

# Content

<b>Introduction</b>	<b>1</b>
<b>Research problem, hypothesis and objectives</b>	<b>3</b>
<b>1 Literature review</b>	<b>5</b>
1.1 Working principle and types of lithium-ion batteries . . . . .	5
1.2 Battery thermal management system . . . . .	7
1.2.1 ANSYS Fluent . . . . .	8
1.3 Battery modeling . . . . .	8
1.3.1 3D-CFD model . . . . .	8
1.3.2 Thermal lumped model . . . . .	9
1.3.3 Heat transfer . . . . .	9
1.3.4 Heat generation . . . . .	10
1.3.5 NTGK model . . . . .	11
1.4 Thermal runaway . . . . .	11
1.5 Electrochemical impedance spectroscopy (EIS) . . . . .	14
1.5.1 Equivalent circuit models . . . . .	15
1.6 State estimation . . . . .	16
1.6.1 Bayesian estimation . . . . .	17
1.6.2 Particle filter . . . . .	18
1.6.3 Artificial evolution of parameters . . . . .	18
<b>2 Methodology</b>	<b>20</b>
2.1 Methodology for thermal modeling of a single cell . . . . .	20
2.1.1 Experimental set-up . . . . .	21
2.1.2 Heat generation estimation . . . . .	23
2.1.3 Heat capacity and internal thermal resistance . . . . .	26
2.1.4 Physical properties and solving . . . . .	27
2.1.5 Battery meshing . . . . .	30
2.2 Methodology for thermal modeling of a battery pack with air cooling . . . . .	31
2.2.1 Materials and equipment for battery pack thermal behavior test . . . . .	34
2.2.2 Temperature profile of experiments . . . . .	34
2.2.3 Numerical modeling of air flow using CFD . . . . .	34
2.3 Methodology for temperature estimation based on particle filter . . . . .	38
2.3.1 Thermal model for a single battery string . . . . .	38
2.3.2 Fractal time model as process equation . . . . .	39

2.3.3	Experiments . . . . .	40
2.3.4	Implementation of particle filter . . . . .	40
2.4	Methodology for thermal runaway modeling and stability study . . . . .	43
2.4.1	Thermal abuse modeling . . . . .	43
2.4.2	Non-dimensional analysis on of LIB thermal stability . . . . .	44
<b>3</b>	<b>Results and discussion</b>	<b>46</b>
3.1	Results of thermal modeling of a single cell . . . . .	46
3.1.1	Heat generation rate . . . . .	46
3.1.2	Heat transfer coefficient . . . . .	47
3.1.3	Temperature performance comparison . . . . .	48
3.1.4	Voltage . . . . .	51
3.2	Results of thermal modeling of a battery pack . . . . .	53
3.2.1	Results for discharging under natural convection . . . . .	53
3.2.2	Cooling-down by forced convection . . . . .	58
3.3	Results of temperature estimation of the battery module using particle filter	60
3.3.1	Particle filter applied during the discharging process . . . . .	60
3.3.2	Particle filter applied at cooling-down . . . . .	62
3.4	Results of thermal stability study of a lithium-ion battery . . . . .	69
3.4.1	Characterization of thermal runaway of a single cell by thermal abuse model . . . . .	69
3.4.2	Qualitative stability analysis . . . . .	70
	<b>Conclusions</b>	<b>73</b>
	<b>Glossary</b>	<b>75</b>
	<b>Bibliography</b>	<b>76</b>
	<b>Annexed: Implemented codes</b>	<b>85</b>