Faculty of Engineering

FUZZY LOGIC ASSISTED RESOURCE-BASED ENERGY MANAGEMENT STRATEGY FOR HYBRID ELECTRICAL VEHICLES

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ABSTRACT

It has been demonstrated that hybrid electric vehicles (HEVs) are a promising solution to environmental pollution and fuel savings. Typically, the benefit of a solution is measured by the quantity of fuel saved, which poses a challenge for the development of energy management strategies (EMSs) for HEVs. Moreover, meeting the design requirements is essential for optimal power distribution, even though this necessitates sacrificing competing goals. To this end, many EMSs have been proposed in the literature, necessitating a better categorization method to classify the design and control contributions, focusing on fuel economy, power demand, and real-time application. In this project, a HEV Simulink model is modified to be integrated with in EMS controller. A fuzzy logic control (FLC) for series-parallel HEV is developed to effectively control the torque distribution between the internal combustion engine (ICE) and electrical motor (EM) by taking the vehicle speed, state-of-charge (SOC) of the battery and trip distance as inputs. The vehicle and controller performance are evaluated regarding fuel consumption to verify the model. The original HEV model is updated by virtually installing the EMS FLC. The proposed EMS is implemented, and the performance of vehicle is evaluated through simulation on standard drive cycles. Show that the proposed EMS is outperforming the conventional rule-based EMS by up to 40.82 % in terms of fuel consumption in selected certain conditions while maintaining battery SOC within it’s over the set lower threshold range.

ABSTRAK

Penggunaan kenderaan elektrik hibrid (HEV) telah terbukti sebagai salah satu penyelesaian yang menjanjikan pengurangan pencemaran alam sekitar dan juga penjimatan penggunan bahan bakar fosil.Kebiasaannya, manfaat yang diperoleh daripada penyelesaian ini dapat diukur berdasarkan kadar kuantiti bakan bakar fosil yang dapat dijimatkan dalam masa yang sama manjadikan ia cabaran dalam memajukan strategi pengurusan tenaga (EMS) untuk HEV. Selain itu, memenuhi kriteria rekabentuk yang dikehendaki amatlah penting untuk pengagihan kuasa yang lebih optimum walaupun ia melibatkan pengorbanan matlamat yang bersaing. Untuk mencapai matlamat ini, pelbagai strategi telah dikemukakan dalam bahan bacaan literarur yang memerlukan kaedah pengkategorian yang lebih baik dalam mengklasifikasikan rekabentuk dan penglibatan kawalan, fokus kepada pengunaan bahan bakar fosil, kuasa yang diperlukan dan pengaplikasian masa nyata. Model yang dibangunkan akan disepadukan bersama kawalan strategi pengurusan tenaga (EMS). Kawalan Logik Kabur (FLC) untuk kenderaan elektrik hibrid (HEV) siri-selari telah dibangunkan bersama alat kawalannya untuk mengawal pengagihan tork di antara enjin (ICE) dan motor elektrik (EM) dengan lebih berkesan disamping mengambil kira kadar kelajuan kenderaan, keadaan cas (SOC) bateri, dan jarak perjalanan yang diambil oleh kenderaan sebagai input. Kenderaan dan alat kawalan akan dinilai menerusi kadar pengunaan bahan bakar fosil untuk mengesahkan model tersebut. Model kenderaan elektrik hibrid (HEV) asli akan dikemas kini dengan memasang kawalan logik kabur (FLC) teknik pengurusan tenaga (EMS). Strategi pengurusan tenaga (EMS) yang dicadangkan akan diguna pakai dan prestasi kenderaan elektrik hibrid siri-selari akan dinilai melalui simulasi bersama dengan kitaran pemanduan biasa yang dipilih. Strategi pengurusan tenaga (EMS) yang dicadangkan berjaya mengatasi strategi pengurusan tenaga berasakan peraturan dari segi penjimatan bahan bakar fosil sebanyak 40.82 % dalam keadaan tertentu disamping mengekalkan cas bateri (SOC) lebih dari julat terendah yang ditetapkan.

