Faculty of Engineering

OPTIMIZATION OF RULE-BASED ENERGY MANAGEMENT STRATEGY FOR HYBRID ELECTRIC VEHICLES

SITI NOR MAZIAH BINTI MOHAMAD ZAINI

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OPTIMIZATION OF RULE-BASED ENERGY MANAGEMENT STRATEGY FOR HYBRID ELECTRIC VEHICLES

SITI NOR MAZIAH BINTI MOHAMAD ZAINI

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ABSTRACT

Environmental issues have commonly happened until now, caused by fossil fuel burning in the industrial and transportation sectors. The excessive use of energy in the combustion of fossil fuels may cause environmental issues such as Carbon Dioxide (CO_2) emission and the contribution of greenhouse gases (GHG). In order to fight the problem of fossil fuel combustion, the automotive industry has developed and implemented electric and hybrid electric vehicles (HEV). It has been proven that HEVs can lower emissions and save gasoline. The significant advantage of using HEV is fuel saving. However, it is not easy to design the appropriate energy management strategies (EMSs) for HEVs. Real-world HEV testing to improve fuel efficiency and battery management proved unattainable due to the extensive programming and other complicated HEV criteria. Hence, this project is conducted to modify and optimize Rule-Based (RB) EMS to increase further the HEV's performance in fuel consumption and battery management at different drive cycles. In this project, the existing HEV model has been modified using MATLAB/Simulink to optimize the RB EMS for HEV by altering the battery charge controller and state-flow RB operation mode. Simulation results have shown that the efficiency percentage of total fuel consumption was improved by 8.09% for Extra Urban Drive Cycle (EUDC) compared to Urban Drive Cycle (ECE R15) by 4.56% and followed by the New European Drive Cycle (NEDC) by 1.02%. For the battery's final State of Charge (SOC), SOC decreased by 5.32% for ECE R15 compared to EUDC by 9.14% at a higher initial SOC. This shows that the optimization increased the efficiency in fuel consumption and battery management.

ABSTRAK

Sehingga hari ini isu alam sekitar sering berlaku disebabkan oleh pembakaran bahan api fosil daripada sektor perindustrian dan sektor pengangkutan. Penggunaan tenaga yang berlebihan dalam pembakaran bahan api fosil boleh menyebabkan isu alam sekitar di muka bumi ini seperti perlepasan karbon dioksida *(CO_2)* dan boleh mengakibatkan gas rumah hijau *(GHG)*. Bagi menangani isu pembakaran bahan api fosil, industri automotif telah mencipta dan menggunakan kenderaan elektrik dan kenderaan elektrik hibrid *(HEV).* Telah terbukti bahawa kenderaan elektrik hybrid boleh mengurangkan perlepasan karbon dioksida dan dapat menjimatkan minyak petrol. Kelebihan utama dalam menggunakan keadaan elektrik hybrid adalah dari segi penjimatan bahan api. Walaubagaimanapun, sukar untuk mereka membentuk strategi bagi pengurusan tenaga yang sesuai untuk kenderaan elektrik hybrid. Telah terbukti bahawa uji kaji yang dilakukan untuk menambahbaik kecekapan bahan api dan pengurusan bateri untuk kenderaan elektrik hybrid di dunia sebenar tidak dapat dilakukan kerana pengatucaraan yang sangat meluas dan terdapat kriteria-kriteria yang ada pada kenderaan elektrik hybrid yang sangat merumitkan. Oleh itu, projek ini dijalankan adalah untuk mengubah suai dan mengoptimumkan strategi pengurusan tenaga berasaskan peraturan bagi meningkatkan lagi prestasi kenderaan elektrik hibrid dalam penggunann bahan api dan pengurusan bateri pada kitaran pemacu yang berlainan. Didalam projek ini, model kenderaan elektrik hybrid yang sedia ada telah diubah suai menggunakan *MATLAB*/Simulasi untuk mengoptimumkan strategi pengurusan tenaga berasaskan peraturan pada kenderaan elektrik hibrid dengan mengubah kawalan pengecajsan bateri dan aliran keadaan yang berasaskan peraturan. Keputusan simulasi telah menunjukkan bahawa peratusan kecekapan jumlah penggunaan bahan api telah meningkat sebanyak 8.90% untuk Kitaran Pemanduan Bandar Tambahan *(EUDC)* berbanding dengan Kitaran Pemanduan Bandar *(ECE R15)* sebanyak 4.56% dan Kitaran Pemanduan Eropah Baharu *(NEDC*) pula, sebanyak 1.02%. Bagi keadaan pengecajsan bateri yang terakhir, telah berkurang sebanyak 5.32% untuk Kitaran Pemanduan Bandar (*ECE R15)* berbanding dengan Kitaran Pemanduan Bandar Tambahan (*EUDC)* sebanyak 9.14% pada keadaan caj awalan bateri yang lebih tinggi. Ini menunjukkan bahawa kecekapan penggunaan bahan api dan pengurusan bateri telah meningkat selepas pengoptimuman.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Alternating Current
APU	-	Auxiliary Power Unit
BSFC	-	Break Specific Fuel Consumption
CPE	-	Constant Phase Elements
CO_2	-	Carbon Dioxide
DC	-	Direct Current
DP	-	Dynamic Programming
EMS	-	Energy Management Strategy
EUDC	-	Extra Urban Drive Cycle
ECE R 15	-	Urban Drive Cycle
EM	-	Electric Motor
EG	-	Electric Generator
ESS	-	Energy Storage System
EACS	-	Electric Assist Control Strategy
GEN	-	Generator
GHG	-	Greenhouse Gases
HEV	-	Hybrid Electric Vehicle
ICE	-	Internal Combustion Engine
IWM	-	In-Wheel Motor
NO_X	-	Nitrogen Oxides
NEDC		New European Drive Cycle
OER	-	Oxygen Excess Ratio
PID	-	Proportional Integral Derivative
PFCS	-	Power Follower Control Strategy
RB	-	Rule-Based
RESS	-	Rechargeable system energy storage
PM	-	Permanent Magnet
PPA	-	Predictive and Protective Algorithm
RB	-	Rule-Based
SO_X	-	Sulphur Oxides

