledge based approach of this task has been given by Sakaguchi and Matsumoto [3]. This concept will be further worked out using PROLOG, since PROLOG offers a more convenient way of handling system descriptions, while the well-known concept of the IF-THEN rules can also easily be applied.

Format A

Outline of Expert System Projects
(Norway-1)

Outline Intelligent Operator Assistant

SINTEF-GRUPPEN

AN INTELLIGENT OPERATORS ASSISTANT

The Intelligent Operators Assistand (OPA) is schematically shown in figure 2.

In general the "Assistant" is continually available for the operator at his desk in the control centre, in the form of a graphic screen with mouse and windowing facilities. "He" acts as an assistant supplying his master with informatin and performs computational work in order to analyse and solve a specific problem.

The "Assistant" is activated on request from the operator, or performs system surveillance functions in default mode, asking for the operators attention if a problem is discovered.

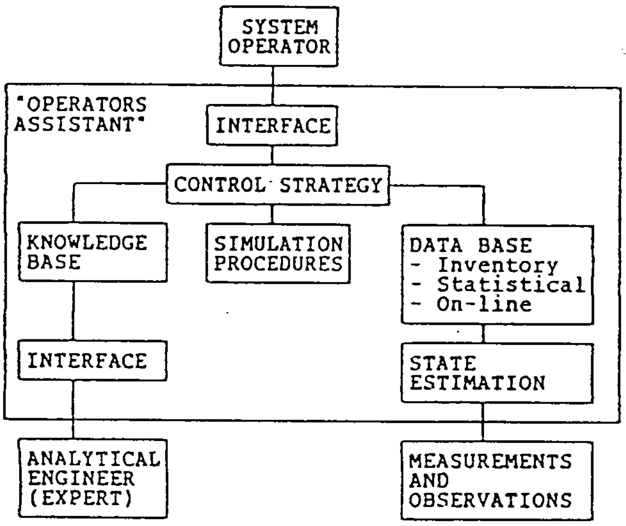


Figure 2: Intelligent Operators Assistant (OPA)

Typical tasks for the "Assistant" are to:

- provide the operator with information about the current state of the power system
- provide an easy access to available tools for analysing the situation
- give advice on how to focus on problems and problems areas, perform an analysis and propose remedial actions to a problem encountered.

The application of expert system techniwues can be grouped into the three following areas.

A flexible and user friendly interface.

The interface has the shape of an Intelligent Front-End (IFE). It covers all the interaction between the "body" of the "Assistant" and the user. Implementation of such a concept offers several advantages.
- Simple automated startup of programs.
- No need for extensive knowledge of input formats and program command sequence setup.
- Input data checked for correctness and consistency.
- Extensive help and explanation facilities.
- Compact presentation of relevant results.

Using Expert Knowledge and Operator Experience.

A special feature of expert system techniques is coding of knowledge in symbolic form. With "symbolic knowledge" is meant experts experience and knowledge expressed in formal statements that can be read and manipulated by a computer.

One type of knowledge is that gained by an operator after years of experience:

- general knowledge about bulk power system performance characteristics both at the component and system level
- knowledge about performance specifically applicable for the system in question.

Another type is the knowledge the analytic engineer uses when he faces with a problem sets up a sequence of analysis that produces results needed to derive a solution. He uses knowledge about:

- modelling on system and component level
- problem solving strategies
  * how to decompose a complex problem into subparts
  * how to interpret the results in order to identify a solution or adjust the problem solving strategy
- problem solving procedures
  * which problems they can solve
  * which input is needed
  * restrictions and simplifications
  * which results are produced
- knowledge about what he knows (meta-knowledge)

A Control Strategy for Efficient Use of Available Analytical Techniques.

To set up a sequence of activities that will produce results needed to solve a stated problem is a typical expert task.

Techniques for organising sequences of activities for solving a problem, or in other words, reaching a goal, has long been an area of research within the expert system field. Backward chaining rulebased systems and blackboard techniques seems for the moment to be the most promising.

Format A

Outline of Expert System Projects
(Sweden-1)

Outline DUBA

ABSTRACT.

The aim of the project is to give support for operators in power system restoration. The power system has two main characteristics, it is complex and dynamic system. The power system must be controlled, operated, planned and analysed.

Operator's control are usually separated in three main parts: Normal operating, interrupted operating and system restoration after a outage.

The operation and control are based on human decision. The decisions is usually a combination of human knowledge and mathematical programs such as loadflow, optimisation etc..

For the system restoration there are special operator instructions which guide operators when they make their decisions. An interesting issue is that these instructions are based on simple and general rules for different kinds of disturbances.

This project aim's at making an automatic system which is able to generate the operator's instruction for a specific power configuration. The rules should be general and portable. We are now working on the first prototype.

Format A

Outline of Expert System Projects
(Sweden-1)

Outline

PROPOSED EXPERT SYSTEM APPROACH.

An expert system operational aid can be to get a quick view over the situation and then to provide a suggestion to operators so that the interrupt time is short. This is very important when larger part of the system are interrupted and a large number of customer is disconnected.

In general the expert system approach is beneficial for problems that involve nontrivial reasoning and human knowledge. The power system restoration problem possesses the following features which suggest an expert system approach.

1. The restoration problem deals with the selection of the most suitable way between two nodes which should be energised, which object (lines, loads etc.) should be connected. The problem involves more logic reasoning and only minor numerical computation.
2. The power restoration requires the operator's judgement on system capacities and specific system or customers information.
3. It is difficult to formulate the configuration restoration as a mathematical programming problem because of its combinatorial nature.

Outline

POWER RESTORATION.

The first prototype contains some assumptions which are presented here:

* A simplified power system configuration is used.
* The system starts deenergised.
* When loads are going to be connected the user consult a loadflow program outside the expert system.

To energise the system with considerations to the assumptions, the following rules are developed.

General rules for strategy.

Nuclear power:
IF nuclear power plants which are not energised exist, THEN nuclear power should have the highest priority (safety reason).

Hydro power:
IF hydro power plants which are not energised exist AND all nuclear power is energised, THEN hydro power should have the highest priority.

Thermal power:
IF thermal power plants which are not energised exist AND nuclear and hydro power are energised, THEN thermal power should have the highest priority.

Loads:
IF there is enough power for frequency control, THEN connect load up to 50% of the total energised power.