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
BCS	-	Baseline Control Strategies
CAD	-	Computer Aided Designs
CATIA	-	Computer Aided Three-Dimensional Interactive Application
CCU	-	Can Not Catch Up
CO_2	-	Carbon Dioxide
CO	-	Carbon Monoxide
CS	-	Combinatorial Strategies
ECE R-15	-	Urban Drive Cycle
EUDC	-	Extra-Urban Driving Cycle
EV	-	Electric Vehicle
EM	-	Electric Motor
EMS	-	Energy Management Strategies
EoC	-	End-of-Charge
ESS	-	Energy Storage System
FCV	-	Fuel Cell Vehicle
FLC	-	Fuzzy Logic Controller
FLS	-	Fuzzy Logic Strategies
GHG	-	Green House Gases
GNP	-	Gross National Product
HEV	-	Hybrid Electrical Vehicle
HIL	-	Hardware-In-The-Loop

HWFET	-	Highway Fuel Economy Test Cycle
ICE	-	Internal Combustion Engine
IWM	-	In-Wheel-Motor
LOFI	-	Luqman Optimizer Fuzzy Integrator
MF	-	Membership Function
NEDC	-	New European Driving Cycle
NEV	-	New Energy Vehicle
OCV	-	Open Circuit Voltage
PHEV	-	Plug-in Hybrid Electrical Vehicle
PFS	-	Power Follower Strategies
RBS	-	Rule Base Strategies
RZR	-	Reach zero and Recharge
SMS	-	State Machine Strategies
SOC	-	State-of-Charge
TS	-	Thermostatic Strategies

CHAPTER 1

INTRODUCTION

1.1 Background

Climate change and the growth of greenhouse gas (GHG) emissions worldwide have been the main issues of debates and discussions. This topic is trending because the environmental effects and impacts include potential causes and concerns of global warming. All the countries worldwide are collectively responsible for the aftermath of global warming, and drastic plans should be taken to mitigate the adverse effects of this phenomenon. Fossil fuels have been burned across the world as the leading to the major cause of GHG and emissions of carbon dioxide (CO_2). The transportation sector is one of the main contributors to emissions of GHG since it is a fast growing sector. The energy produced by the internal combustion engines (ICE) used in conventional vehicles comes from the burning of fuel and air mixture. Exhaust gases are byproducts of the combustion reaction and are released into the atmosphere.

In the past decade, interest in electric vehicles (EVs) and hybrid electric vehicles (HEVs) has been steadily increasing. This interest has been fueled by a deeper understanding of climate change, substantial advancements in battery technology, stronger regulation of pollution standards, and the availability of EVs and HEV with uncompromised performance. All automobiles now have well-established electrification programs and product lines. Moreover, a company such as Tesla has established a significant market presence in this sector. Legislative requirements are motivating manufacturers and subsystem suppliers to develop new and advanced EV and HEV concepts. Plug-in hybrid vehicles (PHEV) have also caught the interest of both academia and industry in recent years [1].

The concept of EV and HEV has already been established earlier. EVs were much more promising in the early days of the automobile, all the way up until the 1910s [2]. Hybridization has quickly become a more viable method for lowering the fuel consumption and environmental effect of conventional vehicles; as a result, the HEV industry has attracted a great deal of interest from a wide range of researchers.

Prior research has demonstrated that HEV optimal energy management strategy (EMS) can reduce fuel consumption by about 20 %, limiting reliance on fuel, GHG emissions like carbon monoxide and mono nitrogen oxide (NOx) [3]. Reducing GHG emissions is crucial because it would minimise the severe dangers presently harming not only the atmosphere but also most of the human body's natural and internal systems. GHG emissions are responsible impacting the average global surface temperature to have risen noticeably over the last century Figure 1.1 involving of ICE-powered automobile in three major areas of concern, including petroleum usage (left), GHG production (centre) and averaged CO and NOx emissions (right) [3].

