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Web-based Failure Analysis of Engineering Systems

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A R T I C L E I N F O

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A B S T R A C T

A methodology has been developed in this study to perform failure and reliability analysis which is extremely important element for improving plant operation and safety. In this methodology, the plant topology plays the major role. It defines the relationships among plant components, systems and structures. It provides the system configurations and causal relationships needed for performing reliability and performance analyses. Information technology is the key technology to complement the achievement of safe operation in all industrial systems including nuclear power plant and petrochemical facilities. The proposed methodology brings the two superior technologies of the millennium, i.e., information technology and the nuclear technology, together to bring industrial safety back to the main focus.

1. Introduction

A methodology has been developed in this paper to perform failure and reliability analysis which is extremely important element for improving plant operation and safety and to show the efficiency of the methodology a software (**F**ailure **A**nd **R**eliability **A**nalyses **S**ystem, FARAS) has been developed also Reliability Work Bench has been used for as benchmark. In this methodology, the plant topology plays the major role. It defines the relationships among plant components, systems and structures. It provides the system configurations and causal relationships needed for performing reliability and performance analyses. The causal relationships modeled by the plant topology are very crucial for evaluating the plant condition and safety. Integrating analysis tool with plant topology is another aspect of the methodology proposed by this paper.

The use of plant topology is a replacement for arrays of logics which usually construct the knowledgebase of an inference engine. The expansion of the plant topology as the basis for explaining the relationships among plant components, systems, and structures, captures the dynamics of plant condition. It is one of the major contributions of this study. On the other hand, information technology is the key technology to complement the achievement of safe operation in all industrial systems including nuclear power plant and petrochemical facilities. The proposed methodology brings the two superior technologies of the millennium, i.e., information technology and the nuclear technology, together to bring industrial safety back to the main focus.

One of the main objectives of this paper, while aiming to fuse the above technologies together, would help to achieve this great objective by introducing a web-based technology to perform on-line failure and reliability analysis and by using the electronic communication technology to share historical data to perform analysis and to share the result with others worldwide.

To show how the methodology developed in this paper may really help the plant engineers, a typical residual heat removal (RHR) system as incorporated in nuclear power generation plants is used as the case study. The methodology would be used to develop the system on a web-based platform and the reliability and failure analysis would then be performed on such platform.

2. System modeling

Modeling the desired system is perhaps the most important step in system reliability assessment and failure analyses. To model a failure/reliability analysis system based on the topology of the system, we need to define and establish relationships such as functional and causal relationships among different elements (i.e., components, trains and structures) of the system (Hadavi, 1998; Modarres, 2006). Such a

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model will succeed only if we well understand the logical/functional relationships between different elements of a system. The system model can be graphical, mathematical, descriptive, or any combination of above showing the system's interdependencies, hierarchy, and the way different parts of the system relate to each other. It is not necessary for every aspect of the system to be included in minute detail, but the model must be sufficiently accurate to allow a thorough system analysis.

Each system is composed of numerous subsystems and components. Each system or subsystem must be decomposed to the lowest level required to meet the objectives of the reliability and failure analysis, and then the logical relationships between systems, subsystems, and individual components must be determined and modeled. In this paper the relationships displayed in piping and instrumentation diagram (P&ID) presentation is used as the basic model for analyzing systems. Representing the relationships in form of P&ID is a convenient way of understanding the causal hierarchy of an engineering system. The convenience of daily use of P&IDs by plant personnel is the major motivation behind presenting the relationships in plant using the P&ID format.

2.1. The GTST-MPLD Framework

A nuclear power plant is a complex system constituted of many layers of structures each associated with one or more functions. Understanding the degrees of complexity and attributes of such system is essential for modeling the inter-relationships between the components, functions and in general different levels of system structures. Also a detail review of properties of complex physical systems in terms of their functions has been done (Modarres, 2006). Establishing the attributes of a complex system, several classes of hierarchy which each explains the properties of the system from different viewpoints such as goal/condition hierarchy, behavioral hierarchy, event hierarchy, structural hierarchy and functional hierarchy has been defined.

