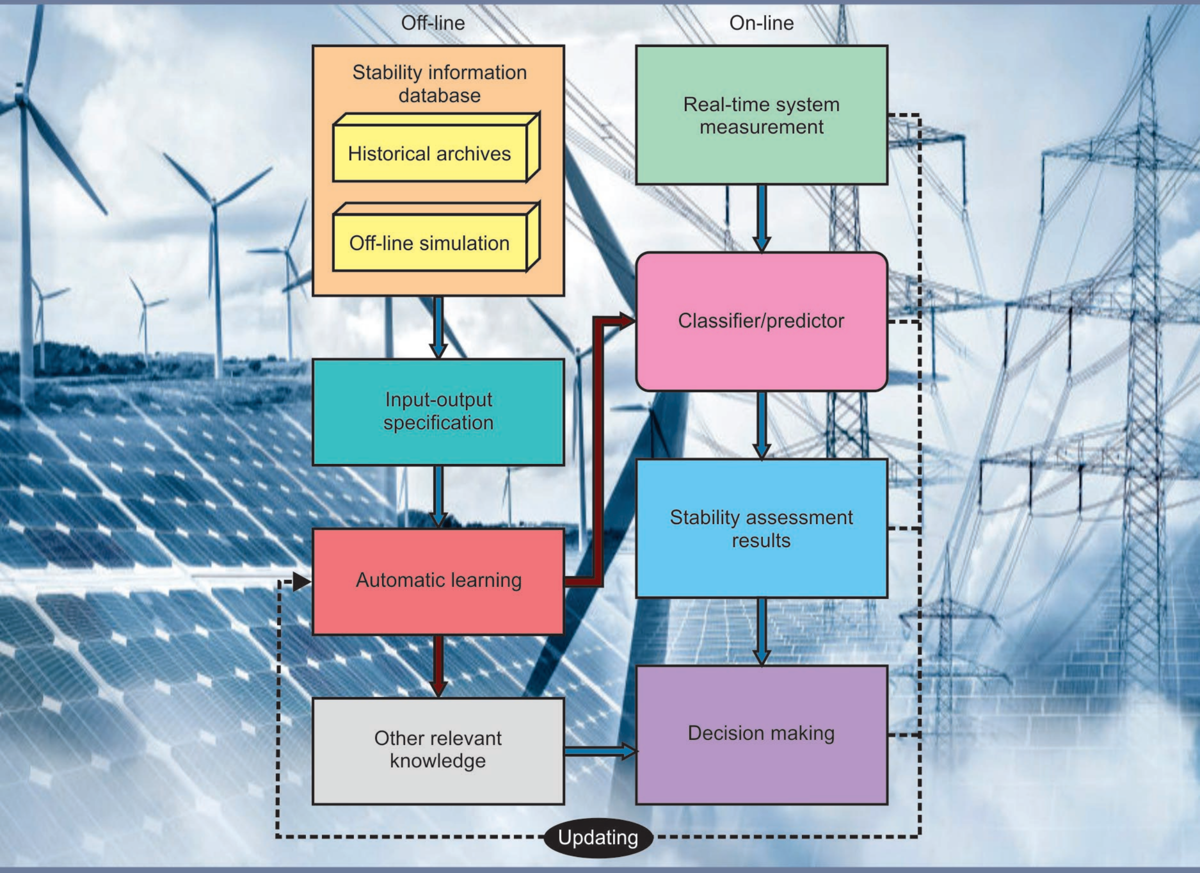
Intelligent Systems for Stability Assessment and Control of Smart Power Grids



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Foreword

Stability is an essential requirement for the power system. Since the new century, modern power systems have seen large-scale integration of renewable energy resources such as wind and solar power, and more non-conventional loads such as electric vehicle charging loads and those support demand response programs. These new elements, due to their different dynamic characteristics and/or high-level randomness, make the power system stability assessment and control a much more challenging task. The conventional model and simulation-based methods become inadequate to adapt to this new environment. In the meantime, with the wide-spread deployment of phasor measurement units (PMUs) and other metering technologies, more measurement data of the power system become available, which opens the opportunity for data-driven stability assessment and control.

This book presents a series of intelligent systems that make use of measurement data for stability assessment and control. Compared with conventional methods, the intelligent system solution has a much faster assessment speed, less reliance on system models, and a stronger ability to provide decision-support knowledge.

