ENERGY MANAGEMENT SYSTEM IN FUEL CELL ELECTRIC VEHICLE
USING FUZZY LOGIC CONTROLLER

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DEDICATION

This thesis is dedicated to my wife, who has been my true supporter throughout my study. This dedication also goes to my parent, who taught me to focus and keep on moving.

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ABSTRACT

In response to the environmental degradation and the climate change impact, the global concerns are now rising towards the alternative source of fuel and carbon emission issues. In the transportation sector, Electric and hybrid vehicles are having the encouraged interest globally, since they are viewed as the most promising alternatives for pollution abatement and carbon emission reduction. This will open the window for the alternative to the reduction of conventional fossil-based fuel usage. Proton Exchange Membrane Fuel Cell (PEMFC) Electric Vehicles (FCEV) are among the options of the kind due to better environment and performance prospects offered compared to the internal combustion engine vehicles (ICEV). However, the Fuel Cells (FC) need to be hybridized with energy storage source to improve the dynamics and power density of the FC systems. Using two sources of power require an intelligent energy management strategy since the FC health and battery state-of-charge (SOC) shall be maintained at optimum level. The energy management control of FCEV is currently an increasing research area in the EV technology development. The goal of this work is to propose an intelligent energy management strategy in controlling the FC's power output, thus maintain the optimum SOC level in a FCEV. A Fuzzy Logic Controller (FLC) is developed in this work. FLC is appropriate for power distribution in FCEV, as it is independent against the technical aspect of FCEV system. A FCEV model is developed, and simulation is implemented in the MATLAB/Simulink environment. A Proportional-Integral (PI) controller technique is also developed, as a comparison to the proposed FLC validity and performance. By adopting Fuzzy Logic Controller, the optimum performance of FCEV is obtained. Consequently, the FC durability and battery lifetime can be enhanced.

ABSTRAK

Sebagai tindak balas kepada degradasi alam sekitar dan kesan perubahan cuaca, kebimbangan global sekarang telah meningkat ke arah sumber bahanapi alternatif dan juga isu pelepasan karbon. Di dalam sektor pengangkutan, kenderaan elektrik dan hybrid sedang mendapat minat yang memberangsangkan di peringkat global, sejak ianya dilihat sebagai cara alternatif yang paling meyakinkan bagi tujuan pengurangan pencemaran dan juga pengurangan pelepasan karbon. Ini akan membuka ruang alternatif kepada pengurangan penggunaan bahanapi yang konvensional berasaskan fosil. Kenderaan Elektrik Sel Bahanapi Membran Penukaran Proton (PEMFC) (FCEV) merupakan antara pilihan daripada kenderaan jenis ini disebabkan prospek yang ditawarkan kepada persekitaran dan prestasi yang lebih baik berbanding dengan kenderaan daripada enjin pembakaran dalaman (ICE). Walau bagaimanapun, Sel Bahanapi (FC) perlu dihibridkan dengan sumber penyimpanan tenaga untuk menambahbaikkan dinamik dan ketumpatan tenaga dalam sistem FC itu sendiri. Menggunakan dua sumber kuasa memerlukan strategi pengurusan tenaga yang pintar disebabkan kesihatan FC dan keberadaan cas (SOC) bateri hendaklah dikekalkan pada paras yang optimum. Pada masa kini, bidang penyelidikan kawalan pengurusan tenaga FCEV sedang mengalami peningkatan di dalam pembangunan teknologi kenderaan elektrik (EV). Kerja ini disasarkan untuk mencadangkan strategi pengurusan tenaga yang pintar dalam mengawal penghasilan kuasa FC, dan seterusnya akan mengekalkan paras SOC yang optimum di dalam FCEV. Pengawal Logik Fuzzy (FLC) dibangunkan di dalam kerja ini. FLC adalah bersesuaian untuk pengagihan kuasa di dalam FCEV kerana ianya adalah bebas daripada aspek teknikal di dalam sistem FCEV. Suatu model FCEV juga dibangunkan, dan simulasi dilaksanakan di dalam persekitaran MATLAB/Simulink. Dengan menggunakan FLC, prestasi FCEV yang optimum akan dicapai. Disebabkan itu, ketahanan FC dan jangkahayat bateri boleh ditingkatkan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFC	-	Alkaline Fuel Cell
BDC	-	Bi-directional DC-DC Converter
DC	-	Direct Current
DMFC	-	Direct Methanol Fuel Cell
DTC	-	Direct Torque Control
ECMS	-	Equivalent Consumption Minimization Strategy
EMS	-	Energy Management System
ESS	-	Energy Storage Source
EV	-	Electric Vehicle
FC	-	Fuel Cell
FCEV	-	Fuel Cell Electric Vehicle
FLC	-	Fuzzy Logic Controller
HESS	-	Hybrid Energy Storage System
HEV	-	Hybrid Electric Vehicle
ICE	-	Internal Combustion Engine
MCMC	-	Molten Carbonate Fuel Cell
MF	-	Membership Function
NiMH	-	Nickel Metal Hydride
PAFC	-	Phosphoric Acid Fuel Cells
PEMFC	-	Proton Exchange Membrane Fuel Cell
PMDC	-	Permanent Magnet DC
PMSM	-	Permanent Magnet Synchronous Motor
PSO	-	Particle Swarm Optimization
SOC	-	State-of-Charge
SOFC	-	Solid Oxide Fuel Cell
UTM	-	Universiti Teknologi Malaysia

