Development of a Thermal Performance Diagnostics Expert System in Identifying MWe Loss Problems

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ABSTRACT

This paper describes the development of a computerized thermal performance diagnostics expert system (TPDES) designed to assist performance engineers at nuclear power plant. The TPDES is the second phase product of the ChinShan plant performance Monitoring, Analysis and Diagnostics Expert System (CS-MADES) project. The objective of this system is to serve as a powerful tool in diagnosing the heat rate degradation problems found in nuclear power plant through man-machine intercommunications. The whole system framework was developed on a personal computer to provide an integrated, user-friendly and menu-driven environment in meeting the operator's requirements. Moreover, it is actuated either in Chinese or English mode.

Some visible benefits have been gained so far through the prototype system installation at the Chinshan nuclear power station. It is believed that TPDES could successfully reduce lost megawatts and save maintenance cost through the early detection of thermal performance deviations.

I. INTRODUCTION

In recent years, the nuclear power industry has evolved from the construction of new plants to the ongoing improvement of existing plants, with emphasis on safety, economic operation, and thermal efficiency. As part of this evolution, custom software programs like expert system are being integrated into nuclear power plant in many areas to achieve these utility goals and meet the requirements of the plant performance staff.

The Institute of Nuclear Energy Research (INER) has been conducting researches on ASME performance test, thermal performance evaluation and heat rate improvement for many years [1,2]. To take one step ahead, INER proposed a project and cooperated with Taiwan Power Company (TPC) to develop a thermal performance monitoring, analysis and diagnostics expert system called CS-MADES. This product, being sponsored by TPC, was implemented at Chinshan nuclear power station which is a GE boiled water reactor (BWR) unit. There are two phases in this research project. The first phase is to develop an on-line real-time performance monitoring and analysis system. This system typically retrieves on-line measurement data from the plant Emergency Response Facility (ERF) computer, and then calculates thermal performance of each turbine cycle component. Furthermore, plant sensors validation, data averaging and qualification, and error detection are also performed. The second phase, which is the major subject of this paper, is to establish a thermal performance diagnostics expert system (TPDES) that can diagnose plant megawatts loss and component malfunction problems in a logical inferable method. It can provide potential causes of performance deficiencies and suggest corrective actions too. The whole system evolution is aimed at identifying problems that affect plant performance during steady state and high power (80% - 100% of rated load) operating conditions.

This paper describes in detail the overall planning of TPDES, including diagnostic signals determination, technical reports acquirement, hardware and software requirements, and expert system tool employment, etc. The diagnosing inference engine, associated with the expert knowledge base and the user interface are also depicted. Finally, some achievements in diagnosing the Chinshan plant megawatts loss problems and recommendations for future enhancement are also discussed.

II. GENERAL FEATURES OF TPDES

CS-MADES functional diagram is illustrated in Fig.1. Three subsystems were generated to support the whole system framework. The Test Data Processing Subsystem (TDPS) and On-line Monitoring and Analysis Subsystem (OMAS) are the working scopes of the first phase task. By utilizing existing plant data acquisition hardware, the system can execute turbine-cycle performance on-line monitoring and analysis during normal operation and quantify component degradation after determining thermal defficiencies and other system losses [3]. While TPDES, the third subsystem, was developed to provide a structured problem evaluation methodology which embodies both performance engineers' expertise and plant historical operating experiences.

