

Contents

List of Tables	ix
List of Figures.....	x
1 Introduction	1
1.1 Motivation.....	1
1.2 Problem Statement.....	3
1.3 Hypotheses.....	4
1.4 Objectives	4
1.4.1 General Objective.....	4
1.4.2 Specific Objectives.....	5
1.5 Scope.....	5
1.6 Contributions.....	5
1.7 Publications.....	6
1.8 Thesis Outline	6
2 Literature Review	7
2.1 Introduction.....	7
2.2 Power System Stability	7
2.3 Impact of CIG on Power System Stability.....	8
2.3.1 Reduction of Short Circuit Levels	9
2.3.2 Reduction of System Inertia	9
2.3.3 Dynamic Response of Power Systems	10
2.4 Modeling Approaches for Simulation of Power System Transients.....	12
2.4.1 Electromagnetic Transient Approach.....	13
2.4.2 Phasor Calculus	14
2.5 Modeling of Power System Components	19
2.5.1 Transmission Lines.....	19
2.5.2 Synchronous Generators.....	20
2.5.3 Converter Interfaced Generation Technologies in Power System.....	21
2.6 Modeling of CIG for Power System Stability Studies.....	29
2.6.1 Models Based on a Current Source Representation	31
2.6.2 Models Based on a Voltage Source Representation.....	32
2.6.3 Comparison of CIG Models Used for Stability Studies	35
2.7 Summary and main findings from the literature review	37
3 Methodology.....	39

3.1	Introduction.....	39
3.2	Methodology for the Comparison of QPC and DPC-Based Models	39
3.2.1	Stage 1: Dynamic Modeling.....	40
3.2.2	Stage 2: Frequency Response.....	42
3.2.3	Stage 3: Modal Analysis.....	42
3.2.4	Stage 4: Sensitivity Analysis	43
3.2.5	Stage 5: Validation Through Time Domain Simulation.....	43
3.3	Methodology for Comparisons of CIG Models Based on QPC	43
3.3.1	Stage 1: Dynamic Modeling.....	44
3.3.2	Stage 2: Sensitivity Analysis	45
3.3.3	Stage 3: Comparative analysis.....	46
3.3.4	Stage 4: Validation Through Time Domain Simulation.....	46
4	Comparative Analysis Between DPC- and QPC-Based Models.....	47
4.1	Description of Power System Under Study	47
4.2	Implemented Models and Software Used.....	49
4.3	Results of Comparative Analysis of DPC and QPC-Based Models	49
4.3.1	Frequency Response Analysis.....	49
4.3.2	Modal Analysis.....	50
4.3.3	Sensitivity Analysis	53
4.3.4	Validation Through Time Domain Simulation.....	56
4.4	Summary of Main Findings	62
5	Comparative Analysis of CIG Models Based on QPC.....	63
5.1	Description of Power System Under Study	63
5.2	Implemented Models and Software Used.....	64
5.3	Results of Comparative Analysis of CIG Models Based on QPC	65
5.3.1	Case Study 1: Impacts of PLL and CIG Levels.....	65
5.3.2	Case Study 2: Impacts of SCR Levels.....	66
5.3.3	Case Study 3: Impacts of Inner Control Loops	67
5.4	Summary of Main Findings	69
6	Conclusions	71
6.1	Future Work.....	72
	Bibliography.....	73
	ANNEXES.....	88
	Annex A: Power System Models Used in Chapter 4.....	89
	A.1 CIG-GFL Model	89

A.2 CIG-GFM Model with Virtual Synchronous Generator.....	92
A.3 Synchronous Generator Model	95
A.4 Transmission lines, transformers, and loads.....	99
Annex B: Power System Models Used in Chapter 5.....	101
B.1 CIG-GFL Model Based on DPC.....	101
B.2 CIG-GFL Models Based on QPC	104
B.3 CIG-GFM Model	107
B.4 Parameter of CIG Models	107
Annex C: Acronyms and Abbreviations.....	110
Annex D: Detailed Analyses Related to Chapter 5	111
D.1 Sensitivity Analysis	111
D.1.1 Case Study 1: Impacts PLL and CIG Levels.....	111
D.1.2 Case Study 2: Impacts of SCR Levels.....	114
D.1.3 Case Study 3: Impacts of Current Control Loops.....	117
D.2 Validation Through Dynamic Simulation	122
Annex E: Extended Abstract	129