The goal tree success tree, GTST, framework has been successfully used to model a number of specific physical systems for various applications such as system health and maintenance monitoring (Hadavi, 1998), software development life cycle model (Kececi and Modarres, 1998), and real-time supervision of hazardous plant (Nordvik et al., 1996). The level of success of this modeling framework for nuclear power plant system is appreciated when we see an appreciable number of them modeling different aspects of nuclear power plants. Among these works, the application of GTST modeling for operator advisory systems, fault administration, reactor safety assessment systems, monitoring systems and operator support expert system can be clearly singled out.

Fig. 1 shows a generalized representation of a GTST. The lowest level of a GTST model explains the interactions between the basic elements of the system (i.e., components, software and human behaviors and actions) and their role in achieving the higher functions as shown in Fig. 2. In order to present the success logic of a very complex interaction system the concept of Master Plant Logic Diagram (MPLD) has been introduced by (Hunt and Modarres, 1987). MPLD is a logical representation of the overall system interactions with respect to the individual systems which shows the interrelationships among the independent parts of the systems including all of support systems. To meet our objective in proper system modeling, part-whole and topological hierarchies have been used in this paper.

2.2. Rule-based nodes

One of the main objectives of this paper is to develop the concept of such analyzing tool which relates the plant operation conditions with the plant topology and structure. To achieve such objective, one needs to develop a tool which enables the user to evaluate plant operational conditions (which manifest itself in plant physical and performance parameters) and the plant system relation and structure (modeled in P&ID) simultaneously without a knowledge of Boolean algebra. Entering plant operational condition into P&ID is not simple, especially for those unfamiliar with Boolean algebra. To accomplish that, the *'rule-based nodes'* are introduced. This is developed based on the capability of including rules and conditions into the structure of *'logic-gates'*. It consequently eliminates the need for including the plant physical parameters in Boolean algebra and also adding extra block to schematic and the P&ID presentation design.

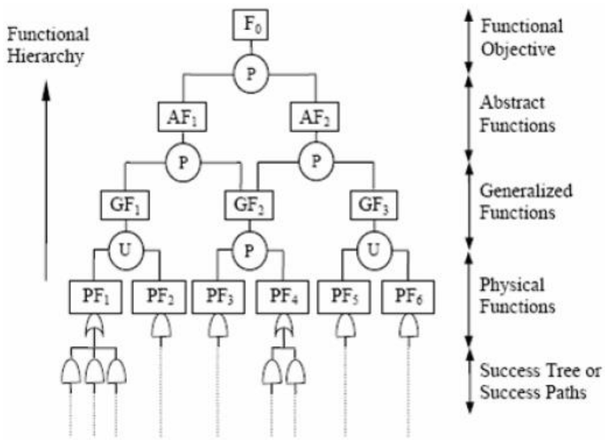

Fig. 1: A conceptual GTST

Each rule-based node has a variable statement that introduces the node, this variable statement enables us to switch between *'AND'* or *'OR'* gates, also instead of adding extra leg to this node which are based on node's rule, they are incorporated into the node's statement. It means that we can weight different inputs with respect to outputs as Shown in Fig. 3.

2.3. Part-whole hierarchy tree

A *'part-whole'* hierarchy tree is another representation of a structural hierarchy tree. The plant SSCs can be grouped together to form systems, subsystems, components, and trains. These groups of components, systems or trains, together may perform a certain function. For example, one can group components together based on their locations or being in specific geometrical location like compartments, buildings, etc. The groups and their structural relations are modeled by *'part-whole'* hierarchy tree. Different levels of abstraction can be reached to access certain components. Each level provides more details of the SSCs and their connections.

If a *'part-whole'* hierarchy tree is viewed from the top, one could see how different systems, subsystems and trains are made. This top-to-bottom navigation attempts to answer the following question: "What a system is made-of?" For instance, consider the *'part-whole'* hierarchy tree shown in Fig. 4. By looking from top, one can see that system A is *made* of two subsystems and subsystem A is *made* of Train-1 and Train-2 and so on".

2.4. Topological hierarchy

The topological hierarchy is basically the connection between the plant components forming the plant P&ID. Considering the priorities of the levels in *'part-whole'* hierarchy tree shown in Fig. 4, the topological hierarchy is the subject of the lowest plane of abstraction. In topological hierarchy tree (also referred to as plant topology), the causal effect of failure of a component is described. It simply shows whether a specific or groups of components become un-operational because of any reason, how the unavailability propagates through plant components and make them nonfunctional. The topological hierarchy tree clearly shows which components are isolated and un-operational due to unavailability of other components.