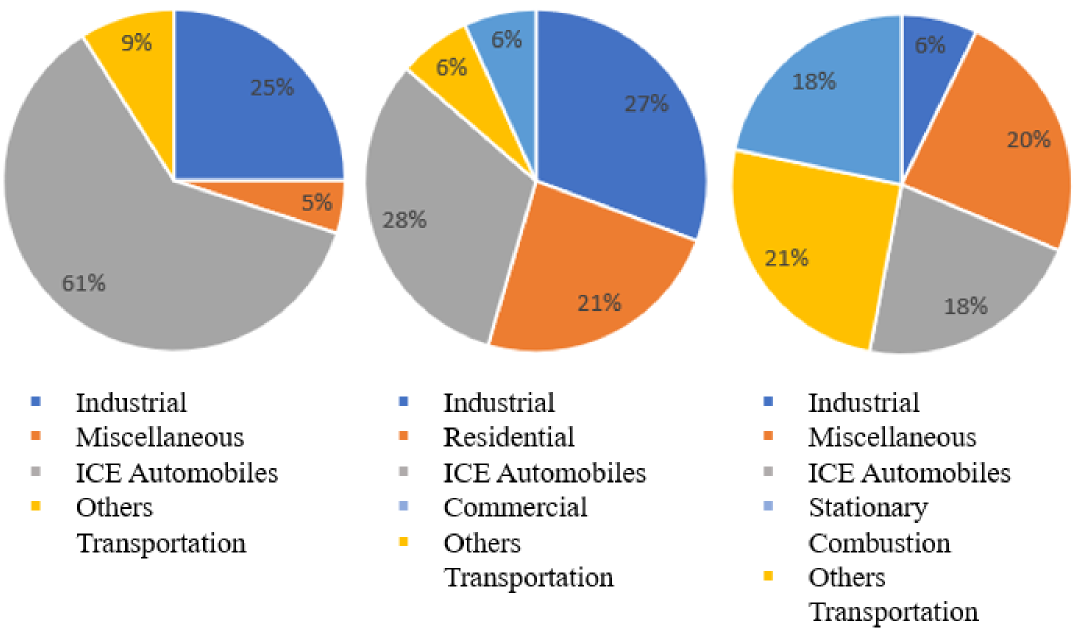

Figure 1.1 Involvement of ICE powered automobile to three major areas.

The drawback ICE-powered vehicles' regarding its hazardous byproducts have driven the introduction of several alternative vehicle technologies- sometimes also known as new energy vehicle (NEV), including HEV, EV, hydrogen powered vehicle. Out of all NEV listed, many people agree that HEVs are one of the most practical answers to the global demand for relatively clean, extra fuel-efficient vehicles [4]. Utilizing hybrid propulsion has helped lower gas emissions and particulate matter emissions, including carbon, nitrogen, and sulphur dioxide [5]. Butler et al. stated that in hybrid vehicles, energy is initially transformed into mechanical energy by an ICE and an electric motor

(EM), respectively, after the fuel undergoes the combustion process and from the electrical storage system (ESS), like a battery pack [6].

1.2 Problem Statement

Due to numerous studies regarding the EV and HEV parameter design, contradictory design goals, and time-consuming process are among the most notable challenges facing the HEV research field. Optimizing EMS using a real hybrid electric car model is very expensive, tedious, and challenging. Moreover, testing new algorithms in an EV will be next to impossible since it will require real testbeds and reprogramming the whole vehicle setup with hundreds of parameters relating to each other. Therefore, to test the overall car's performance, which might be time-consuming and the cheapest solution that can allow more researchers to the field is desirable.

Depending on a given criterion, the most common controller, which is rule-based strategies (RBS), still only prioritizes driving demand in many production HEVs, which leads to inefficient fuel consumption and low efficiency, even if is easy to implement. Plus, there is no single controller that fits all HEV architectures. There is an opportunity to make the controller that can deliver higher-efficiency HEV compared to the current solution.

To ensure the performance of a newly designed EMS controller, a series of testing and simulations are required, thus, the need of a simulation platform that allows development or vehicle model and the EMS controller on a single interface which is a highly sought after solutions chosen by many researchers. The performance and integrity of a EMS controllers must be verified using testing's on standard drive cycles to ensure comparable performance with other studies.

1.3 Objectives

The objective of this research is:

1. To modify a HEV simulation model on MATLAB Simulink for EMS development and simulation.
2. To improve and optimize the rule-based EMS with a new fuzzy logic controller (FLC) to reduce fuel consumption and manage battery SOC.

3. To simulate and evaluate the performance of HEV with FLC on standard drive cycle, focusing on fuel efficiency.

1.4 Scope of the project

This project involves testing real-time HEV data in simulation using MATLAB Simulink software. In this project, the optimisation of the EMS in HEV will be analysed using an existing algorithm 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 HEVs by using drive cycle data, as used in many automotive applications. This project focuses on EMS in series parallel HEV but will only be limited to simulation work.