Format A

Outline of Expert System Projects
(Sweden-1)

Outline

Rules for nuclear power:

IF nuclear power has the highest priority AND there are more then one plant, THEN choose the most suitable station (in our case the most northern station).

IF a nuclear power station has been found, THEN select the closest energised or self-starting hydro station.

IF a nuclear power station AND a nearest station has been chosen, THEN select a suitable way to energise the nuclear power station. This suitable way is then selected by another rule set.

This were some of the general rules that are implemented. There are more rules about power stations, how to choose the most suitable way, how to connect loads and lines, what to do when lines can not be connected for some reason etc.

Outline

IMPLEMENTATION.

The implementation of an expert system involves a number of issues, e.g computer language, knowledge representation, validation of accuracy and performance evaluation. In this study, we have chosen two languages KEE (IntelliCorp) and Epitool (a Swedish system made by Epitec). The languages selection is appropriate because in planning a restoration you need to use both forward and backward chaining. These two methods are embedded in the tools and they are used in the same ruleset.

Besides rules, we use frames to represent the knowledge about a power system. The frame based representation is very suitable because of the structure of a power system. Today our system includes the thirty most important rules.

Format A

Outline of Expert System Projects
(Sweden-1)

Outline

CONCLUSION.

This first prototype has not been completed yet but it shows that expert system techniques are suitable for power system restoration. We have constructed a knowledge base which contains rules that implement a solution approach that the operator can use to restore the power system. The developed rules are general and portable in the sense that they do not depend on any particular system. The accuracy of the knowledge base and reasoning process has not been validated yet but it will be soon. In this first prototype we have not considered the speed of the system.

In the future, with a system like this it should be possible to replace the operators instruction pages with an expert system. The expert system should collect information about the disturbance and decide the severity of it and then perform a suitable power system restoration with respect to the situation.

Format A

Outline of Expert System Projects
(Swiss-1)

Outline Artificial intelligence techniques as an aid to security analysis

Project objectives

To determine the power system security state, load-flow computations are usually performed. Security analysis requires a systematic evaluation of contingencies, therefore a very large number of computations, for interconnected systems.
To obtain efficient computation tools, research in the last twenty years has concentrated on the development of fast numerical methods for solving the load-flow problem. In security analysis, by numerical methods, the knowledge acquired from past situations is not taken into account. Nevertheless, the experience of the control center operator or the engineer is used to help solving difficulties, such as non-convergence, overloads, voltage problems. His knowledge of the likely most severe contingencies helps in reducing the number of outages to examine.
The objective of the project is to take advantage of the experience of the operator in security analysis, and to store and use knowledge of past situations, using AI techniques.

Format A

Outline of Expert System Projects
(Swiss-2)

Outline Expert system in PROLOG for alarm handling in a substation

Substation monitoring and decision making in normal operating state are relatively easy tasks for a human operator. On the contrary, in the case of major disturbances, the operator is no longer able to analyze correctly the large flow of information issued from various alarm devices, and consequently to determine the sequence of interventions in order to bring back the system into normal state.

Recent artificial intelligence techniques can help solving such a problem, using an expert system for improving decision making. The expert system is based on a functional modeling of the elements of the substation. Thus the topology of the substation, the causality relationships of failures, the alarms issued, and the sequences of actions required to manipulate an element are defined. The modeling and a program in PROLOG to generate the information are discussed.
The expert system is composed of four different parts :

- Acquisition of the susbstation topology and of the alarms activated.
- Alarm reduction, determination of the causes of the alarms, and of the elements unavailable due to failure.
- Search for new configurations to satisfy the functions of the substation.
- Determination of the sequence of switching operations to return to the normal state.

Format A

Outline of Expert System Projects
(U.K.-1)

Outline An Expert System for Security Assessment in Operational Planning of Power Systems

This research project aims at the development of an expert decision-support system, which integrates numerical algorithms and logic programming to assist in the decision-making process during the operational planning stage of electric power systems.
The main areas of research, which fall under the steady state security assessment function are:

- Determination of weak boundaries due to active power. Weak boundaries (which depend on current operating conditions) are normally found in interconnected power systems. Simple rules can be used to identify such weak boundaries in order to carry out a more detailed analysis of critical cases.
- Identification of strong/weak areas due to active power [1]. In a power system, there are areas which are stronger/weaker than average. Identification of critical areas in terms of their export/inport flows and the balance between load, generation and reserves would give the planner a general description of the performance of the power system under the planned operating conditions.
- Rule guided heuristic search to handle the evaluation of second contingencices. The selection of potential candidates from the large number of outage events that may violate the security of the power system is a crucial step in security analysis due to the combinatorial explosion of the problem.

Consideration of reactive power/voltage effects is an area worthy of study for further development of the system.
In emulating the way in which an engineer analyses the power system, the expert system chooses the most appropriate algorithm (model) for a particular task, examines the results and determines if a more accurate algorithm (deeper model) is required to produce more reliable results.
The expert system will be developed in POPLOG, a programming environment which offers several artificial intelligence languages and allows routines written in conventional languages to be linked. Pascal has been chosen for the implementation of numerical algorithms and interactive facilities, and Prolog will be used to develop an expert system based on rules and frames.

Format A

Outline of Expert System Projects

(U.K.-2)

Outline O.C.E.P.S (Operational Control of Electrical Power Systems)

The system is currently only in the setting-up and language evaluation stage. Already OPSS has been rejected, PROLOG appears to suit our needs better. We are at the moment waiting for the arrival of POPLOG so PROLOG may be evaluated in this environment.

Format A

Outline of Expert System Projects

(U.K.-3)

Outline Power plant diagnosis using a qualitative model (IQA)

The knowledge represented is the correct behaviour of each component in the plant area concerned. This is expressed in incremental qualitative analysis as sign-value equations, 'CONFLUENCES'.
Fault detection involves determining if the observations are consistent with correct behaviour (constraint satisfaction). If they are not, a fault is present.
Fault diagnosis suspends constraints (confluences) representing the correct behaviour of components until consistency is achieved. The diagnosis is then the components suspended.
Structural knowledge about the interrelationships between components is used to schedule a search order for diagnosis.
The expert system has been applied to a PWR pressuriser sub-system. The time for detection and diagnosis of single failures is only a few (2-10) seconds for the XEROX implementation.

