Article

Parametric Sensitivity Analysis of Rotor Angle Stability Indicators †

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† This paper is an extended version of a paper thatwill be presented at the 8th International Conference on Power and Energy Systems Engineering at Fukuoka Institute of Technology, Fukuoka, Japan, 10–12 September 2021.

Abstract: With the increasing penetration rate of Power Electronic Converter (PEC) based technologies, the electrical power systems are facing the problem of transient stability since the PEC based technologies do not contribute to the system inertia, and the proportion of synchronous generators (i.e., the source of inertia) is in decreasing rate. In addition, PEC based technologies' components have poor inherent damping. It is very important to analyze the system characteristics of a power system to minimize the potential instabilities during the contingencies. This paper presents the parametric sensitivity analysis of the rotor angle stability indicators for the 39-bus New England power system. The indicators of rotor angle stability analysis such as critical fault clearing time (CCT), Eigenvalue points, damping ratio, frequency deviation, voltage deviation, and generator's speed deviation are identified and analyzed for three case scenarios; each scenario has six sub-cases with different inertia constants. The results show that the CCTs for each component will be reduced if the inertia reduces at any section of a multi-machine power system. Although the applied three scenarios with six sub-cases are identified to be stable in this analysis, the decreasing inertia constant has significant impact on the power system dynamics.

Keywords: power system dynamics; power system stability; low inertial power system

1. Introduction

Power systems have become more complex than in the past, caused by the integration of numerous Distributed Generation Resources (DGRs) and the rapidly growing power electronic converter (PEC) based technologies. The modern power system faces complex transformation in all levels, such as generation, transmission, distribution, and utilization [1]. With this rapid transformation, the modern power system faces significant changes in the power system dynamics; one of the main reasons behind this is reduction of system inertia because of these PEC-based technologies [2]. In the conventional power system, most of the power generators were of the synchronous type; they are characterized as the source of rotational inertia in a power system, whereas in a modern power system, the proportion of synchronous generators is at a decreasing rate [3]. Moreover, the PEC-based technologies adopted in the generation (e.g., kinetic energy less solar PV and doubly-fed induction generator based wind turbines), transmission line (e.g., HVDC), distribution system (e.g., controllers), and utilization level (e.g., controller based equipment) do not contribute to the system inertia, which results in a drop of system inertia in the modern power system, resulting in drastic changes in the system dynamics [4]. Not only these but the transient stability of the DGR integrated power system is also highly sensitive to the proportion of the penetration level, fault location and its severity [5]. Titlens et al. presented a detailed study on the relevance of inertia in the operation and control of a power system, which shows that the decreasing system inertia results in the high Rate of Change of Frequency (RoCoF) values and frequency deviation, which may increase the system instability [6]. The DGRs are integrated into the distribution lines at a low voltage

