XA9744375

A NEW DIAGNOSIS METHOD USING ALARM ANNUNCIATION FOR FBR POWER PLANTS

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ABSTRACT

We discuss the methodology diversity for diagnosis reasoning in autonomous operation system, and propose a new diagnosis method using alarm annunciation system. The methodology diversity is assured by preparing plural agents, each of which is based on its own different methodology, therefore, it is expected for the reliability in diagnosis to be improved. Meanwhile, the combination of annunciated alarms is expected to be peculiar to the anomalous phenomenon or accident. Moreover, as the state of affairs is developing, each appearance of the pattern is changing with time peculiarly to each anomaly or accident. The matter is utilized for the new diagnosis method. The patterns of annunciated alarms with progress of the events are prepared in advance under the condition of the anomalies or accidents by use of plant simulator. The diagnostic reasoning can be done by comparing the obtained combination of annunciated alarms with the reference templates, pattern matching method. On the other hand, we have another method, called as COBWEB used for conceptual classification in cognitive science, to reason for diagnosis. We have carried out the experiments using the loop type LMFBR plant simulator to obtain the various combinations of annunciated alarms with progress of the events under the conditions of anomalies and accidents. The examined cases were related to the anomalies and accidents in the water/steam system of the LMFBR power plant. We have obtained the conclusions that it is effective to reason the causes of anomalies using the annunciated alarms. We are going to apply the pattern matching technique or COBWEB method into the diagnostic reasoning to confirm the performance of the proposed diagnosis method based on the alarm annunciation.

1. INTRODUCTION

Since it is desired to enhance availability and safety of nuclear power plants operation and maintenance by removing human factors, there are many researches and developments for intelligent operation and diagnosis using artificial intelligence(AI) technique.

We have been developing an autonomous operation system for nuclear power plants by substituting AI for plant operators and in addition conventional controllers used in existing plants, taking the case of loop type LMFBR power plant (1). With autonomy in the autonomous operation system, the general idea is stated clearly from five items as follows: (1) to operate and maintain the plant fundamentally by itself based on its own given norm, (2) to operate the plant without being dependent on human operator under condition of normal operation mode and of design based anomalous phenomena, (3) to operate the plant as instructed by human under condition of not-design based anomalous phenomena, (4) to inspect and maintain the plant in cooperation with human under normal operation mode, (5) to inspect and repair the plant components as instructed by human for periodical inspection and troubles or accidents of the plant functions. Therefore, it is essential to build up the autonomous operation and maintenance system for the plant by AI and intelligent robot techniques.

For the autonomous operation system, we have adopted a hierarchical distributed cooperative configuration to recognize its function, and a multi-agent architecture, in which each method performing individual function such as diagnosis of plant, state estimation, and operating control, is carried out by each agent respectively, to realize the distributed cooperative system. In the system, we have also proposed a methodology diversification, that consists on applying plural methods based on different principles to a specific task in diagnosis or control. It enables mutual backup to prevent loss of system functions caused by an obstacle occurred in an agent by isolating it, and facilitates the reorganization of the system function using remaining agents. And also, it is expected to improve reliability of diagnosis and to optimize control performance through the methodology diversification.

As the first step of the development, we have been developing the prototype system. As for the diagnosis systems, at present, they consist of two diagnostic reasoning levels, a plant level based on a hierarchical plant functional model, and a local level based on a physical causal network model using qualitative reasoning technique(2).

For the methodology diversification in diagnosis, we now attempt to supply a new diagnostic method besides the qualitative reasoning method. In the paper, we discuss the methodology diversity for the above-mentioned local level diagnostic reasoning, and propose a new diagnosis method using alarm annunciation system. The combination of annunciated alarms is expected to be specific to the anomalous phenomenon or accident. Moreover, as the state of affairs is developing, each appearance of the combination is changing with time specifically to each anomaly or accident. We intend to utilize the matter for the new diagnosis method.

2. DIAGNOSIS METHOD USING ALARM ANNUNCIATION

Regarding the methodology diversification of diagnosis in the autonomous operation system, plural diagnosis methods in which different principles are applied to the same anomalous phenomenon. The concluding diagnostic result is then made by a mutual agreement based on a rational standard from result obtained by each method.

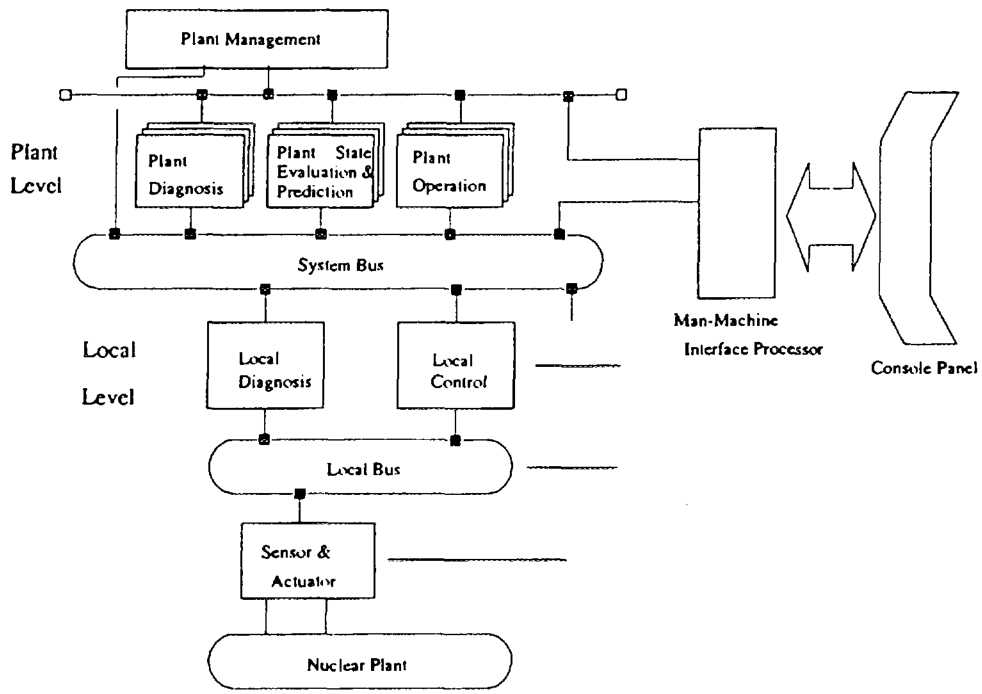

Fig.1: System Configuration of Prototype Autonomous Operation

Figure 1 shows the prototype autonomous operation system which we have been developing as the first step mentioned above. We now intend to discuss about the local level diagnosis in Figure 1. Relation between the methodology diversification in diagnosis and the mutual agreement for rational diagnostic result is shown in Figure 2.

