ENERGY MANAGEMENT SYSTEM FOR THREE-WHEEL LIGHT ELECTRIC VEHICLE USING MULTI-SOURCES ENERGY MODELS

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DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

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ABSTRACT

Hybrid electric vehicles, plug-in hybrid electric vehicles, battery electric vehicles, fuel-cell vehicles are just a few technologies that are being researched worldwide today. Applying renewable energy such as battery, fuel cell and super-capacitor in the electric vehicle is a smart and ideal solution. However, battery as a single-source in electric vehicle has many disadvantages such as limited travel distance and longer charging time. Besides, battery reduces its electrical characteristics through high current flow, high temperature, self-discharge and low battery capacity level. Fuel cell has low power response during sudden energy demand and requires an expensive infrastructure for refueling. In case of light fuel cell vehicle, small tank is practical for exchange tank. In super-capacitor side, it cannot support enough energy for a single powered electric vehicle purposes, however can be used as secondary power supply. Thus, an intelligent energy management system (EMS) of various sources is necessary to counterbalance the drawback of the sources. To solve the problem, the objective of the research is to develop an intelligent EMS which can conduct multi-sources for three wheel light electric vehicle (LEV). A rule-based control algorithm which contains eight states in EMS is designed to control power switches and to ensure sufficient energy is delivered to the load. The work of this research begins by electrical analysis in PSPICE simulation which focuses in circuit design and testing the state condition. A close loop vehicle system implemented with intelligent EMS is designed in MATLAB/Simulink. The simulation model is simulated with a real three wheel scooter specification which has capacity of 5.4 kW DC machine. To show effectiveness of the developed vehicle system, the performance and efficiency of the vehicle simulation is compared with standard drive cycle such as ECE-47 and ECE-15. To justify the simulation model, a scaled-down lab test bench model is designed using dSPACE DS 1104. The LEV model with 18 W load power is implemented in the developed test bench prototype. As a result, the vehicle system specification for the lab test bench model is reduced accordingly to the ratio of load power. The power specifications of the multi-source models such as 30 W for fuel cell, 3 Ah for rechargeable sealed lead acid battery and 100F for super-capacitors have been used. An EMS hardware is designed to offer a bridge between MATLAB/Simulink and dSPACE DS 1104. In the EMS hardware design, the switching relay is used for selection of the sources and current transducers which are used for measuring load current and battery capacity. All input and output signals from the EMS hardware design are connected to the dSPACE DS 1104 for data presentation in graphical user interface. For the uphill simulation test, using ECE-47 drive cycle, multi-source energy models shows that the power effectiveness is 94.6% where as for the battery, as a single-source, it is 84.9%. The lab test bench model also proved that in extension of 33% of speed ECE-47 drive cycle, the energy efficiency of multi-source LEV is 80.2% which is better performance than that of combustion engine energy efficiency of 29.2%. Therefore, the system equipped with an intelligent control algorithm has promising potential in vehicle energy management applications for the future.

