

# Reliability Assessment of Redundant Electrical Power Supply Systems using Fault Tree Analysis, Reliability Block Diagram, and Monte Carlo Simulation Methods

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**Abstract**—This paper deals with the reliability assessment of electrical power supply systems under redundancy. For doing so, three probabilistic safety analysis (PSA) methods are proposed and developed namely fault tree analysis (FTA), reliability block diagram (RBD), and Monte Carlo Simulation (MC) method. The FTA method is performed using RiskSpectrumPSA® software and the RBD and MC methods are coded using Matlab software. The electrical power supply system reliability is analyzed and enhanced considering various cases of redundancy. The FTA method is based on qualitative and quantitative reliability assessment. The quantitative assessment calculates the failure probability of the top event, and the qualitative approach determines the minimal cut sets (MCS). However, the RBD and MC methods are proposed to compute the system failure probability. The considered methods are applied on three case studies and the obtained results are compared to each other. The obtained results show that the three methods provide almost the same results. Furthermore, the reliability of the electrical power supply is clearly enhanced with the number of redundant components.

**Keywords**—electrical power system reliability; probabilistic safety assessment; fault tree analysis; reliability block diagram; Monte Carlo simulation; Redundancy; RiskSpectrumPSA software; minimal cut sets; qualitative and quantitative safety assessment.

## I. INTRODUCTION

The electric energy is considered as the heart of the industry development, the human's life comfort and the operation safety of industrial installations. This electric energy must be reliable and must have the best quality in order to fulfill the predefined industrial installations requirements. Generally, the reliability of a system is defined as the probability that this system can perform its intended function for a specified interval under stated conditions. Therefore, the electrical power supply system of an industrial installation must be designed in a manner that provides a best quality and reliability of electrical power. For this, some critical industries need a high level of electrical power supply reliability and don't allow its loss. However, an unreliable electrical power

supply system can cause severe accidents [1]. Therefore, the electric power supply reliability must be continuously evaluated and assessed. This evaluation can be performed during different lifetime stages of the installation (e.g. design, construction, operation, aging, and/or decommissioning).

Various approaches for systems reliability assessment have been proposed in the literature [2], where, the electrical power supply reliability is usually performed using either the deterministic or the probabilistic methods. The deterministic assessment of electric power reliability is generally based on N-1 and N-2 methods. The N-1 method considers the outage of one electric component (e.g. transmission line, generator, or transformer) and check if the electric parameters of power system remain in the nominal interval of variation. The N-2 method considers the failure of an electric component and the maintenance of another one.

The probabilistic assessment of power system is based on the analysis of all possible events that may occur according to their probabilities in order to compute the failure probability of the overall system. The most popular methods used for power system reliability assessment are: Fault Tree Analysis (FTA), Reliability Block Diagram (RBD), Markov chain, and Monte Carlo Simulation (MC).

The reliability evaluation of electrical systems using FTA has been widely proposed [3-9]. In [6], the qualitative and quantitative reliability assessment of an electrical power supply system is presented using FTA and Minimal Cut Sets (MCS). In [7, 8], the FTA is used to evaluate the power system reliability at the load points. The quantitative and qualitative FTA assessments were used to identify the most important elements in the power system. In [9], the FTA method is applied for customer reliability assessment of a distribution power system.

Many practical uses can be highlighted for utilization of RBD in reliability assessment. In [10], RBD and FTA methods are developed for reliability analysis of a fire pump. Likewise,