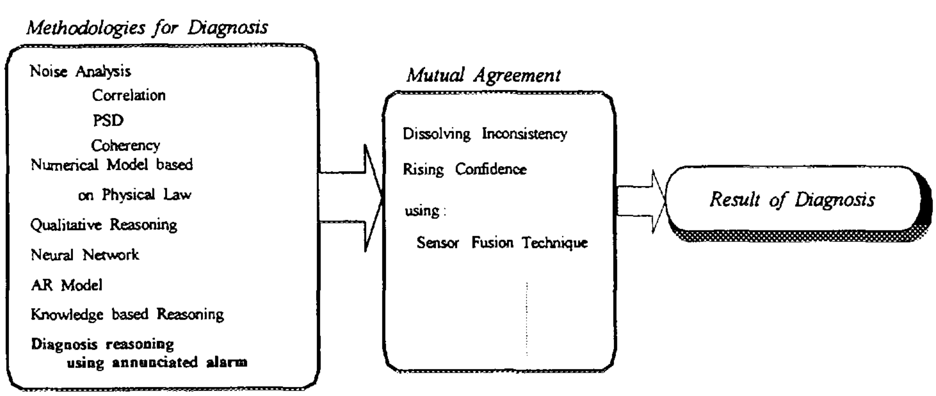

Fig.2 Methodology Diversity in Local Diagnosis

Besides, Figure 3 shows what are the mutual supplement and mutual agreement between the plural diagnosis in the methodology diversification. Various diagnosis methods are applied to the same anomalous phenomenon and rational and confident diagnostic result is obtained through each result from respective diagnosis. At present, in the prototype system, we develop a new diagnosis method using alarm annunciation as a part of the methodology diversification in local level diagnosis system.

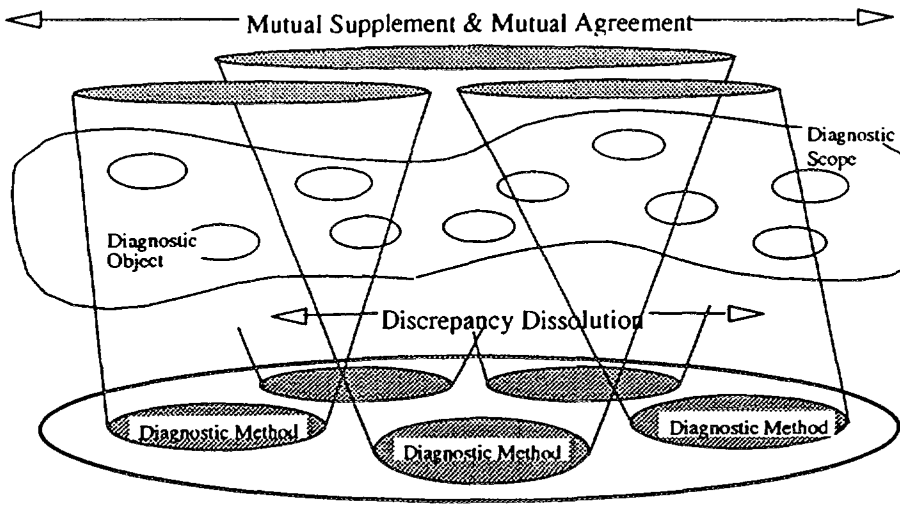

Fig. 3 Objective of Methodology Diversity

It can be said that the diagnosis method using alarm annunciation finds out the cause of anomaly by paying attention to the combination pattern of annunciated alarms and to the change of the annunciated alarm combination pattern as time developing when an anomalous phenomenon or an accident occur in plant. The combination patterns of annunciated alarms with progress of the events are prepared in advance under the condition of anomalies or accidents by use of plant simulator. Each combination pattern is utilized as the templates corresponding with each anomaly or accident, respectively. The diagnostic reasoning can be done by comparing the obtained combination of annunciated alarms with the templates. The diagnostic reasoning can produce the results with the degree of confidence given by the rate of agreement with the templates. Figure 4 shows what is an outline of diagnosis by pattern matching with an annunciated alarm combination pattern immediately after an occurrence of anomaly and the template pattern for diagnostic reasoning. However, it is thought to be difficult to identify the cause of anomaly only from the alarm combination pattern immediately after the occurrence. Therefore, it is necessary to improve a conviction degree of diagnostic result using time change of the alarm combination pattern with development of anomalous phenomenon. In other words, as for an aspect of each change of alarm combination pattern with development of phenomenon, there is expectation that peculiar characteristic behavior dependent on each anomalous phenomenon will be done. What is shown on the point that would be given conviction degree of diagnostic result by degree by using a change with time of the annunciated alarm combination pattern is Figure 5. Here is shown the technique to reasoning cause accompanied with conviction degree for diagnostic result by agreement degree by a method of pattern matching with the annunciated alarm combination pattern and the template pattern as standard.

