

Preface

Most books on reliability theory are devoted to traditional binary reliability models allowing only two possible states for a system and its components: perfect functionality and complete failure. Many real-world systems are composed of multi-state components, which have different performance levels and several failure modes with various effects on the system's entire performance. Such systems are called multi-state systems (MSSs). Examples of MSSs are power systems or computer systems where the component performance is respectively characterized by the generating capacity or the data processing speed. For MSSs, the outage effect will be essentially different for units with different performance rates. Therefore, the reliability analysis of MSSs is much more complex when compared with binary-state systems. In real-world problems of MSS reliability analysis, the great number of system states that need to be evaluated makes it difficult to use traditional binary reliability techniques.

The recently emerged universal generating function (UGF) technique allows one to find the entire MSS performance distribution based on the performance distributions of its elements by using algebraic procedures. This technique (also called the method of generalized generating sequences) generalizes the technique that is based on using a well-known ordinary generating function. The basic ideas of the method were introduced by Professor I. Ushakov in the mid 1980s [1, 2]. Since then, the method has been considerably expanded.

The UGF approach is straightforward. It is based on intuitively simple recursive procedures and provides a systematic method for the system states' enumeration that can replace extremely complicated combinatorial algorithms used for enumerating the possible states in some special types of system (such as consecutive systems or networks).

The UGF approach is effective. Combined with simplification techniques, it allows the system's performance distribution to be obtained in a short time. The computational burden is the crucial factor when one solves optimization problems where the performance measures have to be evaluated for a great number of possible solutions along the search process. This makes using the traditional methods in reliability optimization problematic. On the contrary, the UGF technique is fast enough to be implemented in optimization procedures.

The UGF approach is universal. An analyst can use the same recursive procedures for systems with a different physical nature of performance and different types of element interaction.

The first brief description of the UGF method appeared in our recent book (Lisnianski A, Levitin G. Multi-state system reliability. Assessment, optimization and applications, World Scientific 2003), where three basic approaches to MSS reliability analysis were presented: the extended Boolean technique, the random processes methods, and the UGF. Unlike the previous book that contained only a chapter devoted to the universal generating function, this book is the first to include a comprehensive up-to-date presentation of the universal generating function method and its application to analysis and optimization of different types of binary and multi-state system. It describes the mathematical foundations of the method, provides a generalized view of the performance-based reliability measures, and presents a number of new topics not included in the previous book, such as: UGF for analysis of binary systems, systems with dependent elements, simplified analysis of series-parallel systems, controllable series-parallel systems, analysis of continuous-state systems, optimal multistage modernization, incorporating common cause failures into MSS analysis, systems with multilevel protection, vulnerability importance, importance of multi-state elements in MSSs, optimization of MSS topology, asymmetric weighted voting systems, decision time of voting systems, multiple sliding window systems, fault-tolerant software systems, *etc.* It provides numerous examples of applications of the UGF method for a variety of technical problems.

In order to illustrate applications of the UGF to numerous optimization problems, the book also contains a description of a universal optimization technique called the genetic algorithm (GA). The main aim of the book is to show how the combination of the two universal tools (UGF and GA) helps in solving various practical problems of reliability and performance optimization.

The book is suitable for different types of reader. It primarily addresses practising reliability engineers and researchers who have an interest in reliability and performability analysis. It can also be used as a textbook for senior undergraduate or graduate courses in several departments: industrial engineering, nuclear engineering, electrical engineering, and applied mathematics.

The book is divided into eight chapters.

Chapter 1 presents two basic universal tools used in the book for MSS reliability assessment and optimization. It introduces the UGF as a generalization of the moment generating function and the z -transform; it defines the generic composition operator and describes its basic properties, and shows how the operator can be used for the determination of the probabilistic distribution of complex functions of discrete random variables. The chapter also shows how the combination of recursive determination of the functions with simplification techniques based on the like terms collection allows one to reduce considerably the computational burden associated with evaluating the probabilistic distribution of complex functions. This chapter also presents the GAs and discusses the basic steps in applying them to a specific optimization problem.

Chapter 2 describes the application of the UGF approach for the reliability evaluation of several binary reliability models.

Chapter 3 introduces the MSSs as an object of study. It defines the generic model and describes the basic properties of an MSS. This chapter also introduces

some reliability indices used in MSSs and presents examples of different MSS models.

Chapter 4 is devoted to the application of the UGF method to reliability analysis of the most widely used series-parallel MSSs. It describes the extension of the reliability block diagram method to series-parallel MSS, presents methods for evaluating the influence of common cause failures on the entire MSS reliability, and discusses methods for evaluating element reliability importance in MSSs.

Chapter 5 describes the application of the UGF in the optimization of series-parallel MSSs. It contains definitions and solutions related to various application problems of structure optimization for different types of series-parallel MSS. It shows that, by optimizing the MSS maintenance policy, one can achieve the desired level of system reliability requiring minimal cost. It also considers the problems of survivability maximization for MSSs that are subject to common cause failures. The optimal separation and protection problems are discussed.

Chapter 6 is devoted to the adaptation of the UGF technique to different special types of MSS. It presents the UGF-based algorithms for evaluating the reliability of MSSs with bridge topology, MSSs with two failure modes, weighted voting systems and classifiers, and sliding window systems. For each algorithm it describes the methods for computational complexity reduction. The chapter also considers the problems of structure optimization subject to the reliability and survivability constraints for different types of system.

Chapter 7 is devoted to the adaptation of the UGF technique to several types of network. It presents the UGF-based algorithms for evaluating the reliability of linear multi-state consecutively connected systems and multi-state acyclic networks. The connectivity model and the transmission delay model are considered. The structure optimization problems subject to reliability and survivability constraints are presented.

Chapter 8 is devoted to the application of the UGF technique for software reliability. The multi-state nature of fault-tolerant programs is demonstrated in this chapter and the methods for obtaining the performance distribution of such programs is presented. The reliability of combined software-hardware systems is analyzed. Optimal software modules sequencing problem and the software structure optimization problem are formulated and solved using the techniques presented in the book.

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