

**DEVELOPMENT OF SOLAR STRUCTURAL
SUPERCAPACITOR SYSTEM FOR ELECTRIC
VEHICLE**

BY

KYAW MYO AUNG

**A thesis submitted in fulfillment of the requirement for the
degree of Doctor of Philosophy (Engineering)**

**Kulliyyah of Engineering
International Islamic University Malaysia**

JULY 2022

ABSTRACT

The limitations of the electric vehicles are weight, size, limited range, charging time and high price tag. Thus, the development of a renewable energy-boosting system for EVs is significant. This research proposes the development of the automotive body panels which are capable to generate electrical energy from solar energy and store the energy not only as structural capacitor but also as solar panel. A solar supercapacitor prototype is developed by utilizing Carbon Fiber Reinforced Polymer (CFRP), nano Zinc Oxide (ZnO) and Copper Oxide (CuO) fillers as the positive and negative electrodes and a dielectric layer sandwiched between the electrodes. SSC samples are prepared using the solution casting method and characterization is conducted using SEM, XRD and UV-Vis methods in the laboratory. Different weight percentage compositions of nano CuO/ZnO filled epoxy reinforced Carbon Fiber and different combinations of separators are investigated experimentally for optimal efficiency. Samples with higher nanoparticle composition can boost both the energy generation and storage performance. Simulation study is conducted on solar supercapacitor concept which is hybrid energy storage system, modelled as the supplementary renewable energy source of electric vehicle. Experiment data from the laboratory scale organic solar supercapacitor using CuO/ZnO doped polymer and carbon fiber are considered as input reference data to design solar supercapacitor HESS in Simulink to generate electricity from solar energy and provide storage. A summary and comparison of the previous and on-going solar supercapacitor researches are discussed and essential experiment data are utilized for simulation of solar supercapacitor in Simulink & ANFIS for validation. Performance of the PI controllers and Fuzzy Logic controllers has been investigated to compare the output of the converters. Sensors and logic system has been proposed to make SSC system IoT based. The proposed hybrid energy storage system meets the power and energy requirements of the EV accessories load and provides accurate power distribution between multiple storage systems. With optimal experiment procedures and better nanoparticles synthesis, solar supercapacitor can have solar energy conversion efficiency about 19-22%, power generation of 2800W/day, power density 33 kW/kg, energy density 130 Wh/kg and capacitance $11.17 \mu\text{F}/\text{cm}^2$ at the temperature range of 25 to 30°C and solar irradiance (I_{solar}) 1000 W/m^2 . However, the performance of solar supercapacitor system heavily depends upon the development of supervisory control logic and power efficiency of converters. Moreover, the efficiency and effectiveness of the SSC system is mainly dependent on the irradiance of the sun.