Written by a dedicated research team who has been working on this field for over 10 years, this book offers systematic coverage of state-of-the-art intelligent systems for data-driven power system stability assessment and control. It begins with the introduction of power system stability, offering readers a broad and stimulating overview of the field. It then identifies the problems and difficulties of conventional methods for stability assessment and control in the new environment and justifies the need for the intelligent system solution. Subsequently, the book introduces the framework and major blocks of an intelligent system for stability assessment and control, walking readers from introduction and background to general principle and structure of the intelligent system. After this, the book digs down into technical details on on-line stability assessment and preventive stability control which focus on the pre-fault state of the power system, and real-time stability prediction and emergency control which focuses on the post-fault state of the power system. The authors demonstrate a variety of innovative methodologies for stability database generation, feature extraction and selection, machine learning model design and training, decision-making and result credibility evaluation, parameter optimization, etc. To illustrate the concepts and methodologies, simulation tests on different benchmark testing systems are also given. Finally, the book moves to missing-data issues that often appear in practice and would impair the intelligent systems. Effective methods to address such issues are introduced.

Intelligent Systems for Stability Assessment and Control of Smart Power Grids is a systematic presentation of the authors' research works and their insights into this field. With a balanced presentation of theory and practice, this book is a valuable reference for researchers, engineers, and graduate students in the areas of power system stability assessment and control.

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Preface

Modern power systems are evolving towards the Smart Grid paradigm, featured by large-scale integration of renewable energy resources, e.g. wind and solar power, more participation of demand side, and interaction with electric vehicles. While these emerging elements are inherently stochastic, they are creating a challenge to the system's stability and its control. In this context, conventional stability analysis tools are becoming less effective, and call for the need for alternative tools that are able to deal with the high uncertainty and variability in the smart grid.

In the meantime, Smart Grid initiatives have also facilitated wide-spread deployment of advanced sensing and communication infrastructure, e.g. phasor measurement units at the grid level and smart meters at the household level, which collect a tremendous amount of data in various time and space scales. How to fully utilize the data and extract useful knowledge from them, is of great importance and value to support the advanced stability assessment and control of the smart grid.

The intelligent system strategy has been identified as an effective approach to meet the above needs. After over 10 years' continuous research in this field, we would like to present our intelligent system solutions to power system stability assessment and control in this book:

In Chapter 1, the preliminaries of power system stability are reviewed, including its definition, classification, phenomena, and different stability indices.

In Chapter 2, the problems and difficulties of stability assessment and control are discussed, and the motivation for the intelligent system solution is described. We classify the problems into two types: on-line stability assessment and preventive control, and real-time stability prediction and emergency control.

Chapter 3 introduces the general framework and the major steps for developing a practical intelligent system for stability assessment and control. We also give our insights into the key challenges and discuss our philosophy for addressing these challenges. The developed methodologies in the following chapters are based on this philosophy.

Chapter 4 presents the intelligent system for on-line stability assessment, which aims to use steady-state operating variables to achieve fast stability assessment for potential contingencies. We had originally proposed the credibility-oriented methodology to evaluate the reliability of the output of the intelligent system. If the output is reliable, it can be directly utilized for stability assessment, otherwise alternative methods such as traditional time-domain simulation can be used to replace this result. In such a way, the practicability of the intelligent system can be significantly enhanced. The detailed methods and algorithms for stability database generation, feature selection, machine learning model training, credibility evaluation criteria, ensemble-based decision making, and simulation test results are provided.

Chapter 5 presents the intelligent system for preventive stability control. We aim at transparent and interpretable preventive control actions which manipulate system operating state to counteract possible contingencies. The key methods and algorithms for stability knowledge discovery, interpretable control rules, as well as simulation test results are detailed.

Chapter 6 presents the intelligent system for real-time stability prediction, which aims to use real-time synchronized measurements to foresee the stability status under an ongoing disturbance. In order to balance the real-time stability prediction speed and accuracy, we had originally proposed the time-adaptive decision-making mechanism which can progressively predict the system stability based on available measurements. The detailed approaches for machine learning model design, time-adaptive decision-making process, optimal model parameter tuning, as well as simulation test results are provided.

Chapter 7 presents the intelligent system for emergency stability control. We aim at fast decision-making on stability control actions at the emergency stage where instability is propagating. The key methods and algorithms for emergency control database generation, model input, and output selection, as well as simulation test results, are detailed.

Chapter 8 aims to address the missing-data issue that usually appears in practice and is a critical challenge to the intelligent system. We had originally developed novel methods based on power grid observability and the deep learning technique. Detailed methods for feature selection and clustering, machine learning model training, and decision-making, as well as simulation test results, are presented.

We hope this book serve as a timely reference and guide for researchers, students, and engineers who seek to study and design intelligent systems to resolve stability assessment and control problems in the smart power grids.

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