At the onset of TPDES development, INER performed an assessment to determine the

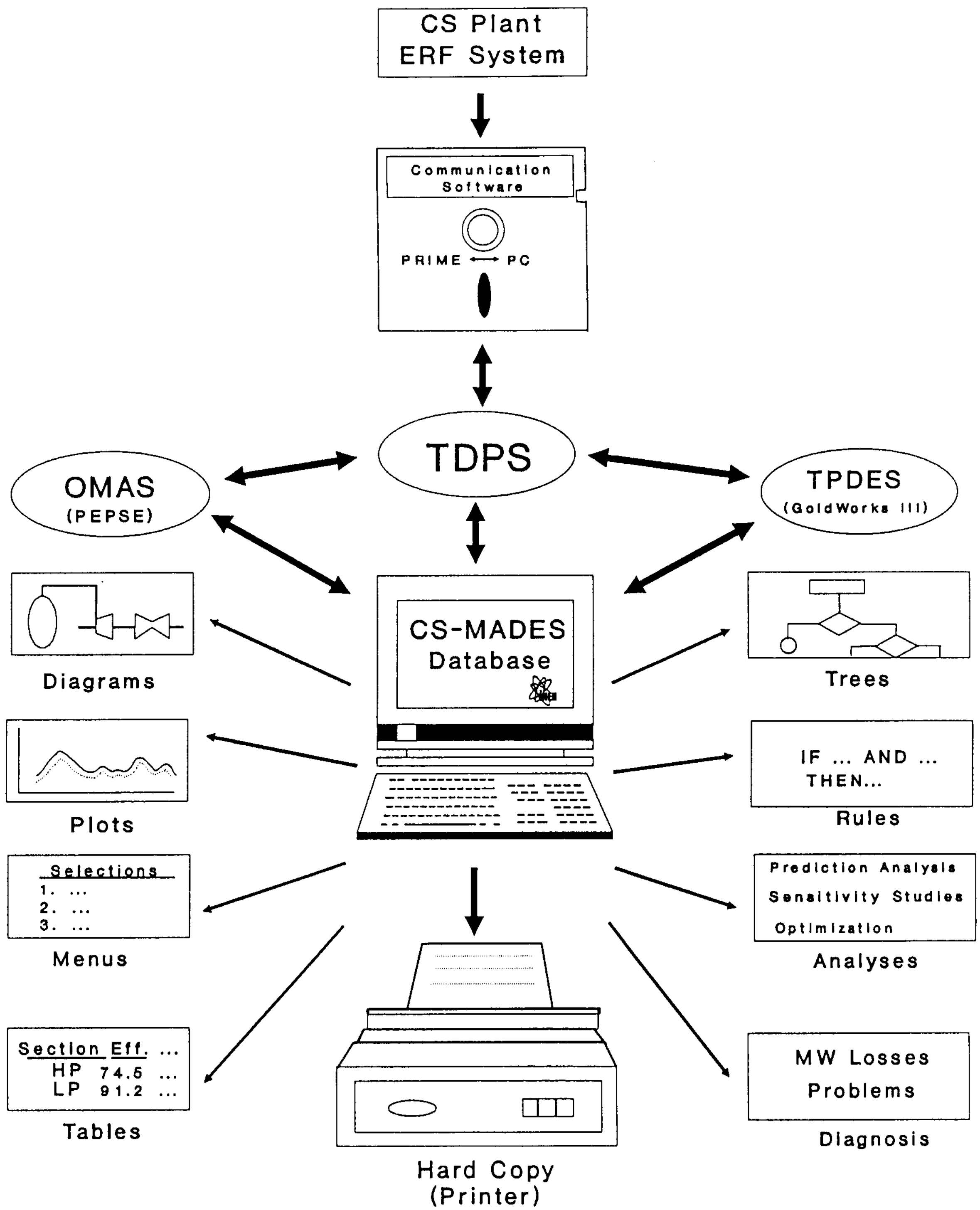

Fig. 1 CS-MADES Functional Diagram.

requirements of the system hardware and software. The objective of this assessment was to set up tools that are powerful enough both for the project at hand and future expansion, while being proven, readily available, and as inexpensive as possible. As a result of these investigations, the hardware requirements include: IBM PC/AT 486 compatibles equipped with 80387 coprocessor, 8 MB RAM with at least 100 MB of hard disk storage, window compatible mouse, high resolution VGA monitor, MICON's statistical multiplexor, HP Laserjet printer, and Tektronix 4694DX color graphic copier. The software requirements are DOS 3.0 or higher version, VTERM III communication software, expert system shell GoldWorks III, Microsoft Windows 3.0 and Chinese MS-Windows driving software 3.0A.

The system architecture of TPDES is shown in Fig. 2. Note that it is some kind of semi-automatic expert system. TPDES is typically designed to accept diagnostic data from two sources. One is the on-line measurement data from the plant ERF computer system and the other is entered by the user. The performance engineer normally tours the plant once a day. Qualitative observation and local instrument inspection should be taken care and collected with a checklist of data through daily walkdown of the plant. Accordingly, the additional information required by TPDES would be gathered to activate the reasoning process step by step along with the on-line measurement data. A powerful expert system shell-GoldWorks III, developed by Gold Hill Computers, Inc. [4], serves as the reasoning engine here. It is specially constructed, based on a number of rule-based knowledges and facts, and operated conducting a deductive reasoning approach strategy. The coding language is written in Golden Common Lisp.

Basically, most of the expert knowledge database and decision trees in TPDES are based on the thermal performance diagnostic manual (TPDM) published in EPRI NP-4990P reports*[5]. The TPDM offers utility engineers a logical, step-by-step procedure for locating the sources of heat rate degradation in nuclear power plants. Certainly, necessary customization would be made according to the specific plant configuration, equipment sensor, operating experience and engineering judgment. A prototype system was customized and implemented accordingly at Chinshan nuclear power station. The major functions of this prototype system will be described in the following section.

III. FUNCTIONAL SPECIFICATION

The system software configuration is illustrated in Fig. 3 and the role of three major parts is as follows.

— Inference engine

This engine controls the search through the knowledge bases, matches appropriate rules and facts, executes the rules, tracks the inference process, and interactes with the user interface.

— Knowledge base

The knowledge elicitation process plays an important role in the accuracy and integrity of the knowledge. Various rule sets are implemented from plant operation experiences,

* Taipower owns a license and grant INER access to the manual.

