

Preface

Most books on reliability theory are devoted to traditional binary reliability models allowing for only two possible states for a system and for its components: perfect functionality (up) and complete failure (down). Many real-world systems are composed of multi-state components that have different performance levels and several failure modes with various effects on the entire system performance. Such systems are called multi-state systems (MSSs). Examples of MSS are power systems, communication systems, and computer systems where the system performance is characterized by generating capacity, communication, or data processing speed, respectively. 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. Since the mid 1970-s and to the present day numerous research studies have been published that focus on MSS reliability.

This book is the second one devoted to MSS reliability. The first book devoted to MSS reliability and optimization was published in 2003 by A. Lisnianski and G. Levitin, *Multi-State System Reliability. Assessment, Optimization and Applications*. World Scientific. Almost 7 years have passed and the MSS extension of classical binary-state reliability theory has been intensively developed during this time. More than 100 new scientific papers in the field have been published since that time; special sessions devoted to MSS reliability have been organized at international reliability conferences (Mathematical Methods in Reliability–MMR, European Safety and Reliability Conferences–ESREL, etc.). Additional experience has also been gathered from industrial settings. Thus, recently MSS reliability has emerged as a valid field not only for scientists and researchers, but also for engineers and industrial managers.

The aim of this book is to provide a comprehensive, up-to-date presentation of MSS reliability theory based on current achievements in this field and to present a variety of significant case studies that are interesting for both engineers and industrial managers.

New theoretical issues (that were not presented previously), including combined random process methods and a universal generating function technique, statistical data processing for MSS, reliability analysis of aging MSS, methods for calculation of reliability-associated cost for MSS, fuzzy MSS, etc., are described. The book presents important practical problems such as life cycle cost analysis and optimal decision making (redundancy and maintenance optimization, optimal

resources allocation) for real-world MSS. Numerous examples are included in each section in order to illustrate the presented mathematical tools. Besides theoretical examples, real-world MSSs (such as power systems, air conditioning systems, production systems, etc.) are considered as case studies. “Reliability is money!” is a main thesis of the book and all theoretical issues are presented from this point of view.

The authors anticipate that the book will be attractive for researchers, practical engineers, and industrial managers in addressing issues related to reliability and performability analysis. In addition, it will be a helpful textbook for undergraduate and graduate courses in several departments including industrial engineering, electrical engineering, mechanical engineering, and applied mathematics. The book is self-contained and does not require the reader to use other books or papers.

It should be noticed that it is impossible to describe all the achievements in the field in a single book. Naturally some interesting results remained outside of the book’s scope. In such cases the authors provide the readers with the corresponding references.

There are eight chapters in this book.

- Chapter 1 introduces the MSSs as an object of study. It defines generic model and describes the basic properties of MSSs. This chapter also introduces reliability indices used in MSSs and presents different examples of MSSs in nature and in engineering.
- Chapter 2 is devoted to modern stochastic process methods for MSS reliability assessment. It presents Markov models of multi-state elements and an entire system and methods for calculation of MSS reliability measures. It also describes Markov reward models as a basic technique for computation of all MSS reliability measures and reliability-associated costs. A combined performance-demand model is presented for reliability assessment of MSSs with random variable demand. The chapter includes a basic description of embedded Markov chains and semi-Markov processes, main properties, and equations for evaluating important characteristics of the processes. The general semi-Markov models for reliability analysis are presented both for single units and entire MSSs. It is shown how the restrictions corresponding to Markov models can be essentially relaxed by using semi-Markov process technique.
- Chapter 3 is devoted to the statistical analysis of reliability data for real-world MSSs. It presents the basic Markov model of a MSS with observed failure and repair data and describes point estimating for transition intensities (failure/repair rates) as well as confidence intervals.
- Chapter 4 is devoted to universal generating function (UGF) method. It contains a basic theory of UGF, key definitions, techniques, and illustrative examples. It demonstrates how one can find MSS reliability measures based on system UGF representation. A technique is demonstrated allowing the entire MSS UGF (u -function) to be obtained using the UGF of individual system components for different types of systems. In addition, Chapter 4 details the methods for evaluating the importance of element in MSS. It provides effective tools for

importance analysis in complex MSSs with different physical natures of performance. An application of the UGF technique to estimating the lower and upper bounds of reliability indices for the continuous-state system is also presented in the chapter.

- Chapter 5 presents combined UGF and stochastic process method as a universal tool for overcoming the problem of “dimension curse.” Based on this method, the reliability analysis of complex MSSs with redundancy is performed. It proves that redundancy in MSSs is essentially different than in binary-state systems. Dynamic reliability assessment for interconnected power systems is presented as a case study.
- Chapter 6 is devoted to reliability-associated cost evaluation for MSSs and optimal management decision making. It introduces reliability (unreliability)-associated cost as a main part of the life cycle cost for any repairable MSS. The history of the life cycle cost analysis, its principles, and recent standards are described. The chapter reveals that incorrect management is the main reason behind great financial losses. Methods for optimal management decision making based on reliability-associated cost analysis are presented in the chapter.
- Chapter 7 introduces aging MSSs and describes methods for their reliability evaluation. It considers a problem of aging in a MSS compared with a binary-state system aging and presents methods for reliability-associated cost assessment for aging MSSs. Corrective and preventive maintenance models are considered for aging MSSs. A real aging air conditioning system is considered as a case study.
- Chapter 8 introduces the basic theory of fuzzy multi-state system (FMSS), basic definitions, and concepts. It is shown that it provides a useful tool to complement conventional MSS reliability theories, where the state probability and/or the state performance level (rate) of a system component cannot be exactly determined but can be represented as fuzzy values. Corresponding numerical examples are presented in order to illustrate the methods.
- The genetic algorithm (GA) is used as the universal optimization technique. Its comprehensive description is presented in Appendix A.
- Appendix B presents parameter estimation and hypothesis testing for the non-homogeneous Poisson process that is used in reliability analysis for aging MSSs.
- Appendix C presents corresponding MATLAB[®] codes.

The authors shared the work in writing this book.

- The preface was written by all the authors.
- Chapter 1 was written by Drs. Lisnianski and Frenkel.
- Chapters 2–4 were written by Dr. Lisnianski.
- Chapter 5 was written by Drs. Lisnianski and Ding.
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- Chapter 7 and Appendices B and C were written by Dr. Frenkel.
- Chapter 8 and Appendix A were written by Dr. Ding.

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