Format A

Outline of Expert System Projects

(U.S.A.-3)

Outline Monitoring PowerSystem Stability based on Voltage Phase Angle measurement from important major regional substations and generation plants

An Expert System provides an opportunity to develop real-time Power System Stability Index (SI) based on real-time Voltage Phase Angle measurements. This SI will be useful during normal and emergency operating conditions by indicating the state of the power system.

An Expert System will use this information and guidelines from off-line stability and load flow studies to make recommendations for increased load transfers and control actions to limit the extent of a power system disturbance.

Format A

Outline of Expert System Projects

(U.S.A.-5)

Outline Near real-time monitoring of sequential events from major intertie substations

The monitoring of sequential events with 1 ms. resolution provides a powerful analysis tool for monitoring stability controls, complex protective relaying, critical alarms, breaker operations, and standing orders. The use of expert system technology can facilitate the automatic analysis capability to assist the Dispatcher in making decisions to restore regional interties, to improve power system reliability, to restore generation and loads; and to call out appropriate operational and maintenance personnel.

Accurate data should be available to the Dispatcher within 60 seconds from the time the disturbance occurred. A minor disturbance can involve the processing of 900 sequential events from 2 substations.

Significant economic benefits can be achieved by the timely and accurate Dispatch decisions to restore regional interties. This information can be used to minimize equipment damage and reduce overtime call-out expenses.

Format A

Outline of Expert System Projects

(U.S.A.-6)

Outline Development of Knowledge Based Systems for Electric Utility Operation using the PROLOG language

The objective of this research project was to investigate the desirability of developing knowledge based systems in the PROLOG, PROgramming in LOGic, language for electric utility system applications. Two major steps were completed to achieve this objective.

To demonstrate the desirability of the PROLOG language, a protection system simulator and diagnostician were developed along the lines of EPRI RP1999-7. This application revealed the speed and ease that rules developed by relay engineers could be translated into rules in the PROLOG language.

Finally a demonstration volt/VAR dispatch knowledge based program was developed in PROLOG. Volt/VAR dispatch is the process of maintaining an acceptable voltage profile in an electrical grid. As a part of this expert system, it was shown that a FORTRAN power flow program could be easily interfaced with the PROLOG expert system. It was shown that a realistic model of an electrical system and its interconnections could be utilized. The knowledge base for the volt/VAR dispatch program and the data base for the power flow program were similar in size to the on-line power flow program utilized in the Load Dispatch Office of the Union Electric Company. The results of the simulation indicated that the decisions reached in the volt/VAR dispatch program were consistent with the operation of a control center. The results of the power flow program compared favorably with the results obtained at Union Electric. This study resulted in the conclusion that PROLOG is a highly desirable language with which to develop knowledge based systems for electric utility system applications. The development of knowledge based systems in the PROLOG language for an operator's assistant should be pursued. Higher levels of logic should be incorporated to develop schemes and plans to control the sequence in which rules are executed so that a wider range of problems and conditions could be evaluated.

Format A

Outline of Expert System Projects

(U.S.A.-7)

Outline Application of Expert System for Short Term Load Forecasting

Several electric utilities in the United States apply demand charge on the basis of coincidental peak demand. The hour during which the utility experiences the highest load (MW) for the month is defined to be the peak hour and this MW value is referred as the "Peak Hour Load" (PHL). The hourly demand meter readings for a month of the particular consumer (e.g., industrial or commercial customer, wholesale purchaser, etc.) are examined to determine their load during this peak hour. The demand charge is computed on the basis of the consumer's contribution to the PHL. Thus it is very valuable for the concerned consumer to receive advance information about this PHL.

We have developed a rule-based forecast (upto 24-hour lead time) for the Virginia Power service area. This is based on the expert knowledge of the operator, and the inference generated from the database of the historical load, weather parameters and other pertinent information. See Rahman and Bhatnagar (1) for further details. This forecast is being used by Old Dominion Electric Cooperative in Richmond, VA to help in their direct load control strategy to minimize their contribution to the system peak hour load. This research started in late 1984 and the system went on-line in early 1986. Detailed description about this work can be found in reference 2. In the process of developing this system and subsequent monitoring we have archived Virginia Power load and relevant weather data for one and a half year's now.

We have continued to work in this area and improved our load forecast accuracy based on the insights gained in the process. We have also programmed some analogical thinking and heuristics, as used by the system operator, into the software. Some of the major considerations that have guided us to the present state of the forecast software include the following.

1. Perform as much off-line computation as possible;
2. Use one-to-two weeks' worth of historical load and weather data for on-line computations;
3. Provide automatic rule updating features; and
4. Implement the software in such a way that it is easily transferable from one computer to another.

Due to the dynamic nature of the relationship between utility load and its governing functions it often becomes necessary to retrain a knowledge-based system. For this purpose a rule revising mechanism is built into the software such that pre-selected rules can be modified if these continue to produce average forecast errors larger than 3% over three consecutive days. This feature is specially useful during the days of season change-over. The error tolerance and duration are to be selected carefully lest we start to follow the noise in the load.

In developing the knowledge based software so far we have intentionally avoided using any expert system shells or traditional AI languages like LISP and Prolog. Rather we have tried to analyze the problem, study its idiosyncrasies and the cause-effect relationships of electric utility load. We have applied statistical packages, intuition and heuristics to develop rules and implemented the software in a UNIX environment using Extended Fortran (EFL) and C languages. We have attempted to fashion tools to reflect the structure of the problem, not the other way around. The result so far has been encouraging.

The expert system based approach to adaptive load forecast will be able to provide choices among plausible alternatives and, if necessary, retract the inferences, undo the effects, and make new choices based on revised beliefs or new evidence. In addition, the system will provide for "what if" type analysis capabilities. This capability is specially important in the light of the significant changes being anticipated in the utility industry, and the associated uncertainties. We will be able to make certain assumptions, let the system make deductions based on them, then withdraw a set of assumptions and bring the system back to a consistent state.

Format A

Outline of Expert System Projects

(U.S.A.-8)

Outline EPRI OTS HEURISTIC SCENARIO BUILDER

In addition to being able to build scenario files by direct instructor input, the OTS has the ability to create scenarios using the automatic Heuristic Scenario Builder (HSB). The main idea behind the HSB is to use knowledge about the training session, generic knowledge about the type of trainee (i.e., knowledge levels such as advanced, beginner, etc.) and general power systems and system operation knowledge to produce detailed sequences of events that match the corresponding scenario goals and trainee's experience. The sequence(s) thus produced are stored into a scenario file to be subsequently accessed by the simulator during a training session.

