

# Contents

<b>List of Figures</b>	v
<b>List of Tables</b>	viii
<b>List of Acronyms</b>	x
<b>Symbols Used</b>	xii
<b>Preface</b>	xvi
<b>Chapter 1. Introduction.....</b>	1
1.1 Motivation.....	2
1.2 Objectives.....	8
1.3 Organisation Of Thesis.....	9
<b>Chapter 2. Background and Literature Review.....</b>	11
2.1 Mathematical Modelling of Microgrid Systems.....	11
2.2 Reduced Order Modelling of Microgrid Systems.....	14
2.3 Optimization Algorithms.....	16
2.3.1 Particle Swarm Optimization and Artificial Bee Colony.....	17
2.3.2 Mixed Sensitivity Objective Function.....	18
2.4 Controller design for Hybrid Microgrid System.....	18
2.5 Eigenvalue Analysis and Stability.....	20
2.6 Summary.....	21
<b>Chapter 3. Small Signal Modelling.....</b>	22
3.1 Preliminaries.....	22
3.1.1 Reference Frames.....	22
3.1.2 Operating Point Evaluation in Linearization.....	24

3.1.3	State Perturbation.....	25
3.2	Small Signal Modelling of AC Microgrid.....	26
3.2.1	AC Microgrid Architecture.....	27
3.2.2	State space modelling in autonomous mode.....	27
3.2.3	State space modelling in grid-tied mode.....	40
3.3	Small Signal Modelling of DC Microgrid.....	49
3.3.1	DC Microgrid Architecture.....	49
3.3.2	Microgrid Component Modelling.....	51
3.3.3	Control scheme for duty ratio regulation.....	55
3.3.4	State Space Representation of DC Microgrid System.....	60
3.4	Simulation Results.....	62
3.5	Summary.....	65
<b>Chapter 4.</b>	<b>Reduced Order Modelling.....</b>	<b>67</b>
4.1	Preliminaries.....	67
4.1.1	Norm based error reduction.....	68
4.1.2	Dominant pole retention.....	69
4.1.3	Direct and Balanced Truncation.....	69
4.1.4	Hankel Singular Value(HSV).....	71
4.1.5	Evolutionary Algorithm.....	71
4.1.6	Concept of time-scale separation.....	77
4.2	Optimal Model Order Reduction of Microgrid System.....	78
4.2.1	Reduced Order Modelling of AC Microgrid.....	78
4.2.2	Reduced Order Modelling of DC Microgrid.....	84
4.3	Simulation Results.....	89
4.3.1	Optimal MOR in AC Microgrid.....	90

4.3.2 Optimal MOR in DC Microgrid.....	107
4.4 Real-time implementation with Typhoon HIL 402.....	112
4.5 Summary.....	116
<b>Chapter 5. Eigenvalue and Stability Analysis.....</b>	<b>118</b>
5.1 Preliminaries.....	118
5.1.1 Eigenvalue.....	118
5.1.2 Eigenvector.....	119
5.1.3 Modal matrix.....	119
5.1.4 Eigenvalue Sensitivity.....	120
5.1.5 Participation Matrix.....	121
5.1.6 State-Space Stability.....	121
5.2 Eigenvalue Analysis of AC Microgrid.....	122
5.2.1 Eigenvalue and stability analysis of autonomous mode.....	122
5.2.2 Eigenvalue and stability analysis of grid-tied mode.....	127
5.3 Eigenvalue Analysis of DC Microgrid.....	132
5.4 Lyapunov based Stability Analysis of Reduced Order DC Microgrid.....	135
5.4.1 Asymptotic stability of unforced system.....	135
5.4.2 ISS analysis of nonlinear system.....	138
5.5 Summary.....	139
<b>Chapter 6. Robust Controller Design.....</b>	<b>141</b>
6.1 Preliminaries.....	143
6.1.1 Robustness and Performance.....	143
6.1.2 Linear Quadratic Regulator.....	144
6.1.3 Small Signal Modelling of Interlinking Converter.....	146
6.2 Robust control of Interlinking Converter model.....	148

6.2.1	PID and FOPI Controller.....	148
6.2.2	Loop Shaping Controller Design.....	150
6.3	Simulation Results.....	155
6.3.1	Controller design through PSO and ABC algorithm.....	155
6.3.2	H-infinity loop shaping controller order reduction.....	158
6.3.3	Case Study of different controller responses.....	161
6.4	Eigenvalue Analysis.....	165
6.5	Summary.....	166
<b>Chapter 7.</b>	<b>Conclusion and Future Work.....</b>	<b>169</b>
7.1	Summary and Research Findings and Conclusion.....	169
7.2	Future Work.....	172
<b>References.....</b>		<b>174</b>
<b>Appendix-A</b>	<b>Stability Theorems.....</b>	<b>187</b>
<b>Appendix-B</b>	<b>MATLAB Functions.....</b>	<b>189</b>