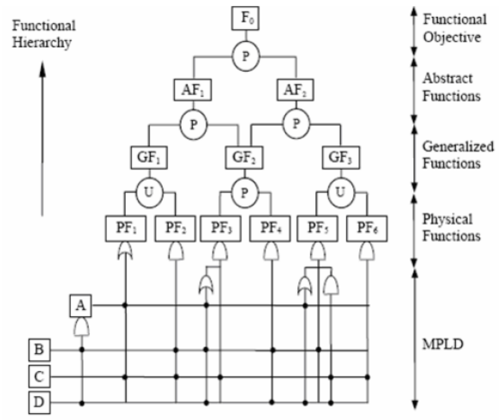

Fig. 2: A conceptual GTST-MPLD model

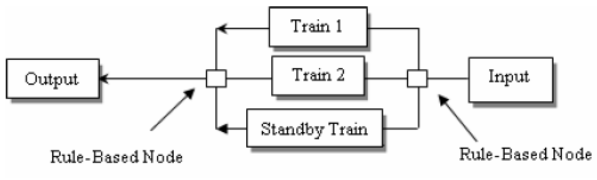

Fig. 3: Implementation of the rule-based node in a three-train configuration

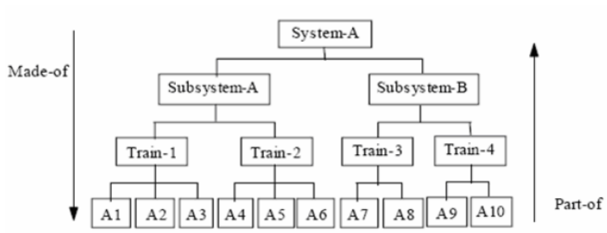

Fig. 4: The concept of a typical *'part-whole'* hierarchy tree

2.5. Dynamic P&ID

The plant P&ID shows connection between components and also connection with electrical and control supports. Distinguishing between fluid and steam flow paths and also electrical wiring and control devices is not an easy task. Showing different types of information to differentiate different classes of connections, components, etc. has made the P&ID very complicated and inconvenient to interpret. On the other hand, considering the complexity of many industrial systems, following certain paths from the beginning to the end is difficult and time-consuming.

Following connections in a P&ID requires studying pages after pages of drawings. The familiarity of industrial plant personnel with the P&ID structure from one hand and complexity and trouble of understanding P&IDs from the other hand has motivated us to use the DP&ID. Despite the similarity of the DP&ID and the traditional static P&ID, there are major differences between the two.

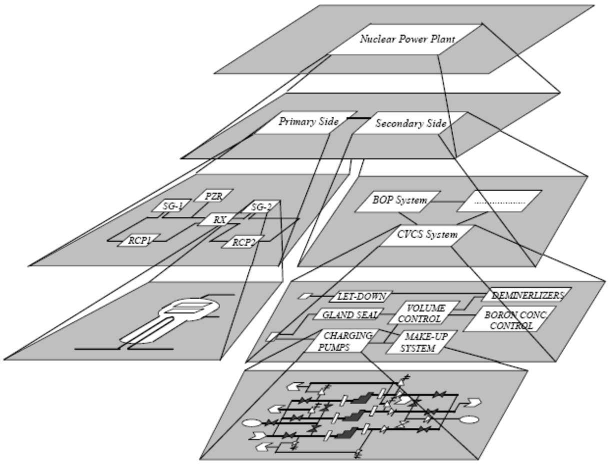

Fig. 5: An example of *'part-whole'* hierarchy tree

3. Web-based technology

With the emerge of powerful computers and the idea of communicating information from remote places through electromagnetic and radio waves, it is believed that data should be collected, processed, and shared. Realizing the importance of reliability and failure analysis and realizing the vital contribution of data in these analyses, it should be understood that, information technology is the key technology to complement the achievement of safe operation in all industrial systems including nuclear power plant.

It seems vital, especially in new millennium, to bring the two superior technologies of the millennium, i.e., information technology and the nuclear technology, together to bring industrial safety back to the main focus. The same thing is through to improve the safety level of oil, gas, and petroleum industries as the vital vein of today's world economy and make it more economical.