Knowledge intensive problem solvers of the type described above are suitable to implementation using the techniques of Artificial Intelligence (AI). The HSB will thus be developed using techniques such as rule based expert systems and heuristic search strategies to explore the large space of possible scenarios normally occurring for a particular training session. Two modes of operation are envisaged for the HSB: an off-line mode where the scenarios are built, and an on-line portion where the scenarios are used during training. Both of these modes of operation can be supervised or unsupervised. During the off-line activity the instructor may be involved in the creation of the scenarios, or a power system expert together with the instructor may be involved in the preparation of the scenarios. If unsupervised, the scenario creation activity will run autonomously and presumably adequate tools will be implemented to control the creation and quality of the scenarios. The advantage of the unsupervised mode is that it is possible to let the HSB run for large periods of time considering various possibilities in a more or less exhaustive manner, although continuously guided by the overall knowledge about scenario creation discussed above.

Format A

Outline of Expert System Projects

(U.S.A.-9)

Outline General purpose expert system shell for EMS applications

GENERAL PURPOSE EXPERT SYSTEM SHELL (EMSES)

- NEW FEATURE OFFERED BY CONTROL DATA AS PART OF STANDARD EMS SYSTEM
- FULLY INTEGRATED WITH OTHER EMS SOFTWARE AND HARDWARE PRODUCTS
- UTILITY EXPERTS WILL BE ABLE TO CREATE THEIR OWN EXPERT SYSTEMS IN VARIOUS DOMAINS OF APPLICATION SUCH AS IAP, UNIT COMMITMENT, RELAY PROBLEMS, ..., USING THIS GENERAL PURPOSE TOOL
- ENHANCES DECISION MAKING CAPABILITY OF POWER SYSTEM OPERATIONS PERSONNEL BY PROVIDING EXPERT LEVEL KNOWLEDGE AT ALL TIMES

GENERAL PURPOSE EXPERT SYSTEM SHELL (EMSES)

- THE EMS EXPERT SYSTEM SHELL INCLUDES THE FOLLOWING SUBSYSTEMS:
  - KNOWLEDGE BASE INPUT AND EDITING FACILITY
  - INFERENCE ENGINE
  - INTERFACE TO MMI
  - INTERFACE TO ON-LINE DATA BASE
  - INTERFACE TO APPLICATION SOFTWARE
- KNOWLEDGE IS REPRESENTED AS PRODUCTION RULES OF THE FORM

  IF <CONDITION> THEN <ACTION>

- INFERENCE ENGINE USES THE KNOWLEDGE STORED IN THE KNOWLEDGE BASE TO DRAW CONCLUSIONS, REQUEST ADDITIONAL INFORMATION FROM USERS, CONSULT THE DATA BASE, EXECUTE APPLICATION PROGRAMS, ETC.
- MMI PROVIDES INTERFACE TO OPERATORS USING CDC'S STANDARD CONSOLE CRT KEYBOARD

Outline IAP - Intelligent Alarm Processor

INTELLIGENT ALARM PROCESSOR

GOALS OF IAP:

- O FOCUS OPERATOR'S ATTENTION ON HIGHEST PRIORITY PROBLEM
- O DO NOT BOTHER OPERATORS WITH REPEATING LOW PRIORITY MESSAGES
- O DIAGNOSE WHAT IS HAPPENING (INFORMATION NOT DATA)

FEATURES OFFERED BY IAP:

- O DISPLAY "MOST URGENT ALARMS"
- O DETERMINE PRIORITY OF ALARM EVENTS AND DISPLAY
- O ANALYSIS OF SITUATION
- O PREDICT NEAR FUTURE EVENTS
- O REMIND OPERATORS OF ACTIONS TO BE TAKEN
- O PROVIDE "HELP" DISPLAY
- O REPEATING ALARMS
  - CONDITION IS TIMED OUT
  - LOCKOUT ALARM IF REPEATED FAIL/NORMAL
  - RESET AFTER NORMAL TIMEOUT