ملخص البحث

تتجلى حدود المركبات الكهربائية في الوزن والحجم والمحدود ومدة الشحن بالإضافة إلى غلاء السعر، وعليه، فإن تطوير نظام تعزيز الطاقة المتجددة للمركبات الكهربائية أمر مهم. يقترح هذا البحث تطوير ألواح جسم السيارة القادرة على توليد الطاقة الكهربائية من الطاقة الشمسية وليس تخزين الطاقة كمكثف هيكلي فحسب، بل كلوحة شمسية أيضاً. تم تطوير نموذج أولي للمكثف الفائق للطاقة الشمسية من خلال استخدام البوليمر المقوى بألياف الكربون (CFRP)، وحشوات أكسيد الزنك النانوي (ZnO) وأكسيد النحاس (CuO) كأقطاب موجبة وسالبة وطبقة عازلة محصورة بين الأقطاب الكهربائية. يتم تحضير عينات SSC باستخدام طريقة الصب بالمحلول كما يتم إجراء التوصيف باستخدام نهج SEM و XRD و UV-Vis في المختبر. يمكن للعينات ذات التركيب العالي للجسيمات النانوية أن تعزز أداء توليد الطاقة وتخزينها. تم إجراء دراسة المحاكاة على مفهوم المكثف الشمسي الفائق وهو نظام تخزين الطاقة الهجين، على غرار مصدر الطاقة المتجددة التكميلي للمركبات الكهربائية. تعتبر بيانات التجربة من المكثف الشمسي العضوي على نطاق المختبر باستخدام البوليمر المخدر CuO / ZnO وألياف الكربون بيانات مرجعية للإدخال لتصميم المكثف الشمسي الفائق HESS في Simulink لتوليد الكهرباء من الطاقة الشمسية وتوفير التخزين. تمت مناقشة ملخصات ومقارنات الدراسات السابقة والحالية المتعلقة بالمكثفات الشمسية الفائقة. وفي نفس الوقت تم استخدام بيانات التجربة الأساسية لمحاكاة المكثفات الشمسية الفائقة في Simulink و ANFIS للتحقق من صحتها. تم فحص أداء وحدات التحكم PI ووحدات التحكم Fuzzy Logic لمقارنة مخرجات المحولات. تم اقتراح أجهزة الاستشعار ونظام المنطق لجعل نظام SSC قائماً على إنترنت الأشياء. تتوفر في نظام تخزين الطاقة الهجين المقترح متطلبات الطاقة لحمل ملحقات المركبات الكهربائية ويوفر التوزيع الكافي والدقيق للطاقة بين أنظمة التخزين المتعددة. من خلال إجراءات التجربة العالية وتوليف الجسيمات النانوية الأفضل يمكن أن يكون للمكثف الفائق للطاقة الشمسية كفاءة تحويل للطاقة الشمسية تبلغ حوالي 19-22٪، وتوليد طاقة 2800 واط / يوم (W/day)، وكثافة طاقة 33 كيلو وات / كجم، وكثافة طاقة 130 واط / كجم، وسعة 11.17 / μF سم 2 عند نطاق درجة الحرارة من 25 إلى 30 والإشعاع الشمسي $1000 \text{ W} / \text{m}^2$ (I_{Solar}) ومع ذلك، فإن أداء نظام الطاقة الشمسية الفائقة يعتمد بشكل كبير على تطوير منطق التحكم الإشرافي وكفاءة الطاقة للمحولات. يضاف إلى ذلك، فإن كفاءة وفعالية نظام SSC تعتمد بشكل أساسي على إشعاع الشمس.

APPROVAL PAGE

The thesis of Kyaw Myo Aung has been approved by the following:

Md. Ataur Rahman
Supervisor

Hannan Moktar
Co-Supervisor

Muhammad Saifuddin Rehan
Co-Supervisor

Muhammad Mahbubur Rashid
Co-Supervisor

Siti Fauziah Bt Toha
Internal Examiner

Rizalman Mamat
External Examiner

Akram Zeki Khedher
Chairman

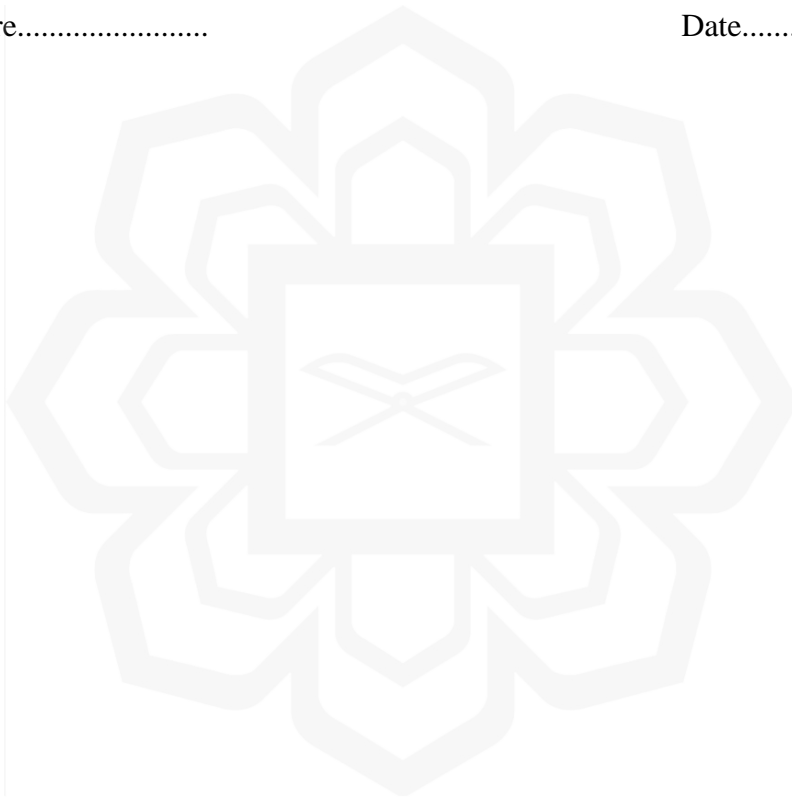
DECLARATION

I hereby declare that this thesis is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

Kyaw Myo Aung

Signature.....

Date.....



INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**DEVELOPMENT OF SOLAR STRUCTURAL
SUPERCAPACITOR SYSTEM FOR ELECTRIC VEHICLE**

I declare that the copyright holder of this thesis is jointly owned by the student and IIUM.

Copyright © 2022 Kyaw Myo Aung and International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.
3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Kyaw Myo Aung

.....

Signature

.....

Date

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**DEVELOPMENT OF SOLAR STRUCTURAL
SUPERCAPACITOR SYSTEM FOR ELECTRIC VEHICLE**

I declare that the copyright holder of this thesis is International Islamic University Malaysia.

Copyright © 2022 International Islamic University Malaysia. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.
3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Kyaw Myo Aung

.....

Signature

.....

Date

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

**DECLARATION OF COPYRIGHT AND AFFIRMATION OF
FAIR USE OF UNPUBLISHED RESEARCH**

**DEVELOPMENT OF SOLAR STRUCTURAL
SUPERCAPACITOR SYSTEM FOR ELECTRIC VEHICLE**

I declare that the copyright holder of this thesis is Kyaw Myo Aung.

Copyright © 2022 Kyaw Myo Aung. All rights reserved.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may only be used by others in their writing with due acknowledgement.
2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purpose.
3. The IIUM library will have the right to make, store in a retrieval system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by Kyaw Myo Aung

.....

Signature

.....

Date

ACKNOWLEDGEMENTS

Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my beloved wife, who supported me and believe in my ability to accomplish this goal: thank you for your support and patience. I wish to express my appreciation and thanks to those who provided their time, effort and support for this project.

Most importantly, special thanks to my beloved Supervisor, Professor Md Ataur Rahman for his continuous support, encouragement and leadership for the past 7 years during my MSc and PhD program and for that, I will be forever grateful.



TABLE OF CONTENTS

Abstract	ii
Abstract in Arabic	iii
Approval Page.....	iv
Declaration	v
Copyright Page.....	vi
Acknowledgements	ix
List of Tables	xiii
List of Figures	xiv
List of Abbreviations	xx
List of Symbols	xxii
CHAPTER ONE: INTRODUCTION	1
1.1 Introduction.....	1
1.2 Problem Statement.....	2
1.3 Research Philosophy.....	3
1.4 Research Scope	3
1.5 Research Objectives.....	4
1.6 Contribution of This Study	4
1.7 Thesis Organization.....	5
1.8 Research Methodology	5
CHAPTER TWO: LITERATURE REVIEW	8
2.1 Introduction.....	8
2.2 Electric Vehicles	8
2.3 Supercapacitor	13
2.4 Electrode Materials for Supercapacitor	16
2.4.1 Carbon	16
2.4.2 Conducting Polymer.....	17
2.4.3 Metal Oxides	18
2.4.4 CuO/ZnO.....	19
2.5 Synthesis of Electrodes Materials.....	22
2.6 Body of EV as Structural Capacitor	28
2.7 Solar Cells.....	33
2.8 Power Consumption of EV	37
2.9 Hybrid Energy Storage System	40
2.10 Internet of Things	43
2.11 Chapter Summary	44
CHAPTER THREE: RESEARCH METHODOLOGY	45
3.1 Introduction.....	45
3.2 Experiment Procedures	47
3.2.1 Epoxy Resin.....	48
3.2.2 Nano CuO/ZnO	49
3.2.3 Separator Materials.....	50
3.2.4 Carbon Fiber	50