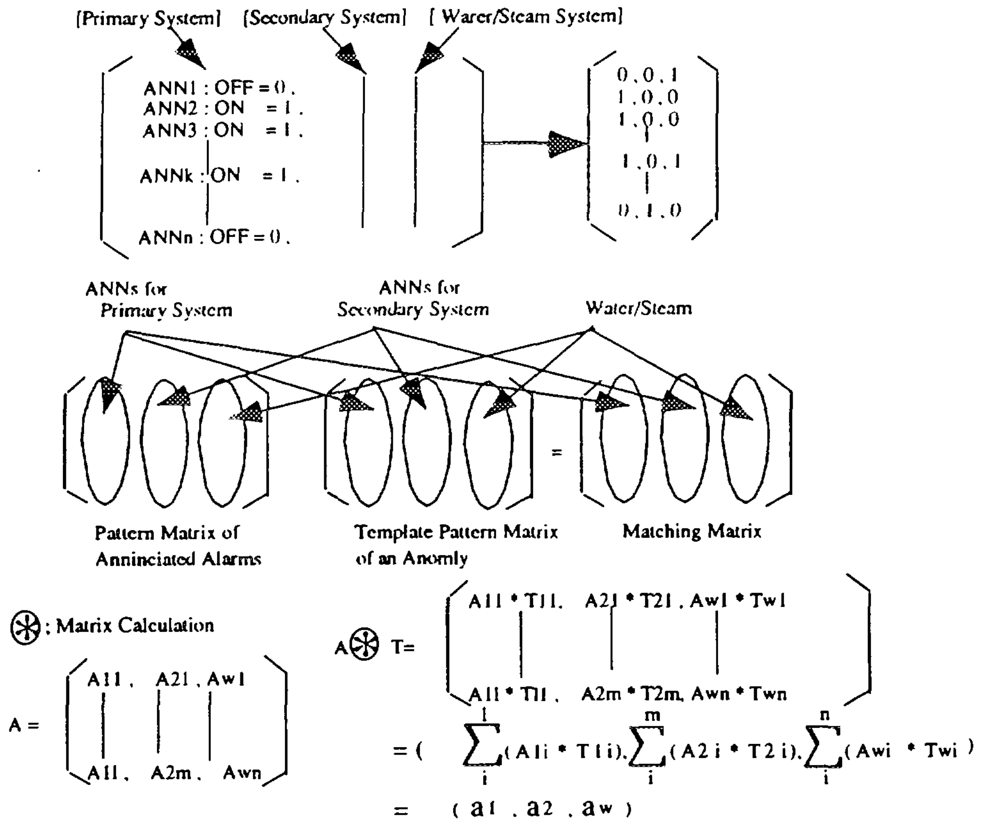

Fig. 4 Pattern Matching Method for Diagnosis

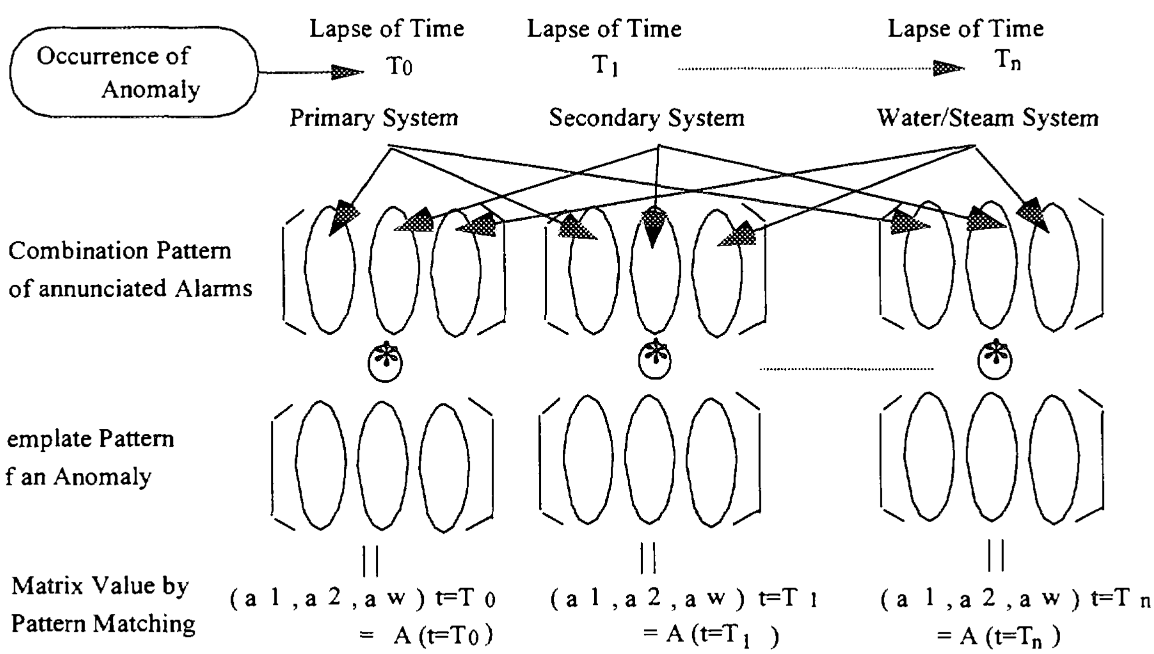

Fig.5 Pattern Matching Method between the Patterns of annunciated Alarms an Templat corresponding to an Anomaly using the Changes of Patterns as Time goes by

On the other hand, there is a different diagnosis method from the above mentioned method of pattern matching technique, that is, a method based on a conceptual clustering(3) as a kind of inductive learning called as learning from observation among unsupervised learning. The conceptual clustering method accepts a set of object descriptions like events, observations, and facts, and produces a classification scheme over the observations. The method does not require a teacher to preclassify objects, but uses a heuristic index, called as category utility for category evaluation based on concept of family resemblance used in the field of cognitive psychology, to discover classes with good conceptual descriptions. Clustering forms a classification tree over objects. Plural cases are classified into hierarchical classes according to their family resemblances by category utility. COBWEB method(4) is known to be a popular and effective method for the conceptual clustering. COBWEB is an incremental method for hierarchical conceptual clustering. The method carries out search just like a hill-climbing through a space of hierarchical classification schemes using operators which enable bi-directional transfer through the space. The method incrementally incorporates objects into a classification tree, where each class or node is a probabilistic concept which represents an object class. The incorporation of an object is a process in itself of classifying the object by going down the tree along an adequate path, renewing category utilities along the path, and executing an operator among four operators at each level class. The four operators are as follows: (1) to classify the object into an existing class, (2) to create a new class, (3) to combine two classes into a single class, (4) to divide a class into two classes, following the value of category utility.