ABSTRAK

Kenderaan elektrik jenis hibrid, hibrid masukan-palam, bateri dan sel fuel adalah sebahagian daripada teknologi yang dikaji di seluruh dunia pada masa kini. Penggunaan tenaga keterbaharuan seperti bateri, sel fuel dan pemuat lampau dalam kenderaan elektrik, adalah satu penyelesaian yang pintar dan unggul. Bateri sebagai satu punca dalam kenderaan elektrik mempunyai banyak kekurangan seperti jarak perjalanan terhad dan masa cas yang panjang. Tambahan pula, bateri akan mengurangkan sifat elektriknya dalam keadaan arus elektrik yang tinggi, suhu yang tinggi, nyahcas-kendiri dan paras kapasiti bateri yang rendah. Sel bahanapi pula mempunyai kuasa tindak balas yang rendah dalam keadaan permintaan tenaga tiba-tiba dan juga memerlukan infrastruktur mahal untuk pengisian semula. Bagi kenderaan sel fuel ringan, tangki yang kecil adalah praktikal untuk tangki pertukaran. Untuk pemuat lampau pula, ia tidak mampu membekalkan tenaga kepada kenderaan elektrik punca satu tetapi mampu digunakan sebagai pembekal kuasa sekunder. Oleh itu, satu sistem pengurusan tenaga (SPT) pintar diperlukan untuk memenuhi masalah kekurangan punca tenaga tersebut. Objektif penyelidikan adalah untuk membangunkan SPT yang boleh diaplikasikan pada kenderaan elektrik ringan (KER) tiga roda pelbagai sumber. Satu algoritma kawalan yang menpunyai lapan keadaan dalam SPT dibangunkan untuk mengawal suis kuasa dan memastikan tenaga yang dibekalkan kepada beban adalah mencukupi. Penyelidikan bermula dengan mengenal pasti litar elektrik melalui simulasi PSPICE. Satu sistem gelung tertutup bersama SPT pintar dibangunkan dalam MATLAB/Simulink. Model simulasi adalah mengikut spefikasi skuter elektrik sebenar dengan kuasa 5.4 kW mesin DC. Untuk menguji kerberkesanan sistem kenderaan tersebut, ianya dibandingkan dengan kitar pandu piawai ECE-47 dan ECE-15. Sebagai pengesahan model simulasi, suatu ujian makmal berskala kecil direka dengan menggunakan dSPACE DS1104. Satu KER prototaip berskala kecil dibangunkan dengan kuasa beban 18 W. Oleh itu, sistem kenderaan juga perlu dikurangkan mengikut nisbah kuasa beban. Spefikasi kuasa bagi sistem pelbagai sumber tersebut adalah 30 W untuk sel bahanpi, 3 Ah bateri cas semula dan 100 F pemuat lampau. Satu litar elektrik SPT direka untuk dijadikan sebagai perantaramuka MATLAB/Simulink dengan dSPACE DS1104. Dalam litar elektrik SPT, terdapat suis geganti untuk memilih kuasa manakala transduser arus untuk mengukur beban arus dan kapasiti bateri. Semua masukan dan keluaran dari litar elektrik SPT disambungkan kepada keluaran dSPACE DS1104 untuk mempersembahkan data dalam antaramuka pengguna grafik. Dalam ujian simulasi mendaki menggunakan kitar pandu ECE-47, model tenaga pelbagai sumber memberi prestasi 94.6% manakala model bateri adalah 84.9%. Model ujian makmal membuktikan bahawa dengan penambahan kelajuan 33% bagi kelajuan ECE-47, kecekapan kuasa bagi KER pelbagai sumber meningkat ke 80.2%, dan memberikan prestasi yang lebih baik dari enjin pembakaran dengan kecekapan 29.2.0%. Justeru, sistem yang dilengkapi dengan algoritma kawalan pintar mempunyai potensi dalam pengurusan tenaga kenderaan pada masa hadapan.

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LIST OF ABBREVIATIONS

ADC	Analog/Digital Converter
AEV	All Electric Vehicle
BC	Battery Capacity
BEV	Battery Electric Vehicle
BLEV	Battery Light Electric Vehicle
CHP	Combined Heat and Power
DOD	Depth of Discharge
DOE	Department of Energy
ECU	Electronic Control Unit
EMS	Energy Management System
EPR	Equivalent Parallel Resistance
ESR	Equivalent Series Resistance
ESS	Energy Storage System
FC	Fuel-cell
FCT	Fully Charged Test
FCV	Fuel-cell Vehicle
GUI	Graphical User Interface
HEV	Hybrid Electric Vehicle
HF	Hybridization Factor
HFCV	Hybrid Fuel Cell Vehicle
ICE	Internal Combustion Engine
IGBT	Insulated Gate Bipolar Transistor
I/O	Input and Output
IPM	Intelligent Power Management
LEV	Light Electric Vehicle
LV	Light Vehicle
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MS-LEV	Multi-Source Light Electric Vehicle
NREL	National Renewable Energy Laboratory
PCT	Partially Charged Test
PD	Power Demand

PEI	Power Electronic Interface
PEMFC	Proton Exchange Membrane Fuel Cell
PHEV	Plug-in Hybrid Electric Vehicle
PO	Pedal Offset
PMS	Power Energy Management
PV	Photovoltaic
PWM	Pulse Width Modulation
RTI	Real-Time Interface
SC	Super-capacitor
SOC	State of Charge
UAV	Unmanned Aerial Vehicle
UC	Ultra-Capacitor
UDDS	Urban Dynamometer Driving Schedule
VSP	Vehicle Simulation Program

