DEVELOPMENT OF SOLAR STRUCTURAL SUPERCAPACITOR SYSTEM FOR ELECTRIC VEHICLE

BY

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

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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 $\mu F/cm^2$ 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 أيضا. 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 ZnO / CuO 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 قائما 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 .$1000\ W / m^2$ (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 SSCتعتمد بشكل أساسي على إشعاع الشمس.

APPROVAL PAGE

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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.

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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.

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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.