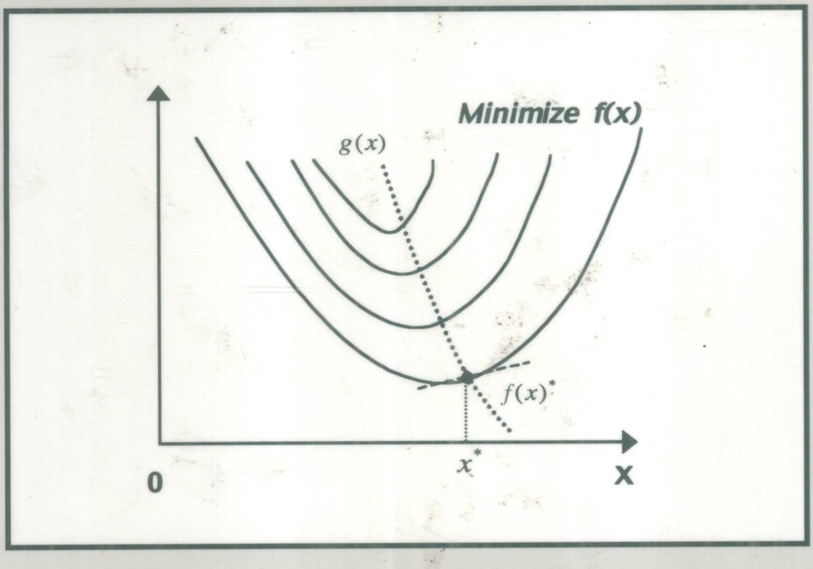
Electric Power System Applications of Optimization



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Series Introduction

Power engineering is the oldest and most traditional of the various areas within electrical engineering, yet no other facet of modern technology is currently undergoing a more dramatic revolution in both technology and industry structure. One of the more impressive areas of technical improvement over the past twenty years has been the emergence of powerful and practical numerical optimization methods for power-system engineering and operation, methods that ensure that the very best electrical and financial performance can be attained. The value contributed by optimization use in power systems is considerable, both in terms of economics—it has and will continue to save literally hundreds of millions of dollars annually—but also in terms of operational reliability and security. Systems run with optimization-based monitoring and control react better to both expected patterns in power demand and equipment availability and unexpected events such as storm damage and sudden equipment failure.

But despite its potential for practical application and the tremendous value it can provide, optimization remains something of a "black art" to many power engineers, in part because there is no accessible reference that covers methods and their application. This newest addition to Marcel Dekker's Power Engineering Series, *Electric Power System Applications of Optimization*, meets this need. Certainly no one is more qualified to write such a book than James A. Momoh, who has long been associated with both productive research and rigorous, practical application of optimization to power-system planning, engineering, and operations.

This book is an excellent text for both the experienced power engineer who desires a single consolidated reference on optimization, and to the beginner who wishes to "ramp up" quickly so that he or she can use optimization to its best advantage. *Electric Power System Applications of Optimization* provides a firm foundation and a uniform technical treatment of the different optimization methods available, their advantages and disadvantages, and the intricacies involved in their application to different power-system problems. The book is particularly easy to use, because it is thorough and uses a sound and consistent terminology and perspective throughout. This permits both novice and expert to understand and apply optimization on a dependable basis.

The Power Engineering Series includes books covering the entire field of power engineering, in all of its specialties and sub-genres, all aimed at providing practicing power engineers with the knowledge and techniques they need to meet the electric industry's challenges in the 21st century. Like all the books in the Marcel Dekker Power Engineering Series, Momoh's *Electric Power System Applications of Optimization* provides modern power technology in a context of proven, practical application. It is useful as a reference book as well as for self-study and advanced classroom use.

H. Lee Willis

Preface

Electric Power System Applications of Optimization is intended to introduce optimization, system theory, foundations of different mathematical programming techniques, and application to selected areas of electrical power engineering. The idea is to present theoretical background material from a practical power-system point of view and then proceed to explore applications of optimization techniques, new directions, and continuous application problems. The need for such a book stems from the extensive and diverse literature on topics of optimization methods in solving different classes of utility operations and planning problems.

Optimization concepts and algorithms were first introduced to power-system dispatching, resource allocation, and planning in the mid-sixties in order to mathematically formalize decision-making with regard to the myriad of objectives subject to technical and nontechnical constraints. There has been a phenomenal increase in research activities aimed at implementing dispatched, resource allocation problems and at planning optimally. This increase has been facilitated by several research projects (theoretical papers usually aimed at operation research communities) that promote usage of commercial programs for power-system problems but do not provide any relevant information for power engineers working on the development of power-system optimization algorithms. Most recently, there has been a tremendous surge in research application with articles on how to apply optimization in electric power engineering.