# Reliability Assessment Of Electrical Power Systems Using Monte Carlo Methods

**Billinton,W. Li**



## **Reliability Assessment Of Electrical Power Systems Using Monte Carlo Methods:**

**Reliability Assessment of Electric Power Systems Using Monte Carlo Methods** Billinton, W. Li, 2013-06-29 The application of quantitative reliability evaluation in electric power systems has now evolved to the point at which most utilities use these techniques in one or more areas of their planning design and operation. Most of the techniques in use are based on analytical models and resulting analytical evaluation procedures. Improvements in and availability of high speed digital computers have created the opportunity to analyze many of these problems using stochastic simulation methods and over the last decade there has been increased interest in and use made of Monte Carlo simulation in quantitative power system reliability assessment. Monte Carlo simulation is not a new concept and recorded applications have existed for at least 50 yr. However, localized high speed computers with large capacity storage have made Monte Carlo simulation an available and sometimes preferable option for many power system reliability applications. Monte Carlo simulation is also an integral part of a modern undergraduate or graduate course on reliability evaluation of general engineering systems or specialized areas such as electric power systems. It is hoped that this textbook will help formalize the many existing applications of Monte Carlo simulation and assist in their integration in teaching programs. This book presents the basic concepts associated with Monte Carlo simulation.

**Risk Assessment Of Power Systems** Wenyuan Li, 2005-05-13 Power system risk assessment is becoming an important and mandatory task in planning, operation, maintenance and asset management of utilities, particularly under the deregulation environment. This book will provide readers with the tools to solve practical problems using appropriate risk assessment techniques. Both analytical and Monte Carlo evaluation methods are discussed with an emphasis on applied techniques and actual considerations in generation, transmission, substation and distribution systems. *Flexible and Active Distribution Networks* Peng Li, Haoran Ji, Yang Mi, Hao Yu, Yue Zhou, Nian Liu, 2021-08-02

**Reliability and Risk Evaluation of Wind Integrated Power Systems** Roy Billinton, Rajesh Karki, Ajit Kumar Verma, 2013-03-15 The world is witnessing a rapid growth in wind and other renewable based electricity generation due to environmental concerns associated with electricity generation from the conventional sources. Wind power behaves quite differently than conventional electric power generating units due to its intermittent and diffuse nature. System planners and operators face the variability and uncertainty of wind power availability and therefore encounter considerable challenges in making decisions to maintain the adequacy and security of wind integrated power systems. This volume intends to bring out the original research work of researchers from academia and industry in understanding, quantifying and managing the risks associated with the uncertainty in wind variability in order to plan and operate a modern power system integrated with a significant proportion of wind power generation with an acceptable level of reliability. Accurate modeling of wind power variability and proper incorporation of the models in reliability and risk evaluation is very important for the planning and operation of electric power systems and will play a crucial role in defining the requirement of various types of resources and services such as storage.

and ancillary services in power systems

**New Computational Methods in Power System Reliability** David

Elmakias, 2008-07-07 Power system reliability is the focus of intensive study due to its critical role in providing energy supply to modern society This comprehensive book describes application of some new specific techniques universal generating function method and its combination with Monte Carlo simulation and with random processes methods Semi Markov and Markov reward models and genetic algorithm The book can be considered as complementary to power system reliability textbooks

**Innovation in Electrical Power Engineering, Communication, and Computing Technology** Renu

Sharma, Manohar Mishra, Janmenjoy Nayak, Bighnaraj Naik, Danilo Pelusi, 2020-02-21 This book features selected high quality papers from the International Conference on Innovation in Electrical Power Engineering Communication and Computing Technology IEPCCT 2019 held at Siksha O Anusandhan Deemed to be University Bhubaneswar India on 13 14 December 2019 Presenting innovations in power communication and computing it covers topics such as mini micro smart and future power grids power system economics energy storage systems intelligent control power converters improving power quality signal processing sensors and actuators image video processing high performance data mining algorithms advances in deep learning and optimization methods

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**Reliability Assessment of Large Electric Power Systems** Roy Billinton, Ronald N.

