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Emissions Predictive Modelling and Simulation for a Plug-in Hybrid Electric Scooter

By

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B. Eng. (Hons.), University of Tasmania, 2005

A Thesis Submitted in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

School of Engineering, University of Tasmania

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ABSTRACT

This thesis presents a comprehensive study on emissions predictive control modelling for hybrid electric scooters. Two approaches were investigated on a constructed hybrid electric scooter. The first approach involves developing a hybrid electric scooter dynamic model using MATLAB-Simulink and the second involves the development of an Emissions Predictive Model using artificial neural network.

The hybrid electric scooter model was developed to further understand and analyze as well as to predict its performance and emissions before proper construction of the prototype begins. The MATLAB-Simulink model consists of four integrated models that formed the complete hybrid scooter model: Battery Model, Engine Model, DC Motor Model and the Vehicle Dynamics Model. The multi-mode controller predicts the required parameters to operate the scooter in an optimize condition. Experimental data were gathered and thus compared to the simulated data to check the model's feasibility and accuracy on four distinct driving cycles: Modified Urban Dynamometer Driving Schedule, New York City Cycle, European Driving Cycle and the Modified Highway Fuel Economy Driving Schedule. Results showed that the developed multi-state hybrid electric scooter model was accurate and feasible with predictive errors of ±10 % for emission levels and fuel economy on the European Driving Cycle. Simulated results were also compared to the existing literature and it was found that the qualitative trends were similar. By having a high-confidence simulation model, performance of the hybrid electric scooter were also simulated over the mentioned driving cycles demonstrating the optimization strategy of the multi-state control system.

For the second approach, the Emissions Predictive Model was then built using artificial neural network techniques to predict the following tailpipe emissions gases; CO, CO_2, HC and O_2. Three feed-forward neural network models were investigated and compared in this study; back-propagation, optimization layer-by-layer and radial basis function networks. Based on the experimental setup, the neural network models were trained and tested to accurately predict the effect of the engine operating conditions on the emissions by varying the number of hidden nodes. The selected optimization layer-by-layer network proved to be the most accurate and reliable predictive tool with prediction errors of ±5 %. The effect of the engine operating conditions on the tailpipe emissions for a scooter is shown to display similar qualitative and quantitative trends between the simulated and the experimental data.

Having accurate predictive models for emissions and fuel economy enable the hybrid electric scooter to be optimized via modelling and simulation before proper construction begins. The developed emissions predictive models could act as a virtual emissions sensor replacing costly hardware for the developed physical hybrid electric scooter. This study provides a better understanding in effects of engine process parameters on tailpipe emissions for the hybrid electric scooter as well as for general hybrid vehicular applications

FULL LIST OF PUBLICATIONS

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2. **Yap, WK** & Karri, V 2010, 'Performance simulation and prediction model for a hybrid electric scooter drive ', *International Journal of Energy Research*, vol. 34, no. 1, pp. 67-83.
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ABBREVIATIONS

AI	artificial intelligence
ANN	artificial neural network
BP1	back-propagation with 1 hidden layer
BP2	back-propagation with 2 hidden layers
BSFC	brake specific fuel consumption
CAFE	Corporate Average Fuel Economy
CL	clutch
CO	carbon monoxide
CO_2	carbon dioxide
DFV	dual-fuel vehicles
ECE-15	Standard European Cycle
EPM	Emissions Prediction Model
EC	energy source
ES	energy converter
EV	electric vehicle
FCV	fuel cell vehicles
HC	hydrocarbon
HEM	hybrid electric motorcycle
HES	hybrid electric scooter
HEV	hybrid electric vehicle
HWFET	Highway Fuel Economy Driving Schedule
I/O	input/output
ICE	internal combustion engine
LVQ	learning vector quantization
M/G	motor/generator unit
NO_3^-	nitrate
NOx	nitrogen oxides
NYCC	New York City Cycle
O_2	oxygen
O_3	ozone
OLL	Optimization Layer by Layer

Pb	lead
PGT	planetary gear train
PM	particulate matter
ppm	parts per million
RBF	Radial Basis Function
RBF+KOH	Radial Basis Function incorporating the Kohonen Network
RMS	root mean square
rpm	revolutions per minute
SC	state of charge
SLA	sealed lead acid
SO_2	sulphur dioxides
SO_4^-	sulphate
tce	trichloroethylene
TPS	throttle position sensor
UDDS	Urban Dynamometer Driving Schedule
US EPA	Environment Protection Agency
WOT	wide open throttle
ZEV	zero emissions vehicle