

**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

by

E.M.C.P. EDIRISINGHE

LIBRARY
UNIVERSITY OF MORATUWA, SRI LANKA
MORATUWA

Supervised by : Dr. Lanka Udawatta

Department of Electrical Engineering

University of Moratuwa, Sri Lanka

January 2009
University of Moratuwa



92961

92961

621.5 "09"

621.3 (043)

TH

92961

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.

UOM Verified Signature

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

I endorse the declaration by the candidate.

UOM Verified Signature

.....
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	18
4.1	Specifications of the Selected HEV	18
4.2	Calculation of required power	19
4.3	Engine Model	22
	4.3.1 Operating Regions	25
4.4	Battery Model	27
5.	Genetic Algorithms	28
5.1	Basics of GA	28
	5.1.1 Individuals	30
	5.1.2 Population	31
	5.1.3 Objective & Fitness Functions	31
	5.1.4 Selection	31
	5.1.4.1 Roulette Wheel Selection	31
	5.1.4.2 Stochastic Universal Sampling	32
	5.1.5 Crossover	33
	5.1.6 Mutation	35
	5.1.7 Termination of the GA	36
5.2	Inherent features of GA	36
6.	GA Based Approach	37
6.1	Problem mapped in GA Domain	37
	6.1.1 Objective Function	37
	6.1.2 Chromosome	37
6.2	GA Parameters	38
6.3	Optimization Process	39
7.	Results and Analysis	42
7.1	Results for NEDC	42
	7.1.1 Velocity profile and relevant power demand	42
	7.1.2 Operating points of ICE	43
	7.1.3 EM Contribution	45
	7.1.4 SOC Variation	46

7.2	Results for CDC	48
7.2.1	Velocity profile and relevant power demand	48
7.2.2	Operating points of ICE	49
7.2.3	EM Contribution	51
7.2.4	SOC Variation	52
7.3	Analysis of Results	54
8.	Conclusions	60
8.1	Conclusions, Remarks and Discussion	60
8.2	Recommendations for Future Research	61
	References	62
Appendix A	Published Research Papers	66
Appendix B	Codlings of MATLAB Programs	73

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	44
Figure 7.6 : ICE Operating points for HEV With 8 Seconds Predictions - NEDC	44
Figure 7.7 : EM Contribution for HEV Without Predictions - NEDC	45
Figure 7.8 : EM Contribution for HEV With 4 Seconds Predictions - NEDC	45
Figure 7.9 : EM Contribution for HEV With 8 Seconds Predictions - NEDC	46
Figure 7.10 : SOC Variation for HEV Without Predictions - NEDC	46
Figure 7.11 : SOC Variation for HEV With 4 Seconds Predictions - NEDC	47
Figure 7.12 : SOC Variation for HEV With 8 Seconds Predictions - NEDC	47
Figure 7.13 : CDC	48
Figure 7.14 : Power demand for CDC	48
Figure 7.15 : ICE Operating points for Conventional Vehicle - CDC	49
Figure 7.16 : ICE Operating points for HEV Without Predictions - CDC	49
Figure 7.17 : ICE Operating points for HEV With 4 Seconds Predictions - CDC	50
Figure 7.18 : ICE Operating points for HEV With 8 Seconds Predictions - CDC	50
Figure 7.19 : EM Contribution for HEV Without Predictions - CDC	51
Figure 7.20 : EM Contribution for HEV With 4 Seconds Predictions - CDC	51
Figure 7.21 : EM Contribution for HEV With 8 Seconds Predictions - CDC	52
Figure 7.22 : SOC Variation for HEV Without Predictions - CDC	52
Figure 7.23 : SOC Variation for HEV With 4 Seconds Predictions - CDC	53
Figure 7.4 : SOC Variation for HEV With 8 Seconds Predictions - CDC	53
Figure 7.25 : Comparison of Fuel Usage	55
Figure 7.26 : Comparison of ICE Operating points for NEDC	56
Figure 7.27 : Comparison of ICE Operating points for NEDC with CDC	57
Figure 7.28 : Comparison of EM Power Contributions of NEDC	58
Figure 7.29 : Comparison of SOC Variation for NEDC with CDC	59

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



University of Moratuwa, Sri Lanka.
Electronic Theses & Dissertations
www.lib.mrt.ac.lk

List of Abbreviations

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