3.3	Characterization and Modelling of SSC	51
3.3.1	Synthesis of SSC	52
3.3.2	Characterization of Nanocomposite	55
3.3.3	Modelling of Organic SSC	61
3.4	Modelling of Electrical Components for SSC	64
3.4.1	Modelling of Battery	65
3.4.2	Modelling of Supercapacitor	70
3.4.3	Modelling of SSC System	73
3.5	Power Management System for SSC.....	78
3.5.1	PI Controller (One-Directional Converter)	78
3.5.2	PI & Fuzzy Controllers (Bi-directional).....	87
3.6	Performance Investigation of Organic SSC.....	106
3.6.1	I-V Characteristic of OSSC	106
3.7	IoT based Protection System for SSC	108
3.8	Data Validation by SIMULINK/ANFIS.....	114
3.9	Chapter Summary	120
CHAPTER FOUR: CONTROLLER IDENTIFICATION.....		121
4.1	Introduction.....	121
4.2	One-directional DC-DC Converter.....	121
4.3	PI Bi-directional Converters	125
4.3.1	Constant Irradiance & Constant Load.....	126
4.4	Fuzzy Logic Bi-directional Converter	130
4.5	Chapter Summary	132
CHAPTER FIVE: RESULTS & DISCUSSIONS.....		133
5.1	Introduction.....	133
5.2	Experimental Results	133
5.2.1	Characterization Result of ZnO/ER.....	133
5.2.2	Performance Investigation of SSC	143
5.3	Simulation Result	152
5.3.1	Response of SSC Protection System	155
5.3.2	SIMULINK Result	157
5.3.3	ANFIS Result	160
5.3.4	Data Validation.....	161
5.4	Chapter Summary	164
CHAPTER SIX: CONCLUSION.....		166
REFERENCES.....		167
APPENDIX I: CHARACTERIZATION PRINCIPLES.....		177
APPENDIX II: MATLAB CODES FOR MPPT & P&O.....		180

LIST OF TABLES

Table 2.1	Comparison of Types of EV in Terms of Commercialization	13
Table 2.2	Basic Properties of CuO	20
Table 2.3	Basic Properties of ZnO	21
Table 2.4	Electrical Properties of Structural Dielectric Capacitors	25
Table 2.5	Dielectric Properties of Epoxy-based Nanoparticles	26
Table 2.6	Comparison between Different Nanoparticle Synthesis Processes	27
Table 2.7	Performance of The Specimen as Vehicle Roof Panel	32
Table 2.8	Summarized Advantages and Limitations of Supercapacitor	33
Table 2.9	Performance of The Specimen as Vehicle Roof Panel	34
Table 2.10	Comparison of performance for different PEC	35
Table 2.11	Energy consumption of various auxiliary systems	39
Table 2.12	Comparison of Linear and Nonlinear Current Controller	41
Table 3.1	Properties of CuO	50
Table 3.2	Composition of Total Solution of ZnO/ER mixture	53
Table 3.3	Blended mixture of ZnO/ER with deionized water	53
Table 3.4	Summary of Characterization Methods	55
Table 3.5	Specification of SEM Machine	57
Table 3.6	Specification of XRD Machine	60
Table 3.7	Specification of UV-Vis Spectrophotometer Machine	61
Table 3.8	List of Composition of Mixture for N-type and P-type semiconductor	63
Table 3.9	Experiment Parameters of Supercapacitor	73
Table 3.10	Gains for Different Controller Types	79
Table 3.11	Parameters of Battery PMS	83