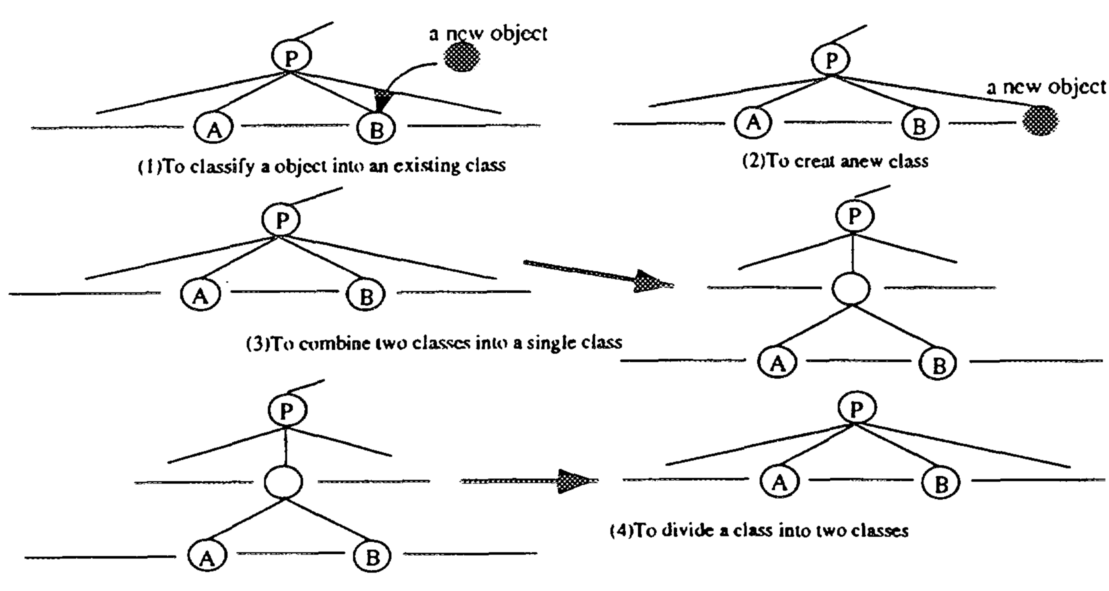

Fig. 6 Four Four Operators in COBWEB

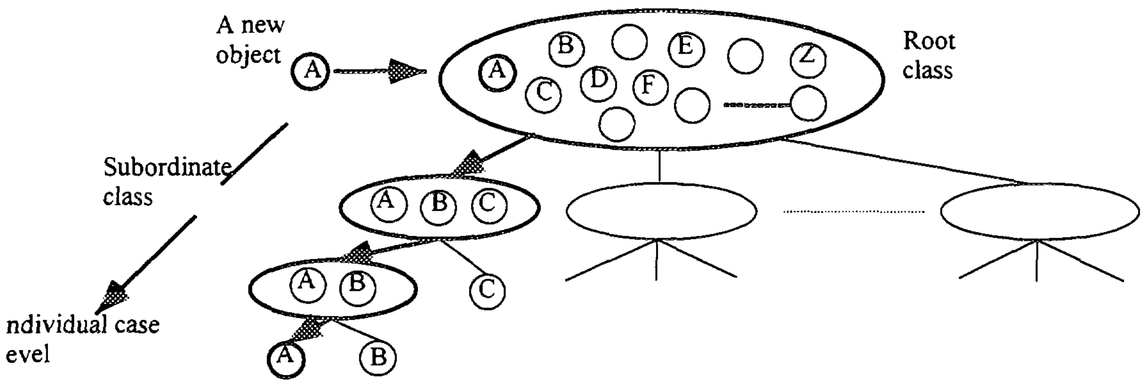

Fig.7 Outline of Process in Classificating a New Object

Figure 6 shows the four operators in COBWEB classification. Figure 7 shows an outline of a process in classifying a new object, that is, corresponding to a process in diagnosis reasoning when is obtained a new annunciated alarm combination pattern by occurring an anomalous phenomenon.

The matter above mentioned is, however, discussion about static objects or cases, that is, the conceptual clustering is done without consideration about attribute of time. In diagnosis for anomalous phenomenon occurred in plant, are important the momentary progress, transition, and propagation of the anomalous phenomenon as time goes by as from the occurrence. Therefore, it is necessary to consider the change of attribute (i.e., each annunciated alarm) as essential attribute for conceptual classification. When we applied COBWEB to the diagnosis using annunciated alarms, state of 'on' or 'off' of each annunciated alarm is regarded as attribute for the classification, and changing time from 'off' to 'on', or from 'on' to 'off' of each annunciated alarm, which is lapse of time starting from first alarm annunciation cased by occurrence of an anomalous phenomenon, is also regarded as attribute. It can be said that there exist two concepts in the conceptual classification, that is, one is a conceptual class made up of attributes of annunciated alarms, another is a conceptual class made up of attributes of changes of state, 'on' or 'off', with changing time of each annunciated alarm. The former conceptual class is called as 'schema class', and the latter is 'state class'(5). Therefore, each hierarchical conceptual schema class, built up from alarms annunciated by an anomalous phenomenon for diagnosis reasoning, involves state classes as time series attributes, respectively. The outline of the hierarchical structure made up of schema classes and state classes is shown in Figure 8. In conceptual classification for anomalous phenomena with time developing, it is divided with two parts, that is, the schema class formations and the state class formations, and it can be done by performing each class formation reflexively.

