Preface

With the increase in size of interconnected power systems, the network structure and the operating mode become more and more complex, which inevitability causes stability problems such as low frequency oscillations (LFO). Generally, LFO represent oscillatory interaction among multi-areas of the network. It has been an important factor for destroying the system stability, reducing the transmission capacity, and limiting the interconnected capability of network.

In recent years, more and more wide-area measurement systems (WAMS) have been applied in power systems. WAMS is the advanced and combined application of synchronized phasor measurement, communication engineering, and information technology in power systems. The aim of WAMS is to realize dynamic monitoring, analysis, and control for stable and efficient operation of the global power system. At present, WAMS research mainly concerns the following two aspects: (1) the construction and application of WAMS in smart grid and (2) the stability analysis and control based on wide-area measurements.

In interconnected power systems, the high-voltage direct-current (HVDC) technology is increasingly used for the network interconnection, and flexible AC transmission systems (FACTS) are used to provide the support of network enhancement. In this book, combining WAMS technology, the flexible and quick control capability of HVDC and FACTS is developed to implement wide-area damping control (WADC) strategies for stability enhancement of interconnected power systems.

This book intends to report the new results of WAMS application in analysis and control of power systems. The book collects new research ideas and achievements such as an online identification method for low-frequency oscillations, a delay-dependent robust design method, a wide-area robust coordination strategy, a hybrid assessment and choice method for wide-area signals, free-weighting matrices method, and its application.

The first motivation for this book is to establish a systematic, multi-scale, and comprehensive approach for estimating the oscillatory parameters, approximate mode shape and energy distribution of the dominant oscillation modes of the interconnected power systems, based on the near real-time data. A systematic method is proposed to extract the oscillation mode from the ensemble measurement matrix. Combing with the rapid development of the smart transmission network and computer technique, it is mature to establish a platform for dynamic oscillation mode estimation, analysis, and control.

The second motivation for this book is to carry out the systemized research on wide-area stability analysis and control for stability enhancement of large interconnected power systems. A flexible and quick control function of HVDC and FACTS is sufficiently developed to implement wide-area damping control strategies for solution of control problems such as how to realize control coordination among multiple WADC, how to choose optimal control-input for multiple WADC, and how to suppress the delay effects of wide-area signals on the control performance of WADC.

The main research results of this book are original from the authors who carried out the related research together for almost 6 years, which is a comprehensive summary for authors' latest research results. This book is likely to be of interest to university researchers, R&D engineers, and graduate students in electrical engineering who wish to learn the core principles, methods, algorithms, and applications of WAMS.

Outlines

This book is divided into 12 chapters. Chapter 1 introduces the status quo and trends of interconnected power systems, WAMS technology and its application in the interconnected systems, and the challenges of wide-area dynamic monitoring and control. The typical stability control problems of WADC are analyzed.

Chapter 2 introduces the theoretical foundation of LFO monitoring and analysis. The LFO phenomenon is described, and two techniques are presented to analyze LFO. One is based on system model and the other is based on measured information. The differences between these techniques are explained, and the advantages and disadvantages of each technique are compared.

Chapter 3 analyzes the shortcomings of the traditional Hilbert-Huang Transform (HHT) in identifying LFO. An improved empirical mode decomposition (EMD) is proposed to address the end effects (EEs) and specific mode-mixing. The intrinsic mode function is analyzed in time and frequency, and the normalized Hiber transform (NHT) is introduced. The improved HHT, which integrates the improved EMD and NHT, is proposed to calculate the oscillatory parameters of the single measured signal.

Chapter 4 presents a relative phase calculation algorithm (RPCA) to explore the spatial distribution of the specific oscillation mode. The concepts of node contribution factor (NCF) and approximate mode shape (AMS) are proposed to describe the phase information of specific oscillation mode based on the multi-measured signals. By combining the improved HHT and RPCA, a nonlinear hybrid method

(NHM) is proposed, which can be used to not only provide the oscillatory parameters of single measured signal and NCFs of every mode, but also to calculate the AMSs of the oscillation modes.

Chapter 5 analyzes the temporal and spatial characteristics of oscillation modes in power system, by using the complex orthogonal decomposition (COD). In order to realize the near real-time application, three different COD methods, including the complex eigenvalues decomposition (C-ED), complex singular value decomposition (C-SVD), and augmented matrix decomposition (AMD), are compared under the different sizes of ensemble measurement matrixes. The measured data from wide-area-protector (WAProtector) is used to verify the effectiveness of the near real-time application of the COD-sliding window recursive algorithm (SWRA).

Chapter 6 presents an overall framework of WADC. The control concept and operating principle of WADC are investigated by studying a single-machine infinite-bus (SMIB) with shunt-type FACTS device. The system linearized modeling method (direct feedback linearization, DFL) is used for system modeling.

Chapter 7 proposes a sequential design and global optimization (SDGO) method to optimize local and wide-area controllers simultaneously. The technical concept and implementation flowchart of this method are described. The modal analysis is used for phase-compensation design of local power system stabilizers (PSS) and HVDC-WADC, and a global optimization method is presented to find suitable control gains for both PSS and HVDC-WADC. The eigenvalue analysis and nonlinear simulation on typical HVDC/AC interconnected systems are carried out to validate the proposed SDGO method.

Chapter 8 proposes a wide-area robust coordination approach for multiple HVDC- and FACTS-WADC to damp multiple inter-area oscillation modes of interconnected power systems. The architecture of wide-area control network (WACN) is presented with the advanced control ability for enhancing the overall stability. The multi-objective mixed H_2/H_∞ control synthesis is used for robust design of HVDC- and FACTS-WADC. The robustness of the closed-loop system with the designed multiple WADCs is evaluated at different operating scenarios.

Chapter 9 proposes a hybrid method to assess and select optimal input signals for multiple WADCs. An index of the relative residue ratio (RRR) is defined to pre-select input signal candidates for multiple HVDC- and FACTS-WADC. The steady-state value and frequency response curve of the elements of relative gain array (RGA) are used to determine the optimal control pairs for multiple WADCs. The proposed method has the advantage of effectively reducing or even eliminating the interaction among multiple controllers.

Chapter 10 presents a new linear design approach on the robust WADC of interconnected power systems. The free-weighting matrices are introduced to convert the optimization object with nonlinear matrix inequality constrains into a set of LMI constraints. A nonlinear optimization algorithm is presented to search the optimal control gain with the maximum delay independent of the wide-area feedback control signals.

Chapter 11 presents the hardware and software design and implementation for WADC. A hardware-in-the-loop (HIL) test system based on the RT-LAB platform®

is established. Three WADC algorithms, i.e., the phase-compensation method, the delay-dependent state-feedback method, and the delay-dependent dynamic output-feedback method are introduced. The software designs of these algorithms are carried out, and the flowcharts are proposed for implementing algorithms in the environment of hardware. A typical interconnected power system is modeled in RT-LAB®, the closed-loop test has been done to validate the proposed control concept and controller design methods in conditions with time-varying delays, and compare the damping performance of WADC using different algorithms.

Chapter 12 presents the design and implementation of parallel processing in embedded phasor data concentrator (PDC) application for monitoring and stability enhancement of interconnected power systems. The structure of an interconnected system equipped with an embedded system with PDC and FACTS-WADC applications is established. The fundamental modules of the embedded system are designed, and the embedded PDC application is implemented on the evaluation kit EVK1100 from Atmel®. The main program workflow of parallel processing in embedded PDC and WADC applications is designed and presented. The closed-loop experiment is carried out to validate the designed results.

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Yong Li
Dechang Yang
Fang Lin
Yijia Cao
Christian Rehtanz

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