Table 3.12	Parameters of SC PMS	84
Table 3.13	Parameters of Solar PMS	86
Table 3.14	Parameters of Bi-directional Controllers	88
Table 3.15	Fuzzy Rules for Battery	93
Table 3.16	Fuzzy Rules for Supercapacitor	96
Table 3.17	Parameters of Solar PMS	99
Table 3.18	Parameters of Battery Bi-directional Converter System	100
Table 3.19	Parameters of SC Bi-directional Converter	101
Table 3.20	Solar Power Simulation Results from Simulink	118
Table 5.1	Parameters of SSC Samples	143
Table 5.2	Capacitance Comparison of Dielectric & EDLC Samples	144
Table 5.3	Overall Performance of different samples	151
Table 5.4	Comparison of Experiment Data & Simulation Data (Solar Power)	161

LIST OF FIGURES

Figure 1.1	Research Methodology Flowcharts	7
Figure 2.1	Drivetrains of Main EVs	10
Figure 2.2	CPV Technology Design for SEVs	11
Figure 2.3	Drivetrain of SEV	11
Figure 2.4	Charge Profile of Supercapacitor	14
Figure 2.5	Discharge Profile of Supercapacitor	15
Figure 2.6	Stress-Strain Behaviour of Polymer	18
Figure 2.7	Mechanical Properties of CuO with ER filler	22
Figure 2.8	Basic Structure of a Dielectric capacitor	23
Figure 2.9	Current Collector Configurations of Dielectric Capacitors	24
Figure 2.10	Sol-Gel Process	28
Figure 2.11	Design of Vehicle Panel Type Battery, CuO with ER Filler	29
Figure 2.12	Thermal conductivity of CuO with ER Filler	31
Figure 2.13	Basic Organic Solar Cell Layers	35
Figure 2.14	Distribution the Total Specific Energy Consumption of Tesla Roadster Vs Car Speed	38
Figure 2.15	Architecture of Rule-Based Control Algorithm System	42
Figure 2.16	Internet of Things	43
Figure 3.1	Working Principle of Solar Supercapacitor Body Panel	46
Figure 3.2	Prototype of CuO/ZnO ER Body Panel	46
Figure 3.3	ZnO Powder	49
Figure 3.4	CuO Powder	49
Figure 3.5	High Quality Grade A Carbon Fiber Fabric 240gsm	51
Figure 3.6	Flowchart for Synthesis of ZnO/ER Nano-composite by SCM	54

Figure 3.7	Scanning Electron Microscope (SEM) JSM-IT100	56
Figure 3.8	Fourier Transform Infrared (FTIR) Spectrometer	58
Figure 3.9	X-Ray Diffraction Machine	59
Figure 3.10	Ultraviolet–Visible Spectrophotometer	60
Figure 3.11	Architecture of Organic SSC	62
Figure 3.12	SSC Sample	63
Figure 3.13	Solar Supercapacitor Basic Simulink System	65
Figure 3.14	Equivalent Circuit of Battery	66
Figure 3.15	Typical Discharge Characteristics of Battery in Simulink	67
Figure 3.16	Charge Characteristic of Lead-Acid & Li-Ion Battery in Simulink	67
Figure 3.17	Parameters & Discharge Properties of Battery Block in Simulink	69
Figure 3.18	Discharge Profile of Battery Model in Simulink	70
Figure 3.19	Equivalent circuit of Supercapacitor	71
Figure 3.20	Parameters of Supercapacitor in Simulink	72
Figure 3.21	Equivalent Electrical Circuit of Solar Module	74
Figure 3.22	Parameters of SSC in SIMULINK for Controller Selection	76
Figure 3.23	Parameters of SSC in SIMULINK from Experiments	77
Figure 3.24	Signal Builder for Irradiance & Temperature Input in Simulink	77
Figure 3.25	One-directional PI PMS in Simulink	81
Figure 3.26	One-directional PMS for Battery	82
Figure 3.27	One-directional PI PMS for Supercapacitor	84
Figure 3.28	One-directional PMS for Solar	85
Figure 3.29	Solver Setting in Simulink	86
Figure 3.30	Bi-directional PI SSC System in Simulink	87

