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Advanced Control Methodologies For Power Converter Systems

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To Our Families

Preface

Power electronic converters have become indispensable devices for plenty of industrial applications over the last decades. Composed by controllable power switches, they can be controlled by effective strategies to achieve desirable transient response and steady-state performance, to ensure the stability, reliability and safety of the system. Due to the limits of conventional proportional-integral control which is adopted as an industry standard, many advanced control methodologies and techniques have been developed to improve the converter performance. This book presents the research work on some advanced control methodologies for several types of power converters, including three-phase two-level ac/dc power converter, three-phase Neutral-Point-Clamped (NPC) ac/dc power converter, dc/dc buck converter and boost converter. Specifically, the disturbance observer-based control strategies are investigated, including disturbance observer-based sliding mode control strategies, $\mathcal{H}_\infty$ control strategies and model predictive control strategies. Based on these works, intelligent control strategies have been investigated. Specifically, adaptive control strategies have been explored to facilitate the self-tuning ability of the converter system. Some sufficient conditions for system variables such as the voltage, current, active and reactive power are obtained. Moreover, to improve the robustness against the system uncertainties, neural network-based control strategies are investigated. The effectiveness and advantage of the proposed control strategies are verified via simulations and experiments.

This book aims to present some advanced control methodologies for power converters. The content of this book can be divided into two parts. The first part focuses on disturbance observer-based control methods for power converters under investigation. The second part investigates intelligent control methods. These methodologies provide a framework for controller design, observer design, stability and performance analysis for the considered power converter systems.

The brief content structure of the book is as follows. The main contents of the first part include: Chap. 2 investigates the disturbance observer-based sliding mode control strategy for three-phase two-level ac/dc power converter; Chap. 3 designs a linear disturbance observer-based proportional-integral control to regulate the dc-link voltage of the three-phase two-level ac/dc power converter; Chap. 4 designs a sliding mode observer-based sliding mode control strategy to regulate the dc-link voltage of three-phase two-level ac/dc power converter; Chap. 5 investigates the disturbance observer-based control strategies for three-phase three-level neutral-point-clamped ac/dc power converter; Chap. 6 proposes the disturbance observer-based control strategy for dc/dc buck converter; Chap. 7 designs a model predictive control strategy for three-phase two-level ac/dc power converter. The main contents of the second part include: Chap. 8 designs two adaptive control strategies for dc/dc buck converter, which are single-loop adaptive control strategy and double-loop adaptive control strategy; Chap. 9 proposes a control strategy consisting of adaptive control and $\mathcal{H}_\infty$ technique for three-phase two-level ac/dc power converter; Chap. 10 investigates adaptive super-twisting sliding mode control-based $\mathcal{H}_\infty$ control method, taking into account both the load variation and component parameter uncertainty of three-phase two-level ac/dc power converter; Chap. 11 investigates radial basis function neural network-based control strategy for three-phase three-level neutral-point-clamped ac/dc power converter.

This book is a research monograph whose intended audience is graduate, post-graduate students, researchers, as well as engineers in power converter control fields.

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Contents

Notations and Acronyms

$\blacksquare$	end of proof
$\blacklozenge$	end of remark
$\triangleq$	is defined as
$\in$	belongs to
$\forall$	for all
$\sum$	sum
$\mathbf{C}$	field of complex numbers
$\mathbf{R}$	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
$\mathbf{Z}$	field of integral numbers
$\mathbf{Z}^+$	field of positive integral numbers
lim	limit
max	maximum
min	minimum
sup	supremum
inf	infimum
$\mathrm{rank}(\cdot)$	rank of a matrix
$\det(\cdot)$	determinant of a matrix
$\mathrm{trace}(\cdot)$	trace of a matrix
$\deg(\cdot)$	degree of a polynomial
$\lambda_i(\cdot)$	ith eigenvalue of a matrix
$\lambda_{\min}(\cdot)$	minimum eigenvalue of a matrix
$\lambda_{\max}(\cdot)$	maximum eigenvalue of a matrix
$\mathbf{Re}(\cdot)$	real part of a complex number
I	identity matrix
I_n	$n \times n$ identity matrix
0	zero matrix
$0_{n\times m}$	zero matrix of dimension $n \times m$
X^T	transpose of matrix X
$X^\star$	conjugate transpose of matrix X

