

Contenido

1	Introduction	1
1.1	Motivation.....	1
1.2	Hypothesis.....	1
1.3	Research Objectives.....	2
1.3.1	Specific objectives.....	2
1.4	Scope.....	3
1.5	Contributions.....	3
1.6	Structure of the document.....	4
2	State of art	5
2.1	Distributed energy resource	5
2.2	Battery energy storage Systems	7
2.2.1	Battery energy storage system.....	8
2.2.2	BESS properties	13
2.3	Microgrids.....	22
2.3.2	Control structure for MG.....	25
2.3.3	Connected and islanded MG	29
2.3.4	Demand response in MG	31
2.3.5	Multi-microgrid.....	32
2.4	Microgrid management.....	33
2.4.1	Uncertainty and robust strategies	36
2.5	MG services and market opportunities	39
2.5.1	Energy arbitrage	41
2.5.2	Demand side management	42
2.5.3	Emission reduction.....	46

2.5.4	Spinning reserve	46
2.5.5	Peak shifting.....	50
2.5.6	Reliability.....	51
2.5.7	Load leveling.....	51
2.5.8	Loss reduction	52
2.5.9	Investment deferral.....	53
2.5.10	Black start.....	54
2.6	Discussion	58
3	Robust EMS formulation	59
3.1	General UC model	59
3.1.1	General equations:.....	59
3.1.2	General Constraints:.....	61
3.2	Connected mode.....	63
3.2.1	Connected mode Constraints:.....	63
3.3	Islanded mode	63
3.3.1	Islanded mode constraints:	64
3.4	BESS Model.....	65
3.4.1	Cyclical aging.....	65
3.4.2	Calendar aging.....	67
3.4.3	Peukert's law	67
3.4.4	Capacity fading	68
3.4.5	Self-discharge.....	69
3.4.6	Charge and discharge limitations	69
3.5	Services	71
3.5.1	Energy arbitrage	71

3.5.2	Demand response	72
3.5.3	Emission reductions	72
3.5.4	Spinning reserve.....	73
3.5.5	Peak shaving.....	73
3.5.6	Reliability.....	74
3.5.7	Capacity bidding	76
4	Case study	78
4.1	Case study: Huatacondo village.....	78
4.1.1	Microgrid topology	79
4.1.2	Load profile.....	79
4.1.3	Renewable resources	80
4.1.4	Unit parameters	81
4.1.5	Available services	81
4.1.6	Scenarios	82
4.1.7	Scenario 1: Isolated MG without BESS cycling	82
4.1.8	Scenario 2: Isolated MG without Peukert's Law	84
4.1.9	Scenario 3: Isolated MG.....	85
4.1.10	Scenario 4: Isolated MG & 10% DR	87
4.1.11	Scenario 5: Isolated MG & 20% DR	89
4.1.12	Scenario 6: Isolated MG & 30% DR	91
4.1.13	Result analysis – Huatacondo.....	94
4.2	Case study: CIGRE MG in Ontario	96
4.2.1	Microgrid topology	96
4.2.2	Load Profile.....	97
4.2.3	Renewable Resources.....	98

4.2.4	Unit parameters	98
4.2.5	Available services	100
4.2.6	Scenarios	101
4.2.7	Scenario 7: Connected MG, LA BESS	102
4.2.8	Scenario 8: Connected MG, Na BESS	103
4.2.9	Scenario 9: Connected MG, emission reduction & arbitrage.....	105
4.2.10	Scenario 10: Connected MG, emission reduction, arbitrage & no calendar life	
	106	
4.2.11	Scenario 11: Connected MG, emission reduction, arbitrage & spinning reserve	
	108	
4.2.12	Scenario 12: Connected MG, emission reduction, arbitrage, spinning reserve & demand response.....	110
4.2.13	Result analysis – Ontario.....	114
4.3	Case study: Santa Rita Jail	116
4.3.1	Microgrid topology	116
4.3.2	Load profile	117
4.3.3	Renewable resources	118
4.3.4	Unit parameters	119
4.3.5	Available services	120
4.3.6	Scenarios	122
4.3.7	Scenario 13: connected MG.....	123
4.3.8	Scenario 14: Connected MG, emission reduction & arbitrage.....	125
4.3.9	Scenario 15: Connected MG, emission reduction, arbitrage & peak shaving...	127
4.3.10	Scenario 16: Connected MG, emission reduction, arbitrage, peak shaving & capacity bidding (May).....	128

4.3.11	Scenario 17: Connected MG, emission reduction, arbitrage, peak shaving & capacity bidding (June).....	133
4.3.12	Scenario 18: Connected MG, emission reduction, arbitrage, peak shaving & capacity bidding (July)	137
4.3.13	Scenario 19: Connected MG, emission reduction, arbitrage, peak shaving & islanding reliability	139
4.3.14	Result analysis – Santa Rita Jail	144
5	Conclusions and Future Work.....	146
5.1	Future Work	147
6	Bibliography.....	148
7	Annexes.....	159
7.1	Annex I: Carbon emission displacement calculation.....	159
7.2	Annex II: Investment deferral value	164
7.3	Annex III: Investment deferral calculation model	165
7.4	Annex IV: Black start capability requirements and MG	166
7.5	Annex V: Requirements for a black start unit in the world	168