SUPERVISORY CONTROL OF PARALLEL HYBRID ELECTRIC VEHICLES USING MATLAB/ SIMULINK

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"To my parents, beloved brothers and sisters"

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Praise be to Allah, The Lord of universe. Only with His uncountable favors that I can finish this work. Wish He accept all of my faithful learning efforts as the way I sincerely express my gratefulness.

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Skudai, Johor - Malaysia
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ABSTRACT

Due to the limitation of fossil fuels and the high consumption rate of this energy for transportation, inclination of vehicle industry toward other sources of energy is inevitable. Electric vehicles and hybrid vehicles could be a good solution. Thanks to the state of art electric motors, power electronics, embedded power train controller, energy storage systems like batteries and ultra capacitors, the performance of the vehicle could become more and more energy efficient. Since the integrating of all these components in a drive train configuration could be a challenge for the manufacturer, computer simulation and modeling before prototyping could be really beneficial in terms of cost, safety and design performance.

The main objective of this study is to establish a systematic approach to parallel hybrid electric vehicle modeling and simulation as well as implementation of the supervisory control in order to improve system efficiency and reduce fuel consumption. This thesis offers an overview of the various applied control strategies in hybrid electric vehicles, specifically to the parallel hybrid electric vehicle. Several control strategies are described in literature as well as important of supervisory control strategy in hybrid electric vehicle and the difference in terms of energy management is discussed.

Different hybrid power-train configuration are presented and explained in this thesis. Hybrid electric vehicle driveline components including electric motor, vehicle dynamic, internal combustion engine and electric energy storage are illustrated. In addition, some of the principles of modeling and simulation are discussed and different methods of modeling are presented. A detailed parallel hybrid vehicle modeling and simulation in Matlab environment using Simscape toolbox is presented. A rule-based supervisory control strategy using Simulink/Stateflow is applied to control hybrid vehicle in order to operate parallel hybrid driveline component in their optimal region and consequently to achieve high-performance low-emission hybrid drive-train. Simulation results for the major components of hybrid driveline are presented to demonstrate the effectiveness of this supervisory control strategy.

ABSTRAK

Disebabkan oleh bahan api fosil yang terhad dan kadar penggunaan bahan api ini yang tinggi bagi kegunaan pengangkutan, kecenderungan industri automotif untuk berubah kepada sumber tenaga lain tidak dapat dielakkan. Kenderaan elektrik dan hibrid merupakan satu penyelesaian yang terbaik. Terima kasih kepada kemampuan motor elektrik, elektronik kuasa, pengawal pemacu, sistem penyimpan tenaga seperti bateri and kapasitor ultra, prestasi kenderaan ini mampu menjadi lebih baik lagi. Disebabkan oleh penggunaan komponen-komponen ini dalam sistem konfigurasi pemacu menjadi satu cabaran kepada industri pembuatan kenderaan, simulasi komputer dan pemodelan sebelum penghasilan prototaip mampu memberi manfaat dari segi kos, keselamatan dan rekabentuk.

Objektif utama kajian ini adalah untuk menghasilkan satu kaedah pendekatan sistematik untuk pemodelan dan penyelakuan kenderaan hibrid elektrik selari serta perlaksanaan kawalan penyeliaan bagi menambah baik kecekapan sistem dan mengurangkan penggunaan bahan api. Thesis ini membentangkan tinjauan tentang pelbagai strategi kawalan bagi kenderaan elektrik hibrid, khususnya kenderaan elektrik hibrid selari. Beberapa strategi kawalan yang telah dihasilkan beserta kepentingan strategi penyeliaan kawalan di dalam kenderaan elektrik hibrid serta perbezaan dari segi pengurusan tenaga juga dibincangkan.