Allan, 2012-12-06 We are very pleased to be asked to co author this book for a variety of reasons one of which was that it gave us further opportunity to work together The scope proposed was very wide with the only significant proviso being that the book should be in a monograph style and not a teaching text This requirement has given us the opportunity to compile a wide range of relevant material relating to present day knowledge and application in power system reliability As many readers will be aware we have collaborated in many ways over a relatively long period and have co authored two other books on reliability evaluation Both of these previous books were structured as teaching texts This present book is not a discourse on how to do reliability evaluation but a discussion on why it should be done and what can be done and achieved and as such does not replace or conflict with the previous books The three books are complementary and each enhances the others The

material contained in this book is not specifically original since it is based on information which we have published in other forms either jointly or as co authors with various other people particularly our many research students We sincerely acknowledge the important contributions made by all these students and colleagues There are too many to mention individually in this preface but their names appear frequently in the references at the end of each chapter Power Systems Leonard L. Grigsby, 2017-12-19 Power Systems Third Edition part of the five volume set The Electric Power Engineering Handbook covers all aspects of power system protection dynamics stability operation and control Under the editorial guidance of L L Grigsby a respected and accomplished authority in power engineering and section editors Andrew Hanson Pritindra Chowdhuri Gerry Shebl and Mark Nelms this carefully crafted reference includes substantial new and revised contributions from worldwide leaders in the field This content provides convenient access to overviews and detailed information on a diverse array of topics Concepts covered include Power system analysis and simulation Power system transients Power system planning reliability Power electronics Updates to nearly every chapter keep this book at the forefront of developments in modern power systems reflecting international standards practices and technologies New sections present developments in small signal stability and power system oscillations as well as power system stability controls and dynamic modeling of power systems With five new and 10 fully revised chapters the book supplies a high level of detail and more importantly a tutorial style of writing and use of photographs and graphics to help the reader understand the material New chapters cover Symmetrical Components for Power System Analysis Transient Recovery Voltage Engineering Principles of Electricity Pricing Business Essentials Power Electronics for Renewable Energy A volume in the Electric Power Engineering Handbook Third Edition Other volumes in the set K12642 Ele Power Systems, Third Edition Leonard L. Grigsby, 2012-04-25 Power Systems Third Edition part of the five volume set The Electric Power Engineering Handbook covers all aspects of power system protection dynamics stability operation and control Under the editorial guidance of L L Grigsby a respected and accomplished authority in power engineering and section editors Andrew Hanson Pritindra Chowdhuri Gerry Shebl and Mark Nelms this carefully crafted reference includes substantial new and revised contributions from worldwide leaders in the field This content provides convenient access to overviews and detailed information on a diverse array of topics Concepts covered include Power system analysis and simulation Power system transients Power system planning reliability Power electronics Updates to nearly every chapter keep this book at the forefront of developments in modern power systems reflecting international standards practices and technologies New sections present developments in small signal stability and power system oscillations as well as power system stability controls and dynamic modeling of power systems With five new and 10 fully revised chapters the book supplies a high level of detail and more importantly a tutorial style of writing and use of photographs and graphics to help the reader understand the material New chapters cover Symmetrical Components for Power System Analysis Transient Recovery Voltage Engineering Principles of Electricity Pricing

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Reliability and safety are core issues that must be addressed throughout the life cycle of engineering systems Reliability and Safety Engineering presents an overview of the basic concepts together with simple and practical illustrations The authors present reliability terminology in various engineering fields viz electronics engineering software engineering mechanical engineering structural engineering and power systems engineering They describe the latest applications in the area of probabilistic safety assessment such as technical specification optimization risk monitoring and risk informed in service inspection Reliability and safety studies must inevitably deal with uncertainty so the book includes uncertainty propagation methods Monte Carlo simulation fuzzy arithmetic Dempster Shafer theory and probability bounds Reliability and Safety Engineering also highlights advances in system reliability and safety assessment including dynamic system modeling and uncertainty management Case studies from typical nuclear power plants as well as from structural software and electronic systems are also discussed Reliability and Safety Engineering combines discussions of the existing literature on basic concepts and applications with state of the art methods used in reliability and risk assessment of engineering systems It is designed to assist practicing engineers students and researchers in the areas of reliability engineering and risk analysis