LIST OF SYMBOLS

F	-	Force
D, d	-	Diameter
v	-	Velocity
r	-	Radius
p	-	Pressure
P	-	Power
°C	-	Degree Celsius (Temperature)

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Problem Background

Environmental degradation and climate change impact such as changes in the climatic season durations i.e. longer period of draughts and increment of tropical storms. According to the Intergovernmental Panel on Climate Change (IPCC), the climate change effects however are differing among the continents of the world, and there will be increment in the global mean temperature of 1 to 3 degree Celsius over the next 100 years based on 1990 level [60]. Some identified root-cause of this issue is the carbon emission into the atmosphere by modern human activities. Due to that, the global concerns are evolved around the alternative fuel to fossil fuels and mitigation of carbon emission in main sectors such as energy, transport, agriculture, waste, and industrial processes.

In the transportation sector, more attentions are given in the reduction of fossil-based fuel usage or even emission-less mode of transportation. In response to this view, electric vehicles (EV) technology is explored rapidly by experts worldwide. The EVs including Hybrid Electric Vehicles (HEVs) are having the encouraged interest globally since they are viewed as the most promising alternatives for pollution abatement and carbon emission reduction in the transportation industry.

Fuel Cell Electric Vehicles (FCEVs) are among the options of the current HEV technology direction. Being powered by renewable source, FCEV emits low carbon emission as compared to the conventional Internal Combustion Engine Vehicles (ICEV). Besides, the advanced available Fuel Cell technology options ensures that the FCEV will be a more efficient type of vehicle. To be functioning at their optimum level, the Fuel Cells (FC) need to be combined with other energy storage source (ESS). These devices such as batteries and supercapacitors (SC) are the typical hybrid combination with the FCs to improve the energy dynamics and power density in the FCEV systems. The evolvement of this adoption requires an intelligent power management strategy for designated purposes such as power splitting and power optimization, since two separate sources of power are combined. Apart from that, the FC health and battery State-of-Charge (SOC) shall be maintained at their respective optimum levels to ensure the longer life-span of the energy units.

Intelligent controllers have various advantages as their design is robust and can be adjusted according to the specific requirements [1]. Among the intelligent and adaptive controller is the Fuzzy Logic Controller (FLC) which is simple yet powerful and better in terms of response time, and other parameters [2], [3].

1.2 Problem Statement

In the modern transportation industry, there are growing interests in the field of EV as the alternative to the conventional ICE vehicles. This is due to the promising prospect that EVs offer especially towards the better environment. Apart from that, there is also increment in the research interest of the Energy Management System (EMS) cluster of the EV, and this is an ever-evolved field of research as each commercially developed EVs would be having a specific operating condition [4]. Thus, it will be beneficial for a specific study on EMS of FCEV to be conducted.

There are several issues with the EMS of FCEV, including but not limited to the followings:

a. Using two sources of power (FC and ESS) require an intelligent power management strategy

b. FC health and battery SOC shall be maintained at optimum level while producing the required amount of power to the FCEV

c. Hydrogen consumption by FC shall be optimized without compromise the FC's power output to complement the FCEV power requirements.

1.3 Research Objectives

In this research work, it is aimed to develop an energy control strategy for a FCPHEV. By clear defining this purpose, the objectives are outlined below:

a. To develop an energy controller based on Fuzzy Logic Controller
b. Application of the developed controller on a selected FCEV model in MATLAB/Simulink environment
c. To apply PI controller for comparison purpose

1.3.1 Research Goal

With the research objectives are outlined clearly in the previous section, this project work is implemented towards a primary goal which is to develop an energy management control strategy for a Fuel Cell Electric Vehicle (FCEV).