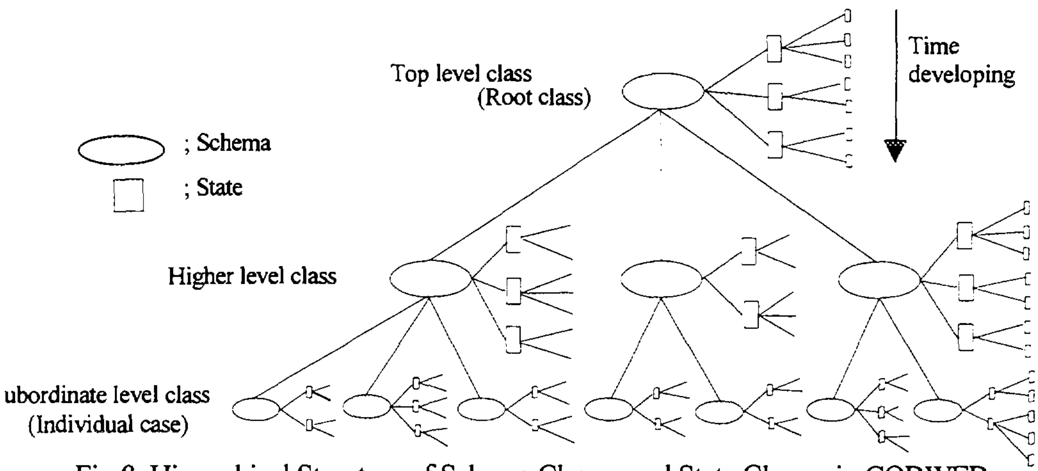

Fig.8 Hierarchical Structure of Schema Classes and State Classes in COBWEB

In actual diagnosis in plants, operators carry out momentary diagnosis reasoning using the annunciated alarms changing as time goes by as from the occurrence of anomalous phenomena. Namely, they do diagnosis reasoning roughly and produce some candidates of causes immediately after the occurrence, and as the state of affairs advances, they specify a candidate of cause gradually. In other words, their diagnosis reasoning become more and more unquestionable as the conviction degree rises higher. Both the pattern matching and COBWEB are the methods of diagnosis reasoning that can provide a reliable result of diagnosis reasoning gradually to us as way as the operators is doing the diagnosis reasoning in existing plants. It can be said that both reasoning methods are essentially equivalent with regard to diagnosis reasoning for dynamic phenomena having schema and state attributes just like an anomaly in plants. While, the pattern matching method is a conceptual classification using observed objects sampled at every specific time, COBWEB is, on the other hand, a conceptual classification involving attributes with all specific times of changes of state of itself.

In any case that the pattern matching or COBWEB method is used in diagnosis reasoning, it is essential that there are specific differences among the combination patterns of annunciated alarms with time developments obtained by occurrences of anomalous phenomena in FBR power plants.

3. EXPERIMENTS BY PLANT SIMULATOR

For confirmation of the propriety of the diagnosis method based on alarm annunciation, that is, the pattern matching method or COBWEB method, it is necessary to examine each combination pattern of annunciated alarms obtained by anomalous phenomena, in advance, using by a plant simulator if each pattern is peculiar to an anomalous phenomenon, respectively. Therefore, we have carried out the experiments using a 3 loop type LMFBR plant simulator to obtain the various combinations of annunciated alarms with progress of the events under the conditions of anomalies and accidents occurring. Figure 9 shows the block diagram of LMFBR modeled in the plant simulator.

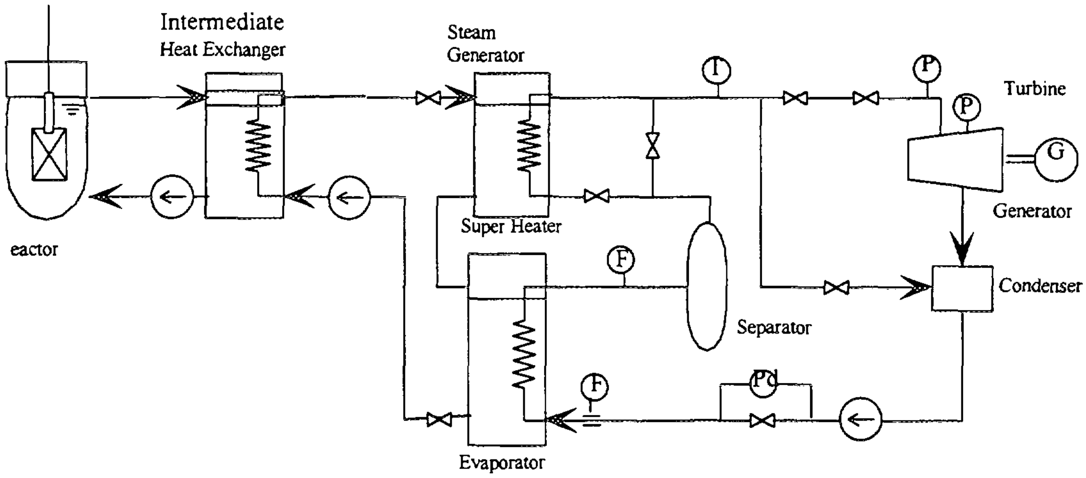

Fig.9 Block Diagram of LMFBR plant Modeled in the Plant Simulator
Used in the Simulation Examination

The examined cases were related to the anomalies and accidents in the water/steam system of the LMFBR power plant. We have examined thirty four kinds of anomalous phenomena, taking time series data of annunciated alarms, events list, together with typical trend process data. And also, we carried out the examination two times at interval of one month to see if the state of affairs in annunciated alarms reappears for each anomalous phenomenon. The examined anomalous phenomena are listed in Table 1. These anomalies are registered as standard malfunctions in the plant simulator. All the examinations have been carried out under the condition that the plant is operated in 100% full power.

Figure 10 shows an example of the timing flowchart arranged from the events list of a series of annunciated alarms as time goes by as the anomalous phenomenon develops, in a case of W-13-01, that is, an anomaly of closing all stopping valves in 3 feedwater loops by mistake. All events lists obtained in the examination tabulated in Table 1 have been arranged into the timing flowcharts as shown in Figure 10, respectively. In the timing flowcharts, the lapse of time in the flowchart starts from the time when the first alarm is annunciated by the occurrence of anomaly. Then, from all the examined cases, it was observed that 201 alarms are annunciated all in examined 34 cases of anomalies on steam/water system of LMFBR plant. We have made the pattern of combination of annunciated alarms from the timing flowchart of events, at interval of specific time, respectively. For example, in Figure 11, is shown the pattern of combination of annunciated alarms obtained in the malfunction of W-13-01 at about 5 sec after the occurrence of anomaly that is regarded as an initial stage of anomaly. In this case, the initially annunciated alarms were 6 alarms of 'EV A FW FLW L/LL', 'EV A,B,C OUTL STM TMP CONT ABNML', 'W/S A OUTL PRS H', and 'FCV DIF CONT ABNML'.