1.5 Report Outlines

This report consists of five important chapters, each of which will deliver different kinds of things and details in this project.

Chapter 1 introduces the background study relating to the current issue happening to a vehicle that releases carbon emissions and the same time, affects air pollution plus EMS in vehicles. The overview of this project is elaborated briefly, including the problem statement that arose, the idea for this report, the objective, and the scope of the study project to finish the task.

For Chapter 2 introduces a literature review, background, development, business conducted by other researchers in the same field, and challenges pertinent to Parallel HEVs and EMS. This chapter examines the preliminary designs of a HEV, focusing on parallel configuration and analyses of the parts.

Chapter 3 provides an overview of the research techniques implemented in this project. This chapter provides an overview of the EMS technique for series-parallel HEV by focusing on previous research works. This chapter describes the pattern and technique that will be used to reduce the fuel consumption of series-parallel HEV. The technique use in this paper is distribute the amount of power between ICE and EM using fuzzy logic strategy (FLS). Discussion regarding the software and platform used to study and modify the controller of the series-parallel HEV model is stated in this section.

In Chapter 4, the series-parallel HEV simulation model result using different common drive cycles, including the graph plot of vehicle speed, power flow, amount of fuel consumption and final battery SOC. The finding will be interpreted in the table and graph; thus, it will be rationale discussed. In this chapter, the comparison between different drive cycles has been presented in detail.

In the last Chapter 5, the conclusion is deduced from findings according to the experimental work that addresses the objective. The future recommendation also included what may be required for this project.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter provides a brief explanation and details on the idea of EMS optimization for HEV. By improving the current approach, technology can be leveraged to enhance and implement EMS more effectively.

2.2 Hybrid Electrical Vehicle

A HEV combines an ICE with an electric propulsion system. It indicates that HEVs can also be driven using an ICE. HEVs create fewer emissions than conventional vehicles of comparable size because their ICE is optimized for optimal efficiency. HEV integrates an ICE's and an EM's propulsion system plus the onboard batteries provide the EM's power source. For HEV, when the ICE and EM work together, it can give positive impact on the ICE since it works on the optimum way [7]. Driving through heavy traffic necessarily requires frequent vehicle starts and stops. The ICE consumes more fuel while idling without performing any beneficial work, which lowers the efficiency and produces wasteful air pollutants. By converting to transmitting power via the EM and shutting off the ICE, the HEV can solves the problem. As a result, no fuel is used while the ICE is idling, and no emissions are produced.

Classic HEV have include an ICE, EM, single or multiple energy storage systems (ESS), power electronic converters, and controllers [8]. The performance of powerful and reliable controller in the field of EM leads to the application of FLC in the system [8]. The fuzzy set or FLC application theory in system controller has achieved worldwide recognition. Therefore, it is simpler to construct and more efficient for the control of the drives.

2.3 How Hybrids Work

HEVs combine the advantages of ICE and EM. They can be developed to fulfil various goals, such as reduce fuel consumption or improve the performance.

Most hybrids employ several cutting-edge technologies:

- Regenerative Braking

Regenerative braking replenishes energy lost while cruising or braking. The ICE is spun by the forward motion of the wheels as a result, the car slows down effect from offered energy [9].

- Drive/Assist EM

The EM provides power to help the ICE accelerate, move, or climb hills, while also enabling the use of a smaller, more economical ICE. In certain hybrids, the EM alone moves the car at low speeds, where ICE is least powerful.

- Stop/Start Automatic

The ICE will turn off by itself as soon as the vehicle on complete stop. The vehicle will only restart when the accelerator pedal is pushed again. It reduces the amount of energy that is lost due to idle.

2.4 Classification of HEV

Typically, hybrid vehicles contain two or more power sources that generate, store, and produce electricity to the EM since these forms of energy are commonly referred to as an ICE and an EM. The concept of hybrid electric architectures' powertrains can be categorized into three types which are series, parallel, and series-parallel configuration.

2.4.1 Series Hybrid

In a series hybrid system, as opposed to a conventional car, the ICE drives the electric generator rather than the wheels. As shown in Figure 2.1 [7], the engine-generator is in charge of charging the battery pack while simultaneously powering the EM that drives the vehicle, with the EM continuing to act as the only source of energy that supplies power to the wheels [10] . Once the vehicle requires a significant amount of power, the EM will frequently extract energy from both the batteries and the generator to produce sufficient power while simultaneously satisfying the driver's requirements.

