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

By

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I would also like to thank Mr. Rob Warren of Reds Motorcycles for his assistance in operating the chassis dynamometer and his extensive knowledge on motorcycles and the Bike Ambulance for transporting the scooter efficiently and punctually.

Special thanks to my parents and I dedicate this thesis to them for their constant support in every way possible. Constant encouragements and phone calls proved invaluable to me and I’m greatly indebted to you.
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, CO₂, HC and O₂. 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
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>AI</td>
<td>artificial intelligence</td>
</tr>
<tr>
<td>ANN</td>
<td>artificial neural network</td>
</tr>
<tr>
<td>BP1</td>
<td>back-propagation with 1 hidden layer</td>
</tr>
<tr>
<td>BP2</td>
<td>back-propagation with 2 hidden layers</td>
</tr>
<tr>
<td>BSFC</td>
<td>brake specific fuel consumption</td>
</tr>
<tr>
<td>CAFE</td>
<td>Corporate Average Fuel Economy</td>
</tr>
<tr>
<td>CL</td>
<td>clutch</td>
</tr>
<tr>
<td>CO</td>
<td>carbon monoxide</td>
</tr>
<tr>
<td>CO₂</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>DFV</td>
<td>dual-fuel vehicles</td>
</tr>
<tr>
<td>ECE-15</td>
<td>Standard European Cycle</td>
</tr>
<tr>
<td>EPM</td>
<td>Emissions Prediction Model</td>
</tr>
<tr>
<td>EC</td>
<td>energy source</td>
</tr>
<tr>
<td>ES</td>
<td>energy converter</td>
</tr>
<tr>
<td>EV</td>
<td>electric vehicle</td>
</tr>
<tr>
<td>FCV</td>
<td>fuel cell vehicles</td>
</tr>
<tr>
<td>HC</td>
<td>hydrocarbon</td>
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<tr>
<td>HEM</td>
<td>hybrid electric motorcycle</td>
</tr>
<tr>
<td>HES</td>
<td>hybrid electric scooter</td>
</tr>
<tr>
<td>HEV</td>
<td>hybrid electric vehicle</td>
</tr>
<tr>
<td>HWFET</td>
<td>Highway Fuel Economy Driving Schedule</td>
</tr>
<tr>
<td>I/O</td>
<td>input/output</td>
</tr>
<tr>
<td>ICE</td>
<td>internal combustion engine</td>
</tr>
<tr>
<td>LVQ</td>
<td>learning vector quantization</td>
</tr>
<tr>
<td>M/G</td>
<td>motor/generator unit</td>
</tr>
<tr>
<td>NO₃⁻</td>
<td>nitrate</td>
</tr>
<tr>
<td>NOₓ</td>
<td>nitrogen oxides</td>
</tr>
<tr>
<td>NYCC</td>
<td>New York City Cycle</td>
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<td>oxygen</td>
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<td>O₃</td>
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<td>Pb</td>
<td>lead</td>
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<td>PGT</td>
<td>planetary gear train</td>
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<td>PM</td>
<td>particulate matter</td>
</tr>
<tr>
<td>ppm</td>
<td>parts per million</td>
</tr>
<tr>
<td>RBF</td>
<td>Radial Basis Function</td>
</tr>
<tr>
<td>RBF+KOH</td>
<td>Radial Basis Function incorporating the Kohonen Network</td>
</tr>
<tr>
<td>RMS</td>
<td>root mean square</td>
</tr>
<tr>
<td>rpm</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>SC</td>
<td>state of charge</td>
</tr>
<tr>
<td>SLA</td>
<td>sealed lead acid</td>
</tr>
<tr>
<td>SO₂</td>
<td>sulphur dioxides</td>
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<td>SO₄⁻</td>
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<tr>
<td>tce</td>
<td>trichloroethylene</td>
</tr>
<tr>
<td>TPS</td>
<td>throttle position sensor</td>
</tr>
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<td>UDDS</td>
<td>Urban Dynamometer Driving Schedule</td>
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<tr>
<td>US EPA</td>
<td>Environment Protection Agency</td>
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