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 Encyclopedia of Operations Research and Management Science Saul I. Gass,Carl M. Harris,2012-12-06 Operations Research 1934 1941 35 1 143 152 British The goal of the Encyclopedia of Operations Research and Operational Research in World War II 35 3 453 470 Management Science is to provide to decision makers and U S Operations Research in World War II 35 6 910 925 problem solvers in business industry government and and the 1984 article by Harold Lardner that appeared in academia a comprehensive overview of the wide range of Operations Research The Origin of Operational Research ideas methodologies and synergistic forces that combine to 32 2 465 475 form the preeminent decision aiding fields of operations re search and management science OR MS To this end we The Encyclopedia contains no entries that define the fields enlisted a distinguished international group of academics of operations research and management science OR and MS and practitioners to contribute articles on subjects for are often equated to one another If one defines them by the which they are renowned methodologies they employ the equation would probably The editors working with the Encyclopedia s Editorial stand inspection If one defines them by their historical Advisory Board surveyed and divided OR MS into specific developments and the classes of problems they encompass topics that collectively encompass the foundations applica the equation becomes fuzzy The formalism OR grew out of tions and emerging elements of this ever changing field We the operational problems of the British and U s military also wanted to establish the close associations that OR MS efforts in World War II **Multi-parametric Optimization and Control** Efstratios N. Pistikopoulos,Nikolaos A. Diangelakis,Richard Oberdieck,2020-11-24 Recent developments in multi parametric optimization and control Multi Parametric Optimization and Control provides comprehensive coverage of recent methodological developments for optimal model based control through parametric optimization It also shares real world research applications to support deeper understanding of the material Researchers and practitioners can use the book as reference It is also suitable as a primary or a supplementary textbook Each chapter looks at the theories related to a topic along with a relevant case study Topic complexity increases gradually as readers progress through the chapters The first part of the book presents an overview of the state of the art multi parametric optimization theory and algorithms in multi parametric programming The second examines the connection between multi parametric programming and model predictive control from the linear quadratic regulator over hybrid systems to periodic systems and robust control The third part of the book addresses multi parametric optimization in process systems engineering A step by step procedure is introduced for embedding the programming within the system engineering which leads the reader into the topic of the PAROC framework and software platform PAROC is an integrated framework and platform for the optimization and advanced model based control of process systems Uses case studies to illustrate real world applications for a better understanding of the concepts presented Covers the fundamentals of optimization and model predictive control Provides information on key topics such as the basic sensitivity theorem linear programming quadratic

programming mixed integer linear programming optimal control of continuous systems and multi parametric optimal control An appendix summarizes the history of multi parametric optimization algorithms It also covers the use of the parametric optimization toolbox POP which is comprehensive software for efficiently solving multi parametric programming problems

Modern Methods of Optimization Werner Krabs,Jochem Zowe,2013-03-14 This volume contains the proceedings of the summer school Modern Methods of Optimization held at the Schlof3 Thurnau of the University of Bayreuth October 1 6 1990 Like other branches of applied mathematics the area of optimization is undergoing a rapid development since the beginning of the computer age Optimizaiton methods are of increasing importance for both science and industry The aim of the summer school was to present state of the art knowledge by inviting 12 specialists from Op timization and related fields to present their areas of activity in the form of survey talks This volume contains 10 of these presentations in slightly extended form Most lectures started from an undergraduate level and outlinad the developments up to the latest scientifique achievements This enabled the audience consisting of about 45 students and young researchers to get an excellent overview of the latest trends in Optimization as w ll as a grasp of the breadth of its potential applications Equally important to the success of the summer school was the nonmeasurable part of the activities inherent in such a summer school Here the inspiring atmosphere of a place like Thurnau helped to establish numerous contacts between teachers and students The summer school was organized by the Universitii t Bayreuth together with the Technische Hochschule Darmstadt and was generously sponsored by the Volkswagen stiftung and the Universitii tsverein Bayreuth Their interest in the meeting and their support is hereby gratefully acknowledged **Parametric Optimization and Related Topics** Jürgen Guddat,Hubertus Th. Jongen,Bernd Kummer,František Nožička,1987-12-31 No detailed description available for Parametric Optimization and Related Topics

Basic Mathematical Programming Theory Giorgio Giorgi,Bienvenido Jiménez,Vicente Novo,2023-07-18 The subject of static optimization also called mathematical programming is one of the most important and widespread branches of modern mathematics serving as a cornerstone of such scientific subjects as economic analysis operations research management sciences engineering chemistry physics statistics computer science biology and social sciences This book presents a unified progressive treatment of the basic mathematical tools of mathematical programming theory The authors expose said tools along with results concerning the most common mathematical programming problems formulated in a finite dimensional setting forming the basis for further study of the basic questions on the various algorithmic methods and the most important particular applications of mathematical programming problems This book assumes no previous experience in optimization theory and the treatment of the various topics is largely self contained Prerequisites are the basic tools of differential calculus for functions of several variables the basic notions of topology and of linear algebra and the basic mathematical notions and theoretical background used in analyzing optimization problems The book is aimed at both undergraduate and postgraduate students interested in mathematical programming problems but also those professionals who use optimization