SOC	-	State of Charge
TTRB	-	Three-phase Thyristor Rectification Bridge
UDDS	-	Urban Dynamometer Driving Cycle
VCS	-	Vehicle Control Strategy

LIST OF SYMBOLS

α	-	Alpha
NR	-	Tooth number on the ring
NS	-	Tooth number on the sun gears
TR	-	Torque ring
TC	-	Torque carrier
TS	-	Tong sun gears
ωR	-	Rotational speed of ring
ωC	-	Rotational speed of carrier
ωS	-	Rotational speed of sun gears

CHAPTER 1

INTRODUCTION

1.1 Background

Technology has induced countless and phenomenal changes in the everyday life of people, which are projected to progress and advance to higher complexity, notably in the field of information technology (IT). Therefore, the utilization of energy becomes higher and contributes to economic growth. However, fossil fuel consumption is still in higher demand, especially for cars across the world. Burning fossil fuels is widely viewed as a primary cause of air pollution, contributing to climate change. The transportation industry is among the most significant fossil fuel consumer and is one of the biggest sources of GHG. GHG includes harmful gases such as nitrogen oxides (NO_x), carbon monoxides (CO), sulphur oxides (SO_x), unburned hydrocarbons, and other pollutants. To mitigate the catastrophic impact on the environment and to meet the 2°C Scenario (2DS) recommended by the 2015 Paris Agreement, industry leaders and researchers are actively working to reduce fuel consumption and emissions in the direction of achieving the year 2050 zero-emission objective [1].

According to Figure 1.1, CO_2 emissions by sector in the world from 1990–2019, transportation is the second-largest source of CO_2 emissions after the electricity and heat producers and followed by industrial sector [2]. The data in Figure 1.1 shows that the transport of CO_2 emissions by sector increased from the year 1990 with a value of 4.610GT CO_2 to 2019 with a value of 8.222GT CO_2. It shows that CO_2 emissions around the world are getting higher, which can negatively affect the environment.