Perbezaan konfigurasi pemacu hibrid akan dibentang dan dibincangkan dalam thesis ini. Komponen kenderaan elektrik pemacuan seperti motor elektrik, dinamik kenderaan, enjin pembakaran dalaman dan penyimpan tenaga elektrik juga disampaikan. Disamping itu, beberapa prinsip permodelan dan simulasi juga dibincangkan dan kepelbagaian teknik permodelan dibentangkan. Satu penerangan terperinci mengenai permodelan kenderaan hibrid selari dan simulasi di dalam persekitaran Matlab menggunakan Simscape dibentangkan. Strategi berasaskan syarat untuk strategi kawalan penyeliaan menggunakan Simulink/Stateflow telah digunakan dalam kawalan kenderaan hibrid untuk memastikan komponen pemacu beroperasi secara optima dan seterusnya mencapai kecekapan tinggi serta perlepasan pencemaran udara yang rendah. Keputusan simulasi untuk komponen utama dalam pemacuan hibrid dibentangkan bagi menunjukkan keberkesanan kaedah penyeliaan kawalan ini.

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LIST OF ABBREVIATIONS

EV	-	Electric Vehicle
HEV	-	Hybrid Electric Vehicle
ICE	-	Internal Combustion Engine
SOC	-	State Of Charge
EM	-	Electric Machine

LIST OF SYMBOLS

A_f	–	Frontal Area
C	–	Capacitance
d	–	Piezoelectric Transmission Coefficient
E	–	Energy
F	–	Force
f	–	Frequency
f_r	–	Resistance Coefficient
C_D	–	Aerodynamic Drag Coefficient
C_r	–	Frictional Constant
J	–	Inertia of the vehicle
M, m	–	Mass
P	–	Power
Q_{tot}	–	Capacitor Total Charge
R_{eq}	–	Capacitor Equivalent Resistance
T	–	Period
V	–	Voltage
$i(t)$	–	Current
i_t	–	Transmission Efficiency
W	–	Weight
r	–	Tire Radius
α	–	Road Gradient
δ	–	Mass Factor
η	–	efficiency
ρ	–	Air Density
τ	–	Torque
ω	–	Angular Velocity
	–	

CHAPTER 1

INTRODUCTION

1.1 Background of the study

The sharp rise in petroleum consumption and fuel importing and consequently detrimental environmental effects of the fuel consuming tool cause serious concern on the economy and environment in the most countries. According to statistics, transportation is the one the most fuel consuming sectors. Two third of the imported petroleum in the developed countries are being consumed in transportation sector.

Since the dominant meant of the transportation has been in the form of the personal automobiles, this area has gained more attention. Limited domestic oil natural reserves and the extensive use of the personal cars have led to some economical concern and countries dependence to foreign oil markets. Half of consumed petroleum in the USA were imported. This shows the extend of the country's economy vulnerability to varying petroleum price and other related issues.

Owing to the fact that personal transportation has significant contribution to fuel consuming sector there still exist some hinder for automobile manufacturer production to meet related regulation regarding to vehicles performance, noise and harmful emission. Hence, Improvement of the fuel consumption and overall energy efficiency is one of the most important subjects for developing and designing new vehicles technologies. It is understandable that there exist a contrast between global concern on sustainable energy use and environmental protection. This contradictory clearly call for new technology to play fundamental role. The promising technology to overcome on these obstacles to meet regulations are exploitation of alternative energy sources in vehicle power-train, improving fuel economy and reducing the harmful emission.

The new vehicle technology appeared in the forms of Electric Vehicle (EV), fuel cell vehicles, Hybrid Electric Vehicle (HEV). Among alternative power-train solution being investigated, HEVs due to their major advantages on other vehicles are more popular. In general, HEVs have two power sourcesto run the traction simultaneously or respectively in order to propel the vehicle wheels. Moreover, the HEVs are more efficient and performed better with compare to conventional engines. In some controlling circumstances HEVs can be run in zero emission vehicle (ZEV) state. So this fact made HEVs a important player in today's automobile market.

Since research and analyzing is a time consuming process, computer based simulation and modelling is an approach to deal with this limitation. Virtual prototyping, however, can be used to reduce the expenses and the length of the design cycle. Variety of the vehicle simulator such as SIMPLEV, HVEC, CarSim, ADVISOR and so on are available.