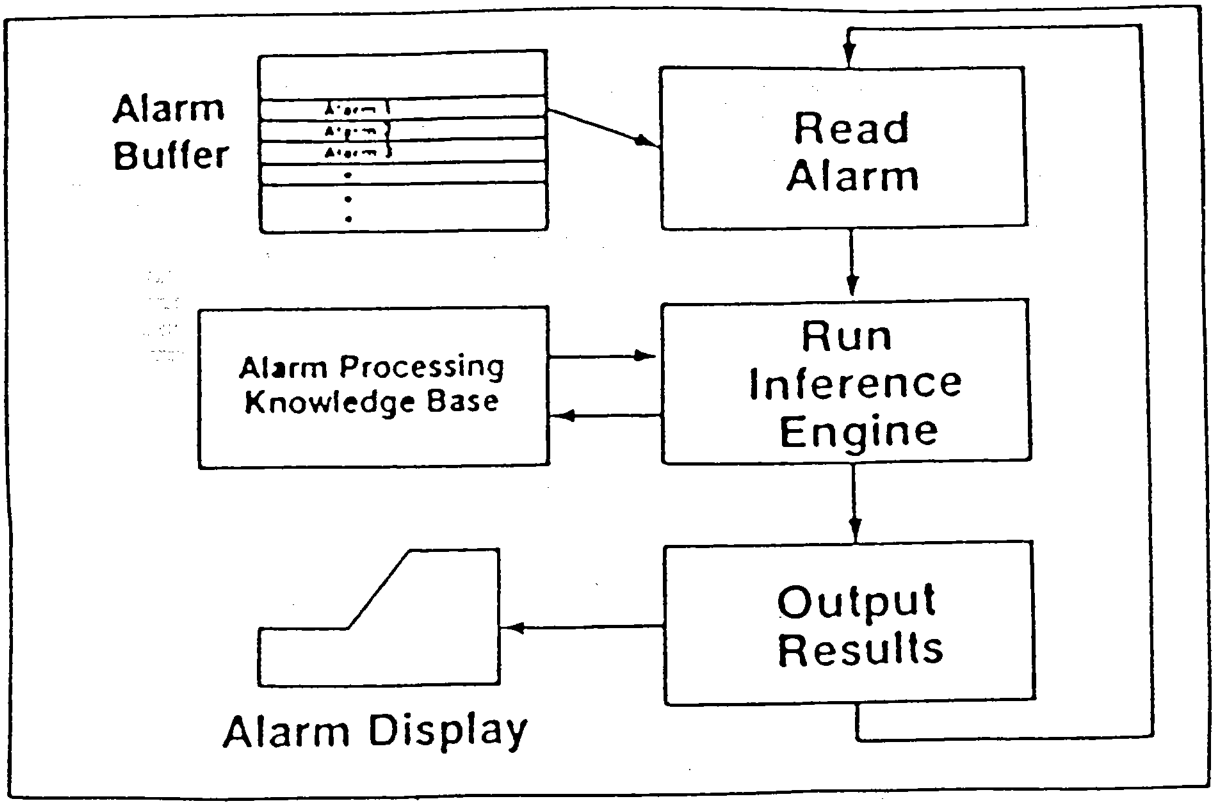
Format A

Outline of Expert System Projects

(U.S.A.-10)

Outline

INTELLIGENT ALARM PROCESSOR (CONT)



Outline Transmission Auto-Reclosure

2.4 AUTOMATIC RECLOSING

Selected transmission breakers are reclosed under computer control via the Automatic Reclosing System. The list of breakers eligible for computer automatic reclosing appears on the Feeder Diagram named AUTORC. In addition, a 'C' appears next to the breakers on the One-line Diagrams.

The entire automatic reclosure scheme is enabled/disabled from the System Summary CRT display. An enterable field is labeled 'AUTOMATIC RECLOSING ON'. Normally, an 'X' will be displayed in the field. To turn automatic reclosing off, the operator enters a blank into the field. To turn the subsystem on, the operator enters any non-blank character into the field. For more information on the System Summary display, refer to the Automatic Generation Control User's Guide.

To initiate automatic reclosing on a breaker, the device must meet certain constraints. Computer automatic reclosing will only be initiated upon the change of state of an eligible circuit breaker. If the line is a one terminal line (radial), the following conditions must be met:

1. The circuit breaker is currently controllable by TRIP/CLOSE commands entered at the SCC.
2. The breaker is presently in the OPEN state.
3. The breaker is normally CLOSED.
4. The breaker is not TAGGED.
5. The last operator initiated TRIP/CLOSE command for the breaker was issued more than two minutes ago.
6. The last computer automatic reclosing initiated CLOSE command for the breaker was issued more than two minutes ago.

If any of the above conditions are false, then the initiating positional alarm is ignored by the automatic reclosing function and no computer reclosing will be undertaken.

On a two terminal line which is eligible for computer automatic reclosing, one breaker is designated as primary and the other is designated as secondary. The primary breaker will always be closed first. If a positional alarm occurs on an eligible breaker on a two terminal line, the following conditions must be true for automatic reclosing to be initiated:

1. The primary circuit breaker is currently controllable by TRIP/CLOSE commands entered at the SCC.
2. The primary breaker is currently OPEN.
3. The primary breaker is normally CLOSED.
4. The primary breaker is not TAGGED.
5. The last operator initiated TRIP/CLOSE command for the primary breaker was issued more than two minutes ago.
6. The last computer automatic reclosing initiated CLOSE command for the primary breaker was issued more than two minutes ago.

Outline

7. The secondary breaker is currently OPEN.

8. The secondary breaker is normally CLOSED.

9. The secondary breaker is not TAGGED.

10. The last operator initiated TRIP/CLOSE command for the secondary breaker was issued more than two minutes ago.

11. The last computer automatic reclosing initiated CLOSE command for the secondary breaker was issued more than two minutes ago.

If any of the above conditions are false, then no automatic reclosing will be initiated. If, however, the conditions are checked and confirmed, reclosure action begins with the closing of the primary breaker. If successful, six seconds are allowed to pass before the secondary breaker is reclosed. Before reclosing the secondary breaker, the following conditions must be met:

1. The primary breaker is currently CLOSED.

2. The last operator initiated TRIP/CLOSE command for the secondary breaker was issued more than two minutes ago.

3. The secondary breaker is currently OPEN.

4. The secondary breaker is normally CLOSED.

5. The secondary breaker is not TAGGED.

Although these checks may appear redundant, conditions may have changed since the first check. If all conditions are met, the secondary breaker is reclosed.

If, during the above sequence, an RTU hardware error occurs or the RTU goes out of scan, this fact will be logged on the System Control Office (SCO) alarm logger. In addition, if the second set of checks on a two terminal line reclosure (when the secondary breaker is about to be closed), do not allow continuance of the reclosing, the message 'AUTO-RECLOSING ABORTED' will be logged on the SCO alarm logger. This message will also appear if the closure of the secondary breaker is not successful. On the other hand, if the line is successfully reclosed, the message 'AUTO-RECLOSING SUCCESSFUL' is logged.

A maximum of sixteen circuit breaker pairs can be operated upon simultaneously by the automatic reclosing subsystem. A designated circuit breaker that has no "partner" is considered as one pair of the sixteen allowed. If field events cause this limit to be exceeded, the excess requests for automatic reclosure will be permanently ignored. If operator control action causes this limit to be exceeded, the computer automatic reclosure function will be automatically shut down.

Format A

Outline of Expert System Projects

(U.S.A.-14)

Outline Intelligent Alarm Processor

This project is in a very early stage of development. The goal is to produce a product which would inform the Power System Operator as to the cause of alarms being presented rather than the alarm data only. In addition, investigation will be made into the possibility of recommending corrective action in certain situations.

Outline of Expert System Projects

(U.S.A.-15)

Outline VCES(Voltage Control Expert System)

When a voltage problem occurs in a power system, several approaches may be taken to restore a normal operating condition. Dispatchers may rely on their experience in selecting neighboring controllers around the problem buses. The other approach would be to apply a reactive dispatch program to come up with an optimized solution. Finally, it is also possible to combine the two approaches to arrive at a control decision.

For the reactive power/voltage control problem, the following empirical rules are identified:

(a) If a load bus voltage drops below (or rises above) the operating limit, control devices such as shunt capacitors, transformer tap changers, generator voltages and synchronous condensers can be switched or adjusted to restore the voltage profile.

