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Hao Lin · Ligang Wu

Robust Control Strategies for Power Electronics in Smart Grid Applications

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Preface

Smart grid, as an emerging power technology, will gradually replace traditional grids and become the development direction of future power systems. With the introduction of diverse renewable energy sources, battery energy storage systems, and other new distributed energy resources, the power supply side of smart grids exhibits characteristics such as diversity, intermittency, and randomness. At the same time, with the emergence of new electric units like electric vehicles, the power consumption side of smart grids displays characteristics such as diversity, randomness, and flexibility. In order to establish friendly and flexible connections among various types of distributed power sources, battery energy storage systems, and new electric units with different attributes, it is necessary to achieve fast and precise energy conversion and control through energy conversion equipment. Power electronic conversion technology, based on power semiconductor devices, circuit topologies, and control theories, is the key and foundation for realizing the aforementioned functionalities. In this context, it is crucial to explore the latest advancements and trends in the field of control technology for power electronics in smart grid applications, in order to better understand how these technologies can be optimized to achieve maximum efficiency and performance.

On the other hand, load frequency control, as an important means to achieve dynamic balance between power generation and consumption in electrical systems, holds significant importance in maintaining system stability and achieving high-quality power output. However, the increasing adoption of plug-in EVs has brought about significant challenges to the load frequency control (LFC) of power grid systems. As the number of plug-in EVs participating in the power grid continues to increase, it becomes increasingly difficult to achieve an economically viable and effective load frequency control while maintaining satisfactory system performance. The intermittent nature of the plug-in EV charging process, the uncertain driving patterns of plug-in EV owners, and the potential impact of large-scale plug-in EV participation on power system stability all pose significant challenges to LFC. In this situation, new control strategies and technologies need to be developed to ensure the efficient and reliable operation of power systems while accommodating the growing number of EVs. This requires a deep understanding of the interactions between plug-in EVs and power systems, as well as the development of innovative solutions that can mitigate the challenges posed by EV participation.

This book aims to provide readers with comprehensive insight into robust control strategies for power electronics used in smart grid applications. The book is organized as follows. Chapter 1 introduces some background knowledge of smart grid, the challenges and opportunities of plug-in EVs for the power system, and the control techniques for smart grid applications. Chapter 2 showcases several control techniques that can be implemented for the three-phase two-level AC/DC power converter. Chapter 3 introduces a high-quality current control approach for the three-level AC/DC power converter. Chapter 4 focuses on direct power control for the three-level AC/DC power converter. Chapter 5 proposes a fuzzy sliding-mode control strategy for the three-level AC/DC power converter. Chapter 6 provides a robust control approach for the operation of two-level AC/DC power converter when subjected to unbalanced grid conditions. Chapter 7 introduces an adaptive optimal control strategy to efficiently alleviate disturbances and uncertainties for the permanent magnet synchronous motor. Chapter 8 presents a distributed economic model predictive control approach for load frequency control that incorporates large-scale plug-in EV participation. Chapter 9 aims to secure the distributed frequency estimation of a large number of plug-in EVs participating in the distributed frequency regulation.

In conclusion, this book provides the reader with an essential overview of the latest developments in the control strategy for power electronics in smart grid applications. It serves as a valuable resource for researchers, engineers, and professionals in the field, facilitating a deeper understanding of robust control techniques and their practical implementation in shaping the future of smart grids.