Figure 3.31	Control System with PI Controllers for Battery and Supercapacitor in Simulink	88
Figure 3.32	Block diagram of Fuzzy Logic Control System	89
Figure 3.33	Bi-Directional Fuzzy SSC System in Simulink	90
Figure 3.34	Control System with FLC for Battery and Supercapacitor in Simulink	91
Figure 3.35	Fuzzy Inference System (FIS) for Battery	91
Figure 3.36	Membership Functions of Battery FIS	93
Figure 3.37	Rule Viewer of Battery FIS	94
Figure 3.38	Surface Viewer of Battery FIS	94
Figure 3.39	Fuzzy Inference System (FIS) for Battery	95
Figure 3.40	Membership Functions of SC FIS	96
Figure 3.41	Rule Viewer of SC FIS	97
Figure 3.42	Surface Viewer of SC FIS	97
Figure 3.43	MPPT Control System for Solar	98
Figure 3.44	DC-DC Converter System of Solar MPPT (P&O)	99
Figure 3.45	Bidirectional Converter System for Battery (PI & Fuzzy).	100
Figure 3.46	Bidirectional Converter System for SC	101
Figure 3.47	Equivalent Circuit of Buck Mode 1	102
Figure 3.48	Equivalent circuit of Buck mode 2	103
Figure 3.49	Equivalent Circuit of Boost Mode 1	104
Figure 3.50	Equivalent Circuit of Boost Mode 2	105
Figure 3.51	Systems of EV Supported by SSC	107
Figure 3.52	Experimental Setup of Organic Solar Cell	108
Figure 3.53	Flowchart of IoT System	108
Figure 3.54	Parameters for Solar Sensor	109
Figure 3.55	Parameters for Supercapacitor Sensor	109

Figure 3.56	Parameters for Battery Sensor	110
Figure 3.57	Parameters for Load Sensor	110
Figure 3.58	MPPT (P&O) Signal System for Solar	110
Figure 3.59	PMS of Battery and Supercapacitor Signal	111
Figure 3.60	System to Display Renewable Power of SSC	111
Figure 3.61	Working Principle of SSC Protection & Backup System	112
Figure 3.62	Logic Controller for Charging the Battery while Parking	113
Figure 3.63	Logic Controller for Backup-Charging from Main Battery to Auxiliary Battery	114
Figure 3.64	Architecture of ANFIS system	115
Figure 3.65	Simulink Power Measurement for Load, Battery, SC & Solar	117
Figure 3.66	Simulink Variable Input and Variable Load to Test Performance of SSC system	117
Figure 3.67	Plot of Psolar Simulink Data in ANFIS	118
Figure 3.68	ANFIS Network Structure for Psolar	119
Figure 3.69	Simulation of Psolar ANFIS System	119
Figure 4.1	Output Voltage Profile of Battery & SC	122
Figure 4.2	Output Voltage Profile of Battery & SC	123
Figure 4.3	Output Voltage Profile of Solar Panel	124
Figure 4.4	Output Voltage Profile of Solar Panel	125
Figure 4.5	Voltage and Load Profile of EV Accessories	126
Figure 4.6	Voltage and Current Profile of Auxiliary Battery	127
Figure 4.7	Ripple Current Profile of Battery	127
Figure 4.8	Voltage & Current Generated by Solar System	128
Figure 4.9	Voltage and Current Profile of Supercapacitor	129
Figure 4.10	Current Profile of Solar Panel at Different Irradiance Setting	129
Figure 4.11	Voltage & Current Profile of Battery (Fuzzy)	130
Figure 4.12	Zoomed In Voltage & Current Profile of Battery (Fuzzy)	131