methods and wish to learn the more theoretical aspects of these questions   **Mathematics of Optimization: Smooth and Nonsmooth Case** Giorgio Giorgi,A. Guerraggio,J. Thierfelder,2004-03-10 The book is intended for people graduates researchers but also undergraduates with a good mathematical background involved in the study of static optimization problems in finite dimensional spaces It contains a lot of material from basic tools of convex analysis to optimality conditions for smooth optimization problems for non smooth optimization problems and for vector optimization problems The development of the subjects are self contained and the bibliographical references are usually treated in different books only a few books on optimization theory deal also with vector problems so the book can be a starting point for further readings in a more specialized literature Assuming only a good even if not advanced knowledge of mathematical analysis and linear algebra this book presents various aspects of the mathematical theory in optimization problems The treatment is performed in finite dimensional spaces and with no regard to algorithmic questions After two chapters concerning respectively introductory subjects and basic tools and concepts of convex analysis the book treats extensively mathematical programming problems in the smmoth case in the nonsmooth case and finally vector optimization problems Self contained Clear style and results are either proved or stated precisely with adequate references The authors have several years experience in this field Several subjects some of them non usual in books of this kind in one single book including nonsmooth optimization and vector optimization problems Useful long references list at the end of each chapter   **Introduction to Numerical Continuation Methods** Eugene L. Allgower,Kurt Georg,2003-01-01 Numerical continuation methods have provided important contributions toward the numerical solution of nonlinear systems of equations for many years The methods may be used not only to compute solutions which might otherwise be hard to obtain but also to gain insight into qualitative properties of the solutions Introduction to Numerical Continuation Methods originally published in 1979 was the first book to provide easy access to the numerical aspects of predictor corrector continuation and piecewise linear continuation methods Not only do these seemingly distinct methods share many common features and general principles they can be numerically implemented in similar ways The book also features the piecewise linear approximation of implicitly defined surfaces the algorithms of which are frequently used in computer graphics mesh generation and the evaluation of surface integrals To help potential users of numerical continuation methods create programs adapted to their particular needs this book presents pseudo codes and Fortran codes as illustrations Since it first appeared many specialized packages for treating such varied problems as bifurcation polynomial systems eigenvalues economic equilibria optimization and the approximation of manifolds have been written The original extensive bibliography has been updated in the SIAM Classics edition to include more recent references and several URLs so users can look for codes to suit their needs Audience this book continues to be useful for researchers and graduate students in mathematics sciences engineering economics and business A background in elementary analysis and linear algebra are adequate prerequisites for reading this book some knowledge from a first course