This paper, while aiming to fuse the above technologies together, would help to achieve this great objective by introducing a web-based technology to perform on-line failure analysis and by using the electronic communication technology to share historical data to perform analysis and to share the result with others worldwide.

3.1. FARAS

Failure and reliability analysis system (FARAS) is web-based software which has been developed for performing reliability and failure analysis.

Briefly, FARAS is internet-enabled software which performs analysis in client side and stores the results and data in the proposed database in the server.

4. RHR system

As mentioned before we have analyzed RHR system as case study. The P&ID of RHR system is shown in Fig. 6.

Assuming constant failure rates as shown in Table 2, failure rate of the system is 0.113 which is the same as the analysis with Reliability Workbench software. The comparison between the results of two softwares after 1000 years has been shown in Fig. 7.

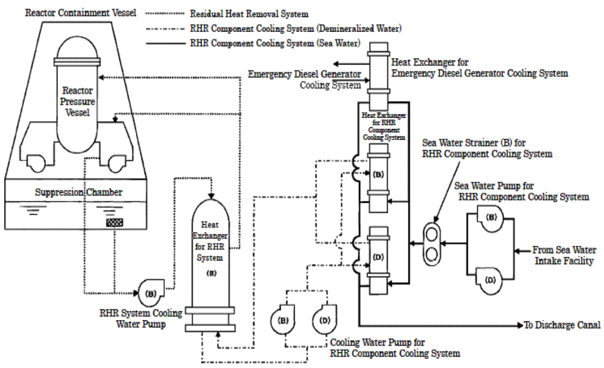

Fig. 6: P&ID of RHR System

5. Conclusion

- By taking advantage of the modeled hierarchical decomposition technique, the impact of component status and condition on other component and system status, and also on plant goals could be evaluated rapidly and smoothly.
- The source of causal unavailability could be identified rapidly.
- The system topology can represent any engineering and non-engineering systems.
- Data can be shared on the web for others to be used to improve plants safety.
- Easy access to state-of-the-art methods and a most recent version of software at any computer connected to the Internet.
- Reduced cost since users do need to keep upgrading their software resulting in lower distribution and handling costs.

Table 2: Failure Rates of RHR System Components

Unit	Pump(B)	Pump(D)	Strainer	H. E. (B)
Failure Rate	0.01	0.01	0.1	0.001
Unit	H. E. (C)	H. E. (D)	Vessel	
Failure Rate	0.001	0.001	0.001	

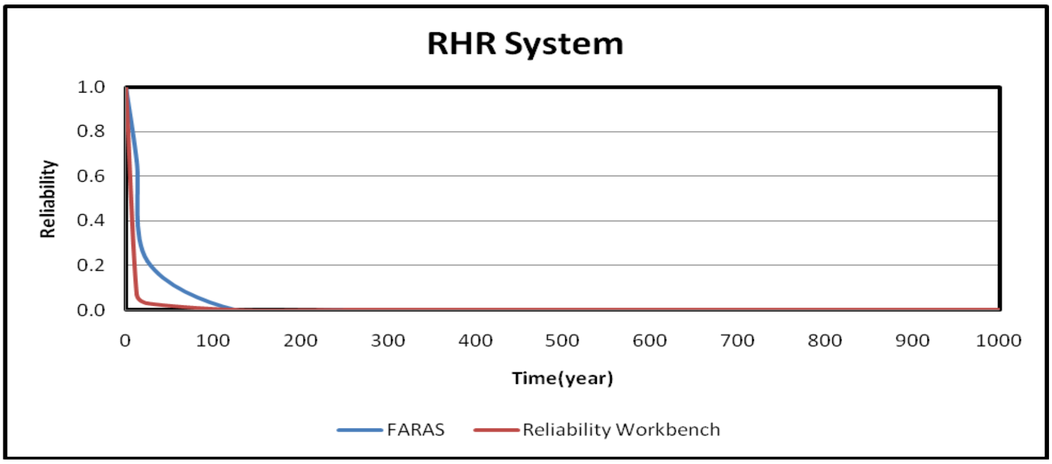

Fig. 7: Comparison between Results

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