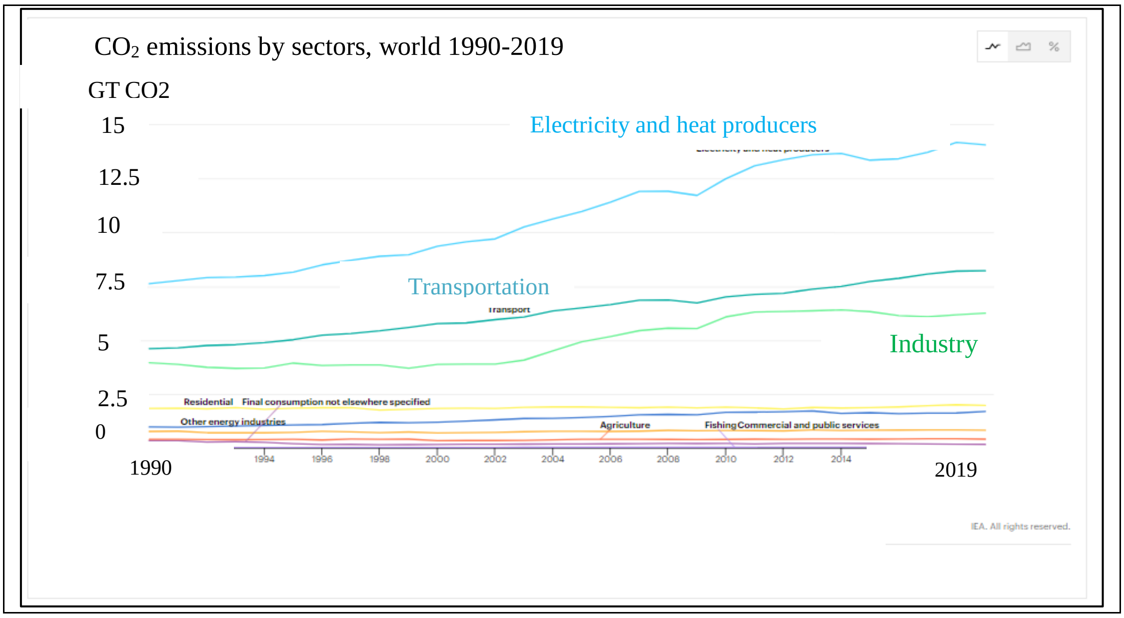

Figure 1.1 World CO_2 emissions by sector 1990-2019 (Image adopted from: International Energy Agencies: IEA)

One of the main focuses to reduce carbon emissions by the automotive industry is developing and using electric or hybrid electric vehicles (HEVs). In recent years, there has been a tremendous effort to limit the usage of traditional internal combustion engine (ICE) automobiles by embracing battery electric vehicles (BEVs), which provide a green and reliable alternative. Demand for electrified vehicles is increasing in terms of market share. A BEVs is a sensible decision for any end-user because of its revolutionary viewpoint and not yet in Malaysia [3]. The term of BEV refers to a vehicle that uses one or more electric or traction motors to provide propulsion [3]. Electric car sales are rapidly rising, accounting for more than 2% of worldwide automobile sales. Ambitious policy pronouncements have been crucial in accelerating the transition to electric mobility in key automobile markets. According to the Figure 1.2 shows that in 2020, there were estimated 10 million electric passenger cars on the road worldwide, a 43% increase over the number of BEVs on the road in 2019. In 2020, 3.2 million electric vehicles are predicted to be sold in Europe, which has the fastest yearly growth rate, despite China having the most [4].

