

Table of Content

List of Abbreviations	xiii
List of Symbols	xv
1 Introduction	1
1.1 Research motivation	1
1.2 Problem statement	2
1.3 Hypotheses	5
1.4 Objectives	6
1.4.1 General objective	6
1.4.2 Specific objectives	6
1.5 Contributions	7
1.6 Thesis structure	9
2 Literature review	10
2.1 Introduction	10
2.2 Microgrids framework	10
2.3 Control of <i>ac</i> MGs	15
2.3.1 Primary control level in <i>ac</i> MGs	15
2.3.2 Secondary control level in <i>ac</i> MGs	16
2.3.3 Tertiary control level in <i>ac</i> MGs	17
2.4 Control of <i>dc</i> MGs	18
2.4.1 Primary control level in <i>dc</i> MGs	18
2.4.2 Secondary control level in <i>dc</i> MGs	19
2.5 Control of hybrid <i>ac/dc</i> microgrids	20
2.6 Distributed model predictive control for microgrids	21
2.7 Distributed secondary control for microgrids in the literature	23
2.7.1 Distributed economic dispatch for <i>ac</i> microgrids	23
2.7.2 Distributed economic dispatch for <i>dc</i> microgrids	25

2.7.3	Distributed economic dispatch for hybrid <i>ac/dc</i> microgrids	26
2.8	Imbalance sharing in <i>ac</i> microgrids	27
2.9	Discussion	29
3	The proposed DMPC scheme for frequency regulation and active power dispatch in <i>ac</i> microgrids	31
3.1	Introduction	31
3.2	Centralised economic dispatch	32
3.3	Proposed DMPC scheme	33
3.4	Dynamic models used for the design of the DMPC strategy	35
3.4.1	Communication network model	35
3.4.2	Dynamic models	37
3.4.3	Discrete time models	38
3.5	Formulation of the distributed model predictive control	38
3.5.1	Cost function	39
3.5.2	Predictive models and constraints	39
3.5.3	Formulation of the quadratic programming	40
3.6	Experimental results	42
3.6.1	Experimental MG configuration	42
3.6.2	Design parameters and test scenarios used to evaluate the DMPC	45
3.6.3	<i>Scenario I</i> (base case) - Load changes	46
3.6.4	<i>Scenario II</i> - Communication delay	48
3.6.5	<i>Scenario III</i> - Communication link failure	49
3.6.6	<i>Scenario IV</i> - Plug-and-play	50
3.7	Discussion	51
4	The proposed DMPC scheme for frequency and voltage regulation within bands and the economic dispatch of active and reactive power for hybrid <i>ac/dc</i> microgrids	53
4.1	Introduction	53
4.2	The active power economic dispatch problem	54
4.3	The reactive power economic dispatch problem	55
4.4	Communication structure	55
4.5	Proposed DMPC scheme for interlinking converters (ILCs)	56
4.5.1	Dynamic models used for the design of the controller for interlinking converters	58
4.6	Formulation of the DMPC for ILCs	58
4.6.1	Cost function	58
4.6.2	Prediction models and constraints	59

4.7	Proposed DMPC scheme for <i>dc</i> Generators	61
4.7.1	Dynamic models used for the design of the controller for <i>dc</i> generators	62
4.8	Formulation of the DMPC for <i>dc</i> generators	63
4.8.1	Cost function	63
4.8.2	Predictive models and constraints	64
4.9	Proposed DMPC scheme for <i>ac</i> Generators	65
4.9.1	Dynamic models used for the design of the controller for <i>ac</i> generators	67
4.10	Formulation of the DMPC for <i>ac</i> generators	68
4.10.1	Cost function	68
4.10.2	Predictive models and constraints	69
4.11	Simulation results	72
4.11.1	Design parameters and test scenarios used to evaluate the DMPC for H-MGs	74
4.11.2	<i>Scenario I</i> (base case) - Load changes	76
4.11.3	<i>Scenario II</i> - Combined communication link failures and Plug-and-Play	78
4.11.4	<i>Scenario III</i> - Comparison against a DAPI-based strategy without economic dispatch for H-MGs	80
4.12	Discussion	82
5	The Proposed DMPC scheme for phase imbalance sharing and frequency and voltage regulation within bands in <i>ac</i> microgrids	84
5.1	Introduction	84
5.2	Proposed DMPC scheme	85
5.3	Dynamic models used for the design of the DMPC strategy	87
5.3.1	Droop control	87
5.3.2	Phase angle model	88
5.3.3	Power transfer models	88
5.3.4	Phase voltage unbalance rate index	89
5.4	Distributed MPC formulation for imbalance sharing	89
5.4.1	Cost function	89
5.4.2	Predictive models and constraints	91
5.5	Microgrid setup and simulation results	95
5.5.1	<i>Scenario I</i> (base case) - Unbalanced load changes	98
5.5.2	<i>Scenario II</i> - Communication delays	103
5.5.3	<i>Scenario III</i> - Combined communication link failures and plug-and-Play	104
5.6	Hardware in the loop validation	107
5.7	Scalability and comparison with a DAPI-based controller	111
5.7.1	Scalability	112

5.7.2	Comparison with a distributed consensus-based controller for imbalance sharing	115
5.8	Discussion	118
6	Conclusions and final remarks	119
6.1	Future work	121
6.2	Publications	122
6.2.1	Journal papers	122
6.2.2	Conference papers	122
	BIBLIOGRAPHY	123
	Annexes	138
A	Extended abstract	138
B	Design of a reduced order nonlinear observer to estimate the voltage after a coupling inductance	140
C	Derivation of predictive linear models used as equality constraints in <i>ac</i> DGs	143
C.1	Continuous time model for equality constraints	143
C.2	Model discretisation	145
C.2.1	Droop equations	145
C.2.2	Phase angle equation	146
C.2.3	Power transfer equations	147
C.3	Prediction model for equality constraints	149
D	Derivation of predictive linear models used as inequality constraints in <i>ac</i> DGs	151
D.1	PVUR inequality	151
D.2	Apparent power rating	156
E	Derivation of predictive linear models used as equality constraints in <i>dc</i> DGs	158
E.1	Continuous time model for equality constraints	158
E.1.1	Droop equation	158
E.1.2	Power transfer equation	159
E.2	Prediction model for equality constraints	160
F	Experimental microgrid setup	161