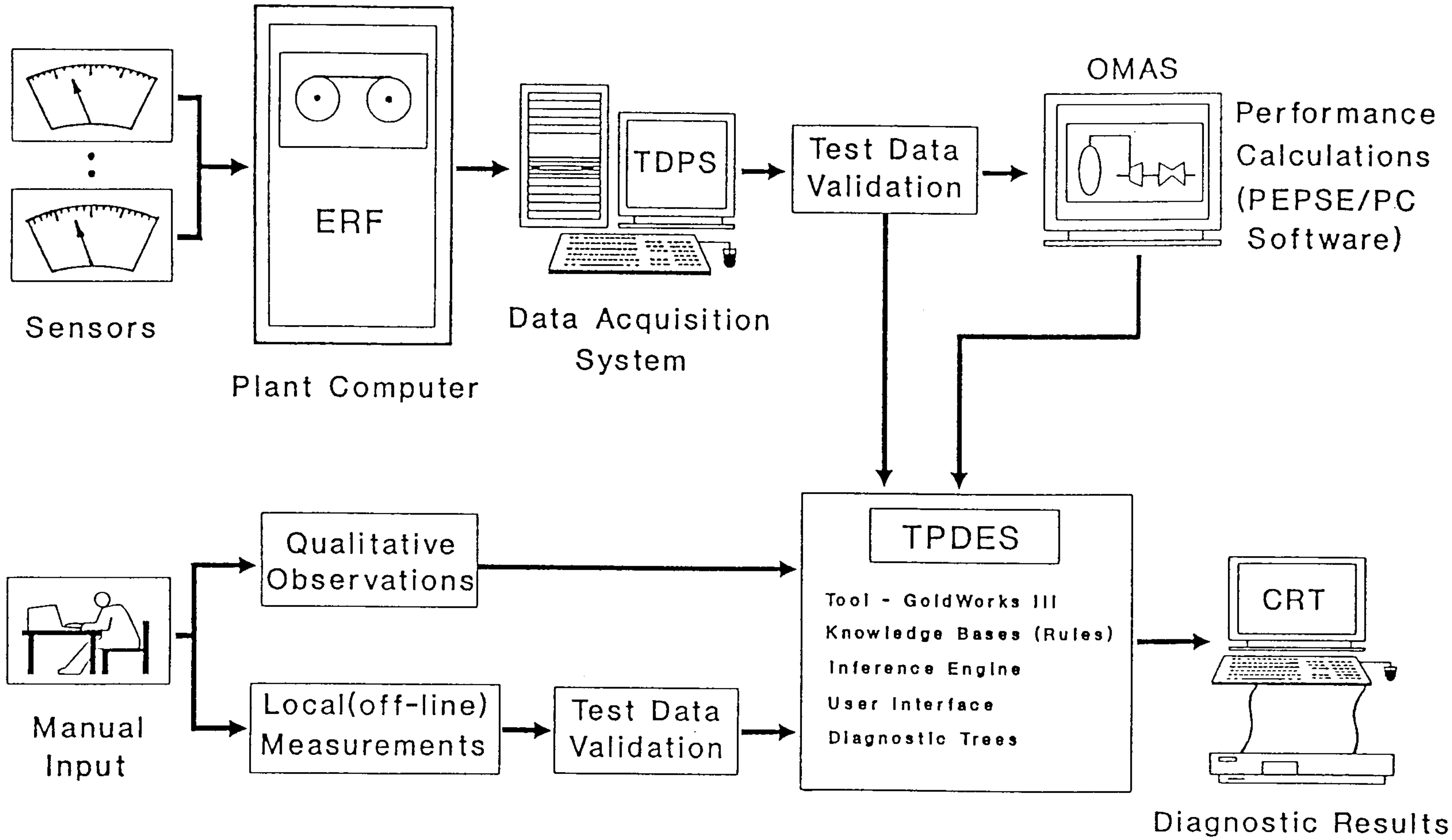

Fig. 2 System Architecture of TPDES.

