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Probabilistic Safety Assessment of Tehran research reactor based on a synergy between plant topology and hierarchical evolutions

Ramin Barati, Saeed Setayeshi*

Faculty of Nuclear Engineering & Physics, Amirkabir University of Technology (Tehran Polytechnic), Hafez Street, Tehran, Iran

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ABSTRACT

Probabilistic Safety Assessment (PSA) is a powerful means in assessing risk and reliability of nuclear plants to complement the achievement of safe operation. A software has been developed in this study to perform failure and reliability analysis (in a PSA context), which are extremely important elements for improving plant operation and safety. This software introduces many advantages such as causal relationships, integrating the analysis tool with plant topology, using plant topology as the basis for explaining the relationships, dynamic navigation through plant model and highlighting fault propagation paths. In the software, plant topology plays the major role. It defines the relationships among plant components, systems and structures and provides the system configurations and causal relationships needed to perform reliability and risk analyses. These advantages are achieved via using some hierarchical evolutions with integrating plant topology (i.e., causal, Part-whole, and Topological hierarchies) and dynamic piping and instrumentation diagrams (DP&IDs). As a case study to verify the software efficiency, PSA of Tehran Research Reactor (TRR) at full power is performed with both the proposed software and System Analysis Programs for Hands-On Integrated Reliability Evaluation (SAPHIRE) (which is used as benchmark software in U.S. Nuclear Regulatory Commission), and good agreement was found.

1. Introduction

A software (FAilure and Reliability Analysis System, abbreviated as FARAS) has been developed in this study to perform failure and reliability analyses (in a PSA context), which are extremely important elements for improving plant operation and safety. The software integrates the failure, risk, and reliability analyses, and system topology into a unified tool to create a great potential for improving plant operation and safety.

In this software, 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 risk analyses.

The causal relationships modeled by the plant topology are very crucial for evaluating the plant condition and safety. Integrating the analysis tool with plant topology is another aspect of the software proposed by this research. The use of plant topology is a replacement for arrays of logics, which usually construct the knowledge-base of an inference engine. Also, 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.

There is a variety of computer codes developed to be used in reliability and risk analyses. Some of the most well-known ones are RISKMAN (PLG, 2009), SAPHIRE (U.S.NRC, 1994), CAFTA (SAIC, 2009) and RiskSpectrum (Scandpower, 2008) which fall short of making use of plant topology and hierarchical evolutions because of their modeling strategies.

Most of the complex systems are formed through some hierarchical evolutions. Therefore, those systems can be best described through hierarchical frameworks. In this paper causal, Part-whole, and Topological hierarchies are utilized to better modeling nuclear plant as a complex system.

To show how the software developed in this research may really help the plant engineers, PSA of TRR is performed as the case study both with the proposed methodology in the paper and SAPHIRE code. Tehran's 5 MW pool-type research reactor is a light water moderated, heterogeneous, solid-fuel reactor in which the water is also used for cooling and shielding. The reactor core is immersed in either section of a two-section concrete pool filled with water. One of the sections of the pool contains an experimental stall into which beam tubes and other experimental facilities converge. The other section is an open pool area for bulk irradiation studies. The pool is

* Corresponding author. Tel.: +98 912 21596746.
E-mail addresses: barati.ramin@aut.ac.ir (R. Barati), setayesh@aut.ac.ir (S. Setayeshi).

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spanned by a manually operated bridge from which an aluminum tower that supports the reactor core is suspended. Control of the reactor is accomplished by the insertion or removal of neutron absorbing-control rods which are suspended from control-drives mounted on the reactor bridge. Additional control is provided by the inherent negative temperature coefficient of reactivity of the system. A general symbolic scheme of TRR is presented in Fig. 1.

Its main components are reactor core, control and safety systems, pool, holdup tank, pumps, heat exchanger, connecting pipes, check valves, gate valves and butterfly valves. Some of the main reactor data are outlined in Table 1 and detailed specifications data are given in (AEOI, 2002).

Section 2 describes system modeling strategies used in the software. System modeling capabilities are discussed in Section 3. In Section 4, PSA for TRR is performed both with FARAS and SAPHIRE codes. Section 5 is devoted to results and discussion. Conclusion is presented in Section 6.