X^{-1}	inverse of matrix X
X^{+}	Moore-Penrose inverse of matrix X
$X^{\perp}$	full row rank matrix satisfying $X^{\perp}X = 0$ and $X^{\perp}X^{\perp T} > 0$
diag	block diagonal matrix with blocks $\{X_1, \ldots, X_m\}$
$\text{sym}(A)$	$A + A^T$
$X > (<)0$	X is real symmetric positive (negative) definite
$X \geq (\leq)0$	X is real symmetric positive (negative) semi-definite
$\mathcal{L}_2\{[0, \infty), [0, \infty)\}$	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)
$\lvert\cdot\rvert$	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) $\ell_2 -$ norm : $\sqrt{\sum_0^{\infty} \lvert\cdot\rvert^2}$ (discrete case)
$\lVert \cdot \rVert_{E_2}$	$\mathbf{E}\{\lVert \cdot \rVert_2\}$
$\lVert\mathbf{T}\rVert_{\infty}$	$\mathcal{H}_{\infty}$ norm of transfer function $\mathbf{T}$: $\sup_{\omega\in[0,\infty)} \lVert\mathbf{T}(\mathrm{j}\omega)\rVert$ (continuous case) $\sup_{\omega\in[0,2\pi)} \lVert\mathbf{T}(\mathrm{e}^{\mathrm{j}\omega})\rVert$ (discrete case)
$*$	symmetric terms in a symmetric matrix
LMI	Linear matrix inequality
PD	Positive definite
ND	Negative definite
SMC	Sliding mode control
SRF	Synchronous rotating frame
PWM	Pulse width modulation
PLL	Phase locked loop
VOC	Voltage oriented control
DPC	Direct power control
THD	Total harmonic distortion
ADRC	Active disturbance rejection control
SMO	Sliding mode observer
LDO	Linear disturbance observer
ESO	Extended state observer
LESO	Linear extended state observer
NESO	Nonlinear extended state observer
NN	Neural network
T-S	Takagi-Sugeno
MPC	Model predictive control

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Chapter 1
Introduction

Abstract This chapter presents the preliminary backgrounds for power converter control strategies, including the linear control strategies such as proportional-integral-derivative control, nonlinear control strategies such as sliding mode control, adaptive control, fuzzy logic control, etc., and the disturbance observer based control strategies. Finally, the outline of the book is listed.

1.1 Power Electronic Converters

The power system is the most important infrastructure for economic and social development, which commissions energy conversion, transmission and distribution. Due to the non-renewability of fossil energy and the deterioration of global climate environment, the modern power system is transitioning to a stage of sustainability and intelligence. On one hand, in order to achieve long-term sustainability, large-scale development of clean renewable energy sources, such as wind and solar energy, is required [1, 2]. At the same time, considering the intermittent nature of such energy sources, it is necessary to equip corresponding energy storage devices [3–7]. Therefore, the grid integration of renewable energy and the energy conversion of energy storage devices are the main tasks of the power system's transition toward sustainability. On the other hand, in order to intelligentize the power system, corresponding control measures need to be taken to enable the power to flow intelligently on demand, thereby improving energy utilization, optimizing power quality and enhancing system reliability [8–11]. Therefore, the bi-directional power flow the fundamental feature and basic task of the intelligent power system. The realization of these tasks all depend on the development of power electronics technology [12–19].

Power electronics technology refers to the electronic technology applied in the power field, involving three major fields such as power, electronics and control, and mainly realizes the conversion of electric energy. Common power conversion methods include ac/dc, dc/ac, ac/ac, dc/dc, etc. The purpose of power conversion is to enable people to use the power more conveniently and effectively. Power electronic converters based on power electronics technology are indispensable devices in modern power systems. Without power electronic converters, the modernization of the

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