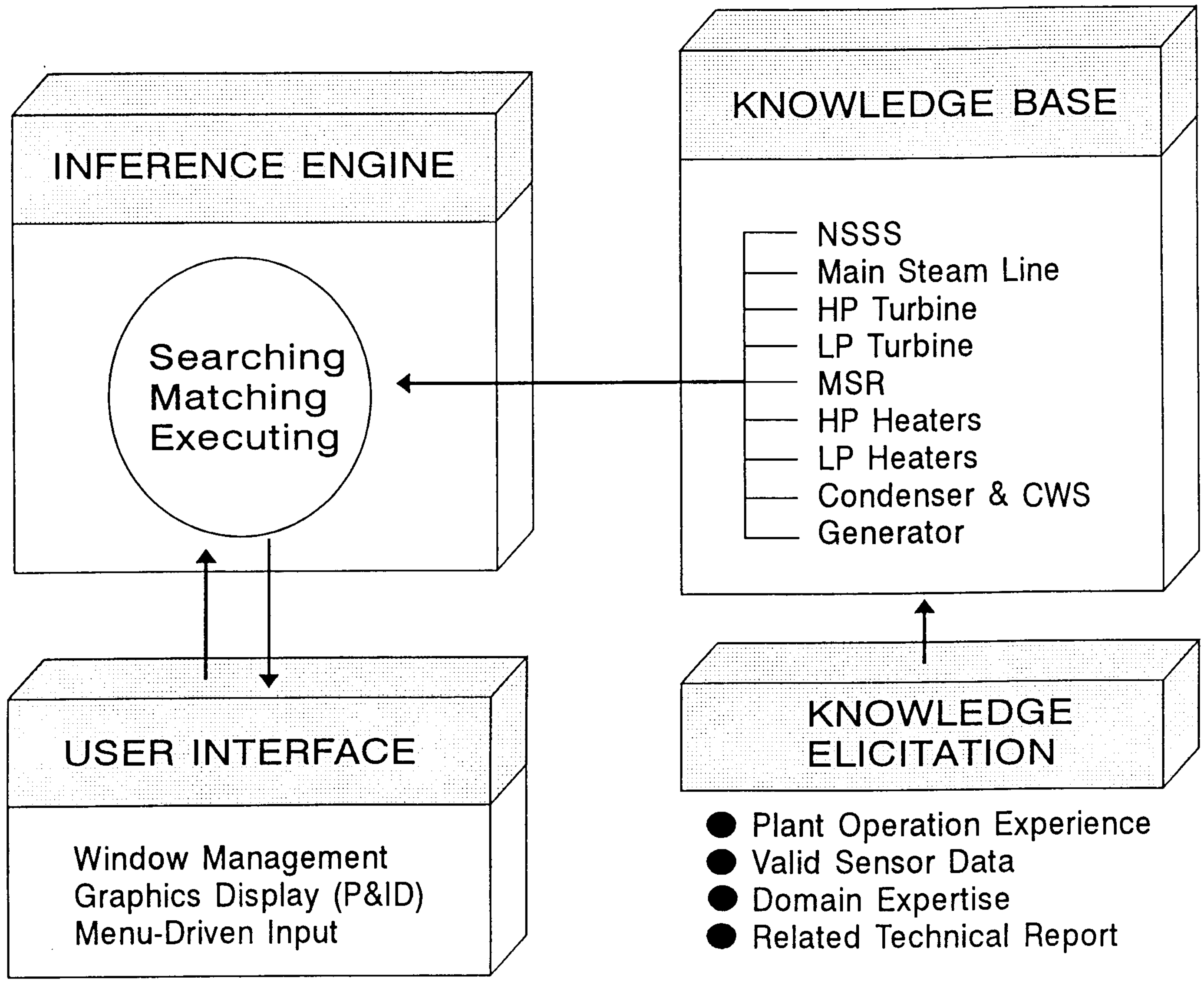

Fig. 3 System Software Configuration.

valid sensor data, domain expertises and related technical reports. The knowledge database was divided into nine plant characteristic areas to facilitate component being diagnosed individually.

— User interface

The user interface controls screen displays and menu-driven operation in interacting with the user. This part is essential for aiding the user in intercommunicating with the TPDES by the keyboard or mouse. It also offers a user-friendly environment to enable users operating the system easily.

The TPDES, a PC-based environment, is a fully integrated and modularized software to generate five major components: the system introduction, the database utilities, the diagnostic signals iconic display, the overall plant diagnosis, and the individual component diagnosis. Each component has a specific and unique function.

System Introduction

This component describes the system objectives, functions, characteristics, and basic operation procedure in brief. Users can catch the whole picture of TPDES and get the guidance in actuating the system through screen display.

Database Utilities

Database utilities component offers a user-friendly environment to investigate, modify and store the on-line and off-line diagnostic data for diagnosis and plant operating history establishment. Three major parts are included in this component.

— Data retrieval and input

In addition to the on-line diagnostic data (93 parameters) acquired automatically from the plant ERF computer as stated previously, the off-line data, including control room panel indicators (100 parameters) and local instruments recorder (46 parameters), are collected through the engineer daily walkdown of the plant. Reference baseline parameters (target data) and their allowable variation range are also established after last scheduled outage at various power levels to verify actual data accuracy. These data sources, serve as the plant operating symptoms, are entered into TPDES to execute a complete diagnosis.

Fig. 4 illustrates the screen display of the on-line diagnostic data from ERF computer system. Note that the capability for modifying or editing data was added to TPDES. Due to instrument reliability concern, users request a reference baseline for correcting measured data that is suspect so that a credible diagnosis could proceed. For this, the target data at the corresponding power level are also displayed for user's reference.

— Data storage

The modified plant data can be entered into TPDES immediately for plant diagnosis or stored in the database for later use. These data records are stored with a unique date/time identifier so that users can retrieve them without difficulty.

