

# Contents

<b>List of Tables</b>	<b>xiii</b>
<b>List of Figures</b>	<b>xv</b>
<b>1. Introduction</b>	<b>1</b>
1.1. Motivation . . . . .	1
1.2. Hypothesis . . . . .	2
1.3. Objectives . . . . .	2
1.3.1. General Objectives . . . . .	2
1.3.2. Specific Objectives . . . . .	2
1.4. Scope . . . . .	3
<b>2. Theoretical Background</b>	<b>5</b>
2.1. Microgrids . . . . .	5
2.1.1. Definition . . . . .	5
2.2. Inverter Characterization . . . . .	7
2.2.1. Classification of Power Converters in AC Microgrids . . . . .	7
2.2.2. Droop-controlled Inverter Modelling . . . . .	11
2.3. Stability in Microgrids . . . . .	18
2.3.1. Control System Stability . . . . .	19
2.3.2. Power Supply and Balance Stability [19] . . . . .	20

2.4. Small-Signal Stability . . . . .	20
2.4.1. State-Space Representation . . . . .	21
2.4.2. State-Space Linearization . . . . .	21
2.4.3. Small-Signal Analysis . . . . .	22
2.5. Small-Signal Stability in Microgrids . . . . .	26
2.5.1. Small-Signal Impedance . . . . .	26
2.5.2. Small-Signal Stability Criteria . . . . .	26
<b>3. Methodology</b>	<b>29</b>
<b>4. Inverter Models Development</b>	<b>33</b>
4.1. M1: Ideal Source . . . . .	33
4.1.1. Linearization . . . . .	34
4.2. M2: Active Power Droop-Controlled Source . . . . .	35
4.2.1. Linearization . . . . .	36
4.3. M3: Reactive Power Droop-Controlled Source . . . . .	38
4.3.1. Linearization . . . . .	39
4.4. M4: Active and Reactive Power Droop-Controlled Source . . . . .	40
4.4.1. Linearization . . . . .	41
4.5. M5: Active and Reactive Power Droop-Controlled Source Considering LCL Filter	42
4.5.1. Linearization . . . . .	43
4.6. M6: Full Model . . . . .	45
4.6.1. Linearization . . . . .	46
<b>5. Analytical Assessment</b>	<b>49</b>
5.1. M1: Ideal Source . . . . .	49
5.1.1. Small-Signal Impedance Obtainment . . . . .	49
5.1.2. Bode Plot Analytic Characterization . . . . .	50

5.1.3.	Critical Parameters Determination . . . . .	52
5.2.	M2: Active Power Droop-Controlled Source . . . . .	55
5.2.1.	Small-Signal Impedance Obtainment . . . . .	55
5.2.2.	Bode Plot Analytic Characterization . . . . .	56
5.2.3.	Critical Parameters Determination . . . . .	58
5.3.	M3: Reactive Power Droop-Controlled Source . . . . .	64
5.3.1.	Small-Signal Impedance Obtainment . . . . .	64
5.3.2.	Bode Plot Analytic Characterization . . . . .	64
5.3.3.	Critical Parameters Determination . . . . .	66
5.4.	Summary . . . . .	69
<b>6.</b>	<b>Numerical Assessment</b>	<b>71</b>
6.1.	Study Case Definition . . . . .	71
6.2.	Sensitivity Analysis . . . . .	73
6.2.1.	Comparison of Models . . . . .	74
6.2.2.	M6: Full Model Numerical Assessment . . . . .	76
6.3.	Reference Frame Angle Sensitivity . . . . .	98
<b>7.</b>	<b>Conclusions</b>	<b>101</b>
7.1.	Future Work . . . . .	102
<b>8.</b>	<b>Bibliography</b>	<b>103</b>
<b>A.</b>	<b>Numerical Assessment</b>	<b>107</b>
A.1.	M1: Ideal Source . . . . .	107
A.2.	M2: Active Power Droop-Controlled Source . . . . .	112
A.3.	M3: Reactive Power Droop-Controlled Source . . . . .	117
A.4.	M4: Active and Reactive Power Droop Controlled Source . . . . .	122

## A.5. M5: Active and Reactive Power Droop Controlled Source Considering LCL Filter 127