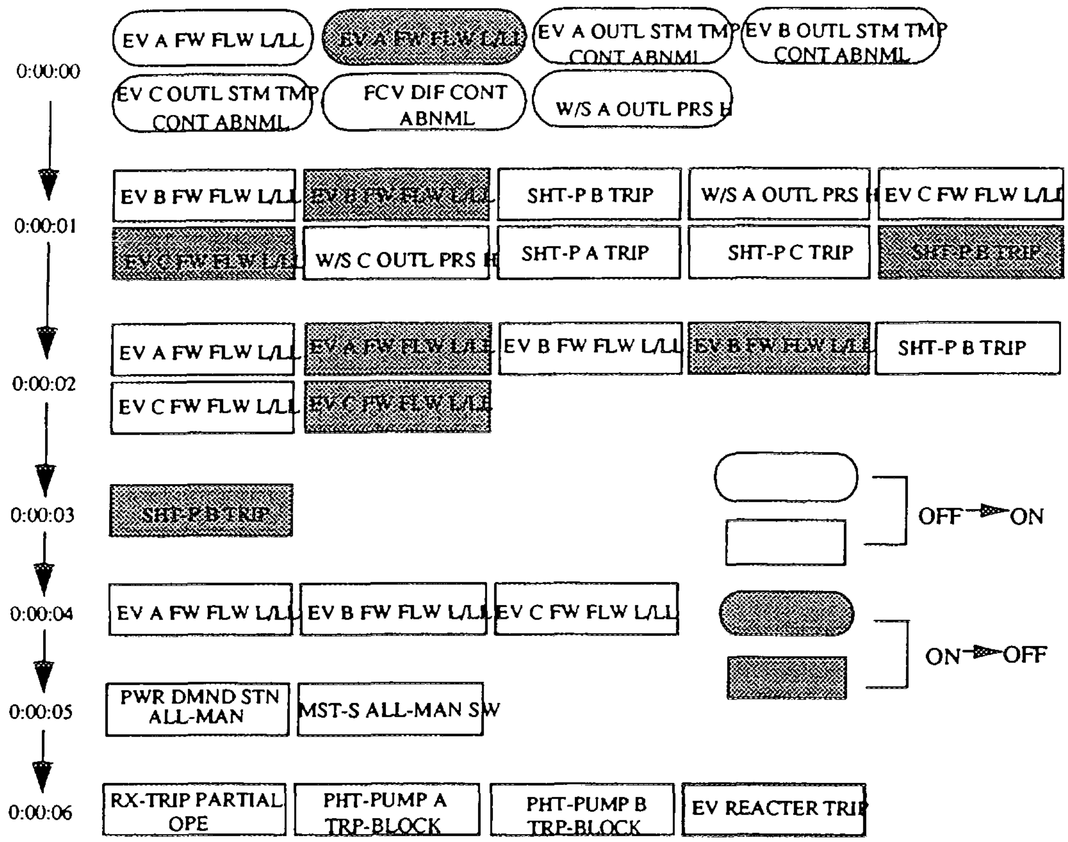

Fig. 10 Timing Flowchart Arranged from the Events List in Case of W-13-01 Corresponding to Anomaly of Closing all Stopping Valves in 3 Feedwater Loops

By the way, it was observed that there were plural cases in which the alarm, 'EV A OUTL STM TMP CONT ABNML', appeared as an initially annunciated alarm among the examined cases. These cases were the anomalies of W-06-01, W-08-01, W-09-01, W-11-01, W-13-01, W-13-02, W-17-01, W-18-01, W-27-01, and W-27-02 tabulated in Table 1. We can not define the cause of anomaly among the above mentioned candidates only from the initially annunciated alarm, 'EV A OUTL STM TMP CONT ABNML'. However, comparing the annunciated alarms in these cases at about 5 sec after the occurrence of anomaly such as shown in Figure 11, it was observed that, in the cases of W-06-01 and W-08-01, the alarms of 'EV B,C OUTL STM TMP CONT ABNML' and 'FCV DIF CONT ABNML' were annunciated initially, in the case of W-09-01, the alarm of 'EV B,C OUTL STM TMP CONT ABNML' was annunciated and the alarm of 'FCV DIF CONT ABNML' followed after that. Besides, in the case of W-11-01, there was not any alarm without the alarm of 'EV A OUTL STM TMP CONT ABNML', and in the case of W-13-01, were initially annunciated the above mentioned alarms and the alarms of 'PHT- PUMP A,B TRP-BLOCK', 'EV B,C FW FLW L/LL', 'SHT-P A,B,C TRIP', 'MST-S ALL-MAN SW', and 'RX-TRIP PARTIAL OPE' follow after that. In the case of W-13-02, it was almost similar to the case of W-13-01 except for annunciating the alarms of 'SHT W/STM TRIP DMND' and 'B,C FW SHT NA FLW MIS-MATCH'. There were no differences between the case of W-09-01 and the cases of W-17-01, W-27-01, and W-27-02. The case of W-18-01 was similar to the case of W-13-01 except for annunciating the alarm of 'W/S A OUTL PRS H'. It was done to define each anomaly of W-11-01, W-13-01, W-13-02, and W-18-01 from the combination patterns of annunciated alarms at 5 sec after the occurrences, respectively. The other cases were regarded as an same group, and could not be distinguished each other. But we could see the differences between these cases difficult to distinguish, comparing the changes of annunciated alarms as time goes by after that. That is, seeing the timing flowchart of annunciated alarms corresponding with each anomaly, in the case of W-06-01, the alarm of 'EV A,B,C OUTL STM TMP CONT ABNML' once changed from 'on' to 'off' at 9 sec after the initial annunciation of alarm, and changed from 'off' to 'on' over again at 2 sec after that. In the case of W-08-01, the alarm of 'EV A,B,C OUTL STM TMP CONT ABNML' changed from 'on' to 'off' at 9 sec after the initial annunciation. In the case of W-09-01, the alarm of 'EV A,B,C OUTL STM TMP H/HH' was annunciated at 13 sec after. On the other hand, in the case of W-17-01, the alarm of 'EV A,B,C OUTL STM TMP H/HH' was annunciated at about 9 sec after. In the case of W-27-01, the alarm of 'FCV DIF CONT ABNML' changed from 'on' to 'off' at 10 sec after, and the alarm did not return to 'on' for about 90 sec after that, and, in the case of W-27-02, meanwhile, the alarm behaved in the similar way but returned to 'on' at about 30 sec after that. Besides, the alarm of 'HP-2HTR DRN LVL H/L' was newly annunciated at about 30 sec after.

Fig. 11 Pattern of Combination of Annunciated Alarms Obtained at 5 sec after from the Initial Alarms for the Malfunction W-13-01 of the Simulation Test by the LMFBR Plant

As is mentioned above, when the alarm of 'EV A OUTL STM TMP CONT ABNML' was initially annunciated, are reasoned as candidates of causes of anomalies the cases of W-06-01, W-08-01, W-09-01, W-11-01, W-13-01, W-13-02, W-17-01, W-18-01, W-27-01, and W-27-02, and, at 5 sec after the initially annunciating, is distinguished the case of W-11-01, W-13-01, W-13-02, and W-18-01, respectively, among them, and, at 15 sec after that, is distinguished the case of W-06-01, W-08-01, W-09-01, and W-17-01, respectively, and lastly, at about 30 sec after, the case of W-27-01 and W-27-02, respectively, is finally rezoned. The sequence of the reasoning mentioned above is shown in Figure12. It can be said that it is possible to reason and distinguish each cause of anomalous phenomenon among all the anomalies in the water/steam system of LMFBR from the patterns of annunciated alarms with the changes of the patterns as time goes by.