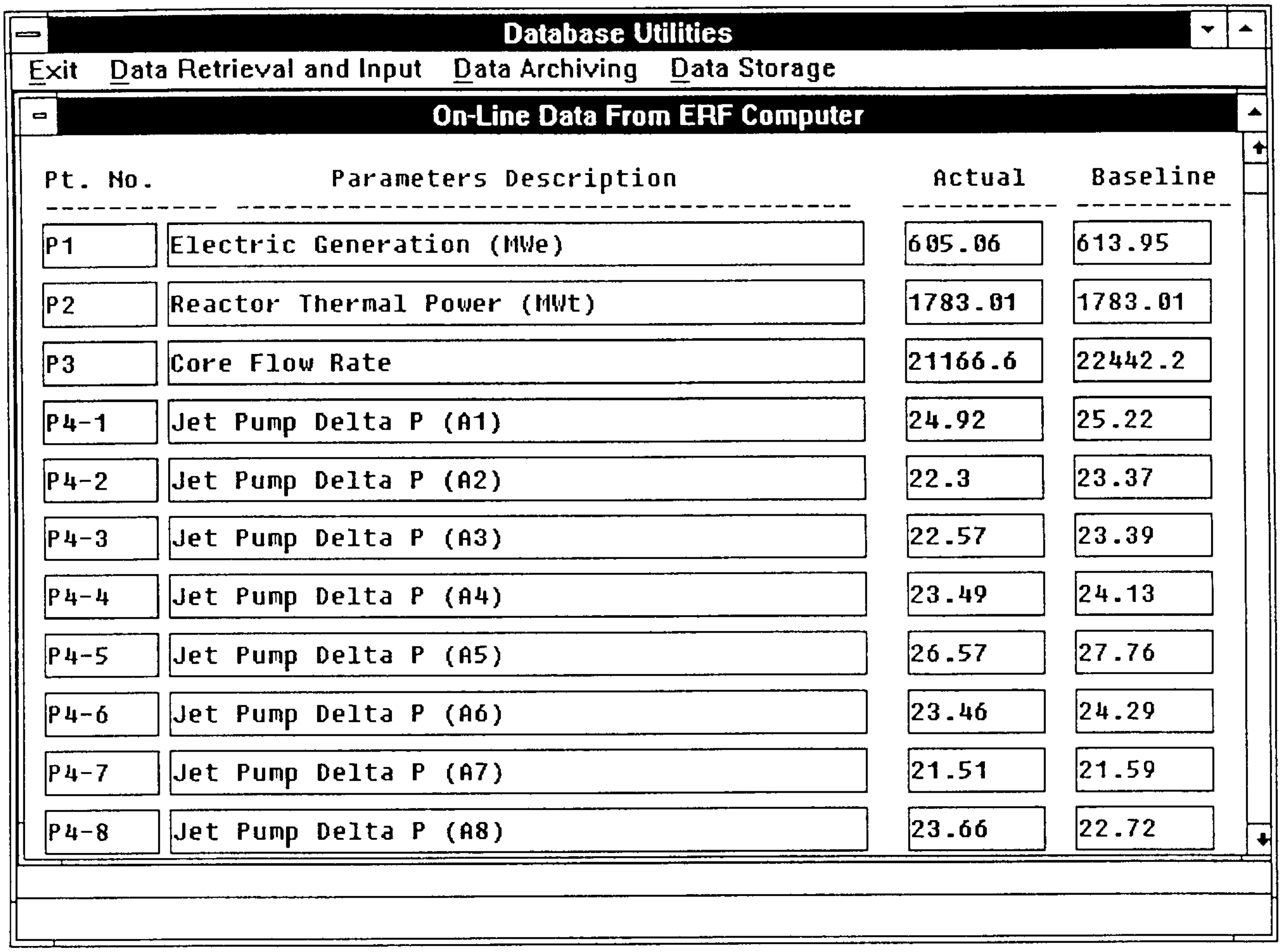

Fig. 4 Screen Display of On-line Data From ERF Computer System.

— Data archiving

All performance data entering the system can be accumulated and stored on its hard disk by using this option. Due to the limited space of the hard disk, users can remove the older records from the databases and write these records to the floppy diskettes. If required at a later date, this archived data can be retrieved from the floppy diskettes to the hard disk.

Diagnostic Signals Iconic Display

This component provides a hierarchical or top-down view of the plant. This feature offers the means to conceptualize the relationships between instrumentation and related system components of the plant. Each system component has an iconic representation within the TPDES. As shown in Fig. 5, the user can browse the system by using a mouse to select firstly, the plant view screen (highest level), and then lower level screens arranged hierarchically and selectable by components. Fig. 5 depicts a simple representation of the feedwater heaters along with instrument icons and parameter numbers for monitoring plant variables.

The instrument icons are color coded according to the reasoning process and diagnostic results. Green color means that the parameters are used in the diagnosing process and their values are evaluated in normal conditions. While the red instrument icons indicate that some diagnostic parameters discrepancies are identified and they point to the problem. The instrument icons with white color are not used in the diagnosing process.

Overall Plant Diagnosis

The flow of diagnosis used in the thermal performance diagnostic trees in general follows the energy flow as determined by the steam and condensate flow directions. For each problem, the plant symptoms, expressed in terms of perturbations in the diagnostic parameters and observations, were integrated into the diagnostic tree logic diagrams. The diagnostic tree is, in effect, a graphical representation of the human diagnostic thinking process. Fig. 6 shows the diagnostic (decision) trees logic diagram of the low pressure feedwater heaters. The format of this graphical decision tree consists of a set of decision points represented by diamonds, labeled branches for the decision points, terminal points represented by circles, and transfers represented by arrows.

Decision criteria are specified within the decision point diamond. Typically, the decision criteria are based on the status of a single parameter (i.e., "condensate system temperature high?"), although more complex criteria may be used. Each decision point has two or three branches which are labeled with the potential results of evaluating the decision criteria (i.e., "yes", "no", or "high", "normal", "low"). The decision tree is traversed by evaluating the decision criteria and selecting the appropriate branch based on the outcome. This process is repeated until a terminal point is reached. The terminal points are the potential causes of the initial problem [6].

In alternate expressions, these diagnostic trees logic diagram can be translated into a number sets of rules, which are incorporated and coded into the expert system shell-

