PERFORMANCE SIMULATION OF PEM FUEL CELL POWERTRAINS FOR ALL-TERRAIN VEHICLES (ATVs)

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"This thesis is dedicated to my father for his endless love, support and encouragement"

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In the name of Allah, the Compassionate, the Merciful

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ABSTRACT

Fuel cell hybrid vehicles (FCVs) including batteries and fuel cell are being studied. In hybridisation of fuel cell the consideration of fuel economy, efficiency, emissions and characteristics of power output are necessary. Hybridization allows the size of the fuel cell is to be reduced by using a battery and an Ultracapacitor, and it is beneficial when the power demand is high, like with higher loads or acceleration, and it permits the fuel cell system to be operated more efficiently. In association with the above, the cost of vehicle can be reduced by reducing the cost of expensive fuel cell. When the power demand is low, the fuel cell will provides the required power. Battery and Ultracapacitor will assist in fast start up of the fuel cell and allows capture of the regenerative energy. This study deals with the comparison between two powertrain strategies for the All-Terrain Vehicles (ATVs): a Fuel Cell-Battery powertrain strategy and a Fuel Cell-Battery-Ultracapacitor powertrain strategy. A methodology of modeling hybrid vehicle configurations with three energy devices in Advanced Vehicle Simulator (ADVISOR) 2003 was developed. The vehicle models, including the ATV (golf cart) physical model, the ATV Fuel Cell (FC) system of 4.8 kW, and the power bus of the Fuel Cell-Battery-Ultracapacitor powertrain, were programmed in MATLAB/Simulink. Large scale simulations were run in order to find the optimized powertrain strategy. The cost function in this study considered the acceleration performance, gradeability, hydrogen consumption, and powertrain cost. According to the cost function, FC-BT vehicle powertrain cost is 7% less than the cost of FC-BT-UC powertrain and 10% less than the pure FC vehicles.

ABSTRAK

Fuel cell hybrid vehicles (FCVs) termasuk bateri dan sel minyak telahpun dikaji. Didalam penghibridan sel minyak, pertimbangan terhadap ekonomi minyak, efisiensi, pelepasan dan ciri-ciri output kuasa adalah perlu. Penghibridan membenarkan pengecilan saiz sel minyak menggunakan satu bateri dan kapasitor dan ia bermanfaat apabila kuasa permintaan tinggi, dengan tekanan atau pecutan yang tinggi dan ia membenarkan sistem sel minyak untuk beroperasi dengan lebih efisien. Berkaitan di atas, kos untuk kenderaan dapat dikurangkan dengan mengurangkan kos sel minyak yang mahal. Apabila permintaan kuasa menjadi rendah, sel minyak akan menyediakan kuasa. Bateri dan Ultra-kapasitor akan membantu dalam mempercepatkan sel minyak da membenarkan penangkapan kuasa penjanaan semula. Kajian ini berkait rapat dengan perbandingan antara dua strategi powertrain untuk semua All-Terrain Vehicles (ATVs): satu strategi powertrain Fuel Cell-Battery dan satu strategi powertrain Fuel Cell-Battery-Ultracapacitor. Satu metodologi tentang konfigurasi untuk model kenderaan hybrid dengan tiga alatan tenaga telah dibangunkan dalam Advanced Vehicle Simulator (ADVISOR) 2003. Model-model kenderaan termasuklah model fizikal ATV (kereta golf), Sistem ATV Fuel Cell (FC) dengan 4.8kW dan bas kuasa dengan powertrain Fuel Cell-Battery-Ultracapacitor telah diprogramkan dalam Matlab/Simulink. Simulasi berskala besar telah dijalankan untuk mencari strategi powertrain yang optimum. Fungsi kos dalam pengkajian ini mempertimbangkan prestasi pecutan, gradeablility, penggunaan hydrogen dan kos powertrain. Berkaitan fungsi kos, kos powertrain untuk kenderaan FC-BT is 7% kurang daripada kos powertrain FC-BT-UC dan 10% kurang daripada kenderaan FC yang asli.

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LIST OF ABBREVIATIONS

ADVISOR	-	ADvanced VehIcle SimulatOR
ATV	-	All-Terrain Vehicle
ESS	-	Energy storage system
EV	-	Electric Vehicle
FC	-	Fuel Cell
FC-BT	-	Fuel Cell-Battery
FC-BT-UC	-	Fuel Cell-Battery-Ultracapacitor
HEV	-	Hybrid Electric Vehicle
IMA	-	Integrated Motor Assist (Honda)
IC	-	Internal Combustion (Engine)
Li-ion	-	Lithium ion
NEV	-	Neighborhood Electric Vehicle
NEVDC	-	Neighborhood Electric Vehicle Driving Cycle
Ni-MH	-	Nickel Metal hydride
NREL	-	U.S. National Renewable Energy Laboratory
Pb	-	Lead Acid
PEM	-	Proton Exchange Membrane (fuel cell)
PM	-	Permanent magnet (motor)
SLPM	-	Standard Liters per Minute
SOC	-	State of Charge
VW	-	Volkswagen
“bx-uy”	-	Energy storage system with number of x battery modules and number of y Ultracapacitor cells

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CHAPTER 1

INTRODUCTION

1.1 Background

The increasing number of vehicles on the road and the dependency on limited non-conventional energy resources has raised questions about environmental issues and sustainability. In developing countries like India and China automobile market is booming, however in US and Europe the need for vehicle is increasing day by day. China rushed past Japan to become worlds number two vehicle market after the United States [1]. The first National Household Travel Survey of the 21^{st} century shows that the average of 1.9 personal vehicles is available to US household although the driver per household is 1.8 percent [1]. This market trend shows that the number of vehicles on the roads throughout the world is going to increase on a daily basis.