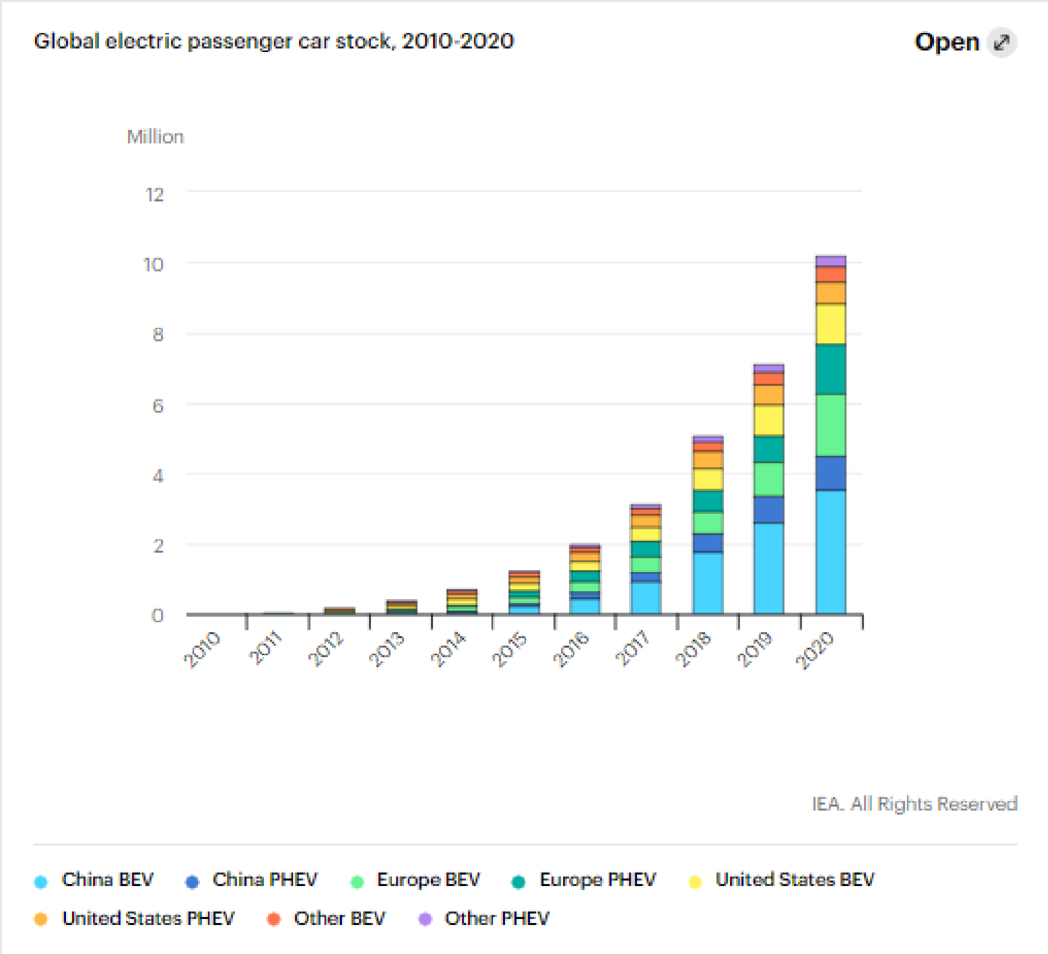

Figure 1.2 Global electric passenger car stock, 2010-2020 (Image adopted from: International Energy Agencies: IEA)

The total number of vehicles is constantly increasing due to the rapid development of the economy and people's living standards. Currently, conventional vehicles powered solely by ICE remain the most common vehicle type. However, hybrid electric vehicles/plug-in hybrid electric vehicles (HEVs/PHEVs), BEVs, and fuel cell vehicles (FCVs) are the most common types of new energy vehicles [5]. In this way, HEVs are growing in a market that is still debating the best answer for implementing zero-emission vehicles in the future, even if they are the most popular option now. Dr. Ferdinand Porsche, a German, designed the Lohner Electric Chaise in 1898. For the first time, a front-wheel-drive hybrid vehicle was available, with an ICE generating electricity for electric motors (EMs) in the wheel hubs, which supplied power to the vehicle's EM. The car's battery alone could travel nearly 40 miles [6]. Other than that, in 1997, the Toyota

Prius, the first contemporary HEV, was released in Japan, setting the globe on a new course.

HEVs are a type of vehicle that combines the characteristics of conventional cars powered by ICEs and BEVs into a single package that delivers uncompromised performance while emitting less pollution [7]. In other words, HEVs are vehicles that use ICEs in conjunction with one or more EMs connected to a battery pack as a secondary energy storage system (ESS) to provide propulsion for the wheels, either simultaneously or separately [7]. On the basis of their design characteristics, HEVs are divided into three categories: series, parallel, and power-split series-parallel configurations. The power-split or series-parallel design, which combines series and parallel designs to overcome the shortcomings of the individual designs and capitalise on their strengths.

The COVID-19 pandemic has made the income gap much higher, and the prices of fossil fuels are ever-increasing. As a result, the cost of living has increased, especially in our daily consumption. As employees or drivers, they need to be frugal people, especially with the use of fuel in their vehicles to commute wherever they want to go. Therefore, we know that all drivers want the best vehicle criteria in energy management strategies, especially fuel consumption. The goal of HEVs is to reduce fuel consumption and emissions while fulfilling drivers' power needs by researching effective energy management strategies (EMSs). Energy management seeks to achieve an ideal power split in the face of complex driving conditions while also minimising fuel consumption and pollutants [8]. It is widely agreed that improving the fuel efficiency of HEVs, and thus reducing their emissions is a big part of how they manage their EMSs. Other than that, it can be challenging for EMSs to work well because of the complicated configuration and behaviour of multi-source hybrid energy systems. Regardless of the powertrain topology, the EMS goal is to manage the power flows from the energy converters in real time to fulfil the control objectives [9]. It's important to note that the best control algorithms for a given driving cycle are the main research topic in the field of EMSs. Generally, the optimization of this project consists of simulation based on a method that will be used in energy management strategies. In this project, optimization of the EMS will be using a deterministic rule-based (RB) method to improve the efficiency, regulate power, and storage of the electrical energy in a series-parallel HEV.