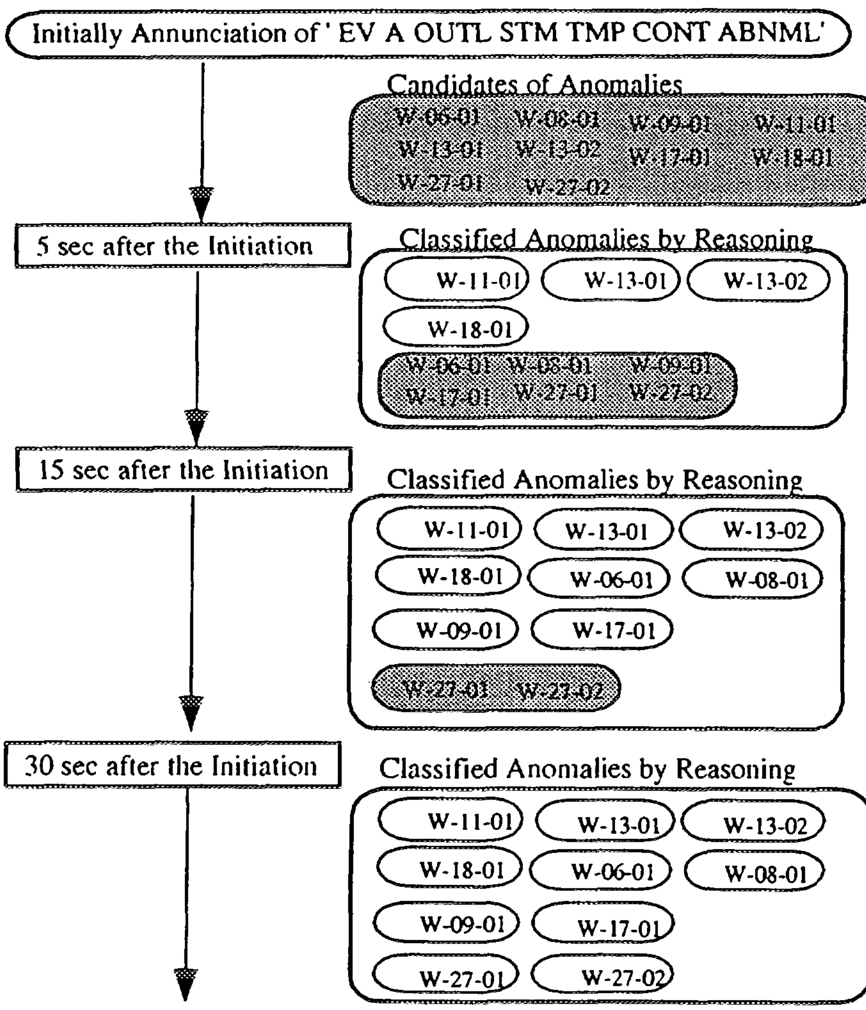

Fig. 12 Process of Reasoning the Cause of an Anomaly among the Candidate of Anomalies in the Case that a Same Alarm is Initially

Next, we have tried the classification of the above mentioned cases by COBWEB method. Firstly, has been done the classification without attributes of time when the status of alarms change from 'off' to 'on' or from 'on' to 'off', that is, considering only the status of 'on' or 'off' of alarms. The result of classification without attributes of time is shown in Figure 13. Secondly, we have tried the classification of the cases with attributes of time when the status of alarms change from 'off' to 'on' or from 'on' to 'off', and Figure 14 shows the result of the classification. Seeing each result of classification, it may be said that both of the classification without and with attributes of time produce the appropriate conceptual classification, respectively, where resemble cases are classified into a single unit class. From the present results, we are sorry to say that there are no conspicuous differences between the results without and with attributes of time. However, at any rate, it has been found that COBWEB method has a potentiality to furnish an effective result of classification for diagnosis reasoning using only annunciated alarms without any knowledge about the plant constitutions and functions. But, on the other hand, there are some problems solved to apply COBWEB to diagnosis reasoning, that is, how to obtain the general result of classification independently on calculation parameters, how to calculate in real-time in spite of process using great many attributes for classification, and so on. These are future subjects.