(b) If a load bus voltage drops below (or rises above) the operating limit, it is most efficient to apply the reactive compensation locally. If the capacity of local compensators is insufficient to resolve the voltage problem, then compensators with next highest sensitivities should be chosen.

(c) If the voltage is low (high) at a bus, the tap position of the local transformer tap changer can be raised (lowered) to correct the problem. However, increasing (decreasing) the tap position may cause other load bus voltages to drop (rise).

(d) Generator bus voltages can be raised (lowered) to solve the low (high) load voltage problems.

The proposed rule-based system VCES serves as an operator's aid in resolving voltage problems. It was suggested that empirical rules be used when the problem is minor (few low voltages). On the other hand, if the problem is severe, then a reactive dispatch algorithm will be called upon to generate a solution. The general framework of the integrated rule-based and number-crunching programs can be described by Fig. 1. It is noted that to apply the linear program (reactive dispatch) it is necessary to linearize the system equations around the selected operating point. The interface block in Fig. 1 represents the solution of a load flow and evaluation of partial derivatives for use in the formulation of the linear program.

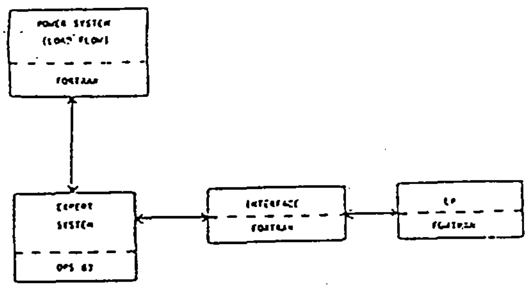


Figure 1- Voltage Control Expert System(VCES)

Format A

Outline of Expert System Projects

(U.S.A.-16)

Outline CRAFT (Customer Restoration And Fault Testing)

Faults may occur in transmission lines due to accidents, etc. Typically, each line is equipped with power circuit breakers on both slides which are designed to trip within cycles after a fault occurs in order to protect equipment from damage. Transmission lines in the 115kV range often have substation taps between these power circuit breakers. A tripping of the breakers will lead to interruption for customers supplied through taps along the faulted line. To minimize the power interruption during the line faults, an effective scheme is to install automatic switches between some sections of the line. These switches are designed to close or open depending on the status (hot or dead) of the component (line or bus). The switches are provided with a delay time setting for the operation; system designers can coordinate the time settings among switches in order to achieve minimal power interruptions under specified fault conditions.

Upon the occurrence of a fault, the operation of supervised automatic switches will result in alarms presented to system dispatchers. Unsupervised automatic switches require communication from the field before a dispatcher has an indication of the device operation. In practice, dispatchers need to examine the system configuration following the fault and possibly they will need to perform a set of test actions to determine the faulted section. The decision-making process involves reasoning based on system status, functions of automatic switches and empirical judgements related to specific line conditions. Since the dispatchers also have to retrieve system data from handbooks and/or computer storage, the decision-making process can be time-consuming, depending on the complexity of the line and the fault event.

This problem solving approach followed by the dispatchers, i.e. heuristics, operational guidelines, etc., suggests an expert system approach. In this paper, we present an expert system for assisting dispatchers in a control center when line sections become faulted and automatic switching is insufficient to maintain service to all customers on the line in question.

Fig. 1 shows how the solution process proceeds in the developed expert system. The system has been written in a production system language, OPS83. Specialized production system languages~~, such as OPS83,~~ provide many features which facilitate development of an expert system. However, the high level of these languages may present difficulties when communicating with other software. Other computer support, such as the SCADA system, is typically written in more conventional languages, e.g. on-line code in assembly language and applications programming in FORTRAN. OPS83 provides a convenient interface to FORTRAN.

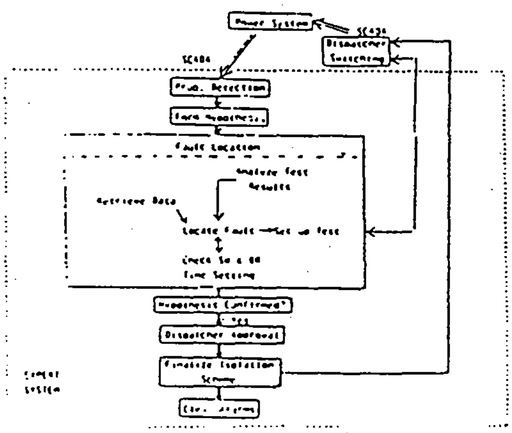


Fig. 1 Solution Process in Fault Isolation

Outline of Expert System Projects

(U.S.A.-17)

Outline DFSR (Distribution Feeder System Restoration)

In a dispatching center, system operators monitor the system through the distribution SCADA and the real-time database. An expert system operational aid can be used to provide suggestions to operators so that customers can be restored quickly. This is particularly meanininingful in emergency conditions when a large number of customers are interrupted.

The function of the proposed expert system can be described by the block diagram in Fig. 1. This study deals with system restoration and therefore it is asssumed that the fault location is already known.

The function of Restoration Planner (RP) is to come up with necessary switching actions to restore the customers affected in an outage. Based on the assumptions that the fault location is known and that the system data and switch status are available, RP is capable of formulating a set of breaker and/or switch actions so that the maximal number of outage zones and the feeders can be restored. To do this, the general strategy is hierarchical; one first identifies the whole outage area and divides it into groups of zones based on the adjacency of feeders. In other words, it is intended to restore each group from a neighboring feeder. However, the capacity and operating constraints will be checked to ensure the restoration is feasible.

Now, if any feeder is unable to pick up an assigned group, the zones in this group will be attempted one by one. This process will be called zone restoration. After this step, if some zone cannot be restored, then a load transfer would be necessary. By transferring enough load from a neighboring feeder to a farther one, the neighbor will be able to pick up a zone. The transfer will be attempted for every feeder adjacent to the neighboring feeder. In this sense, the program attempts to restore the maximal number of outage zones.

We selected Prolog for the implementation. The function RP is implemented with approximately 180 rules. Two slightly different versions of the Prolog programs were developed; one for a medium-size mainframe IBM-4341 and the other for an IBM-PC. In general, the developed Prolog system is efficient enough for this application; a typical program execution would take 2-5 seconds on IBM-4341 mainframe and 3-9 seconds on IBM-AT.