1.2 Problem Statement

Due to the large number of coupled design parameters, conflicting design objectives, and time-consuming process, optimising energy management in HEV using a real electric vehicle is very expensive, tedious, and challenging. Moreover, testing new algorithms in an electric vehicle will be next to impossible since it will require reprogramming the whole vehicle setup with hundreds of parameters conflicting with each other.

HEVs provide better fuel economy compared to ICE based vehicles conventional vehicles. The problem plaguing the energy management in HEVs are the algorithms that decide the power split between engine and motor in order to improve the fuel economy and optimize the performance of HEVs. The algorithms are sometimes inefficient and un-optimized. In this study, a RB method continued from the optimization part to enhance the EMS in series-parallel HEVs.

Evaluating the performance of energy management in the HEV on-road in standard drive cycles using newer algorithms is impossible as there are a lot of unknowns. Standard test drive cycles are highly unlikely to be performed in real world conditions as the driving pattern will be different from testing conditions, which may make it difficult to obtain greater fuel efficiency.

1.3 Objectives

The objectives of the research are:

1. To modify an HEV simulation model by MATLAB/Simulink for testing the performance of the energy management system.
2. To modify and optimize rule-based EMS to further increase the HEV performance in fuel consumption and battery management.
3. To analyse the improvement of HEV performance through simulation using standard drive cycles to improve fuel efficiency.

1.4 Scope of Project

This project involves testing real-time HEV data in a simulation using MATLAB software. In this project, we will try to optimize the EMS in a HEV by using existing algorithms proposed by other researchers in the literature. This project will test the on-road real-time testing data used by automotive manufacturers and researchers on their current production HEV. Simulations will be performed using MATLAB Simulink using existing RB algorithms to optimize the EMS in HEV. The advantage of using a simulation model is that it reduces the cost of testing rather than testing on a real-time vehicle, which needs a lot of hardware to be purchased along with the HEV itself. The present simulation model enables fast identification of the optimised EMS while considering all defined system performance requirements.

1.5 Report Outlines

This report contains five chapters, and each chapter will elaborate in detail on this project.

The first chapter will introduce the background study, which is related to the current issue of vehicle emissions and pollutants and EMS in vehicles. The overview of this project was elaborated briefly, including the problem statement that arose the idea for this project, the objectives, and the scope of work of this project as a guide to finish the project.

Chapter two is a literature review that will explain and analyze previous work that has been done by the other authors. It is considered analysis of recent results regarding the methods used to optimize EMS in HEV.

Chapter three explains the approach and method employed for this project. It included project flow charts and a series-parallel HEV model with an explanation of power flow in power-split in HEV. They were followed by the method or algorithm that will be used to optimize the EMS of HEV, the basic model or components that are required in this project, and the software development used to simulate and generate the result.

Chapter four discusses about the data analysis of results with and without optimization from the observation that has been made. These two levels of initial state of charge (SOC) of the battery were used, such as 100% (High) and 60% (Medium). Meanwhile, three types of drive cycles are also included. All the data comparison with and without optimization has been explained in this chapter.

Finally, chapter five will draw a conclusion from the result and recommendation for any improvement needed for this project in future.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

A brief description and information about the concept of optimization of EMS for HEV is presented in this chapter. The existing knowledge of technology can be used to enhance and implement energy management more efficiently by optimizing previous methods.

2.2 Hybrid Electric Vehicles

The propulsion systems of hybrid cars have been designed to utilize two different types of energy sources: a high-capacity storage system that usually made of liquid or gaseous chemicals, and a lower-capacity rechargeable energy storage system (RESS), which may be used to store excess energy or to help the vehicle's motion. Electrochemical (batteries or supercapacitors), hydraulic/pneumatic (accumulators), or mechanical (flywheel) RESS are all possibilities [10]. In order to utilize the RESS's dual energy storage capabilities and allow for bidirectional power flow, two energy converters must be present, at least one of which must be able to support bidirectional power flow [10].

In the automotive world, a HEV powered by more than one power source which are used electromechanical batteries as the RESS, and Ems as secondary energy converters [11]. Typically, HEVs include a primary power source the ICE as well as one or more EM. When the engine is not performing optimally, it is advantageous to reinforce it with an EM. While pure BEVs are best in terms of pollutants and fuel economy, they typically do not provide the same level of road performance as conventional vehicles due to their lack of adaptability. Hybrid electric cars and fuel cell automobiles are the most