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Notations and Acronyms

$\triangleq$	Is defined as
$\simeq$	Approximately equals to
$\ll$	Is much less than
$\gg$	Is much greater than
$\in$	Belongs to
$\forall$	For all
$\sum$	Sum
$\lvert\cdot\rvert$	Euclidean vector norm
$\lVert\cdot\rVert$	Euclidean matrix norm (spectral norm)
$\lVert\cdot\rVert_2$	$\mathcal{L}_2$ − norm: $\sqrt{\int_0^\infty \lvert\cdot\rvert^2 dt}$ (continuous case)
	ℓ_2 − norm: $\sqrt{\sum_0^\infty \lvert\cdot\rvert^2}$ (discrete case)
$\mathcal{L}_2\{[0, \infty), [0, \infty)\}$	Space of square summable sequences on $\{[0,\infty), [0,\infty)\}$ (continuous case)
$\ell_2\{[0, \infty), [0, \infty)\}$	Space of square summable sequences on $\{[0,\infty), [0,\infty)\}$ (discrete case)
$\frac{\partial f}{\partial x}$ or $\frac{\partial}{\partial x} f$	The derivative of the function f with respect to x
$\mathbf{R}$	Field of real numbers
$\mathbf{R}^n$	Space of n-dimensional real vectors
$\mathbf{R}^{n\times m}$	Space of $n \times m$ real matrices
X^{T}	Transpose of matrix X
X^{-1}	Inverse of matrix X
$X > (<) 0$	X is real symmetric positive (negative) definite
$X \geq (\leq) 0$	X is real symmetric positive (negative) semi-definite
$*$	Symmetric terms in a symmetric matrix
0	Zero matrix
$0_{n\times m}$	Zero matrix of dimension $n \times m$
I	Identity matrix
I_n	$n \times n$ identity matrix
$\mathrm{col}\{x_1, \ldots, x_n\}$	Column vector $[\mathrm{x}_1, \ldots, \mathrm{x}_n]^{\mathrm{T}}$ with n elements

det(·)	The determinant computed from the elements of a square matrix
$\mathrm{diag}\{X_1, \ldots, X_m\}$	Block diagonal matrix with blocks $X_1, \ldots, X_\mathrm{m}$
inf	Infimum, the greatest lower bound
lim	Limit
ln(·)	The natural logarithm of a number
max	Maximum
min	Minimum
rank(·)	Rank of a matrix
sign(·)	The signum function of a real number
sup	Supremum, the least upper bound
$\lambda_{\min}(\cdot)$	Minimum eigenvalue of a real symmetric matrix
$\lambda_{\max}(\cdot)$	Maximum eigenvalue of a real symmetric matrix
$3\mathrm{L} - \mathrm{NPC}$	Three-level diode neutral point clamped
AC	Alternating Current
AFE	Active Front-End
AI	Artificial Intelligence
AO	Adaptive Observer
AOCS	Adaptive Optimal Control Strategy
DC	Direct Current
DEMPC	Distributed Economic Model Predictive Control
DLFC	Distributed Load Frequency Control
DOBC	Disturbance Observer-Based Control
DoS	Denial-of-Service
DSP	Digital Signal Processor
DSRF	Double Synchronous Reference Frame
DTC	Direct Torque Control
EMS	Energy Management System
ESMDO	Extended Sliding Mode Disturbance Observer
ESO	Extended State Observer
EVs	Electric Vehicles
FCR	False Connect Rate
FDI	False Data Injection
FDIA	False Data Injection Attack
FIR	False Isolate Rate
FLS	Fuzzy Logic System
FOC	Field Oriented Control
FSMC	Fuzzy Sliding-Mode Control
FSTA	Fuzzy Super-Twisting Algorithm
IGBT	Insulated Gate Bipolar Transistor
LFC	Load Frequency Control
LO	Luenberger Observer
MATI	Maximum Allow Time Interval
MESs	Micro-Energy Systems
MPC	Model Predictive Control

NPC	Neutral Point Clamped
PEVs	Plug-In Electric Vehicles
PI	Proportional Integral
PID	Proportional-Integral-Derivative Control
PLL	Phase Locked Loop
PMSM	Permanent Magnet Synchronous Motor
PMUs	Phase Measurement Units
PR	Proportional-Resonance
PWM	Pulse-Width Modulation
RES	Renewable Energy Sources
RMS	Root Mean Square
RTUs	Remote Telemetry Units
SMC	Sliding Mode Control
SOSM	Second-Order Sliding Mode
SRF	Synchronous Reference Frame
STA	Super-Twisting Algorithm
STD	Super-Twisting Differentiator
STESO	Super-Twisting Extended State Observer
STO	Super-Twisting Observer
THD	Total Harmonic Distortion
V2G	Vehicle-to-Grid

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