

**ENERGY MANAGEMENT SYSTEM FOR
CONTROLLING SERIES HYBRID ELECTRIC
MOTORCYCLE**

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**ENERGY MANAGEMENT SYSTEM FOR
CONTROLLING SERIES HYBRID ELECTRIC
MOTORCYCLE**

by

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TABLE OF CONTENTS

ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iii
LIST OF FIGURES	vi
LIST OF TABLES	xiii
LIST OF ABBREVIATIONS	xiv
LIST OF SYMBOLS AND ANNOTATIONS	xv
ABSTRAK	xx
ABSTRACT	xxii
CHAPTER 1 Introduction	1
1.1 Research Background	1
1.2 Problems Statement	3
1.3 Objectives	4
1.4 Research Approach	5
1.5 Research Scopes	7
1.6 Thesis Outline	8
CHAPTER 2 Literature Review	9
2.1 Overview	9
2.2 Hybrid Electric Vehicles	9
2.2.1 Series Hybrid Electric Vehicles	10
2.2.2 Parallel Hybrid Electric Vehicles	10
2.2.3 Series-Parallel Hybrid Electric Vehicles	11
2.3 Energy Management System of HEV	13
2.3.1 Deterministic Rule Based	16
2.3.2 Fuzzy Rule Based	18

2.3.3 Global Optimization	22
2.3.4 Real-Time Optimization	25
2.3.5 Summary of Control Strategies	29
2.4 Filtering in Energy Management System	30
2.4.1 Moving Averaging	30
2.4.2 Kalman Filter	30
2.5 Subsystems of HEV	32
2.5.1 Electrical Machines	33
2.5.2 Internal Combustion Engine	38
2.5.3 Batteries	41
2.6 Hybrid Electric Motorcycle	44
CHAPTER 3 Methodology	48
3.1 Overview	48
3.2 Battery System Characterization	48
3.3 Traction System Characterization	54
3.4 Onboard Range Extender System Characterization	56
3.5 Vehicular Dynamic	60
3.6 Dynamic Programming	66
3.7 Formulation of Energy Management System	70
3.7.1 Algorithm of EMS during Charging	70
3.7.2 Algorithm of EMS Prior to Charging	75
3.7.3 Algorithm for Best Traveling	77
3.7.4 Filtering and Pre-processing	83
3.8 Experimental Validation and Performance Evaluation	89
3.9 Summary	94

CHAPTER 4 Results and Discussions	98
4.1 Overview	98
4.2 Results and Modeling of Electrical Energy Storage System.....	98
4.2.1 Discharge Model.....	99
4.2.2 Charge Model	109
4.3 Results and Modeling of Traction System	120
4.4 Results and Modeling of Onboard Range Extender System	122
4.4.1 Minimum Fuel Consumption Strategy	124
4.4.2 Minimum Emissions Strategy.....	126
4.4.3 Optimum Fuel and Emissions Strategy	127
4.5 Results and Discussions of Simulation of Pre-EMS Development.....	131
4.6 Results and Discussions of Simulations of EMS	135
4.7 Results and Discussions of Experimental Validation.....	143
4.8 Results and Discussions of EMS Performance Evaluation	153
CHAPTER 5 Conclusions and Future Work	169
5.1 Conclusions	169
5.2 Research Contributions	171
5.3 Future Work.....	172
REFERENCES.....	173
LIST OF PUBLICATIONS	192
APPENDICES	

LIST OF FIGURES

	Page
Figure 1.1: Research flowchart	5
Figure 2.1: Power flow of series HEV	10
Figure 2.2: Power flow of parallel HEV	11
Figure 2.3: Power flow of series-parallel HEV	11
Figure 2.4: Popular EMS design control techniques	14
Figure 2.5: ECE-R40 drive cycle (Barlow et al., 2009)	15
Figure 2.6: Typical chassis dynamometer test setup	15
Figure 2.7: Speed profile of modified ECE-R40 drive cycle	16
Figure 2.8: Thermostat control with 75%SOC bottom limit and 90%SOC upper limit	17
Figure 2.9: Architecture of parallel HEV studied (Delprat et al., 2004)	22
Figure 2.10: Operation of Kalman filtering (Fisher, 2014)	32
Figure 2.11: Classification of traction motors for HEV	33
Figure 2.12: Torque/Power requirement for traction motors (Zhu & Howe, 2007).	34
Figure 2.13: Graph of fuel price/liter vs. year as of October 2014 (Tan, 2015)	38
Figure 2.14: Schematic of the proposed series HEM	46
Figure 3.1: Constant current sink	48
Figure 3.2: Improved constant current sink circuit	49
Figure 3.3: Constant current sink	50
Figure 3.4: Constant current source circuit	51