Figure 5.1	SEM Images	135
Figure 5.2	Absorbance of Light Energy by ZnO/ER Film	137
Figure 5.3	X-ray Diffraction Patterns of ZnO/ER Films	140
Figure 5.4	Optical Band Gap Energy of ZnO/ER Films	143
Figure 5.5	Discharge Voltage of SSC	146
Figure 5.6	Current Profile of Dielectric SC Samples	147
Figure 5.7	Current Profile of Double-Layer SC Samples	147
Figure 5.8	Voltage Comparison between EDLC and Dielectric SSC	148
Figure 5.9	Stored Energy of SSC Samples (a) Charging (b) Discharging	149
Figure 5.10	Current Density (A/m^2) of EDLC SSC Samples	150
Figure 5.11	Failed Samples	151
Figure 5.12	Loss Estimation of Solar Converter	154
Figure 5.13	Loss Estimation of Battery Converter	155
Figure 5.14	Signal Response of SSC Protection System	156
Figure 5.15	Signal Response of Backup Power Management System from Main Traction Battery	156
Figure 5.16	Voltage, Current and Power Measurement of EV Load	158
Figure 5.17	Voltage, Current and Power Measurement of SSC	158
Figure 5.18	Voltage, Current & Power Measurements of Battery	159
Figure 5.19	Errors between ANFIS Data and Simulink Data for Solar Power	160
Figure 5.20	Solar Power at Different Irradiance Setting by ANFIS	161
Figure 5.21	Efficiency of Converter with Current	162
Figure 5.22	Irradiance Profile of Malaysia from satellite image, 25 th Jan 2021	162
Figure 5.23	Solar Power Profile with Practical Solar Irradiance	163
Figure A.1	Working principle of SEM	177
Figure A.2	Schematic Representation of FTIR Spectroscope	178

Figure A.3	Working Principle of X-Ray Diffraction Machine	178
Figure A.4	Schematic Interaction of Light with Matter	179



LIST OF ABBREVIATIONS

EV	Electric Vehicle
RDM	Regenerative Deceleration Mode
GO	Graphene Oxide
CuO	Copper Oxide
ZnO	Zinc Oxide
CF	Carbon Fiber
Li	Lithium
Rpm	Revolutions per Minute
GHG	Green House Gas
ICE	Internal Combustion Engine
SSC	Solar Supercapacitor
HESS	Hybrid Energy Storage System
PV	Photovoltaic
ER	Epoxy Resin
SCM	Solution Casting Method
SEM	Scanning Electron Microscope
FTIR	Fourier Transform Infrared Spectroscopy
XRD	X-ray Diffraction
DC	Direct Current
PMS	Power Management System
EMS	Energy Management System
IoT	Internet of Things
ANFIS	Adaptive Neuro Fuzzy Inference System
PI	Proportional Integral

PID	Proportional Integral Differential
FLC	Fuzzy Logic Controller
AEV	All Electric Vehicle
BEV	Battery Electric Vehicle
HEV	Hybrid Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
EREV	Extended Range Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
PEM	Polymer Electrolyte Membrane
SEV	Solar Electric Vehicle
CPV	Concentrating Photovoltaic
CNT	Carbon Nanotubes
EDLC	Electrochemical Double Layer Capacitor
ALP	Aluminium Laminated Polypropylene
CC	Constant Current
CV	Constant Voltage
P&O	Perturbation and Observation

LIST OF SYMBOLS

w_{ZnO}	Weight Percentage of Zinc Oxide
w_f	Weight of Filler Material
w_p	Weight of Epoxy Resin
K	Shape Factor
λ	Wavelength of Cu
β	Full Width at Half Maximum
θ	Peak Position
V	Voltage
I	Current
R	Resistance
C	Capacitance
P	Power
FF	Fill Factor
η	Efficiency
V_{oc}	Open-circuit Voltage
K_p	Proportional Gain
K_i	Integral Gain
K_d	Differential Gain
D	Duty Cycle
V_{pv}	Solar Voltage
I_{pv}	Solar Current
P_{solar}	Solar Power