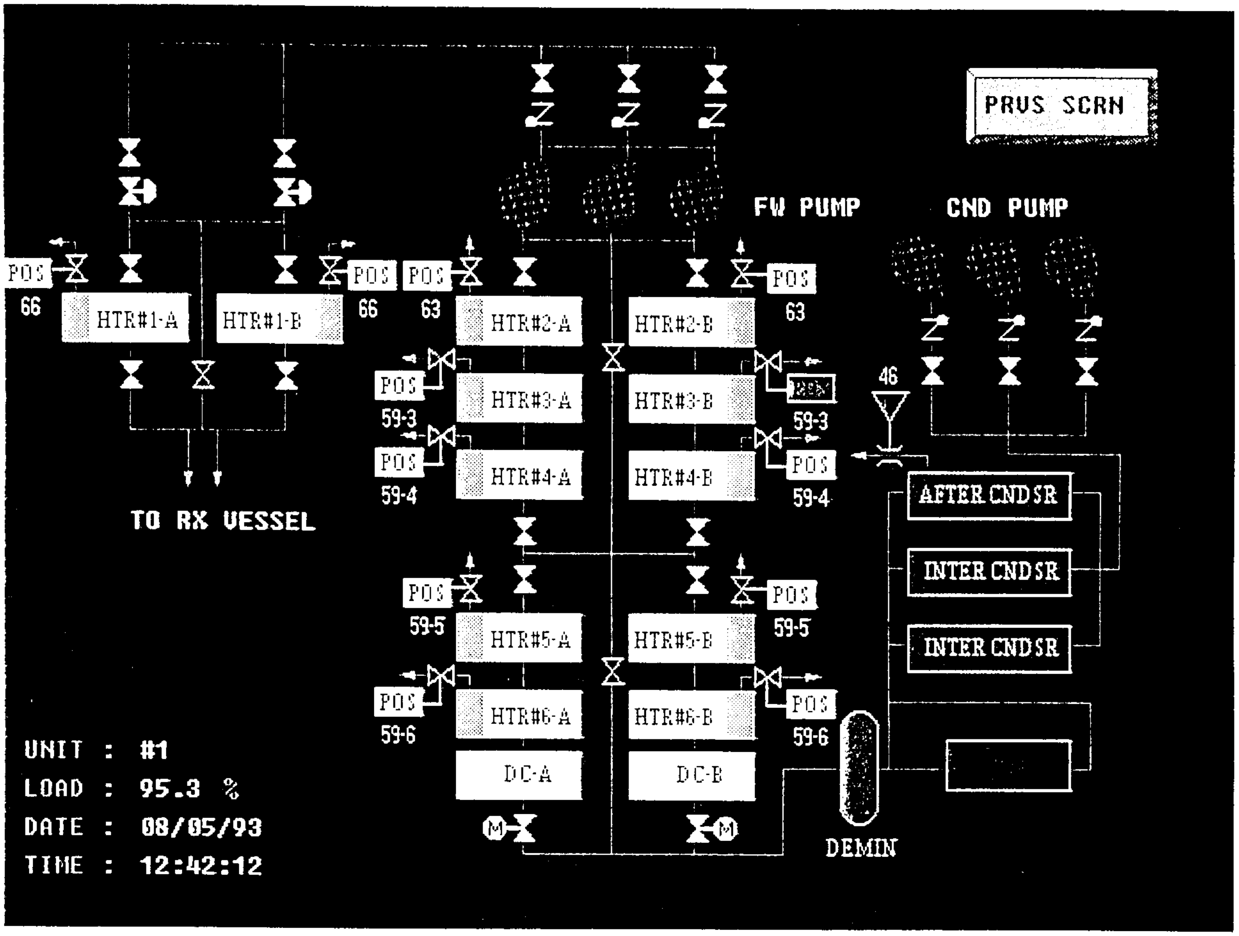

Fig. 5 Diagnostic Signals Iconic Display.

