Preface

Electricity market activities and a growing demand for electricity have led to heavily stressed power systems. This requires operation of the networks closer to their stability limits. Power system operation is affected by stability related problems, leading to unpredictable system behavior. Cost efficient solutions are preferred over network extensions. In many countries, permits to build new transmission lines are hard to get, which means the existing network has to be enforced to fulfill the changing requirements.

Power electronic network controllers, the so called FACTS-devices, are well known having several years documented use in practice and research. Several kinds of FACTS-devices have been developed. Some of them such as the Thyristor based Static Var Compensator (SVC) are a widely applied technology; others like the Voltage Source Converter (VSC) based Static Compensator (STATCOM) or the VSC-HVDC are being used in a growing number of installations worldwide. The most versatile FACTS-devices, such as Unified Power Flow Controller (UPFC), although still confined primarily to research and development applications, have the potential to be used widely beyond today's pilot installations.

In general, FACTS-devices can be utilized to increase the transmission capacity, the stability margin and dynamic behavior or serve to ensure improved power quality. Their main capabilities are reactive power compensation, voltage control and power flow control. Due to their controllable power electronics, FACTS-device provide always a fast controllability in comparison to conventional devices like switched compensation or phase shifting transformers. Different control options provide a high flexibility and lead to multi-functional devices.

To explore the capabilities of FACTS-devices, a specific operation and control scheme has to be designed. Fundamental to their operation and control is their proper modeling for static and dynamic purposes. The integration of FACTS-devices into basic tools like power flow calculation and optimal power flow (OPF) is mandatory for a beneficial system operation. Due to the wide area and dynamic impact of FACTS-devices, a pure local control is desired, but is not sufficient in many cases. The requirements for normal and emergency operation have to be defined carefully. A specific control design has to address these different operational conditions. This book introduces the latest results of research and practice for modeling and control of existing and newly introduced FACTS-devices.

Motivation

This book is motivated by the recent developments of FACTS-devices. Numerous types of FACTS-devices have been successfully applied in practical operation. Some are still in the pilot stage and many are proposed in research and development. From practical experience it has been seen that the investment into FACTS-devices, in most of the cases, only pays off by considering their multi-functional capabilities, particularly in normal and emergency situations. This requires a three-phase modeling and a control design addressing both normal and emergency conditions which, in most of the cases, uses wide area information. The recent results and requirements for both modeling and control have motivated this book.

Focus and Target

The focus and target of this book is to emphasize advanced modeling, analysis and control techniques of FACTS. These topics reflect the recent research and development of FACTS-devices, and foresee the future applications of FACTS in power systems. The book comprehensively covers a range of power system control problems like steady state voltage and power flow control, voltage and reactive power control, voltage stability control and small signal stability control using FACTS-devices.

Beside the more mature FACTS-devices for shunt compensation, like SVC and STATCOM, and series compensation, like TCSC and SSSC, the modeling of the latest FACTS-devices for power flow control, compensation and power quality (IPFC, GUPFC, VSC HVDC and Multi-VSC-HVDC, etc.) is considered for power system analysis. The selection is evaluated by their actual and future practical relevance. The multi-control functional models of FACTS-devices and the ability for handling various internal and external operating constraints of FACTS are introduced. In addition, models are proposed to deal with small or zero impedances in the voltage source converter (VSC) based FACTS-devices. The FACTS-device models are implemented in power flow and optimal power flow (OPF) calculations. The power flow and OPF algorithms cover both single-phase models and especially three-phase models. Furthermore the unbalanced continuation power flow with FACTS is presented.

The control of FACTS-devices has to follow their multi-functional capabilities in normal and emergency situations. The investment into FACTS is normally justified by the increase of stability and primarily by the increase of transmission capability. Applications of FACTS in power system operation and control, such as transfer capability enhancement and congestion management, are used to show the practical benefits of FACTS devices.

A comprehensive FACTS-control approach is introduced based on the requirements and specifications derived from practical experience. The control structure is characterised by an autonomous system structure allowing, as far as possible, control decisions to be taken locally, but also incorporating system wide information where this is required. Wide Area Measurement System (WAMS) based control methodologies, which have been developed recently, are introduced for the first time in a book. In particular, the real-time control technologies based on Wide Area Measurement are presented. The current applications and future developments of the Wide Area Measurement based control methodologies are also discussed. As a particular control topic, utilizing the control speed of FACTS-devices, a special scheme for small-signal stability and damping of inter-area oscillations is introduced. Advanced control design techniques for power systems with FACTS including eigenvalue analysis, damping control design by the state-of-the art Linear Matrix Inequalities (LMI) approach and multiple damping controller coordination is presented. In addition, the time-delay of wide area communications, which is required for a system wide damping control, is considered.

These aspects make the book unique in its area and differentiate from other books on the similar topic. The work presented is derived both from scientific research and industrial development, in which the authors have been heavily involved. The book is well timed, addressing current challenges and concerns faced by the power engineering professionals both in industries and academia. It covers a broad practical range of power system operation, planning and control problems.

Structure

The first chapter of the book gives an introduction into nowadays FACTS-devices. Power semiconductors and converter structures are introduced. The basic designs of major FACTS-devices are presented and discussed from a practical point of view. The further chapters are logically separated into a modeling and a control part. The modeling part introduces the modeling of single and multi-converter FACTS-devices for power flow calculations (Chapter 2 and 3) and optimal power flow calculations (Chapter 4). The extension to three phase models is given in chapter 5. This is fundamental for proper system integration for steady state balanced and unbalanced voltage stability control or the increase of available transmission capacity.

Chapter 6 and 7 present the steady state voltage stability analysis for balanced and unbalanced systems. The increase of transmission capacity and loss reduction with power flow controlling FACTS-devices is introduced in chapter 8 along with the financial benefits of FACTS. From these results it can be seen, that the benefits of FACTS can be increased by utilizing the fast controllability of FACTS together with a certain wide area control scheme.

The control part of the book starts with chapter 9 introducing a non-intrusive system control scheme for normal and emergency situations. The chapter takes the view, that a FACTS-device should never weaken the system stability. Based on this condition, the requirements and basic control scheme for FACTS-devices are derived. Chapter 10 introduces an autonomous control system approach for FACTS-control, balancing the use of local and global system information and considering normal and emergency situations. Due to the influence of FACTS-devices on wide system areas, especially for power flow and damping control, an exchange of information with the FACTS controllers is required. A wide area control scheme for power flow control is introduced in chapter 11.. Only with wide area system information can the benefits of power flow control be achieved.

The control options available with FACTS-devices can provide effective damping capability. Chapter 12 and 13 deal with small signal stability and the damping of oscillations, which is a specific application area utilizing the control speed of FACTS. The coordination of several FACTS damping controllers requires a formally introduced wide area control scheme. This approach has to consider communication time delays carefully, which is a specific topic of chapter 13.

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