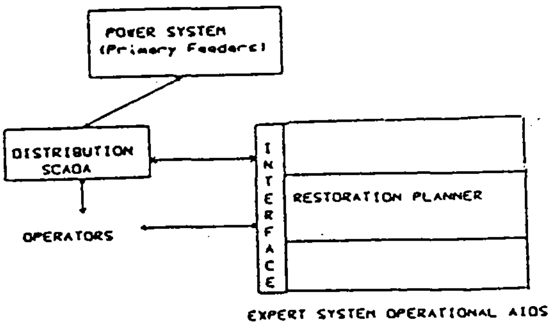


Fig. 1 Functional description of expert system operational aid

Appendix <G>

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Appendix <H>

Glossary of Expert System Terminology

Appendix <H> Glossary of Expert System Terminology

Abduction. A syllogism, of which the major premiss is certain, and the minor only probable, so that the conclusion has only the probability of the minor; apagoge (see Deduction, Induction).

Algorithm. An explicit, finite set of instructions for solving a problem.

Artificial intelligence (AI)[2]. A broad definition: A growing set of computer problem-solving techniques that are being developed to imitate human thought or decision-making processes or to produce the same results as those processes.

Artificial intelligence (A.I.)[1]. A discipline devoted to developing and applying computational approaches to intelligent behavior; also referred to as machine intelligence or heuristic programming.

Atom. An individual; a proposition in logic that cannot be broken down into other propositions.

Augmented Transition Network (ATN). A grammar representation used in natural language systems to parse input. ATNs are strings representing legal sequences of parts of speech. Input text is compared to the strings. If the parts of speech represented by words in the input match the parts of speech in an ATN string, the system recognizes the input as legal. Actions to be performed on or with input may be associated with an ATN.

Automatic program synthesis. The automatic computer construction of programs from rigorous and nonalgorithmic specifications describing what the programs should do.

Automatic program verification. The use, by a computer, of mathematical techniques to show that programs behave according to their formal specifications, in order to prove the correctness of programs.

Automatic programming. The application of artificial intelligence techniques to the general goals of automatic program construction and automatic program transformation.

Backtracking. Returning the database, or conditions, in a system to a previous state in order to try an alternative solution path.

Backward chaining. Attempting to solve a problem by stating a goal and looking in the database for the conditions that would cause it to come about, then reiterating this process, using those conditions as the goals and searching for their preconditions, and so on (see Forward chaining).

Blackboard. A data structure on which a system can post information on internal states of objects or registers in the system for consultation and appropriate action by operators in the system.

Blackboard approach. A problem-solving approach whereby the various system elements communicate with each other via a common working data storage called the blackboard.

Blocks world. A small artificial world consisting of blocks and pyramids, used to develop ideas in computer vision, robotics, and natural language interfaces.

Certainty factor. A tag associated with a piece of information supplied to an expert system. The tag describes the application developer's degree of confidence that the piece of information is likely to be true.

Cognition. An intellectual process by which knowledge is gained about perceptions or ideas.

Compile. The act of translating a computer program written in a high-level language (such as LISP) into the machine language that controls the computer's basic operations.

Computational logic. A science designed to make use of computers in logic calculus.

Computer architecture. The way various computational elements are interconnected to achieve a computational function.

Conceptual dependency. An approach to natural language understanding in which sentences are translated into basic concepts that are expressed as a small set of semantic primitives.

Conceptual dependency. A knowledge representation used in natural language systems A conceptual dependency translates input into an internal representation usable by the system. A conceptual dependency makes use of a small number of basic components signifying meaning that can be combined to represent more complex meanings.

Confidence factor. See Certainty factor.

Connected-speech system. A system that can understand a stream of speech in which the speaker does not pause between words to emphasize the beginnings and ends of the words.

Control structure. Reasoning strategy --the strategy for manipulating the domain knowledge to solve a problem.

Data base. An organized collection of data about a subject.

Data base management system. A computer system for storing and retrieving information about some domain.

Data structure. The form in which data are stored in a computer.

Declarative knowledge representation. Representation of facts and assertions.

Deduction. The process of reaching a conclusion by logical means (see Induction, Abduction).

Document generation system. A system that synthesizes text by manipulating stored information in response to specifications for the output. A type of document understanding system.

Document understanding system. A system that accepts textual input, stores and classifies it, and then utilizes the input in response to specifications for tasks. Some document understanding systems provide paraphrases, some answer questions, some perform translation, and some draw inferences.

Domain. The problem area about which a system has knowledge and an ability to manipulate the knowledge.

Editor. A software tool to aid in modifying a software program.

Ellipsis. The omission of words so that a sentence is not grammatically complete but is still comprehensible to the intended audience.

Embed. To write a computer language on top of (embedded in) another computer language (such as LISP).

Expert system. A computer program that uses knowledge and reasoning techniques to solve problems normally requiring the abilities of human experts.

Explanation facility. A feature of many expert systems. The part of a system that tells what steps were involved in the processing by which it arrived at a solution. These facilities can be simple traces of steps or they can be more complex, supplying encoded reasons and references for the reason the solution takes one alternative rather than another.

Fifth-generation computer[1]. A non-Von Neumann, intelligent parallel-processing form of computer now being pursued by Japan.

Fifth-generation computer[2]. An upcoming generation of computers that will not depend on a von Neumann architecture. The first four generations of computers processed instructions sequentially. Definitions of the fifth-generation computer vary, depending on the goals of the researchers working on different fifth-generation projects, but most include the ability to do parallel processing and an architecture suited to knowledge processing.

First-order predicate logic. A popular form of logic used by the A.I. community for representing knowledge and performing logical inference First-order predicate logic permits assertions to be made about variables in a proposition.

Forward chaining. The type of activity done in a system that applies operators to a current state in order to produce a new state, and so on until the solution is reached (see Backward chaining).

Frame. A knowledge representation based on the idea of a frame of reference. A frame carries with it a set of slots which can represent objects that are normally associated with the subject of the frame. The slots can then point to other slots or frames. This gives frame systems the ability to carry out inheritance and simple kinds of inferencing.

General problem solver (GPS). The first problem solver (1957) to separate its problem-solving methods from knowledge of the specific task being considered. The GPS problem-solving approach employed was "means-ends analysis."