Figure 3.5: Constant current source (charger)	51
Figure 3.6: Schematic of experimental setup for battery characterization	51
Figure 3.7: Experimental setup for traction system characterization	55
Figure 3.8: Schematic of experimental setup for ORE characterization	57
Figure 3.9: Experimental setup for ORE characterization	58
Figure 3.10: Marking on the throttle control knob	58
Figure 3.11: Schematic of the control of ORE with Arduino microcontroller	60
Figure 3.12: Free body diagram of a moving motorcycle	61
Figure 3.13: Traction power demand for modified ECE-R40 drive cycle	62
Figure 3.14: Algorithm for drive cycle simulation	63
Figure 3.15: Experimental setup for vehicular dynamic characterization	65
Figure 3.16: Reversed modified ECE-R40 drive cycle	67
Figure 3.17: Flow chart of dynamic programming for modified ECE-R40	68
Figure 3.18: Indication of deficiency of energy management in series HEM	70
Figure 3.19: Generalized <i>SOE</i> curve subjected to cyclical modified ECE-R40 test	71
Figure 3.20: Linearized traveling distance curve	72
Figure 3.21: <i>SOE</i> curve with traveling distance information implanted	72
Figure 3.22: Illustration of decision making on start point of charging	75
Figure 3.23: Designed averaged load profile for evaluation of EMS algorithm	76
Figure 3.24: Rule based control algorithm during charging for efficient use of fuel	77
Figure 3.25: Rule based control algorithm prior to charging	78

Figure 3.26: Illustration of unbounded solution of equation (3.20)	78
Figure 3.27: Implementation of Algo1	80
Figure 3.28: Implementation of Algo2	81
Figure 3.29: EMS algorithm implemented in series HEM in this research	82
Figure 3.30: Demonstration of suitable Algo1 to Algo2 swapping point	83
Figure 3.31: Unprocessed and pre-processed P input for HEM simulation	84
Figure 3.32: Algorithm of Kalman filtering adapted to this research	84
Figure 3.33: Magnified response of KF for P smoothing	85
Figure 3.34: Peak detection algorithm developed and implemented	86
Figure 3.35: Bottom detection algorithm developed and implemented	87
Figure 3.36: Algorithm of preprocessor of the EMS	88
Figure 3.37: Designed averaged P profiles (a) slow changes, (b) drastic changes	89
Figure 3.38: Algorithm of the compiled EMS coded in the Arduino UNO	90
Figure 3.39: Customized average P for validation test	91
Figure 3.40: Experimental setup used for validation test	92
Figure 3.41: Block diagram of series HEM proposed	95
Figure 3.42: Block diagram of EMS	97
Figure 4.1: Graph of discharge time as a function of discharge current at 48.0 V	100
Figure 4.2: Discharge curve of EES at 1 A discharge	101
Figure 4.3: Significance of linear model in discharge voltage modeling	103
Figure 4.4: Discharge map of EES	104

Figure 4.5: Error map of discharge time estimation	106
Figure 4.6: <i>SOE</i> vs. discharge time curve at 20 A constant current discharge	107
Figure 4.7: Relationship of <i>SOE</i> , V_d and I_d of the EES	107
Figure 4.8: Performance comparison of difference <i>SOE</i> estimation methods	109
Figure 4.9: Charge internal resistance model	110
Figure 4.10: Charge response of 2 A charging with 2 A discharge to 44.5 V <i>DOD</i>	110
Figure 4.11: EES charge internal resistance map	113
Figure 4.12: ΔV_{ch} at 2A charging, 46.0V <i>DOD</i> with 7A discharge	116
Figure 4.13: Average rate of change of charge voltage for the experimented cases	117
Figure 4.14: Rate of change of charge voltage plotted with equation (4.29)	117
Figure 4.15: EES rate of change of charge voltage map built with models (4.30)	118
Figure 4.16: Designed charge limit as a function of <i>SOE</i>	119
Figure 4.17: Efficiency map of traction system	121
Figure 4.18: Traction motor power demanded for modified ECE-R40 drive cycle	121
Figure 4.19: bsfc map of ORE system	122
Figure 4.20: Carbon monoxide emission map of ORE system	123
Figure 4.21: Hydrocarbon emission map of ORE system	123
Figure 4.22: Nitrogen oxides emission map of ORE system	124
Figure 4.23: Minimum bsfc as a function of output power	125
Figure 4.24: Emission performance of minimum bsfc operation	125
Figure 4.25: Emissions performance of minimum emissions operation	127