Innovations in Power Systems Reliability George Anders, Alfredo Vaccaro, 2011-02-16 Electrical grids are in general among the most reliable systems in the world These large interconnected systems however are subject to a host of challenges aging infrastructure transmission expansion to meet growing demand distributed resources and congestion management among others Innovations in Power Systems Reliability aims to provide a vision for a comprehensive and systematic approach to meet the challenges of modern power systems Innovations in Power Systems Reliability is focused on the emerging technologies and methodologies for the enhancement of electrical power systems reliability It addresses many relevant topics in this area ranging from methods for balancing resources to various reliability and security aspects Innovations in Power Systems Reliability not only discusses technological breakthroughs and sets out roadmaps in implementing the technology but it also informs the reader about current best practice It is a valuable source of information for academic researchers as well as those working in industrial research and development Unifying Electrical Engineering and Electronics Engineering Song Xing, Suting Chen, Zhanming Wei, Jingming Xia, 2013-08-24 Unifying Electrical Engineering and Electronics Engineering is based on the Proceedings of the 2012 International Conference on Electrical and Electronics Engineering ICEE 2012 This book collects the peer reviewed papers presented at the conference The aim of the conference is to unify the

two areas of Electrical and Electronics Engineering The book examines trends and techniques in the field as well as theories and applications The editors have chosen to include the following topics biotechnology power engineering superconductivity circuits antennas technology system architectures and telecommunication      The Electric Power Engineering Handbook - Five Volume Set Leonard L. Grigsby, 2018-12-14 The Electric Power Engineering Handbook Third Edition updates coverage of recent developments and rapid technological growth in crucial aspects of power systems including protection dynamics and stability operation and control With contributions from worldwide field leaders edited by L L Grigsby one of the world's most respected accomplished authorities in power engineering this reference includes chapters on Nonconventional Power Generation Conventional Power Generation Transmission Systems Distribution Systems Electric Power Utilization Power Quality Power System Analysis and Simulation Power System Transients Power System Planning Reliability Power Electronics Power System Protection Power System Dynamics and Stability Power System Operation and Control Content includes a simplified overview of advances in international standards practices and technologies such as small signal stability and power system oscillations power system stability controls and dynamic modeling of power systems Each book in this popular series supplies a high level of detail and more importantly a tutorial style of writing and use of photographs and graphics to help the reader understand the material This resource will help readers achieve safe economical high quality power delivery in a dynamic and demanding environment Volumes in the set K12642 Electric Power Generation Transmission and Distribution Third Edition ISBN 9781439856284 K12648 Power Systems Third Edition ISBN 9781439856338 K13917 Power System Stability and Control Third Edition 9781439883204 K12650 Electric Power Substations Engineering Third Edition 9781439856383 K12643 Electric Power Transformer Engineering Third Edition 9781439856291      Applications of Computing, Automation and Wireless Systems in Electrical Engineering Sukumar Mishra, Yog Raj Sood, Anuradha Tomar, 2019-05-31 This book discusses key concepts challenges and potential solutions in connection with established and emerging topics in advanced computing renewable energy and network communications Gathering edited papers presented at MARC 2018 on July 19 2018 it will help researchers pursue and promote advanced research in the fields of electrical engineering communication computing and manufacturing      **Sustainable Power Systems** Nava Raj Karki, Rajesh Karki, Ajit Kumar Verma, Jaeseok Choi, 2017-01-10 This book deals with quantifying and analyzing the risks associated with sustainable energy technology growth in electric power systems and developing appropriate models and methodologies to mitigate the risks and improve the overall system performance The rapid increase in the installation of renewable energy sources in electric power systems has given rise to a wide range of problems related to planning and operation of power systems to maintain quality stability reliability and efficiency Additionally there is a growing global environmental concern regarding increasing emissions from the electric power generation required to meet rising energy needs and support sustainable and inclusive development The phenomenon of low voltage ride through LVRT common to wind energy systems is

discussed and ways to tackle the same are proposed in the first chapter Subsequent chapters propose methods of optimizing a sustainable and smart microgrid and supplying electricity to remote areas of a developing country with no immediate possibility of national grid extension The economic benefit and technical challenges of forming localized minigrid are also discussed The book proposes a method for reliability assessment of a power grid with sustainable power transportation system The issue of weak link in power system is very important as it will provide the system operators and planners to take necessary measures to strengthen the system An approach to determine the weak parts of the system and its unreliability is proposed With increasing installation of HVDC power transmission and development of efficient and low cost power electronic devices the DC microgrids are becoming a common phenomenon Their existence together with AC Grids result in Hybrid AC DC Microgrids which are discussed in this book It further presents a method for reliability evaluation of a distribution system with network reconfiguration in the presence of distributed generation The important problems in sustainable energy growth and their potential solutions discussed and presented in the book should be of great interest to engineers policy makers researchers and academics in the area of electric power engineering