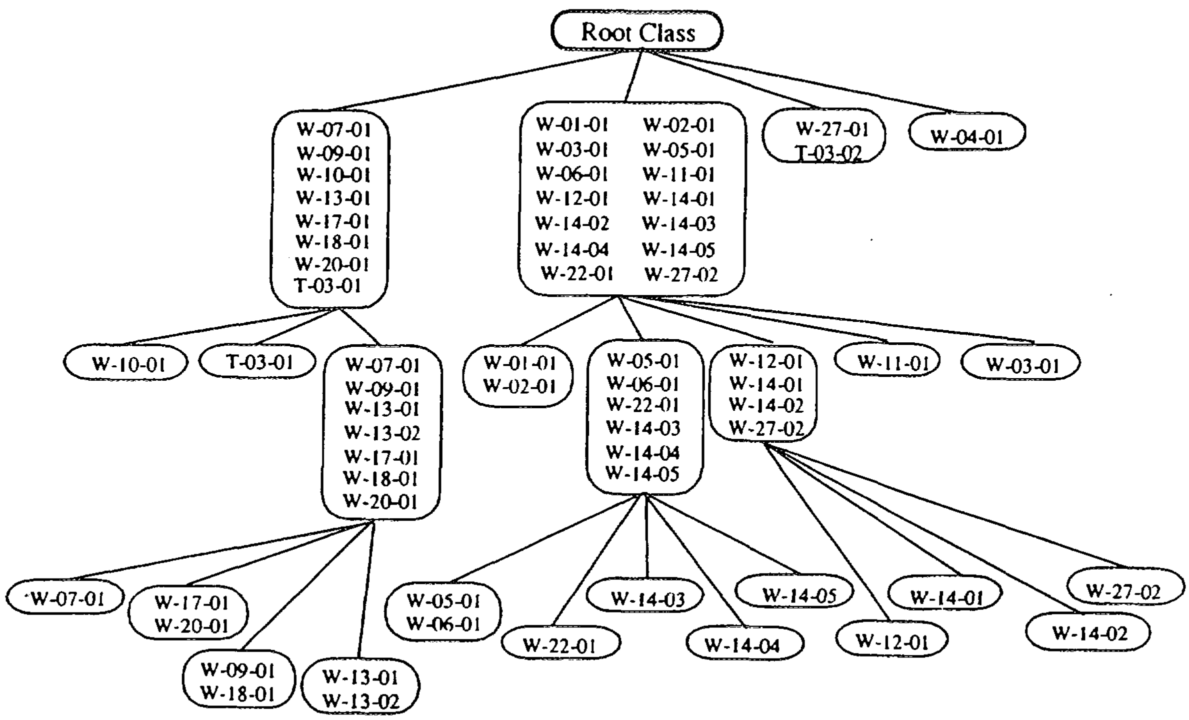

Fig. 13 Example of Classification for Anomalies Simulated Using Plant Simulator Without Attributes of Time

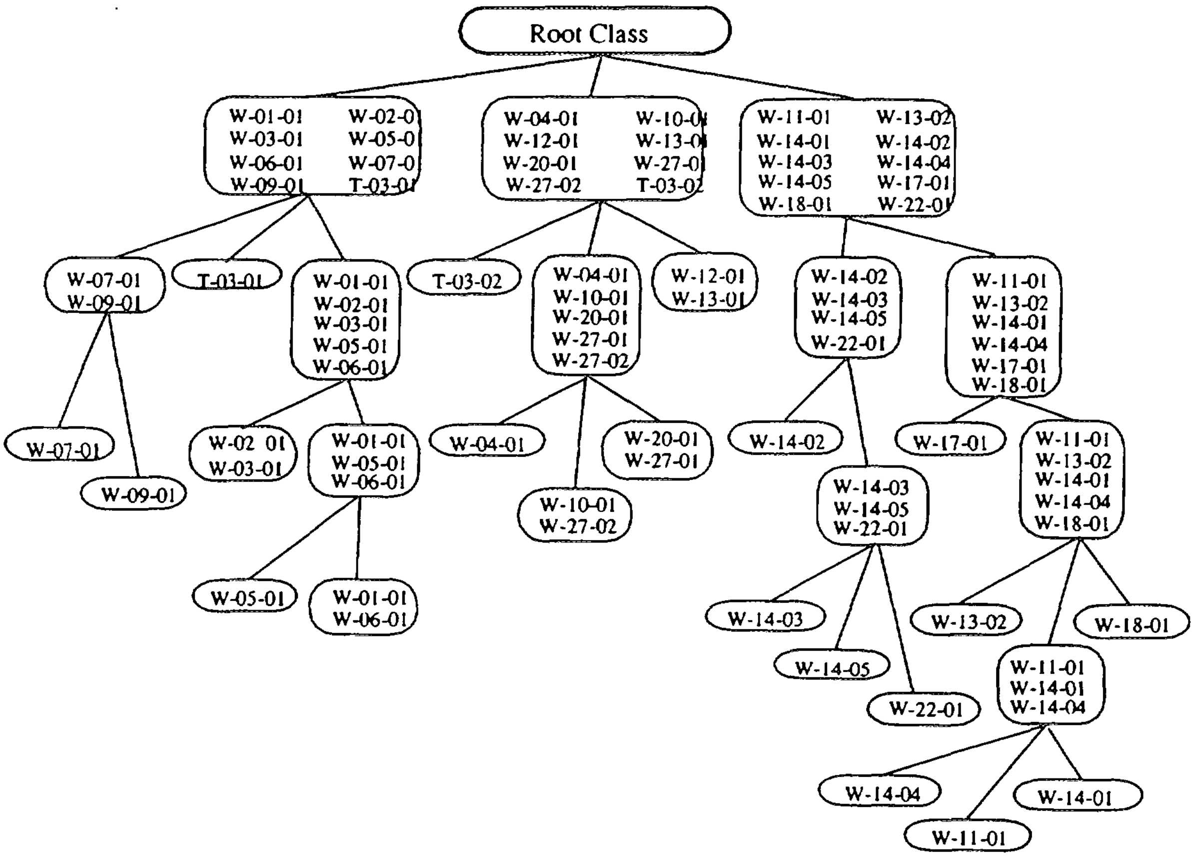

Fig. 14 Example of Classification for Anomalies Simulated Using Plant Simulator with Attributes of Time

4. CONCLUSIONS

We have now presented a new diagnosis method using alarm annunciation from a point of view of methodology diversification for diagnosis for autonomous plant operation system, and have also carried out simulation examinations to estimate the efficiency of the diagnosis method. We have obtained the conclusions from the results of examinations by plant simulator as follows:

(1) it is possible to reason and classificate the cause of anomalies from the patterns of annunciated alarms with regard to anomalous phenomena in the water/steam system.

(2) it is essential to utilize the change of the pattern of annunciated alarms with time for reasoning the causes of anomalies.

(3) it is expected to progress the reasoning and focusing among the candidates of causes of anomalies with improved conviction degree as time goes by from the occurrences of anomalies.

We have also found that it is promising to use the method of the pattern matching or COBWEB for diagnosis reasoning. There are, however, some subjects solved in applying the methods to diagnosis reasoning. We will investigate in the future which method is more effective for diagnosis reasoning using annunciated alarms, the pattern matching or COBWEB, clearing the problems to be solved in applying to diagnosis reasoning for LMFBR plants.

5. ACKNOWLEDGEMENTS

We would like to thank H.YAMAMOTO for putting the massive data obtained in the simulation test by plant simulator in order. We would also like to acknowledge T. Odo, N. Koyagoshi, T. Okude, T. Kawanishi and other members of Monju Construction Office, PNC for supporting and cooperating in carrying out the simulation test by plant simulator. Further, we would like to thank A. Saiki of Industrial Electronics & System Laboratory, Mitsubishi Electric Corp. for calculating by COBWEB for conceptual classification with regard to the cases obtained in the simulation examination by the plant simulator.

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