Figure 4.26: Minimum J and engine operating trajectory	128
Figure 4.27: Emissions performance of minimum fuel-emissions operation	128
Figure 4.28: Comparison of fuel consumption of ORE operating strategies	129
Figure 4.29: Engine speed versus throttle angle	130
Figure 4.30: Simulated performance of electric motorcycle under modified ECE-R40 drive cycle (a) voltage response, (b) current response, (c) SOE response, (d) mileage	132
Figure 4.31: Simulated performance of series HEM under modified ECE-R40 drive cycle (a) voltage response, (b) current response, (c) SOE response, (d) mileage	133
Figure 4.32: Optimum performance of series HEM under modified ECE-R40 drive cycle (a) voltage response, (b) current response, (c) SOE response, (d) mileage	134
Figure 4.33: % SOE and charge rate of EMS algorithm at low load	135
Figure 4.34: Performance of Algo2 at low load	136
Figure 4.35: Effect of unprocessed and filtered P on generation of charge rate	137
Figure 4.36: Performance of KF for P smoothing on profile shown in Figure 3.23	138
Figure 4.37: Performance of peak and bottom detection algorithms	139
Figure 4.38: Application of KF on Peak and Bottom signals	139
Figure 4.39: Performance of the developed preprocessor in average P estimation	140
Figure 4.40: $xPAvg$ for (a) slow changes profile, (b) drastic changes profile	141
Figure 4.41: Factor affecting EKF filter lag	142
Figure 4.42: Effect of selection of Q and R on load identification	143

Figure 4.43: Experimental results (a) motorcycle speed, (b) electromagnetic torque, (c) terminal voltage, (d) discharge current, (e) charge current, (f) fuel consumption	145
Figure 4.44: Experimental results for the first drive cycle (a) motorcycle speed, (b) electromagnetic torque, (c) terminal voltage, (d) discharge current	146
Figure 4.45: EES discharge voltage vs. time graph	147
Figure 4.46: Simulated (a) discharge voltage and (b) discharge current response	148
Figure 4.47: Comparison of averaged discharge (a) voltage, and (b) current	149
Figure 4.48: Comparison of simulated and measured charge voltage response	150
Figure 4.49: Comparison of simulated and measured charge resistance	150
Figure 4.50: Difference of charge resistance vs. charge current	151
Figure 4.51: Comparison of improved simulated and measured charge voltage	152
Figure 4.52: Difference in charge current generation of Eq. (4.47) and Eq. (4.43)	152
Figure 4.53: Comparison of simulated and experimented fuel consumption	153
Figure 4.54: Comparison of fuel consumption at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	154
Figure 4.55: Comparison of HC emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	155
Figure 4.56: Comparison of NO _x emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	156
Figure 4.57: Comparison of CO emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	157
Figure 4.58: Comparison of fuel consumption at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	158

Figure 4.59: Comparison of HC emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	159
Figure 4.60: Comparison of NOx emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	160
Figure 4.61: Comparison of CO emissions at (a) over-loaded ECE-R40, (b) modified ECE-R40 and (c) under-loaded ECE-R40	161
Figure 4.62: Charge power filtering response vs. time graph	165
Figure 4.63: Charge power response vs. time curve of EMS with current gain	165
Figure 4.64: filtered P_{ch} lowering with KF tuning	166
Figure 4.65: Effect of selection of Q on the performance of load identification	167
Figure 4.66: Effect of the choice of initial value of (a) Pk and (b) x^-	168

LIST OF TABLES

Table 3.1: Assumed coefficient values	61
Table 3.2: Suggested boundary conditions and constraints for DP simulation	67
Table 4.1: Raw data of EES constant current discharge test	99
Table 4.2: Summarized experimental data of EES charge test	111
Table 4.3: Charge resistance	112
Table 4.4: g_c/g_l data deduced from simulation data	135
Table 4.5: Traveling performance of EMS and thermostat control strategy	162

LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
bsfc	Brake Specific Fuel Consumption
CC	Constant Current
CO	Carbon Monoxide
DC	Direct Current
DP	Dynamic Programming
ECMS	Equivalent Consumption Minimization Strategy
EES	Electrical Energy Storage System
EMS	Energy Management System
FLOPS	Floating-Point Operations Per Second
GPS	Global Positioning Systems
HC	Hydrocarbon
HEM	Hybrid Electric Motorcycle
HEV	Hybrid Electric Vehicle
ICE	Internal Combustion Engine
ISG	Integrated Starter Generator
KF	Kalman Filter
NO _x	Nitrogen Oxides
ORE	Onboard Range Extender
PSU	Power Supply Unit
SOC	State of Charge
<i>SOE</i>	State of Energy
TIS	Traffic Identification System
ZEBRA	Zero Emissions Batteries Research Activity

LIST OF SYMBOLS AND ANNOTATIONS

SYMBOL (Unit)	DESCRIPTION
A	State Transition Matrix
$A_f(\text{m}^2)$	Frontal Area
α (Nm)	Average Value of Electromagnetic Torque over a Number of Sampling Data
a (ms^{-2})	Translational Acceleration
$a_i _{i=1,2,3...N}$	Empirical Constants
$availE$ (Joule)	Electrical Energy Left Over in EES
$availE_{max}$ (Joule)	Maximum Electrical Energy Allowed to be Discharged
* (Asterisk)	Current Event
B	Control Input Matrix
$Bottom$	Bottom Point Detected
$bufferE$ (Joule)	Sum of Charged Energy Minus Sum of Discharged Energy
$bsfc$ ($\text{ml.W}^{-1}.\text{s}^{-1}$)	Brake Specific Fuel Consumption
C (Ah)	Battery Capacity
C_d	Drag Coefficient
D (l)	Fuel Consumption of ICE at Specific Gear Number
DOD (V)	Depth of Discharge
d (m)	Traveling Distance
d_p (m)	Predicted End of Trip Distance Traveled
$deficit$ (Joule)	Additional Energy Needed to Fulfill $refP_i$
E (Joule)	Energy Content of EES
E_b (V)	Back Electromotive Force
E_e (Joule)	Electrical Energy
E_f (Joule)	Fuel Energy
E_m (Joule)	Mechanical Energy
$\%Error$	Percentage of Error
E_d (Joule)	Discharge Energy
E_{max} (Joule)	Capacity of Electrical Energy Storage System
e^-	Estimate Error

e	A Posteriori Estimate Error
$errR_{ch}$ (Ohm)	Difference between Simulated and measured Charge Internal Resistance
ϵ	Measurement Noise
F (N)	Force
F_{ad} (N)	Air Drag
F_{grad} (N)	Gradient Force
F_{ine} (N)	Inertial Force
F_{rr} (N)	Rolling Resistance Force
$F_{traction}$ (N)	Traction Force
f_r	Rolling Friction Coefficient
g (ms ⁻²)	Gravitational Acceleration
gb	Gearbox
g_c (%.s ⁻¹)	Gradient of Charge
g_l (%.s ⁻¹)	Gradient of Load
g_{SOE} (%.s ⁻¹)	Gradient of <i>SOE</i>
γ	Ratio of a Traveling Trip
H	Transformation Matrix
Hi	End of Peaking Signal Transient
h (Subscript)	History Event
I	Identity Matrix (unless or otherwise specified in the text)
I_{bat} (A)	Current Flowing Through Battery
I_{ch} (A)	Charge Current
I_d (A)	Discharge Current
I_p (A)	Single Phase Current
i	Current Point in an Event
Im (Superscript)	Imaginary Event
J	Objective Function
K	Kalman Gain (unless or otherwise specified in the text)
$K_{P_{ORE}}$ (W.V ⁻¹)	Control Gain of Output Power of ORE
K_τ (Nm.A ⁻¹)	Brushless DC Motor Torque Constant
$K_{\omega_{ORE}}$ (rpm.V ⁻¹)	Control Gain of Rotational Speed of ORE