1.4 Work Scope

To ensure that this project work is conducted within the stipulated time, and for the ease of activity workflow management, the following scopes are outlined:

a. A Fuzzy Logic Controller shall be developed.
b. The newly developed controller will be implemented in MATLAB/Simulink Environment on a selected developed model of FCEV for validation purpose.
c. The evaluation of controller will be based on its performance against the parameters such as optimal battery SOC, and optimal FC power production against the FCEV power demand.

1.5 Report Outline

This project report consists of 6 chapters including Conclusion at the 6th Chapter. The Chapters are organized as follows:

- Chapter 1

  This chapter consists of problem background, problem statement, and research objectives. It also discuss on the work scopes, report outline and finally project execution planning and arrangement.

- Chapter 2

  In this chapter, literature reviews are made on Hybrid Electric Vehicles, followed by reviews on Fuel Cell Hybrid Electric Vehicle. Under this subsection, reviews on Fuel cell and Energy storage system are made. This is followed by reviews on Fuzzy Logic Controller and PI Controller. These reviews also discussed on the previous related works.

- Chapter 3

  This chapter discuss on the identified research methodology which started with the overview on the research works outline. This is followed by the identification and development of the energy management controller for this work is Fuzzy Logic Controller. After the development of FLC, the methods in selection and development of FCEV model is discussed. As mentioned previously, the developed controlled is compared against the PI controller, thus this subsection will conclude the chapter.

- Chapter 4

  After all components are developed and in place, then the whole system performance is tested in MATLAB/Simulink environment. This chapter will discuss on the controllers performance which includes the comparison of the controllers performance. This is discussed with the achieved simulation results.

- Chapter 5

  Chapter 5 concludes the whole work. Further realistic possible future works are proposed as well.

1.6 Project Planning and Execution

For the whole 2 semesters of this project works, the planned activities are presented in the following Gantt chart:

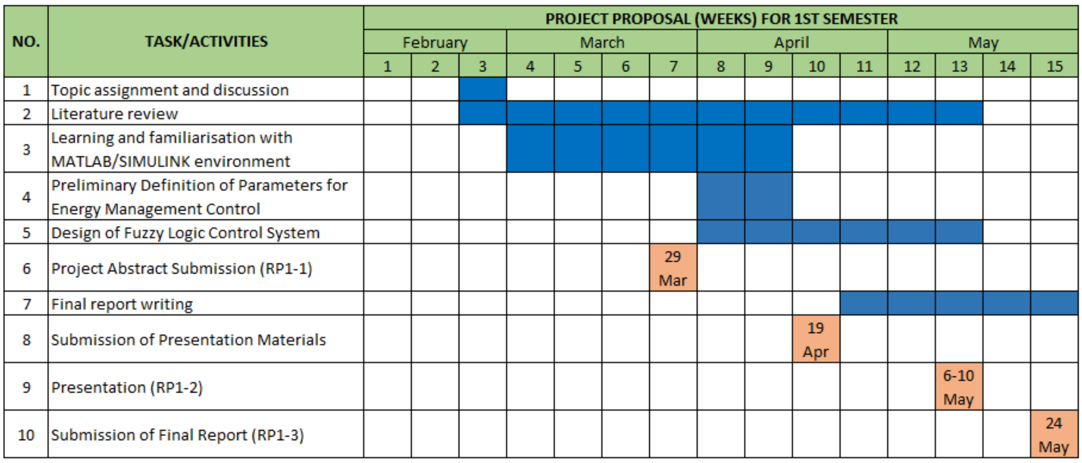

Figure 1.1 Project Working Plan for First Semester

NO.	TASK/ACTIVITIES	PROJECT PROPOSAL (WEEKS) FOR 2ND SEMESTER														
		September			October				November				December			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of PEMFC-PHEV Components Identification and Definition															
2	Set-up of EV Model and Verification															
3	Application of Fuzzy Logic Control System based on the developed PEMFC-PHEV Model in MATLAB/SIMULINK															
4	Design of PI Controller System															
5	Application of PI Controller in the developed PEMFC-PHEV Model in MATLAB/SIMULINK															
6	Results Comparison and Analysis															
7	Preparation for Presentation															
8	Submission of Presentation Materials															
9	Presentation															
10	Preparation of Thesis															
11	Submission of Thesis															

Figure 1.2 Project Working Plan for Second Semester

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