FUEL ECONOMY OF A HYBRID ELECTRIC VEHICLE WITH SHORT TERM VELOCITY PREDICTIONS:
GA BASED APPROACH

A dissertation submitted to the Department of Electrical Engineering, University of Moratuwa in partial fulfillment of the requirements for the degree of Master of Science

E.M.C.P. EDIRISINGHE

Supervised by: Dr. Lanka Udawatta

Department of Electrical Engineering
University of Moratuwa, Sri Lanka

January 2009
DECLARATION

The work submitted in this dissertation is the result of my own investigation, except where otherwise stated.

It has not already been accepted for any degree, and is also not being concurrently submitted for any other degree.

........................................
E.M.C.P. Edirisinghe.
Date: 30th January 2009.

I endorse the declaration by the candidate.

........................................
Dr. Lanka Udawatta.
CONTENTS

Declaration i
Abstract v
Dedication vi
Acknowledgement vii'
List of Figures xiii
List of Tables x
List of Abbreviations xi

1. Introduction 1
   1.1 Literature Surveyor of Previous Work 1
   1.2 Objectives of the Research 3
   1.3 Hybrid Electric Vehicles 4
   1.4 Intelligent Vehicles 5
   1.5 ADVISOR Software 6

2. HEV Classifications 7
   2.1 Parallel HEVs 7
   2.2 Series HEVs 9
   2.3 Parallel - Series ( Dual ) HEVs 10
   2.4 Basic HEV Components 11
      2.4.1 Electric Motor 11
      2.4.2 Energy Storage System 11
      2.4.3 Power Splitter 13
   2.5 Characteristics of Hybrid Systems 13
   2.6 Advantages & Disadvantages of HEVs 14

3. Drive Cycles 15
   3.1 New European Drive Cycle ( NEDC ) 16
   3.2 Colombo Drive Cycle ( CDC ) 17
4. HEV Model used for Simulations
4.1 Specifications of the Selected HEV
4.2 Calculation of required power
4.3 Engine Model
   4.3.1 Operating Regions
4.4 Battery Model

5. Genetic Algorithms
5.1 Basics of GA
   5.1.1 Individuals
   5.1.2 Population
   5.1.3 Objective & Fitness Functions
   5.1.4 Selection
      5.1.4.1 Roulette Wheel Selection
      5.1.4.2 Stochastic Universal Sampling
   5.1.5 Crossover
   5.1.6 Mutation
   5.1.7 Termination of the GA
5.2 Inherent features of GA

6. GA Based Approach
6.1 Problem mapped in GA Domain
   6.1.1 Objective Function
   6.1.2 Chromosome
6.2 GA Parameters
6.3 Optimization Process

7. Results and Analysis
7.1 Results for NEDC
   7.1.1 Velocity profile and relevant power demand
   7.1.2 Operating points of ICE
   7.1.3 EM Contribution
   7.1.4 SOC Variation
7.2 Results for CDC
  7.2.1 Velocity profile and relevant power demand
  7.2.2 Operating points of ICE
  7.2.3 EM Contribution
  7.2.4 SOC Variation
  7.3 Analysis of Results

8. Conclusions
  8.1 Conclusions, Remarks and Discussion
  8.2 Recommendations for Future Research

References

Appendix A Published Research Papers
Appendix B Codlings of MATLAB Programs
Abstract

The increasing of fuel price and environmental concerns, researches were pushed to think about more fuel-efficient and less emission vehicles. As a result of this great enthusiasm, researchers were able to introduce Hybrid technology to the field of automobile. In hybrid electric power trains, an internal combustion engine (ICE) together with an electric motor (EM) is used as two energy sources. Use of an electrical motor in place of the ICE during different stages of driving results a definite saving in fuel usage.

Researches did not satisfy with this saving and these endless efforts gave the birth to the concept of intelligent vehicles or telematics – enabled Hybrid Electric Vehicles (HEV). These vehicles may use a sensor network to obtain the information about the degree of traffic flow in the environment which they are operating, and subsequently adjust their drive cycle to get the better improvement in fuel economy based on these information.

In this thesis, a conventional vehicle and a HEV with different amount of traffic flow information are compared in terms of fuel economy over two different drive cycles. First simulation results for conventional vehicle was compared with simulation results for an HEV without traffic flow information and HEV with available of traffic flow information for 4 seconds & 8 seconds ahead of current time, over New European Drive Cycle (NEDC). Thus estimated the same for a Sri Lankan Drive Cycle named Colombo Drive Cycle (CDC).

Results show that with increase of traffic flow information, the fuel economy of the HEV is increased. Finally two drive cycles were compared and the comparison shows that the improvement in fuel saving is very significant for CDC.
Dedication

I dedicate this dissertation to my loving parents.
Acknowledgement

First I would like to thank Dr. Lanka Udawatta for guiding me successfully in completing this research within the time frame. As the research supervisor, he directed me to find all necessary literature and to do the research work up to the standards.

I would like to extend my heart gratitude to Prof. Saman Halgamuge and Mr. Sunil Adikari, School of Engineering, University of Melbourne, Australia for providing the necessary research materials and information of HEVs for this study.

I should convey my gratitude to all the lectures of Electrical & Mechanical Engineering Departments of University of Moratuwa, who participated for the progress review presentations. Their valuable and fruitful comments helped me a lot to achieve the goals of this work.

Then I would like to convey my sincere thanks to my three colleagues Miss. Thusharie Mundigala, Mr. Sudath Wimalendra & Mr. Sudarshana Karunarathne. They encouraged me in making this task a success from the very beginning second to the very last moment.

My thanks are also due to Mrs. Hiranya Walpola for her kind support and patient in proof reading.