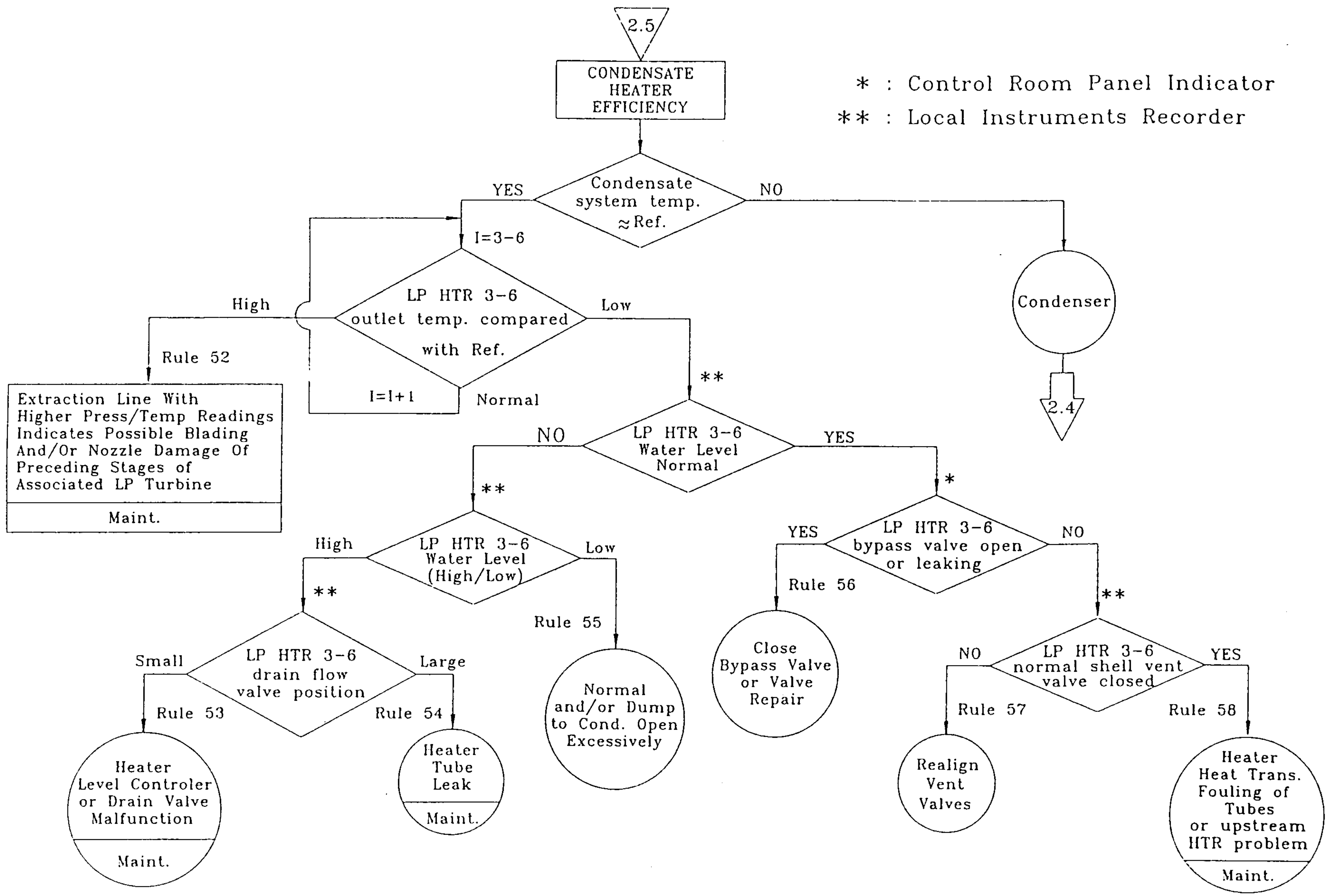

Fig. 6 Diagnostic Trees Logic Diagram of LP feedwater heaters.

GoldWorks III. The method of inference applied to TPDES is primarily ruled-based deduction, which is performed by searching <IF-AND-THEN> form rule sets. This inference method is the best means available today for codifying the problem-solving knowledge of human experts.

The overall plant diagnosis is actuated from the discrepancy between electric generation and thermal power. The built-in tracing capability in the system allows operators to follow the reasoning process step by step and to intercommunicate with each other by using the mouse click or keyboard input. Fig. 7 illustrates the sample display of the diagnostic process and results. According to this output, the performance engineer can obtain an explanation on how TPDES reaches this conclusion, to which TPDES responds by displaying a list of observed supporting symptoms (rules) of each candidate problem. This can give users a reinforcement and a substantial insight into the problem.

Individual Component Diagnosis

The plant performance monitoring model accomplished by using PEPSE code [7] in OMAS subsystem can be automatically assessed to obtain a detailed performance information. It accurately determines the plant state, discriminates against errors in the measured data, and quantifies component degradation effects. As a result, the performance engineer can subsequently select the corresponding component for diagnosis to which the OMAS has already allocated the potential generation losses attribution.

The plant system components and knowledge rule bases in TPDES are divided into nine characteristic areas which include nuclear steam supply system (NSSS), main steam line, high pressure turbine, low pressure turbine, moisture separator and reheaters (MSRs), high pressure heaters, low pressure heaters, condenser and circulating water system (CWS), and generator. A mouse click actuation can initiate the diagnostics of the dedicated component, and obtain the solutions more quickly. The reasoning process and intercommunication method are the same as the overall plant diagnosis.

IV. ADVANTAGES

The nuclear power industry has an urgent need for a proper method to aid in monitoring, identifying, and correcting the causes of lost power generation. It has been proven that TPDES can meet this purpose as a powerful tool for the performance engineers. Some visible benefits have been gained so far through the prototype system installation at Chinshan nuclear power station.

According to the EOC-12 and EOC-11 scheduled outage for Chinshan unit no. 1 and 2, respectively, the plant staff noticed that the generated electric power were less than the last cycle by about 10 MWe under full load reactor thermal power conditions. Thus, CS-MADES, incorporating monitoring and diagnostic functions, has taken charge of simulating the plant actual operating conditions and concluded five potential causes for this lost megawatts problem. These included: (1) mismeasurement of feedwater flow rate, (2) abnormal control valve position due to turbine DEH system control problem, (3) degraded heat transfer effectiveness of feedwater heating system, (4) leakage of bypass valve

