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Dynamic reliability networks with self-healing units

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Abstract

This paper presents an analytical approach for dynamic reliability networks used for the failure limit strategy in maintenance optimization. The proposed approach utilizes the moment generating function (MGF) and the flow-graph concept to depict the functional and reliability diagrams of the system comprised of series, parallel or mix configuration of self-healing units. The self-healing unit is featured by the embedded failure detection and recovery mechanisms presented by self-loop in flow-graph networks. The newly developed analytical approach provides the probability of the system failure and time-to-failure data i.e., mean and standard deviation time-to-failure used for maintenance optimization.

Keywords: Reliability block diagram; Flow-graph; Maintenance optimization; Failure limit strategy

1. Introduction

Industries, Military, and Airlines depend on the safe, reliable and productive operation of their assets. It is estimated that approximately 80% of the industry dollars is spent to correct chronic failures of machines, systems, and people. For example, each year US industry spends well over $300 billion on plant maintenance and operation [17,18]. To reduce the maintenance cost between 40% and 60%, several maintenance strategies e.g., reliability-based maintenance strategy have been developed.

The reliability-based maintenance strategy monitoring reliability index dictates preventive maintenance to be performed only when reliability measures of the unit reach a predetermined level [1,3,4]. Based on operation of the system, this strategy depends on performing system reliability modeling and analysis without or with considering the time factor. In static reliability modeling and analysis, the units' probability of success or failure does not vary with time (i.e., it remains constant). However, dynamic reliability modeling and analysis computes mean time-to-failure and failure rates based on collected failure data-related information on units (i.e., unit's reliability is non-constant).

Functional block diagram, reliability block diagram and state transition diagram are most commonly used methods for reliability modeling and analysis.

The functional block diagram is the simplest of graphical methods to generate and understand by one not familiar with reliability methods. A functional block diagram represents the physical or electrical relationship between the units rather than the logical relationship required for system reliability model and analysis.

Reliability network is commonly used to represent the reliability architecture of a system. It is a simple pictorial approach to represent the effects of all possible configurations of functioning and failed units on the functioning of the system.

These types of evaluation or analysis are usually a form of preliminary or elementary analysis for a system without subsystems or units featured by failure detection and recovery mechanisms.

For most systems, there are more modes of operation than just working or failed called states of the system. There are a variety of different working modes where

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certain units have failed but are being covered due to redundancy, a variety of different failed modes where different units have failed and brought down the system, and other modes of degraded operation, which cannot be conveniently labeled as working or failed. As such, state transition diagram is a picture of all of the different possible states of operation of the system, with arrows representing possible transfers in the mode of operations of the system. Using Markov model, probability of being in each state used for computing availability of the system can be calculated. However, crucial to all Markov methods is the assumption that all transition times are exponential.

Alternatively, this study proposes an analytical approach employing flow-graph concept and moment generating function (MGF) for dynamic reliability modeling and analysis that leads to time-to-failure data and failure probability. This approach is meant to consider logical relationship among self-healing units in reliability networks and utilize the appropriate transform function for dynamic reliability analysis without necessarily exponential transition times.

The reminder of the paper is organized as follows. The next section is devoted to the review of the literature and problem description, the notation and the assumption. In Section 3, flow-graph concept concerning series and parallel self-healing units is described. In Section 4, we obtain the failure probability of and time-to-failure of the air conditioning packs used in an aircraft. Concluding remarks are made in Section 4. Detailed information and calculation for series and parallel networks are provided in Appendices A, B, and C.

2. Problem description

2.1. The problem

Consider a system composed of several independent units featured with embedded fault detection, isolation, and recovery mechanisms as shown in Fig. 1. If the unit 'i' fails with probability 'P_{g_i}' and a random variable time-to-failure, the system may be able to detect the failure with probability 'P_{u_i}'. The time-to-detection the failure depends on fault coverage factor and the level of monitoring systems i.e., real-time embedded mechanism, periodic status check, etc. As such, the failed unit may be restored with probability 'P_{r_i}' in a random time period.

Definitely, having probability of the failure system and time-to-failure data known as operational reliability measures play a vital rule in condition-based maintenance optimization. Therefore, various studies on reliability networks to calculate reliability and availability of the system have been carried out by researchers. General results can be found in [5–8] where the basic theory and many principles and applications are presented.

In [2], a new method to handle Boolean models with loops for fault trees and reliability networks was proposed. This study proposed a logical framework to clarify the meaning of looped sets of Boolean equations based on binary decision diagrams.

In [9], using network reliability techniques, authors presented an overall process for the reliability evaluation of an entire power system. They used the equivalent technique to simplify the analysis procedure for the complex distribution system and network reduction technique for sub-transmission and switch stations.

In [10], several condition monitoring methods used for failure analysis and predictive maintenance are investigated. Authors discussed maintenance strategies and their requirements i.e., failure maintenance, preventive maintenance, and equipment condition-based preventive maintenance.

In [11], authors presented the information about the function of online and offline vibration monitoring and oil analysis used for preventive maintenance via a cost justification for fan bearing case study.

In [12], a simple method to deal with latent condition in fault tree analysis based on detectability of basic events was introduced. The detectability depends on the condition monitoring that may be continuously or non-continuously performed in the system. In continuous detection mechanism, the system experiences no delay for detecting the failure in the system. In opposition, the non-continuous detecting mechanism depends on the failure find interval resulting in a delay up to next probing time.

In [13], we extended fault tree analysis for a system with condition monitoring system featured the detection, isolation and recovery mechanisms associated with probability and time distribution function.

In [14], authors presented a Monte-Carlo simulation technique for reliability networks representing early failure in integrated circuits.

To bring the analysis of reliability networks in line with real-time embedded condition monitoring and recovery mechanisms, a new method capable to calculate probability of the system failure and time-to-failure data is required. This method must take into account fault coverage probability, probability of failure occurrence, detection, and recovery associated with time distribution functions for the system comprised of series, parallel or mix configuration of several non-identical self-healing units. The end results from the method may help in improving maintenance optimization using the following measures:

- reliability of system;
- availability of system;
- mean time to system failure (MTTF);
- standard deviation time of system failure (STTF).

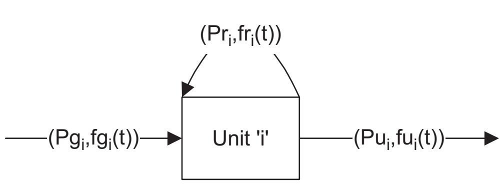

Fig. 1. Self-loop unit.