Reliability Engineering & System Safety
Volume 101, May 2012, Pages 35 – 47

Hybrid reliability model for nuclear reactor safety system

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http://dx.doi.org/10.1016/j.ress.2012.01.004, How to Cite or Link Using DOI

Abstract

The dependability of critical safety systems needs to be quantitatively determined in order to verify their effectiveness, e.g. with regard to regulatory requirements. Since modular redundant safety systems are not required for normal operation, their reliability is strongly dependent on periodic inspection. Several modeling methods for the quantitative assessment of dependability are described in the literature, with a broad variation in complexity and modeling power. Static modeling techniques such as fault tree analysis (FTA) or reliability block diagrams (RBD) are not capable of capturing redundancy and repair or test activities. Dynamic state space based models such as continuous time Markov chains (CTMC) are more powerful but often result in very large, intractable models. Moreover, exponentially distributed state residence times are not a correct representation of actual residence times associated with repair activities or periodic inspection. In this study, a hybrid model combines a system level RBD with a CTMC to describe the dynamics. The effects of periodic testing are modeled by redistributing state probabilities at deterministic test times. Applying the method to the primary safety shutdown system of the BR2(Belgian Reactor 2)—nuclear research reactor, resulted in a quantitative as well as a qualitative assessment of its reliability.

Keywords

Hybrid reliability model; Markov process; Reliability block diagram; Shutdown system; Belgian reactor 2

Figures and tables from this article:

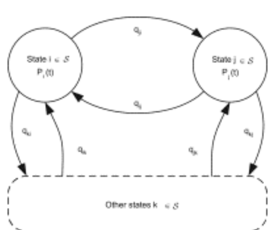

Fig. 1. Directed graph representation of a CTMC.

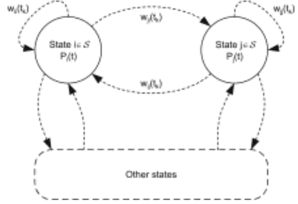

Fig. 2. Directed graph for a time-discrete transformation process.

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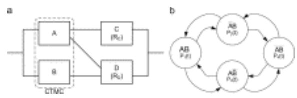

Fig. 3. Hybrid model; (a) System level RBD; (b) Sub level CTMC.

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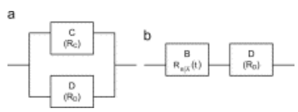

Fig. 4. Decomposition of Fig. 3(a); (a) Component A ' good ' ; (b) Component A ' failed ' .

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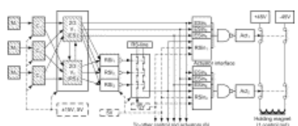

Fig. 5. Block level schematic of the BR2 Linear neutron flux measurement chains (L-chains).

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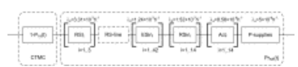

Fig. 6. RBD with regard to safe system failure (reactor scram).

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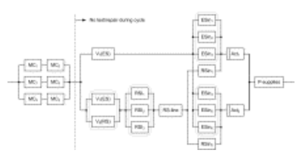

Fig. 7. RBD with regard to dangerous system failure.

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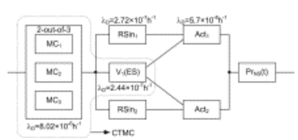

Fig. 8. Simplified RBD with regard to dangerous system failure.

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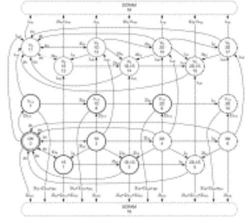

Fig. 9. Markov model for the measurement front end.

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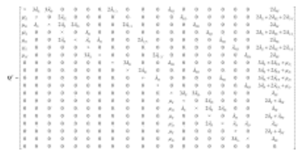

Fig. 10. Transition matrix for the CTMC.

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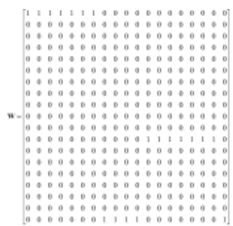

Fig. 11. Redistribution matrix to model the effects of periodic testing.

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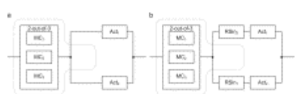

Fig. 12. RBD decomposed with V1(ES) as keystone element.

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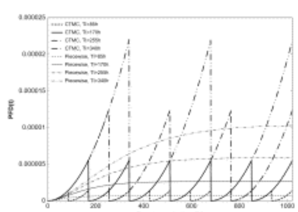

Fig. 13. Probability of failure on demand (PFD).

Figure options

Table 1. Basic component reliability data.

The total failure rate of any component *j* is noted as $\lambda_j = \lambda_{j,D} + \lambda_{j,S}$.

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Table 2. Markov chain state space description.

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Table 3. PFDavg as a function of T_i.

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