K_p (Ah ⁻¹)	Polarization Coefficient
k	Stage Number
L_o	End of Bottoming Signal Transient
lim (Subscript)	Limit
m (kg)	Mass
m (Subscript)	Electric Motor
max (Subscript)	Maximum
min (Subscript)	Minimum
N	Number/Duration of an Event
η (p.u. or %)	Efficiency
$overC$ (J)	Excessed Energy Poured into the EES
P (W)	Discharge Power
$Peak$	Peak Point Detected
$Prate$ (W)	Charge Energy Minus Discharge Energy
P_{ORE} (W)	Output Power Generated by ORE
PaM	Particulate Matters
Pk^-	Covariance for a Priori Estimate Error
Pk	Covariance for a Posteriori Estimate Error
P_{ch} (W)	Charge Power
p	Probability Factor (unless or otherwise specified in the text)
$pBottom$	Partial Bottom Point Detected
$pPeak$	Partial Peak Point Detected
$preR_{ch}$ (Ohm)	Uncompensated Charge Internal Resistance
$preSOE$ (%)	Unfiltered <i>SOE</i> Estimated with Mathematical Models
φ	Normalized Emission Function
Q	Covariance for Process Noise
Q_{rated} (Ah)	Rated Capacity
Q_{ac}	Available Active Material
R	Covariance for Measurement Noise
R_{ch} (Ohm)	Charge Internal Resistance
R_{int} (Ohm)	Internal Resistance
R_p (Ohm)	Resistance

RR	Reduction Ratio
ρ (kg.m ⁻³)	Air Density
r (m)	Radius
red	Reduction Gear
$refP_i$ (W)	Reference Discharge Power
$Si g_{ORE}$	Engine Ignition Signal
SOC_f (%)	Final State of Charge
SOE (%)	State of Energy
s	Equivalence Factor
s - (Prefix)	Shadow Process
T (s)	Predicted Time Length
T (s)	Time
t_B (s)	Buffer Time
t_e (s)	Elapsed Time
t_{ch} (s)	Charge Time
t_d (s)	Discharge Time
t_p (s)	Predicted End of Trip Time
τ (Nm)	Torque
τ_e (Nm)	Electromagnetic Torque
θ (°)	Angle
θ_{thr} (°)	Throttle Angle of Onboard Range Extender
u	Control Variables
V_f (l)	ORE Fuel Tank Capacity
$V_{P_{ORE}}$ (V)	Voltage Used to Control Power Generation of ORE
$V_{\omega_{ORE}}$ (V)	Voltage Used to Control Rotational Speed of ORE
V_{bat} (V)	Battery Voltage
V_{cc} (V)	Supply Voltage
V_{ch} (V)	Charge Voltage
V_d (V)	Discharge Voltage
V_{in} (V)	Input Voltage
V_{GS} (V)	Gate-Source Voltage
V_s (V)	Starting Voltage
v (ms ⁻¹)	Translational Speed

w	Weighting Factor
wh	Wheel
ω (rad.s ⁻¹)	Rotational Speed
x	State Vector
xP_{Avg} (W)	Filtered Averaged Discharge Power
x - (Prefix)	Filtered Variables
\tilde{x}	Approximated State Vector
\hat{x}	A Posteriori State Estimate
\hat{x}^-	A Priori State Estimate
z	Input Data/ Measurement Data
\tilde{z}	Approximated Measurement Vector
ζ	Performance Measure
σ	Process Noise

SISTEM PENGURUSAN TENAGA UNTUK MENGAWAL MOTOSIKAL HIBRID ELEKTRIK SESIRI

ABSTRAK

Isu pencemaran dan kekurangan bahan api fosil telah mendorong pembangunan kenderaan hibrid. Motosikal digunakan secara meluas di negara membangun dan Asia, motosikal digemari kerana bersaiz kecil, kos rendah dan pergerakan yang mudah dipandu. Motosikal menghasilkan pencemaran yang serius disebabkan oleh kekurangan teknologi pencegahan pencemaran yang berkesan. Banyak kerja-kerja penyelidikan berkaitan dengan kereta hibrid telah dilakukan, tetapi penerbitan berkaitan dengan motosikal hibrid jarang dijumpai. Oleh itu, sifat-sifat dan prestasi motosikal hibrid tidak diketahui dengan lengkap. Hibridisasi motosikal konvensional diperlukan kerana peningkatan penggunaan motosikal disebabkan oleh peningkatan populasi dan taraf kehidupan akan membawa bencana akibat perubahan iklim jikalau tabiat penggunaan motosikal sekarang tidak diubah. Salah satu masalah yang masih lagi tidak diselesaikan dengan memuaskan untuk motosikal hibrid adalah ramalan perjalanan masa depan. Banyak teknik telah dicipta untuk ramalan, tetapi teknik-teknik tersebut sama ada terlalu kompleks, mahal ataupun berprestasi buruk. Penyelidikan ini dijalankan untuk menambahbaik prestasi motosikal elektrik melalui hibridisasi. Oleh itu, komponen asas motosikal hibrid dikaji dan diterangkan melalui modal matematik. Melalui simulasi pengaturcaraan dinamik, sifat-sifat penggunaan motosikal hibrid dengan cekap dapat dikenalpasti. Sifat-sifat tersebut akan diguna untuk merumus sistem pengurusan tenaga. Penapis Kalman lanjutan disesuaikan dengan sistem pengurusan tenaga yang dibina untuk memproses data yang diukur terus dari trafik. Penapis Kalman hanya memerlukan 2