**Electrical Distribution Networks** Nouredine Hadjsaïd, Jean-Claude Sabonnadière, 2013-01-22 This book describes the fundamental aspects of the new generation of electrical distribution grids taking as its starting point the opportunities that exist for restructuring existing infrastructure It emphasizes the incorporation of renewable energy sources into the distribution grid and the need for a technological evolution towards the implementation of smartgrids The book is organized into two parts the first part analyzes the integration of distributed energy sources into the distribution grid and the impact of these sources on grid operation After a general description of the general characteristics of distribution grids and renewable energy sources it then analyzes the economics of electrical energy distribution networks and presents the impact of these sources on grid operation The second part of the book then analyzes the various functions which allow for safe operation of the grid and realization of the path towards real world application of smartgrids

**Reliability Analysis of Modern Power Systems** R. K. Saket, P. Sanjeevikumar, 2024-08-01 A reader friendly introduction to reliability analysis and its power systems applications The subset of probability theory known as reliability theory analyzes the likelihood of failure in a given component or system under given conditions It is a critical aspect of engineering as it concerns systems of all kinds not least modern power systems with their essential role in sustaining the technologies on which modern life relies Reliability Analysis of Modern Power Systems is a thorough accessible book introducing the core concepts of reliability theory as they apply to power systems engineering as well as the advanced technologies currently driving new frontiers in reliability analysis It is a must own for anyone looking to understand and improve the systems that power our world Readers will also find Detailed discussion of reliability modeling and simulation of composite systems using Typhoon HIL 404 Reliability assessment of generation systems transmission systems distribution systems and more Information on renewable energy integration for more sustainable power grids



Reliability Analysis of Modern Power Systems is ideal for professional engineers and researchers in power system design and reliability engineering as well as for advanced undergraduate and graduate students in these and related subjects

Systemic Design Methodologies for Electrical Energy Systems Xavier Roboam, 2012-12-17 This book proposes systemic design methodologies applied to electrical energy systems in particular analysis and system management modeling and sizing tools It includes 8 chapters after an introduction to the systemic approach history basics fundamental issues index terms for designing energy systems this book presents two different graphical formalisms especially dedicated to multidisciplinary devices modeling synthesis and analysis Bond Graph and COG EMR Other systemic analysis approaches for quality and stability of systems as well as for safety and robustness analysis tools are also proposed One chapter is dedicated to energy management and another is focused on Monte Carlo algorithms for electrical systems and networks sizing The aim of this book is to summarize design methodologies based in particular on a systemic viewpoint by considering the system as a whole These methods and tools are proposed by the most important French research laboratories which have many scientific partnerships with other European and international research institutions Scientists and engineers in the field of electrical engineering especially teachers researchers because of the focus on methodological issues will find this book extremely useful as will PhD and Masters students in this field

Electrical Power Systems and Computers Xiaofeng Wan, 2011-06-21 This volume includes extended and revised versions of a set of selected papers from the International Conference on Electric and Electronics EEIC 2011 held on June 20-22 2011 which is jointly organized by Nanchang University Springer and IEEE IAS Nanchang Chapter The objective of EEIC 2011 Volume 3 is to provide a major interdisciplinary forum for the presentation of new approaches from Electrical Power Systems and Computers to foster integration of the latest developments in scientific research 133 related topic papers were selected into this volume All the papers were reviewed by 2 program committee members and selected by the volume editor Prof Xiaofeng Wan We hope every participant can have a good opportunity to exchange their research ideas and results and to discuss the state of the art in the areas of the Electrical Power Systems and Computers

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