2. System modeling

Modeling the desired system is perhaps the most important step in system reliability assessment, failure, and PSA studies. 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 (Modarres, 2006; Modarres and Cheon, 1999; Hadavi, 1998). Such a 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 research, the relationships are displayed in piping and instrumentation diagram (P&ID) presentation (i.e., a form of Topological hierarchy) which 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. The P&ID then in a detailed level is changed to a fault tree framework using different

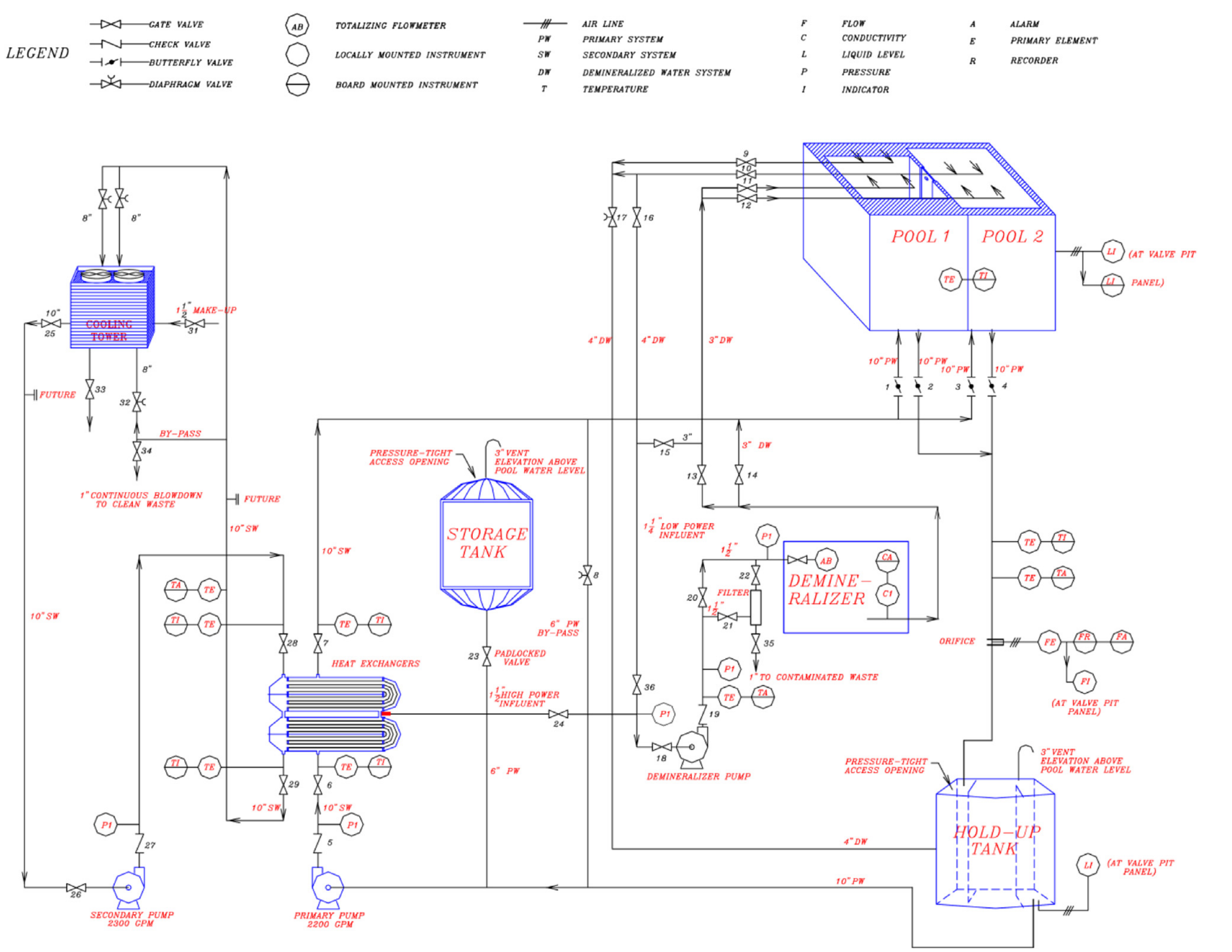

Fig. 1. The symbolic scheme of TRR (AEOI, 2002; Barati and Setayeshi, 2013).