LIST OF SYMBOLS

R_1, R_2, R_3	Resistors network circuit
C_1, C_2, C_3	Capacitors network circuit
C_b	Battery capacitance
R_p	Self-discharge resistance
R_{1C}, R_{1D}, C_1	Represent voltage drop during charge and discharge
R_{SC}, R_{SD}	Resistance of the electrolyte and resistance of the battery plates
T	Battery temperature
R	Universal gas constant
F	Faraday’s constant
P_{H_2}	Partial pressures of hydrogen
P_{O_2}	Partial pressures of oxygen
P_{H_2O}	Partial pressures of water
J_a	Actual current density of the cell (A/m^2)
$J_{\max}$	Typical values range of 500-1500 mA/cm^2
N	Number of cells in the stack
L	Voltage Loss
P_{std}	Standard pressure
Q_{SC}	Energy stored in SC
I_L	Light generated current
I_o	Initial current
K	Boltzmann constant
q	Electron charge
$V_{SC,OC}$	Open circuit voltage in SC
d	Distance between plates
ε	Permittivity
q_{SC}	SC charge
C_{SC}	SC capacitance
i_{SC}	Charging current flow

$V_{SC,\max}$	Maximum SC voltage
$V_{SC,\min}$	Minimum SC voltage
R_{SC}	Line resistance
$V_{SC,i}$	Initial SC voltage
$V_{SC,f}$	Final SC voltage
t_{on}	Length of the ON state of the switch
D_C	Duty cycle
i_L	Inductor current
t_{off}	Length of the OFF state of the switch
$MAX_{capacity}$	Maximum battery energy in Ampere hour
AH_{used}	Energy usage in Ampere hour
P_{EM}	Peak power of the electric motor
P_{ICE}	Peak power of the ICE (internal combustion engine)
V_{Batt}	Battery open voltage
R_{int}	Battery internal resistance
t_{S5}	Switching control for battery
V_FC	FC open voltage source
$V\_FC\ act$	FC actual voltage when reach transient time
t_{S3}	Switching control for FC
V_SC	SC open voltage source
Rp	Parallel internal resistance in SC
Rs	Series internal resistance in SC
t_{S1}	Switching control for SC
$V_{S1_{on}}$	SC voltage at start S1 active switching
$V_{S1_{off}}$	SC voltage at final S1 off switching
V_{batt}	Battery constant load voltage
V_0	Battery no load voltage
K	Polarized voltage constant
Q	Battery capacity

N	Numbers of the cell
A_v	Exponential voltage
$\ln$	Natural logarithm
i_{fc}	FC current
E_{fc}	Generated energy of FC
RC	Time-constant formed by resistor and capacitor
E_{SC}	SC consumed energy
V_f	SC final voltage
n_s	Number of capacitors in series
n_p	Number of capacitors in parallel
ESR	Equivalent series resistance
$V_{SC\max}$	SC maximum voltage
I_{dsc}	Constant discharge current
E_{batt}	Energy from Battery
E_{FC}	Energy from FC
E_{SC}	Energy from SC
I_{ref}	Reference current
$Speed_{ref}$	Reference speed of vehicle / Drive cycle reference
$Speed_{act}$	Actual speed of vehicle
k_p, k_i	Proportional and integrator gain
I_a	Armature current
r	Tyre radius
m	Vehicle mass
A	Frontal area
d	Air density
C_d	Drag coefficient
μ_r	Rolling coefficient
g	Gravity acceleration
α	Angle slope

V_{out}	Measured current in output voltage
I_{PN}	Primary nominal rms current
I_P	Primary current, measuring range
$u_1(t)$	Signal from pedal offset through A/D converter
T_1	Timer relay for SC
$u_2(t)$	Signal from current load through A/D converter
T_2	Timer relay for FC
C	Tangent of Current/voltage graph
$i(t)$	Battery current to the load
$DutyCycle_{offset}$	Additional offset value of duty cycle
T_e	Electromechanical torque