Goal. The solution a system attempts to reach using operators. Sometimes, in order to reach the goal, subgoals must first be achieved.

Heuristic. (Used as a noun in AI.)[2] A process, sometimes a rule of thumb, that may help in the solution of a problem, but that does not guarantee the best solution, or indeed, any solution.

Heuristics[1]. Rules of thumb or empirical knowledge used to help guide a problem solution.

Heuristic search techniques. Graph-searching methods that use heuristic knowledge about the domain to help focus the search. They operate by generating and testing intermediate states along potential solution paths.

High-order language (HOL). A computer language (such as FORTRAN or LISP) requiring fewer statements than machine language and usually substantially easier to use and read.

Icon. A symbol to which a computer user can point an interface device in order to select a function, such as "move window."

Image processing. The examination by a computer of digitized data about a scene and the features in it in order to extract information.

Induction. The process of inferring a general law or principle from the observation of particular instances (see Deduction, Abduction).

Inference. A conclusion based on a premise.

Inference engine[2]. The part of a rule-based system that selects and executes rules.

Inference engine[1]. The control structure of an A.I. problem solver in which the control is separate from the knowledge.

Instantiation. Replacing a variable by an instance (an individual) that satisfies the system (or satisfies the statement in which the variable appears).

Intelligent system. A system equipped with a knowledge base that can be manipulated in order to make inferences.

Isolated-word system. A speech-understanding system whose input must consist of words enunciated separately, instead of run together, to make word identification easier for the system.

Knowledge base[2]. The part of a knowledge-based system that contains codified knowledge and heuristics used to solve problems.

Knowledge base[1]. An A.I. data base that is made up not merely of files of uniform content, but of facts, inferences, and procedures corresponding to the types of information needed for problem solution.

Knowledge engineering. The activities of software engineers who acquire knowledge for knowledge-based systems and decide how to represent it for use in the system.

Knowledge representation. A structure in which knowledge can be stored in a way that allows the system to understand the relationships among pieces of knowledge and to manipulate those relationships.

LISP (LIST PROCESSING LANGUAGE). The basic A.I. programming language.

Logical operation. The execution of a single computer instruction.

Logical representation. Knowledge representation by a collection of logical formulas (usually in first-order predicate logic) that provide a partial description of the world.

Machine translation. The translation by computer of text in one human native language into text in another language.

Metaknowledge. Knowledge about knowledge. Knowledge that tells a system something about what it knows, how its knowledge can be utilized, and what the limits of its knowledge are.

Means-end analysis. A problem-solving approach (used by GPS) in which problem-solving operators are chosen in an iterative fashion to reduce the difference between the current problem-solving state and the goal state.

Natural language. A person's native tongue. Natural language systems attempt to make computers capable of processing language the way people normally speak it instead of requiring specialized programming languages.

Natural language processing. Processing of natural language (English, for example) by a computer to facilitate human communication with the computer --or for other purposes, such as language translation.

Object-oriented programming[2]. Programming that focuses on objects rather than on procedures.

Object-oriented programming[1]. A programming approach focused on objects that communicate by message-passing. An object is considered to be a package of information and of descriptions of procedures that can manipulate that information.

Parallel processing. Simultaneous processing, as opposed to the sequential processing in a conventional (Von Neumann) type of computer architecture.

Pattern recognition. The process of classifying data into predetermined categories.

Parsing. Identifying the components of language statements as various parts of speech.

Predicate logic. A form of logic that can be utilized in knowledge-based programs. The basis of the AI language Prolog.

Procedural knowledge representation. A representation of knowledge about the world by a set of procedures --small programs that know how to do specific things in well-specified situations.

Production rule. A condition/action rule that produces change in a system that results in new conditions and new actions, and so on. Most rules are structured in an "if...then...." format.

Programming environment. The total programming setup that includes the interface, the languages, the editors, and other programming tools.

PROLOG (PROGRAMMING IN LOGIC). A logic-oriented A.I. language developed in France and popular in Europe and Japan.

Propositional logic. An elementary logic that uses argument forms to deduce the truth or falsity of a new proposition from known propositions.

Protocol. A set of rules for accomplishing an activity.

Robot. A multifunctional manipulator that can be programmed and reprogrammed to perform tasks.

Rule. See Production rule.

Rule interpreter. The control structure for a production rule-based system.

Script. A knowledge representation form based on stereotyped situations. When activities fit into stereotypes, a system equipped with a script can predict other likely events by analogy, "assuming" that the script will continue to hold true.

Search. The process of trying different actions in a system until a sequence of actions is discovered that will achieve a goal state.

Search space. The implicit graph representing all the possible states of the system that may have to be searched to find a solution. In many cases, the search space is infinite.

Semantic network. A knowledge representation for describing the properties and relations of objects, events, concepts, situations, or actions, by a directed graph consisting of node and table edges (arcs connecting nodes).

Semantic primitives. Basic conceptual units in which concepts, ideas, or events can be represented.

Semantics. The meaning of words within context.

Sensing system. A system that processes digitized signal input about shape, weight, pressure, friction, temperature, and other sensation information. Sensing systems interpret the input by comparing it to stored patterns.

Slot. See Frame.

Solution path. A successful path through a search space.

Speaker-dependent system. A speech-generation system that is trained to recognize words as they are spoken by specific individuals on the basis of training with samples of that speaker's pronunciation.

Speech-generation system. A system that translates text into audible speech with correct pronunciation

Speech-understanding system. A system that converts the digitized signals of audible speech into printed text.

State graph. A graph in which the nodes represent the system and the connecting arcs represent the operators that can be used to transform the state from which the arcs emanate into the state at which they arrive.

Syllogism. An argument expressed or claimed to be expressible in the form of two propositions called the premisses, containing a common or middle term, with a third proposition called the conclusion, resulting necessarily from the other two.

Symbolic. Relating to the substitution of abstract representations (symbols) for concrete objects.

Syntax[1]. Order or arrangement (for example, the grammar of a language).

Syntax[2]. The structure into which words fit.

Vision system. A system that interprets digitized input about the shape, location, and sometimes the color of objects, in order to determine what the input represents and/or what the significant features of the object are.

Von Neumann architecture. The current standard computer architecture that uses sequential processing.

Working memory. In OPS5, the dynamic portion of a production system's memory. Working memory contains the changing database of the system as rules fire.

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