ENERGY MANAGEMENT SYSTEM FOR CONTROLLING SERIES HYBRID ELECTRIC MOTORCYCLE

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by

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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
NOx	Nitrogen Oxides
ORE	Onboard Range Extender
PSU	Power Supply Unit
SOC	State of Charge
SOE	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 (m^2)	Frontal Area
α (Nm)	Average Value of Electromagnetic Torque over a Number of Sampling Data
a (ms^{-2})	Translational Acceleration
$a_i\|_{i=1,2,3\ldots N}$	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 ($ml.W^{-1}.s^{-1}$)	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 *SOE*
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
Lo	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 *SOE* 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
Sig_{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. Hibridasi 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 diselesai 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.