kB untuk beroperasi dengan Atmel ATmega328p berbanding dengan 10 kB yang diperlukan oleh penapis purata bergerak mudah. Motosikal hibrid elektrik sesiri yang dilengkapi dengan sistem pengurusan tenaga mencapai jarak perjalanan sebanyak 89.58 km setiap kali dicas berbanding dengan 19.30 km setiap kali dicas untuk motosikal elektrik di bawah ECE-R40 kitaran memandu yang diubahsuaikan. Prestasi sistem pengurusan tenaga yang dibina juga lebih baik berbanding strategi kawalan termostat konvensional dari segi jarak perjalanan dan lebih optimum dari segi penggunaan bahan api. Sistem pengurusan tenaga yang dicadang mencapai lebih daripada 80 % prestasi kaedah pengaturcaraan dinamik, bagi jarak perjalanan yang jauh, system yang dicadang mencapai 98.06 % prestasi yang ditunjukkan oleh kaedah pengaturcaraan dinamik. Penyelarasan dan penyesuaian algoritma kawalan juga telah ditunjukkan supaya penyelidik boleh menggunakan algoritma yang dibina untuk aplikasi mereka. Beberapa sumbangan telah dibuat: daya kilas elektromagnet motor arus terus tanpa berus boleh dianggar dengan hanya mengukur arus fasa-tunggal. Modal matematik yang dibina untuk komponen-komponen subsistem dan teknik-teknik eksperimen akan memanfaatkan pembina motosikal hibrid masa depan. Selain itu, prestasi motosikal hibrid elektrik yang kompeten boleh dicapai dengan algoritma kawalan yang mudah dan cekap.

ENERGY MANAGEMENT SYSTEM FOR CONTROLLING SERIES HYBRID ELECTRIC MOTORCYCLE

ABSTRACT

Pollution issues and scarcity of fossil fuel inspire the development of hybrid electric vehicle. Motorcycles are widely used in developing countries and Asia for their size, cost, and maneuverability. They create enormous pollutants due to the lack of viable pollution prevention technologies. There are plenty of research on hybrid cars, but very limited literature on hybrid motorcycle, thus, the behavior and performance of hybrid motorcycle are not completely known. Hybridizing conventional motorcycle is necessary because of the increasing usage due to the population growth and rising living standard and these can bring about disastrous climate change if current habit persisted. One of the problems that remain unsolved in hybrid motorcycle is the prediction of the future trip. Various techniques have been used for the prediction, but these are either too complex, expensive, or performed poorly. This research improves the performance of an electric motorcycle by hybridization where the performance of the building blocks for hybrid motorcycle were studied and characterized. Via dynamic programming simulation, efficient use of hybrid motorcycle was found. The characteristics identified from the dynamic programming were then used for the formulation of the energy management system. Kalman filtering was applied to the energy management system to pretreat the signals measured from the traffic. Kalman filter requires only 2 kB when implemented with Atmel ATmega328p compared to 10 kB required by simple moving average filter. The series hybrid electric motorcycle embedded with the energy management system achieves 89.58 km per charging compared to 19.30 km

per charging for the electric motorcycle under the modified ECE-R40 drive cycle. In addition, the energy management system outperformed the conventional thermostat control strategy in terms of traveling distance and it has more optimized fuel usage. The energy management system proposed achieves above 80 % performance of the dynamic programming approach, for long traveling distance, it achieves as high as 98.06 %. Tuning and adaptation of the control algorithm had been demonstrated so developers can make use of them for their applications. Several contributions are made: electromagnetic torque of brushless DC motor can be estimated based on the single-phase current sensing. The mathematical models developed for subsystem components and the experimental techniques are invaluable for hybrid motorcycle developers. Besides, efficient series hybrid electric motorcycle performance is obtainable with simple and efficient control algorithm developed.