Many studies and researches have been carried out on hybrid electric vehicles. However, most of them used different simulation and modelling tools to perform their study. In the reference [10] a series hybrid and electric vehicle drive-train is modelled and simulated on PSCAD which is a transient simulation program. In addition in references [3], [14], [15],[16],[17],[18] various topologies of the hybrid electric vehicle have been investigated. In ref [1] PSAT is used to analyze performance of the HEV. Furthermore, researcher in ref[14] modeled and compared in both HEVSIM and ADVISOR then simulation results which is more accurate were compared. On the other hand, many technical control strategies have been proposed and at the same time investigated by references [8], [5], [1], [11] in which in ref [12] authors tried to introduce new vehicle controlling to fully meet driver desires. Past control methods were sensitive to different driving habits and vehicle parameters variation. Thus researcher in ref [12] has implemented neural network concept as control strategy to eliminate this flaw. Moreover, in ref [6], [19] several available types of batteries in the ADVISOR library are introduced. In addition, the temperature impact on the vehicle performance and life cycle of the battery is studied. Finally, a optimization study has been conducted to achieve low-weight and more fuel-economy HEV in ref [2].

1.2 Statement of the problem

It is evident that the great amount of the fuel is being consumed by personal transportation and they have significant contribution on harmful emissions. Therefore, increasing concerns about environmental issues such as global warming and greenhouse emissions as well as natural oil sources depletion have made energy efficiency and being environmentally friendly as primary selling point for automobiles. In spite of the fact that HEVs offer some important advantages in comparison to conventional engines, their configuration comprise more component and greater complexity with higher initial price. Thus, implementation of the simulator software to predict the behaviour of the vehicular system under various circumstances are inevitable.

Compared to conventional vehicles, hybrid electric vehicles consist of more component (electrically and mechanically) and this increase the complexity of the vehicle system. In addition to these electrification component and subsystems, the dynamic analysis of the various component interaction becomes difficult. Modelling and simulation are absolutely necessary for concept evaluation, prototyping and analysis of the newly design HEV. Therefore, a modelling and simulation environment to model subsystems, embedded software and component is needed[2] .

In the other word, in order to realize the benefits of HEVs, the designs must be extensively modelled and refined before improved emissions and fuel economy can be implemented on a large scale. This will require accurate, flexible simulation tools, which will expedite the design processes for HEVs. This will enable engineers to compare the relative performance of one design to another and concentrate on the best designs.

1.3 Purpose of the study

with an increasing growth of the concerns about environmental related issues which is partly contributed by the passengers cars in harmful emissions draws attention to this sector. Furthermore, the selection and analysis of the appropriate propulsion systems role in the reduction of the fuel consuming, long travelling range and efficiency are considerable.

This increasing demand for more implementation of the fuel economy and efficient vehicles cause automobile designer to shift toward the design of new generation power-trains beyond the conventional (fuel-only) engines. Hence, the vehicles hybridization and enhanced design leads to fulfil the constraints and regulations on petroleum and environment. Simulation is one the efficient way in the design and analysis of different levels of the propulsion system before physical testing and construction begins. Furthermore, it provide this capability to examine various control strategy to have efficient running of the vehicle. The purpose of this study is to achieve greater understanding of the HEVs design and simulation, as well as, their impact on environment.

1.4 Objectives of the study

The objective of this study are:

- To simulate parallel configuration of the Hybrid Electric Vehicle using Matlab/Simulink
- To implement supervisory control of the HEV to optimal operation of the hybrid vehicle's component using stateflow toolbox of the MATLAB/Simulink.
- To investigate HEV's environmental impact
- To compare different topologies of the HEV in terms of their performance, fuel consumption and emission.
- To achieve more understanding of the Hybrid Electric Vehicles.

1.5 Significant and scope of the study

Currently many studies there are have been carried out to model and simulate of the different topologies of the HEVs. The result of this study can be used as part of the approach to new vehicle component selection. Therefore, the evaluation of the vehicle performance criteria including gradeability, acceleration, driving range, pollution, energy consumption will be the scope of this study[3].

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