Finally, I would like to thank everyone who supported me even in a single word to complete this research work successfully.
List of Figures

Figure 2.1 : Block Diagram of Pre – Transmission Parallel HEV 8
Figure 2.2 : Block Diagram of Post – Transmission Parallel HEV 8
Figure 2.3 : Block Diagram of all wheel drive Parallel HEV 8
Figure 2.4 : Block Diagram Series HEV 10
Figure 3.1 : NEDC 16
Figure 3.2 : CDC 17
Figure 4.1 : Velocity Input 19
Figure 4.2 : HEV on the Road 20
Figure 4.3 : Engine Fuel Rate Map 23
Figure 4.4 : Engine Efficiency Map 24
Figure 4.5 : Engine Efficiency Contours 24
Figure 4.6 : Shape of the efficiency variation curve with torque for any speed 25
Figure 4.7 : ICE operated in Region 3 26
Figure 4.8 : ICE operated in Region 2 26
Figure 5.1 : Evolutionary algorithm mechanism 30
Figure 5.2 : Roulette Wheel Selection 32
Figure 5.3 : Stochastic Universal Sampling 33
Figure 5.4 : One-point crossover 34
Figure 5.5 : Multi-point crossover, m = 4 34
Figure 5.6 : Mutation Operator 35
Figure 6.1 : n second Time Slot 37
Figure 6.2 : Chromosome 38
Figure 6.3 : Optimized EM Power contribution for n second Time Slot 39
Figure 6.4 : Optimization Process 40
Figure 7.1 : NEDC 42
Figure 7.2 : Power demand for NEDC 42
Figure 7.3 : ICE Operating points for Conventional Vehicle - NEDC 43
Figure 7.4 : ICE Operating points for HEV Without Predictions - NEDC 43
Figure 7.5: ICE Operating points for HEV With 4 Seconds Predictions - NEDC
Figure 7.6: ICE Operating points for HEV With 8 Seconds Predictions - NEDC
Figure 7.7: EM Contribution for HEV Without Predictions - NEDC
Figure 7.8: EM Contribution for HEV With 4 Seconds Predictions - NEDC
Figure 7.9: EM Contribution for HEV With 8 Seconds Predictions - NEDC
Figure 7.10: SOC Variation for HEV Without Predictions - NEDC
Figure 7.11: SOC Variation for HEV With 4 Seconds Predictions - NEDC
Figure 7.12: SOC Variation for HEV With 8 Seconds Predictions - NEDC
Figure 7.13: CDC
Figure 7.14: Power demand for CDC
Figure 7.15: ICE Operating points for Conventional Vehicle - CDC
Figure 7.16: ICE Operating points for HEV Without Predictions - CDC
Figure 7.17: ICE Operating points for HEV With 4 Seconds Predictions - CDC
Figure 7.18: ICE Operating points for HEV With 8 Seconds Predictions - CDC
Figure 7.19: EM Contribution for HEV Without Predictions - CDC
Figure 7.20: EM Contribution for HEV With 4 Seconds Predictions - CDC
Figure 7.21: EM Contribution for HEV With 8 Seconds Predictions - CDC
Figure 7.22: SOC Variation for HEV Without Predictions - CDC
Figure 7.23: SOC Variation for HEV With 4 Seconds Predictions - CDC
Figure 7.24: SOC Variation for HEV With 8 Seconds Predictions - CDC
Figure 7.25: Comparison of Fuel Usage
Figure 7.26: Comparison of ICE Operating points for NEDC
Figure 7.27: Comparison of ICE Operating points for NEDC with CDC
Figure 7.28: Comparison of EM Power Contributions of NEDC
Figure 7.29: Comparison of SOC Variation for NEDC with CDC
List of Tables

Table 2.1 : Comparison of Hybrid Systems 10
Table 2.2 : Comparison of Batteries 12
Table 4.1 : Specifications of the selected HEV 18
Table 7.1 : Comparison of Fuel Usage 53
## List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADVISOR</td>
<td>ADvanced Vehicle SimulatOR</td>
</tr>
<tr>
<td>CDC</td>
<td>Colombo Drive Cycle</td>
</tr>
<tr>
<td>DOE</td>
<td>Department of Energy – United States of America</td>
</tr>
<tr>
<td>EM</td>
<td>Electric Motor</td>
</tr>
<tr>
<td>ESS</td>
<td>Energy Storage System</td>
</tr>
<tr>
<td>FC</td>
<td>Fuel Cells</td>
</tr>
<tr>
<td>GA</td>
<td>Genetic Algorithm</td>
</tr>
<tr>
<td>GHG</td>
<td>Greenhouse Gas</td>
</tr>
<tr>
<td>HEV</td>
<td>Hybrid Electric Vehicle</td>
</tr>
<tr>
<td>ICE</td>
<td>Internal Combustion Engine</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electronic and Electrical Engineers</td>
</tr>
<tr>
<td>IGBT</td>
<td>Insulated Gate Bipolar Transistors</td>
</tr>
<tr>
<td>NEDC</td>
<td>New European Drive Cycle</td>
</tr>
<tr>
<td>NREL</td>
<td>National Renewable Energy Laboratory</td>
</tr>
<tr>
<td>SCRAM</td>
<td>Signal Coordination in Regional Areas of Melbourne</td>
</tr>
<tr>
<td>SOC</td>
<td>State of Charge (of the battery)</td>
</tr>
<tr>
<td>SUS</td>
<td>Stochastic Universal Sampling</td>
</tr>
<tr>
<td>UN</td>
<td>United Nations</td>
</tr>
<tr>
<td>w.r.t</td>
<td>With Respect To</td>
</tr>
</tbody>
</table>