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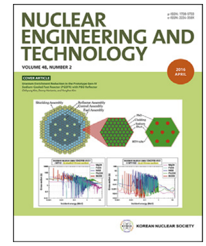

Original Article

Improvement of the Reliability Graph with General Gates to Analyze the Reliability of Dynamic Systems That Have Various Operation Modes

Seung Ki Shin [a], *Young Gyu No* [b], *and Poong Hyun Seong* [b,*]

[a] *Division of Research Reactor System Design, Korea Atomic Energy Research Institute, Daedeok-daero 989-11, Yuseong-gu, Daejeon 305-353, Republic of Korea*

[b] *Department of Nuclear and Quantum Engineering, Korea Advanced Institute of Science and Technology, Daehak-ro 291, Yuseong-gu, Daejeon 305-338, Republic of Korea*

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ABSTRACT

The safety of nuclear power plants is analyzed by a probabilistic risk assessment, and the fault tree analysis is the most widely used method for a risk assessment with the event tree analysis. One of the well-known disadvantages of the fault tree is that drawing a fault tree for a complex system is a very cumbersome task. Thus, several graphical modeling methods have been proposed for the convenient and intuitive modeling of complex systems. In this paper, the reliability graph with general gates (RGGG) method, one of the intuitive graphical modeling methods based on Bayesian networks, is improved for the reliability analyses of dynamic systems that have various operation modes with time. A reliability matrix is proposed and it is explained how to utilize the reliability matrix in the RGGG for various cases of operation mode changes. The proposed RGGG with a reliability matrix provides a convenient and intuitive modeling of various operation modes of complex systems, and can also be utilized with dynamic nodes that analyze the failure sequences of subcomponents. The combinatorial use of a reliability matrix with dynamic nodes is illustrated through an application to a shutdown cooling system in a nuclear power plant.

1. Introduction

Various studies have been conducted for the development of safety analysis methods suitable for nuclear power plants. The fault tree analysis is the most widely used method for a reliability and safety evaluation in the field of safety engineering [1], and the safety of nuclear power plants is estimated using a probabilistic risk assessment method adopting

* *Corresponding author.*
E-mail address: phseong@kaist.ac.kr (P.H. Seong).
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the fault tree analysis [2,3]. However, the construction of fault trees for large and complex systems is usually difficult, time-consuming, and susceptible to human errors. A fault tree may not follow a system diagram, and as a result, it may not be easy to relate the system flow to the logic that leads to a failure in the model [4]. Several methods such as the reliability graph with general gates (RGGG) [5], GO-FLOW [6], and various uses of Petri nets [7,8] have been proposed for a convenient and intuitive graphical modeling of complex systems and can be used as alternatives or complementary methods to the fault tree analysis.

The conventional fault tree method also has several difficulties in a reliability analysis of dynamic systems. In this paper, a dynamic system is defined as a system whose failure is dependent on the failure sequences of subcomponents and/or that have various operation modes with time. To analyze dynamic systems, various failure mechanisms with time requirements such as failure orders of the subcomponents and changes of the system states need to be modeled and quantitatively estimated. To overcome the limitations of the conventional static fault tree analysis and model dynamic systems, two types of dynamic fault trees have been developed: a dynamic fault tree with dynamic gates [9] and a dynamic fault tree with house events [10]. Dugan et al [9] proposed four dynamic gates to model dynamic systems whose failures are dependent on the failure sequence of the subcomponents. The proposed dynamic gates are a functional-dependency (FDEP) gate, spare gates [cold spare (CSP), hot spare (HSP), and warm spare (WSP)], a priority AND gate (PAND), and a sequence-enforcing (SEQ) gate. Cepin and Mavko [10] introduced house events and a house events matrix to the conventional fault tree to handle various operation modes and configuration changes with time.

Dynamic fault trees provide ways to analyze the reliability of dynamic systems, but they also cannot escape from the complexity of modeling fault trees which is the aforementioned shortcoming of the conventional static fault tree. In addition, it is not easy for dynamic fault trees to concurrently handle both dynamic features: sequentially dependent failures and operation mode changes with time.

Shin and Seong [11,12] developed a convenient dynamic modeling method using the RGGG by adding dynamic nodes (FDEP, Spare, PAND nodes) for the qualitative and quantitative analysis of dynamic systems whose failures depend on the failure sequence of the subcomponents. The RGGG is an improved reliability graph model developed for the intuitive modeling of a target system from its functional block diagram and paves the way for a convenient reliability analysis of complex systems [5].

In this paper, a reliability estimation method using the RGGG is proposed for an analysis of dynamic systems that have various operation modes with time by introducing a reliability matrix for the RGGG. The proposed method provides convenient and intuitive modeling of configuration changes of complex systems. In addition, both the dynamic features of sequentially dependent failures and operation mode changes can be analyzed at once using the dynamic nodes developed in works of Shin and Seong [11,12] in combination with the reliability matrix.

The remainder of this paper is structured as follows: The second section introduces briefly the RGGG and the dynamic fault tree with house events. The third section proposes the RGGG with a reliability matrix and explains how to utilize the reliability matrix in the RGGG for the various cases of configuration changes. The fourth section shows the applicability of the proposed method through an application to a simple electrical system that has various operation modes then, the reliability of a shutdown cooling system in a nuclear power plant is estimated using the RGGG with dynamic nodes and the reliability matrix in the fifth section. The sixth

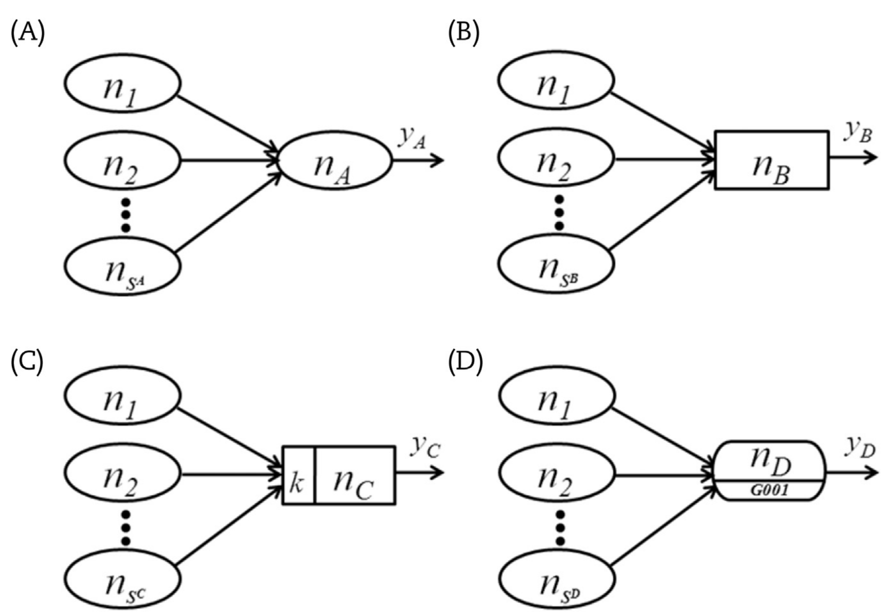

Fig. 1 – Definition of the nodes of the reliability graph with general gates. (A) OR node; (B) AND node; (C) *k*-out-of-*n* node; and (D) a general purpose node.