However, there is currently no book that serves as a practical guide to the fundamental and application aspects of optimization for power-system work. This book is intended to meet the needs of a diverse range of groups interested in optimization application. They include university faculty, researchers, students, and developers of power systems who are interested in or who plan to use optimization as a tool for planning and operation. The focus of the book is exclusively on the development of optimization methods, foundations, and algorithms and their application to power systems.

The focus was based on the following factors. First, good references that survey optimization techniques for planning and operation are currently available but they do not detail theoretical formulation in one complete environment. Second, optimization analysis has become so complex that examples which deal with non–power system problems are only studied and many issues are covered by only a few references for the utility industry. Finally, in the last decade, new optimization technologies such as interior point methods and genetic algorithms have been successfully introduced to deal with issues of computations and have been applied to new areas in power system planning and operation.

The subject matter presented in this book provides both the analytical formulation of optimization and various algorithmic issues that arise in the application of various methods in power-system planning and operation. In addition, the book provides a blend of theoretical approach and application based on simulation.

In Chapter 2, we revise electric power-system models, power-system component modeling, reactive capabilities, ATC, and AGC. The chapter concludes with illustrated examples. In Chapter 3, we introduce the theoretical concepts and algorithms for power-flow computation using different numerical methods with illustrative examples and applications for practical simulation studies.

To treat the problem of optimization in one easy, concise form, Chapter 4 deals with classical unconstrained and constrained techniques with simple applications to power systems. This chapter concludes with illustrative examples. Chapter 5 is dedicated to linear programming theory, methods, and its extension to integer programming, postoptimization (sensitivity analysis) and its application to power systems, with illustrative examples. Chapter 6 deals with new trends in optimization theory such as interior point optimization methods for both linear and quadratic formulation. The chapter includes examples and applications to power systems. In Chapter 7, we discuss non–linear programming technique and its extension to recent interior point methods such as barrier methods. The computational algorithm for each of the nonlinear programming variants is presented.

Chapter 8 presents the dynamic programming optimization algorithm with illustrative examples. In Chapter 9, the Lagrangian relaxation concept and algorithm are discussed. Their applicability to unit commitment and resource allocation is described. In Chapter 10, the decomposition method for solving large-scale optimization problems is presented. Illustrative examples are given following the procedure. In Chapter 11, optimal power flow, modeling, and selected programming techniques derived from earlier chapters are used for solving difficult objective functions with constraints in power-system operation and planning. Illustrative examples are included. Chapter 12 addresses unit commitment concepts, formulation, and algorithms. Examples and applications to power-systems dispatching are presented. In Chapter 13, genetic algorithms (GA) are presented as tools for optimization. I discuss the definition of GA computation, approach, and algorithm. Application areas of genetic algorithms as a computational tool in power-system operation and planning are described.

It is hoped that the application areas discussed in this book will offer the reader an overview of classical optimization method without sacrificing the rudiments of the theory. Those working in the field or willing to engage in optimal power flow will find the material useful and interesting as a reference or as a good starting point to engage in power-system optimization studies.

A significant portion of the material presented in the book is derived from sponsored projects, professional society meetings, panel sessions, and popular texts in operation research in which I have had personal involvement. These include research and development efforts, which were generally supported by funding agencies such as the Electric Power Research Institute (EPRI), the National Science Foundation (NSF), and Howard University. I wish to acknowledge the significant contribution made by the engineers of Bonneville Power Authority (BPA), Commonwealth Edison (ComEd), and the Department of Energy (DOE) in the development and testing of optimal power flow using variants of optimization techniques such as genetic algorithms and interior point methods.

This book would not have been possible without the help of the students in the optimization and power-system group at Howard University and CESaC research staff who provided dedicated support in optimal power-flow algorithm testing, in problem-solving, and in the task of preparing this book for publication. I remain in debt to my colleagues for their keen interest in the development of this book, specifically, Professor Kenneth Fegly of the University of Pennsylvania, Professor Bruce Wollenberg of the University of Minnesota, Professor Emeritus Hua Ting Chieh of Howard University, and Professor Mohammed El-Hawary of Dalhousie University, who offered valuable criticism of the book during the preparation stage.

Finally, I wish to thank Mrs. Lee Mitchell of Howard University for proofreading and the admirable students in the CESaC family for helping to

type. Finally, I offer my deepest personal thanks to those closest to me who have provided support during the time-consuming process of writing this book.

James A. Momoh

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