DISTRIBUTED COOPERATIVE CONTROL FOR AUTONOMOUS MICROGRIDS

by Mahmuda Begum

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the degree of

Doctor of Philosophy

under the supervision of A/Prof. Li Li (Principal Supervisor)
and Prof. Jianguo Zhu (Co-Supervisor)

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Certificate of Original Authorship

I, *Mahmuda Begum* declare that this thesis, is submitted in fulfilment of the requirements for the award of *Doctor of Philosophy*, in the *Faculty of Engineering and IT* at the University of Technology Sydney.

This thesis is wholly my own work unless otherwise referenced or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

This document has not been submitted for qualifications at any other academic institution.

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Abstract

Distributed control for microgrids (MGs) is the current development due to its numerous benefits compared to traditional central control systems, such as system reliability, reducing its sensitivity to failures, and eliminating the requirement for central computing and communication structure. Although many research works have been accomplished on the design of MG control, distributed secondary control (DSC) needs more attention. There is still a lack of appropriate DSC design for islanded AC MGs which can restore the frequency and voltage along with precise power-sharing with detailed stability analysis. Another concern is the simplicity of DSC system design. Moreover, very little research addressed the DSC for distributed energy storage units (DESUs) for MGs considering state of charge (SoC) balancing along with frequency and voltage restoration with precise power-sharing.

This thesis proposes MG control that addresses frequency and voltage restoration with precise power-sharing, and optimises the control parameters by utilising intelligent controller and SoC balancing for DESUs in a single control strategy with detailed stability analysis. The significant contributions of this thesis are to: (1) design a DSC for MGs which covers all the control aspects in a single control strategy; (2) model the MGs for the proposed DSC in a systematic way and perform a detailed stability analysis; (3) verify the presented control with several case studies; (4) consider SoC balancing along with other control aspects in designing DSC for DESUs; (5) propose intelligent control methods to find the optimal control parameters for stability enhancement of MGs and verify their effectiveness with different case studies.

Firstly, a novel DSC with an incremental cost-based droop controller is proposed. The parameters of the proposed DSC are designed utilising the particle swarm optimization (PSO) method. A linearised small-signal state-space model considering DSC with stability studies of an islanded AC MG is also presented. The dynamic response of DSC initiates additional oscillatory modes, which affects the damping performance of the system. To enhance the system stability with DSC, a fuzzy logic based intelligent controller is also offered for tuning the secondary control parameters for the best functioning of the offered DSC. This research also introduces a new DSC system for DESUs in an islanded AC MG. By applying the suggested methodology, all the DESUs achieve exactly the same SoC with the power proportional to their capacity at the steady state, and hence the uneven degradation of DESUs is avoided.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AC-Alternating Current

ADM-Active Demand Management

DC-Direct Current

DER-Distributed Energy Resources

DG-Distributed Generation

DQ-Direct Quadrature

DSC-Distributed Secondary Controller

DSFC-Distributed Secondary Frequency Controller

DSM-Demand Side Management

DSVC-Distributed Secondary Voltage Controller

ED-Economic Dispatch

EES-Electrical Energy Storage

GPS-Global Positioning Control

ILC-Interlinking Converter

LC-Inductor-Capacitor

LCL-Inductor-Capacitor-Inductor

(P-f) Droop-(Active Power-Frequency) Droop

PI-Proportional-Integral

PV- Photovoltaic

PCC-Point of Common Coupling

PSO-Particle Swarm Optimisation

PWM-Pulse Width Modulation

RL-Resistor-Inductor

RC-Resistor-Capacitor

RLC-Resistor-Inductor-Capacitor

MAS-Multi-Agent System

MATLAB-Matrix Laboratory

MG-Microgrid

MCC-Microgrid Central Controller

MPC-Model Predictive Control

SoC- State of Charge

(*Q*-*v*) Droop- (Reactive Power-Voltage) Droop

VSI-Voltage Source Inverter

List of Publications

Journal Papers:

1. **Begum, M.,** Li, L. & Zhu, J. 2021, 'Fuzzy-Based Distributed Cooperative Secondary Control with Stability Analysis for Microgrids', *Electronics, vol 10, issue 4.*

Conference Papers:

2. **Begum, M.**, Li, L. & Zhu, J. 2020, 'Distributed Secondary Control of Energy Storage Units for SoC balancing in AC Microgrid', *IEEE Innovative Smart Grid Technologies (ISGT-North America)*, Washington DC, USA.

3. **Begum, M.**, Li, L. & Zhu, J. 2019, 'PSO-based Secondary Frequency Control and Active Power Sharing', *IEEE Innovative Smart Grid Technologies (ISGT-Asia)*, Chengdu, China.

4. **Begum, M.**, Li, L. & Zhu, J. 2018, 'State-Space Modelling and Stability Analysis for Microgrids with Distributed Secondary Control'-, *The 27th IEEE International Symposium on Industrial Electronics (ISIE)*, Cairns, Australia.

5. **Begum, M.**, Li, L. & Zhu, J. 2017, 'Distributed Control Techniques for Autonomous AC Microgrids-A brief Review', *The 5th International Conference on IEEE Region 10 Humanitarian Technology Conference (R10HTC)*, Dhaka, Bangladesh.

6. **Begum, M.**, Li, L. & Zhu, J. 2017, 'Distributed Secondary Voltage Regulation for Autonomous Microgrid', *20th IEEE International Conference on Electrical Machines and Systems (ICEMS)*, Sydney, Australia.

7. Abuhilaleh, M., Li, L. & Zhu, J., **Begum, M.** 2017, 'Power Management and Control Strategy for Hybrid AC/DC Microgrids in Autonomous Operation Mode', *20th IEEE International Conference on Electrical Machines and Systems (ICEMS)*, Sydney, Australia.