in numerical analysis may also be helpful   Nonlinear Optimization and Applications Gianni Pillo,F. Giannessi,2013-11-11 This volume contains the edited texts of the lectures presented at the workshop on Nonlinear Optimization Theory and Applications held in Erice at the G Stampacchia School of Mathematics of the E Majorana International Centre for Scientific Culture June 13 21 1995 The meeting was conceived to review and discuss recent advances and promising research trends concerning theory algorithms and innovative applications in the field This is a field of mathematics which is providing viable of Nonlinear Optimization tools in engineering in economics and in other applied sciences and which is giving a great contribution also in the solution of the more practiced linear optimization prob lems The meeting was attended by approximately 70 people from 18 countries Besides the lectures several formal and informal discussions took place The result was a broad exposure providing a wide and deep understanding of the present research achievements in the field We wish to express our appreciation for the active contributions of all the partici pants in the meeting Our gratitude is due to the Ettore Majorana Center in Erice which offered its facilities and stimulating environment its staff was certainly instrumental for the success of the meeting Our gratitude is also due to Francisco Facchinei and Massino Roma for the time spent in the organization of the workshop and to Giuliana Cai for the careful typesetting of this volume   **Acta Numerica 1993: Volume 2** Arieh Iserles,1993-04-30 Continuing the tradition established with the 1992 volume this 1993 s Acta Numerica presents six invited papers on a broad range of topics from numerical analysis Papers treat each topic at a level intelligible by any numerical analyst from graduate student to professional   *Finite-Dimensional Variational Inequalities and Complementarity Problems* Francisco Facchinei,Jong-Shi Pang,2007-06-14 The nite dimensional nonlinear complementarity problem NCP is a s tem of nitely many nonlinear inequalities in nitely many nonnegative variables along with a special equation that expresses the complementary relationship between the variables and corresponding inequalities This complementarity condition is the key feature distinguishing the NCP from a general inequality system lies at the heart of all constrained optimi tion problems in nite dimensions provides a powerful framework for the modeling of equilibria of many kinds and exhibits a natural link between smooth and nonsmooth mathematics The nite dimensional variational inequality VI which is a generalization of the NCP provides a broad unifying setting for the study of optimization and equilibrium problems and serves as the main computational framework for the practical solution of a host of continuum problems in the mathematical sciences The systematic study of the nite dimensional NCP and VI began in the mid 1960s in a span of four decades the subject has developed into a very fruitful discipline in the eld of mathematical programming The velopments include a rich mathematical theory a host of e ective solution algorithms a multitude of interesting connections to numerous disciplines and a wide range of important applications in engineering and economics As a result of their broad associations the literature of the VI CP has bene ted from contributions made by mathematicians pure applied and computational computer scientists engineers of many kinds civil ch ical electrical mechanical and systems and economists of diverse exp

tise agricultural computational energy nancial and spatial   *Numerical Continuation Methods* Eugene L. Allgower,Kurt Georg,2012-12-06 Over the past fifteen years two new techniques have yielded extremely important contributions toward the numerical solution of nonlinear systems of equations This book provides an introduction to and an up to date survey of numerical continuation methods tracing of implicitly defined curves of both predictor corrector and piecewise linear types It presents and analyzes implementations aimed at applications to the computation of zero points fixed points nonlinear eigenvalue problems bifurcation and turning points and economic equilibria Many algorithms are presented in a pseudo code format An appendix supplies five sample FORTRAN programs with numerical examples which readers can adapt to fit their purposes and a description of the program package SCOUT for analyzing nonlinear problems via piecewise linear methods An extensive up to date bibliography spanning 46 pages is included The material in this book has been presented to students of mathematics engineering and sciences with great success and will also serve as a valuable tool for researchers in the field

    Optimization and Applications Nicholas N. Olenev,Yuri G. Evtushenko,Milojica Jaćimović,Michael Khachay,Vlasta Malkova,2021-11-04 This book constitutes the refereed proceedings of the 12th International Conference on Optimization and Applications OPTIMA 2021 held in Petrovac Montenegro in September October 2021 The 22 full and 3 short papers presented were carefully reviewed and selected from 63 submissions The papers are organized into the following topical sub headings mathematical programming global optimization discrete and combinatorial optimization optimal control optimization and data analysis and game theory and mathematical economics   **Distributed and economic model predictive control: beyond setpoint stabilization** Matthias A. Müller,2014 In this thesis we study model predictive control MPC schemes for control tasks which go beyond the classical objective of setpoint stabilization In particular we consider two classes of such control problems namely distributed MPC for cooperative control in networks of multiple interconnected systems and economic MPC where the main focus is on the optimization of some general performance criterion which is possibly related to the economics of a system The contributions of this thesis are to analyze various systems theoretic properties occurring in these type of control problems and to develop distributed and economic MPC schemes with certain desired closed loop guarantees To be more precise in the field of distributed MPC we propose different algorithms which are suitable for general cooperative control tasks in networks of interacting systems We show that the developed distributed MPC frameworks are such that the desired cooperative goal is achieved while coupling constraints between the systems are satisfied Furthermore we discuss implementation and scalability issues for the derived algorithms as well as the necessary communication requirements between the systems In the field of economic MPC the contributions of this thesis are threefold Firstly we analyze a crucial dissipativity condition in particular its necessity for optimal steady state operation of a system and its robustness with respect to parameter changes Secondly we develop economic MPC schemes which also take average constraints into account Thirdly we propose an economic MPC framework with self tuning terminal

