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Neural Control of Renewable Electrical Power Systems

Springer

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Preface

Nowadays, the share of power using clean power generators is continuously increasing in all over the world; hence, penetration of distributed energy resources (DERs) into grid is also increasing. On the other hand, in order to reach better exploration of the renewable energy that is generated from different DERS, the microgrid concept is the key. Regarding high penetration of renewable energy generation in medium- and high-voltage networks, modern grid codes enforce the DERs to have Low-Voltage Ride-Through (LVRT) capacity, which is the capability of a specific electric generator to stay connected to the main grid in presence of grid disturbances for a short period. This requirement is one of the most dominant grid connection requirements to be met by DERs. To achieve adequate LVRT capacity, the installed local controllers of each microgrid subsystem should guarantee transient stability to enhance resilience of microgrid operations.

Recently, technology advances have forced control engineers to deal with complex systems, which include unknown dynamics, strong interconnection terms, and disturbances. Then, conventional control techniques are unsuccessful to provide an effective solution to control this class of systems. Neural networks are recently a well-established methodology for identification and control of general nonlinear and complex systems. Applying neural networks, control schemes can be developed to be robust in the presence of disturbances, parameter variations, and modeling errors.

In this book, robust control schemes based on neural network identification are developed to enhance, firstly, the LVRT capacity of grid-connected Doubly Fed Induction Generator (DFIG)-based Wind Turbine (WT) and, secondly, to improve the LVRT capacity of DERs, which are installed in a grid-connected microgrid. The outline of this work is as follows. In Chap. 1, an introduction, which exposes the state of art and the different research works regarding the wind power system and grid-connected micro grid, is presented. In Chap. 2, mathematical preliminaries, which are used in the development of this book, are introduced. Then, the mathematical model of wind power system is given in Chap. 3 including the mechanical, the DC-link, and the DFIG models. Next, different control schemes based on the proposed neural network identifiers are synthesized in Chap. 4. Those controllers are the discrete-time neural sliding mode field oriented control, the discrete-time neural sliding mode linearization control, and the discrete-time neural inverse optimal control. All those proposed controllers are synthesized for the grid side converter and the rotor side converter. Simulation results using Matlab are discussed considering the tracking of time-varying reference, robustness to parameter variation, sensitivity to wind speed changing effects, and robustness in presence of grid disturbances. After that, real-time results of the proposed controllers for the DFIG-based WT considering time-varying reference tracking, maximum power extraction, and robustness to grid disturbances are presented in Chap. 5. In Chap. 6, the mathematical models of the solar power system, the battery bank, and their corresponding converters are introduced. In addition, the proposed discrete-time neural sliding mode linearization control is extended for the microgrid components. The real-time simulation results are presented under normal grid conditions regarding time-varying trajectories tracking and in presence of three grid fault type: single-phase-to-ground, two-phase-to-ground, and three-phase-to-ground. Finally, the perspective conclusions and the directions for future researches are presented.

This book is intended for researchers and students with a control background and wishing to expand their knowledge of wind power generation and distributed energy resources installed into a grid-connected microgrid. Additionally, this can be useful to the scientist in the automatic control field especially whom looking for innovative control ideas and their applications in renewable energy systems. It will also interest practicing engineers dealing with power generation technologies, who will benefit from the utilization of neural networks in systems modeling and control synthesis.

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Abstract

Renewable energy generation is one of the most efficient and effective solutions to face global warming. Taking into account high penetration of Distributed Energy Resources (DERs) in medium- and high-voltage networks, modern grid codes enforce the DERs to have Low-Voltage Ride-through (LVRT) enough capacity. In this book, different control schemes based on neural network identification are proposed for a Wind Power System (WPS) based on Doubly Fed Induction Generator (DFIG) connected to the grid and grid-connected microgrid.

Firstly, the proposed controllers are used to track the WPS dynamics references which are the DC voltage, the grid power factor, and the stator active and reactive power. The performances of the proposed neural control schemes for the WPS are initially validated via simulations using SimPower ToolBox of Matlab, by means of considering time-varying references tracking, robustness to parameter variations, and wind speed changes. In addition, LVRT capacity enhancement in presence of grid disturbances is tested. Moreover, those controllers are experimentally validated on a 1/4 HP DFIG prototype under both normal and abnormal grid conditions. The experimental results illustrate that the proposed controllers have adequate performances for WPS, even in presence of references variations, and wind turbine speed changes, compared with conventional control schemes. In addition, those controllers are able to operate WPS for extracting the maximum power from the wind under different fault scenarios, enhancing the LVRT capacity and ensuring transient stability.

Secondly, a neural sliding mode linearization control scheme is extended to control the generated power from each DER installed into grid-connected microgrid. The proposed microgrid is composed of a WPS, a Solar Power System (SPS), a Battery Bank (BB), and a load demand. In addition, the microgrid under study is interconnected to an IEEE 9-bus system to evaluate its connection performance and response in presence of grid disturbances. The whole system is real-time simulated using an Opal-RT (OP5600) simulator. Results illustrate effectiveness of the proposed control scheme to achieve trajectory tracking for DER active and reactive powers. In addition, the LVRT capability of the proposed control strategy is verified in presence of grid disturbances.

Contents

Notations

$\Re$	set of all real numbers
k	sample time
$\forall$	for all
Σ	sliding surface subset
$\in$	belonging to
$\mathbb{Z}^+$	set of positive integers
$\|\bullet\|$	Euclidean norm
$\sum$	sum up
$(\bullet)^{-1}$	denotes matrix inverse
$(\bullet)^T$	denotes matrix transpose
$(\bullet)^*$	denotes optimal function
$\|\bullet\|$	the Euclidean norm
$\vert \bullet \vert$	absolute value
Ω	compact subset of real numbers
S	subset of real numbers
Δ_k	identification error function
ΔV	denotes the Lyapunov difference
V	denotes Lyapunov function candidate
u_0	the upper control bound
u_k	the system input
$s(x)$	the sliding surface
x_k	Real vector state
χ_k	Estimated vector state
ω_i	Adaptive neural identifier weights
ϖ_i	Fixed neural identifier weights
y_k	the output to be controlled
e_k	tracking error

Acronyms

BB	Battery Bank
DFIG	Doubly Fed Induction Generator
EKF	Extended Kalman Filter
FOC	Field Oriented Control
GSC	Grid Side Converter
HAWT	Horizontal Axis Wind Turbine
LVRT	Low-Voltage Ride-Through
N-IOC	Neural Inverse Optimal Control
NN	Neural Network
N-SM	Neural Sliding Mode
N-SMFOC	Neural Sliding Mode Field Oriented Control
N-SML	Neural Sliding Mode Linearization
RHONN	Recurrent High Order Neural Network
RSC	Rotor Side Converter
SGUUB	Semiglobally Uniformly Ultimately Bounded
SM	Sliding Mode
SM-FOC	Sliding Mode Field Oriented Control
SM-L	Sliding Mode Linearization
SM-VOC	Sliding Mode Vector Oriented Control
SPS	Solar Power System
VOC	Vector Oriented Control
VSWT	Variable Speed Wind Turbine
WPS	Wind Power System
WT	Wind Turbine

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