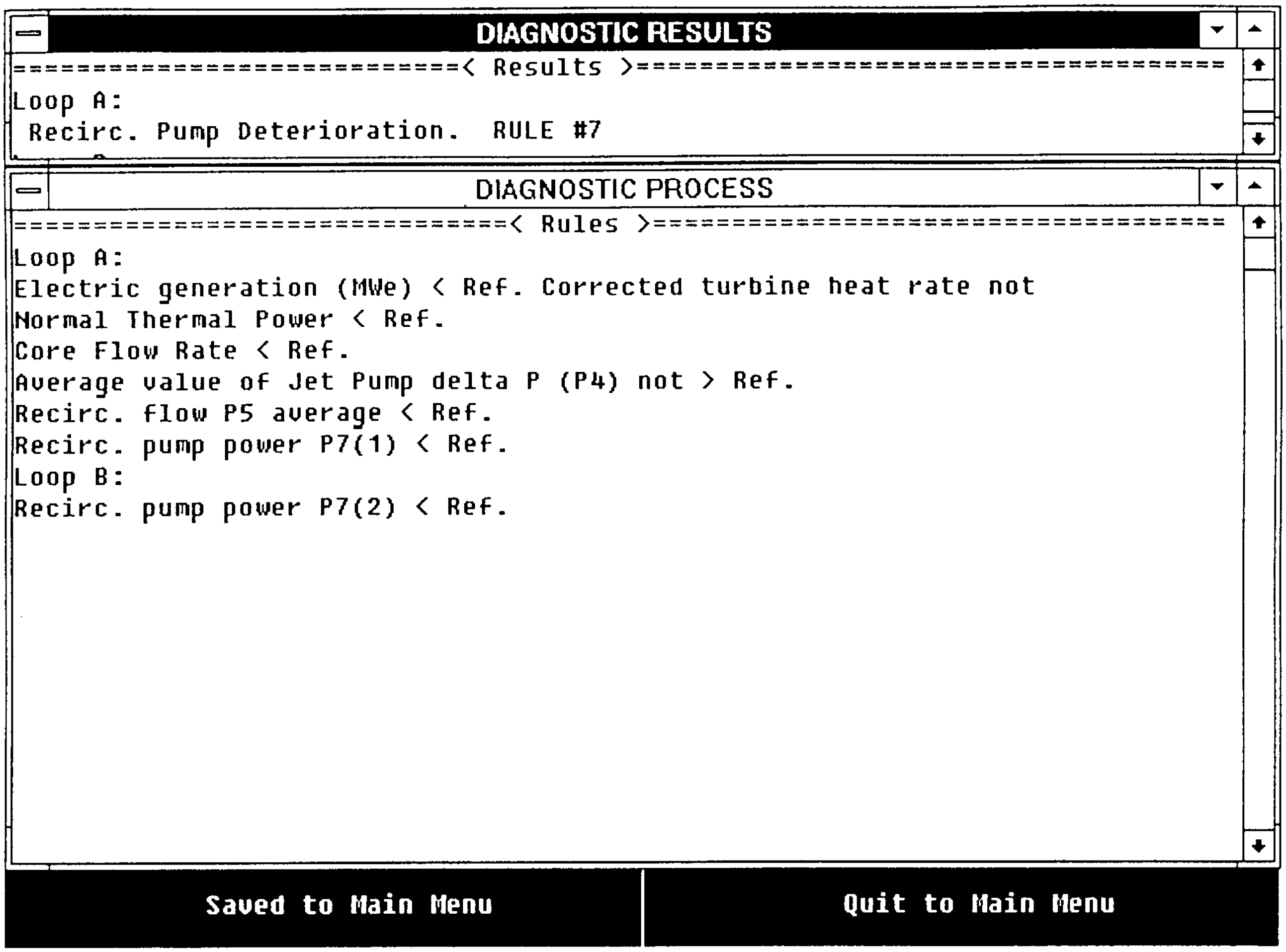

Fig. 7 Sample Display of Diagnostic Process and Results.

or other isolated system, and (5) poor steam quality. As a result of these investigations without shutdown of the reactor, conclusions (1) and (4) were identified and a total of 2MW electric was recovered. Also, other potential sources of lost load were scheduled for prior maintenance in the next refueling outage.

Although the prototype system was customized according to the performance engineer's expertise and plant historical operating experiences, the actual plant operating conditions always change with time and the system will become impractical. Thus, the TPDES was designed to be easily maintained and improved. If the diagnostic results are not reasonably accepted from the symptoms of plant performance degradation, revision of the rule-based knowledges can be easily modified and extended to fit these particular conditions. A heuristic procedures were provided to guide users doing this task and it enables the TPDES performance to be increased.

V. RECOMMENDATIONS AND CONCLUSIONS

So far, the expert system technology has a short history, but is expected to play a major role in the power industry's future. The needs to maximize plant efficiency, increase availability and extend the operating lives of plant equipments are greater than ever and show more sophistication. A thermal performance diagnostics expert system was developed at INER and implemented at Chinshan nuclear power plant of TPC. Some visible benefits have been achieved from the employment of this prototype system. However, some recommended system enhancements are given. First, TPDES could be enhanced as an on-line system which would provide more timely information and less manual data collections. However, the feasibility of such a system depends on the high accuracy of the instrumentations and the upgrade of plant process computer system. Second, the certainty factors with statistical analysis should be employed in the system to judge the conclusions which the operator has drawn. In the current system, the terminal result is unique and is not reasonably accepted sometimes according to the actual plant symptoms. Diagnoses with certainty factor schemes could provide several solutions to be considered possible. The higher the certainty factor value is, the more likely the diagnostic result will be. However, the way of determining the value of certainty factors is difficult. It strongly requires the professional domain expertise in nuclear plant operating experiences.

In summary, the TPDES, a computerized aid to the thermal performance engineer, integrates expert system technology to monitor nuclear power plant for thermal defficiencies and offer associated diagnoses addressing these defficiencies. Several useful functions are provided and they include:

(1) Accumulating on-line and off-line performance data for subsequent retrieval and storage,
(2) Diagnosing the overall plant or specific component performance via operator's selections,
(3) Actuating the diagnostic inference process by step through interactive dialogue and obtain the potential causes of the performance degradation problem,
(4) Monitoring the diagnostic signal status in graphic screen display,

(5) Offering a user-friendly environment in modifying the diagnostic rules and upgrade the system performance, and
(6) Printing any displayed screen or a document that summarize the diagnostic process and results.

It is expected that after a few years of testing and enhancement, plant performance engineer, with the assistance of the developers, can really identify and confirm the sources of plant deficiencies as well as give proper corrective actions. At that time, the maturely developed TPDES will reside in the plant performance engineer's office as an assistant and be available at any time to analyze the state of the plant.

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