cost and a generalized terminal constraint and we show how self tuning update rules for the terminal weight can be derived such that desirable closed loop performance bounds can be established *Recent Advances in Multidisciplinary Analysis and Optimization* ,1989 **Advances in Mathematical Optimization** J. Guddat et al.,2022-01-19 No detailed description available for Advances in Mathematical Optimization <u>Parametric Integer Optimization</u> Bernd Bank,Reinhard Mandel,1988 **Computation and Control** Kenneth L. Bowers,John Lund,2012-12-06 The problem of developing a systematic approach to the design of feed back strategies capable of shaping the response of complicated dynamical control systems illustrates the integration of a wide variety of mathemat ical disciplines typical of the modern theory of systems and control As a concrete example one may consider the control of fluid flow across an airfoil for which recent experiments indicate the possibility of delaying the onset of turbulence by controlling viscosity through thermal actuators located on the airfoil In general there are two approaches to the con trol of such a complica ted process the development of extremely detailed models of the process followed by the derivation of a more dedicated feed back law or the development of a more simple model class followed by the derivation of control laws which are more robust to unmodelled dynamics and exogeneous disturbances In either approach the two twin themes of approximation and computation play a significant role in the derivation and implementation of resulting control laws And there is no doubt that the cross fertilization between these twin themes and control theory will increase unabated throughout the next decade not just as an important component of design and implementation of control laws but also as a source of new problems in computational mathematics In this volume we present a collection of papers which were deliv ered at the first Bozeman Conference on Computation and Control held at Montana State University on August 1 11 1988 **Parametric Optimization and Related Topics** ,1991 **Mathematical Programming with Data Perturbations** Anthony V. Fiacco,2020-09-23 Presents research contributions and tutorial expositions on current methodologies for sensitivity stability and approximation analyses of mathematical programming and related problem structures involving parameters The text features up to date findings on important topics covering such areas as the effect of perturbations on the performance of algorithms approximation techniques for optimal control problems and global error bounds for convex inequalities **Constrained Markov Decision Processes** Eitan Altman,2021-12-24 This book provides a unified approach for the study of constrained Markov decision processes with a finite state space and unbounded costs Unlike the single controller case considered in many other books the author considers a single controller with several objectives such as minimizing delays and loss probabilities and maximization of throughputs It is desirable to design a controller that minimizes one cost objective subject to inequality constraints on other cost objectives This framework describes dynamic decision problems arising frequently in many engineering fields A thorough overview of these applications is presented in the introduction The book is then divided into three sections that build upon each other

This book delves into Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21. Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21 is a crucial topic that needs to be grasped by everyone, from students and scholars to the general public. The book will furnish comprehensive and in-depth insights into Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21, encompassing both the fundamentals and more intricate discussions.

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   - Chapter 3: Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21 in Everyday Life
   - Chapter 4: Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21 in Specific Contexts
   - Chapter 5: Conclusion

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5. In chapter 4, the author will scrutinize the relevance of Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21 in specific contexts. The fourth chapter will explore how Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21 is applied in specialized fields, such as education, business, and technology.
6. In chapter 5, this book will draw a conclusion about Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21. The final chapter will summarize the key points that have been discussed throughout the book.
   This book is crafted in an easy-to-understand language and is complemented by engaging illustrations. It is highly recommended for anyone seeking to gain a comprehensive understanding of Sensitivity Stability And Parametric Analysis Mathematical Programming Study 21.

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
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