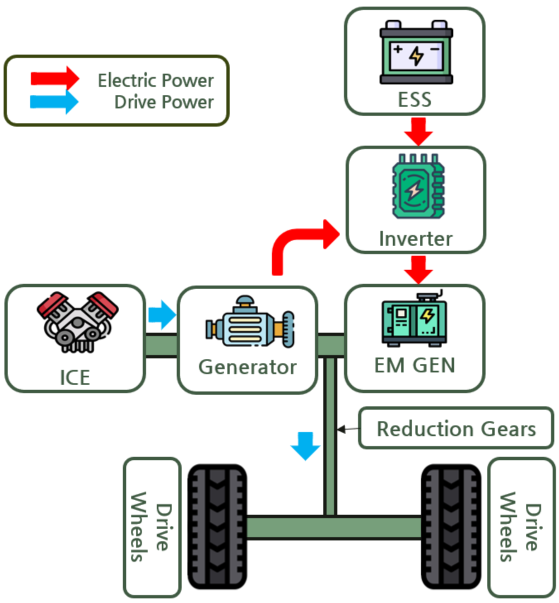

Figure 2.1 Configuration of series hybrid model.

2.4.2 Parallel Hybrid

In parallel hybrid systems, the ICE and an EM are linked together mechanically in parallel to an automatic transmission. The ICE and the EM are attached mechanically. This coupling system has numerous design possibilities, including an extra generator [2]. Usually, the layout architecture for parallel hybrid eliminates both the regular starter motor and alternator in favour of a single large electrical generator and EM, which is normally positioned between the ICE and the transmission [7], since it can greatly help in term of reducing fuel consumption of the vehicle. When the vehicle runs in lower speed mode, the EM will deliver the power to reduce fuel usage. Thus, this structure can maintain a higher efficiency and better fuel consumption [11]. The battery can be recharged both during regenerative braking and while the vehicle is cruising (when the ICE power is larger than the essential power for propulsion).

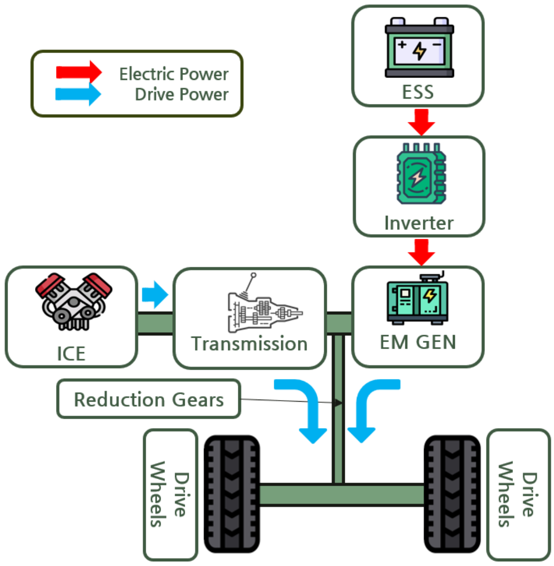

Figure 2.2 Configuration of parallel hybrid model.

Referring to Figure 2.2 [7], the ICE and EM operate in tandem. Typically, the ICE is the primary propulsion system, with the EM working as a reserve power or torque booster. In this case, lighter, compact batteries and more effective braking systems are used to slow down the vehicle and store energy while it does so.

2.4.3 Series-Parallel Hybrid

Based on Figure 2.3 [7], this form of architecture merges series and parallel architecture model and enable the vehicle to move in variously such are fully electrical (series hybrid), combustion vehicle (parallel hybrid) or as a series-parallel mode which is the combination between two. Furthermore, this power train is the most complicated compared to others. Systems that combine hybrid technology have traits of both parallel and series hybrids. A dual mechanical and electrical connection exists between the ICE and the driving axle. The coupling of mechanical and electrical power is made possible by the split power channel, but it is increasing complexity in layout. The power train contains power-split components, and the power delivered to the wheels may be mechanical, electrical, or a combination of both [7].

The fundamental idea is to separate the driver's power requirements from the power given by the primary source. In a combination hybrid, this approach works as a series HEV when the speed is low while switching to an ICE at higher speeds thus the series