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

The development of commercialized electric vehicles has yet to be accelerated due to the lack of electrification. EV energy deficit could be supported by integrating different renewable energies through the improvements of the storage devices and the cost reduction of power system. Energy independent vehicles are promoting the new technologies which might speed up the trends of EVs introduction. It makes them more scalable as they are less dependent on electric infrastructure. Electric transportations are considered as the green technology for the future to reduce greenhouse gas emission, cost and weight and the use of the renewable energy in the power system. The battery pack is one of the crucial parts of the electric vehicle nowadays. It may become less important if the EV makes energy independent. In some extent, no battery may be required at all if multimode energy harvesting technology, efficient power train and light-weight electric vehicles are introduced. The new multimode renewable energy technologies can be electromagnetic shock absorber generator, radio wave generator, regenerative deceleration mode (RDM) and smart nano-filler epoxy composite body panel. The composite body may serve as structural battery or capacitor and solar energy harvester, which might be 30% energy contributor of EV energy independent. However, the smart body panel is lacking in laboratory-based research. VOLVO, James Dyson Foundation and International Islamic University Malaysia EV/Energy research team have been focusing their research on the development of smart body panel for the EV. Furthermore, harvesting both electrical and solar energies from a single hybrid system is highly desirable and representing a new trend of all-in-one multiple energy harvesting technology (Min et.al, 2012; Lee et.al, 2010).

The energy independent EV is a great transportation technology which enhances the EV's travelling range. EV could be made independent by developing panel type composite body with high conductive metal oxides (Graphene Oxide, Copper Oxide, Zinc Oxide etc.) Nano-micro filler epoxy resin sandwiched by Carbon

Fibre and Lithium thin plate, suspension generator and RDM system. The Nano-micro filler epoxy resin could play a crucial role on the clean energy technology by reducing weight and functioning as a battery or capacitor which can store the energy of RDM system from the deceleration of vehicle's motor speed range, 3000~2500rpm. While, the suspension generator has the potential to generate 250~300W by converting the sprung mass movement. The researchers, Rahman et.al (Rahman et.al, 2015a; Rahman et.al, 2015b), VOLVO (2013) and the James Dyson Foundation have proposed panel type vehicle body for the structural battery or capacitor mentioned above. The panel type battery has multifunctional characteristics, weight saving, energy storing/supplying on demand and protecting vehicle's body from external heat as an insulator. Based on their investigation, it can be summarized that downsizing of battery pack and capacitor replacement can be made by using light and efficient composite body panel.

1.2 PROBLEM STATEMENT

Climate change is regarded as one of the greatest environmental threats facing the world today. EV commercialization has been supported by governments in recent years because it has the potential to reduce the impact of the IC engine vehicle which accounts for almost 90% of the national greenhouse gas (GHG) emissions. Electricity is a potential clean energy substitute for vehicles in the future which can eliminate usage of fuel and GHG emission. One of the biggest setbacks is the lack of fast charging stations for EV. Electric charging stations are still in the development stages. Moreover, EVs are limited by range and speed. Most of the EVs have mileage range about 50 to 100 and low speed. EV's battery has longer charging time. While it only takes a couple of minutes to fill up the fuel tank of IC vehicle, EVs take about 4 to 6 hours to get fully charged. Depending on the type and usage, batteries of all EVs must be replaced every 3 to 10 years. Besides, main traction batteries of EV are overloaded by car accessories, radios, air conditioning and electrical system. These applications drain the battery more quickly and charging takes more time. Batteries of EV are considerably heavy. A battery pack of average EV weighs about 1000 pounds or 450 kg. This heavy weight puts more pressure on batteries and energy drains out faster.