The conventional energy supply system is causing the pollution of the environment on the expense of depleting fossil fuel. This pollution includes emissions of GHGs and other harmful chemicals. The excessive emission of GHGs causing depletion of ozone layer of the atmosphere thereby increasing the temperature of the atmosphere. The combustion of hydrocarbon fuels in IC engines releases CO_2 and water. Apart from this combustion products contain NOx, CO, unburned hydrocarbons. It may ultimately cause smog, acid rain and degradation of monuments. Carbon monoxide is poisonous to human being, it affects the mental ability of the human being [2, 3]. Hence all of these pollutants pollute the atmosphere and affecting the human beings in an adverse manner. The United States committed to reducing the GHGs intensity by 18 percent over the 10 year period from 2002 to 2012 [1].

The conventional vehicle operating on ICE was developed in late 1800's which are running on gasoline and diesel. It is obvious that the increase in the number of vehicles increases the world oil consumption. In order to reduce the consumption of oil, hefty money and more efforts have been put together to improve the fuel economy and reduce the GHG emissions. However this concept may not be good to meet the energy requirement and the emission control in the near future.

One of the possible solutions to meet the energy requirement and emission crises is the use of alternative fuel in place of the conventional fuels. The alternative fuel is defined as any available non-conventional energy source such as methanol, ethanol, chemically stored energy (batteries and fuel cells), Biomass, hydrogen, non-fossil methane [2]. Another possible solution is the development of non-conventional vehicle technologies such as electric vehicle, hybrid vehicles and fuel cell vehicles [2].

Electric vehicles are those vehicles which use an electric motor for traction and batteries, ultra-capacitor, supercapacitor as their corresponding energy sources. The electric vehicle has many advantages over the conventional ICE vehicles such as absence of emissions, higher efficiency and smooth operation. The range of operation is the greatest concern regarding electric vehicles. The operation range per battery charge of electric vehicle is less competitive than ICE due to the low energy content of the batteries as compare to the high energy content of the gasoline [2]. Another problem associated with the EVs is recharging, these things make it inconvenient for long distance travel.

Hybrid vehicles are those vehicles which have two or more energy resources in order to propel the vehicle. These sources are normally ICE, an ESS (energy storage system), an electric motor, etc. The combination of motor and ICE makes it hybrid electric vehicle. A HEV includes the advantage of both electric and ICE vehicles and somehow eliminates the disadvantages of both the engines up to a certain extent but the complication in designing the power train configuration is another issue associated with HEVs. The vehicles reduce the emissions but do not eliminate them completely because whenever there is a combustion there should be some emissions.

Fuel cell vehicles are those which incorporate the alternative fuel technology and non-conventional propulsion technology. Hydrogen is used as the fuel and an electric motor propels the vehicle. In today's automotive industry most of the research focuses on the development of FCVs [4]. The most demanding need of the current scenario is clean, green, efficient and environmentally friendly transport system. The current progress in Hybrid and fuel cell vehicle can be seen as a new age of the automobile technology [2]. In the next two decade it is expected that the fuel cell and hybrid vehicle will capture the market due to the fact that they are able to deliver the same functionality at a higher fuel economy and low emissions [2, 4].

All-terrain vehicles (ATVs) defined by the American National Standard Institute (ANSI) are those that design for off road use, travels on low pressure tyres with a seat that straddled by the operator along with the handle bar for steering control. ATVs are designed to handle a wider variety of terrain than other vehicles. The current study focuses on golf cart (ATV). As the name suggest, Golf cart applications are not limited to the golf driving range, but the same vehicles have substantial demand at the malls, airports, hospital so and so forth. The standard golf cart holds two to four people and their clubs [5].

1.2 Problem Statement

Fuel cell hybrid vehicles (FCVs) including batteries and fuel cell is being studied. In hybridisation of fuel cell the consideration of fuel economy, efficiency, emissions and characteristics of power output are necessary. Hybridization allows the size of the fuel cell is to be reduced by using a battery and an Ultracapacitor, and it is beneficial when the power demand is high, like with higher loads or acceleration, and it permits the fuel cell system to be operated more efficiently. In association with the above, the cost of vehicle can be reduced by reducing the cost of expensive fuel cell. When the power demand is low, the fuel cell will provides the required power. Battery will assist in fast start up of the fuel cell and allows capture of the regenerative energy. This study deals with the comparison between two powertrain strategies for All-Terrain vehicle (Golf cart): Fuel cell-Battery and a Fuel cell-Battery-Ultracapacitor powertrain strategy. A methodology of modelling hybrid vehicle configurations with three energy devices in ADVISOR, 2003 has developed. The ATV physical model, the FC system and the power bus of the FC-BT-UC powertrain were programmed in MATLAB/Simulink. The models then applied to the simulation and comparison of the powertrain strategy. The cost function in this study considered the hydrogen consumption, gradeability, acceleration performance and powertrain cost.

1.3 Objectives of the Project

1. To undertake a computer simulation using an existing simulation tool to build up hybrid FC powertrain models. Simulate the performance of each hybrid powertrain and verify the feasibility of the hybrid FC power systems for specific driving cycles.
2. Carry out comparison between two powertrain configurations by using simulation results of acceleration time, gradeability, and fuel economy.
3. Determine an energy system strategy for the ATV based on comparison.

1.4 Scope of the Project

- Literature review
- Component sizing for each ESS to achieve the desired vehicle performance
- ATV(Golf cart) general features, operations, and drive features

- Development of power distribution strategies for each powertrain based on power, energy, efficiency of both battery and Ultracapacitor
- Provide a complete system recommendation necessary for implementing the powertrain for ATV(Golf cart)

1.5 Flow chart of the Project

This section describes the schematic flow diagram of the project progress in order to get the desired outcomes.

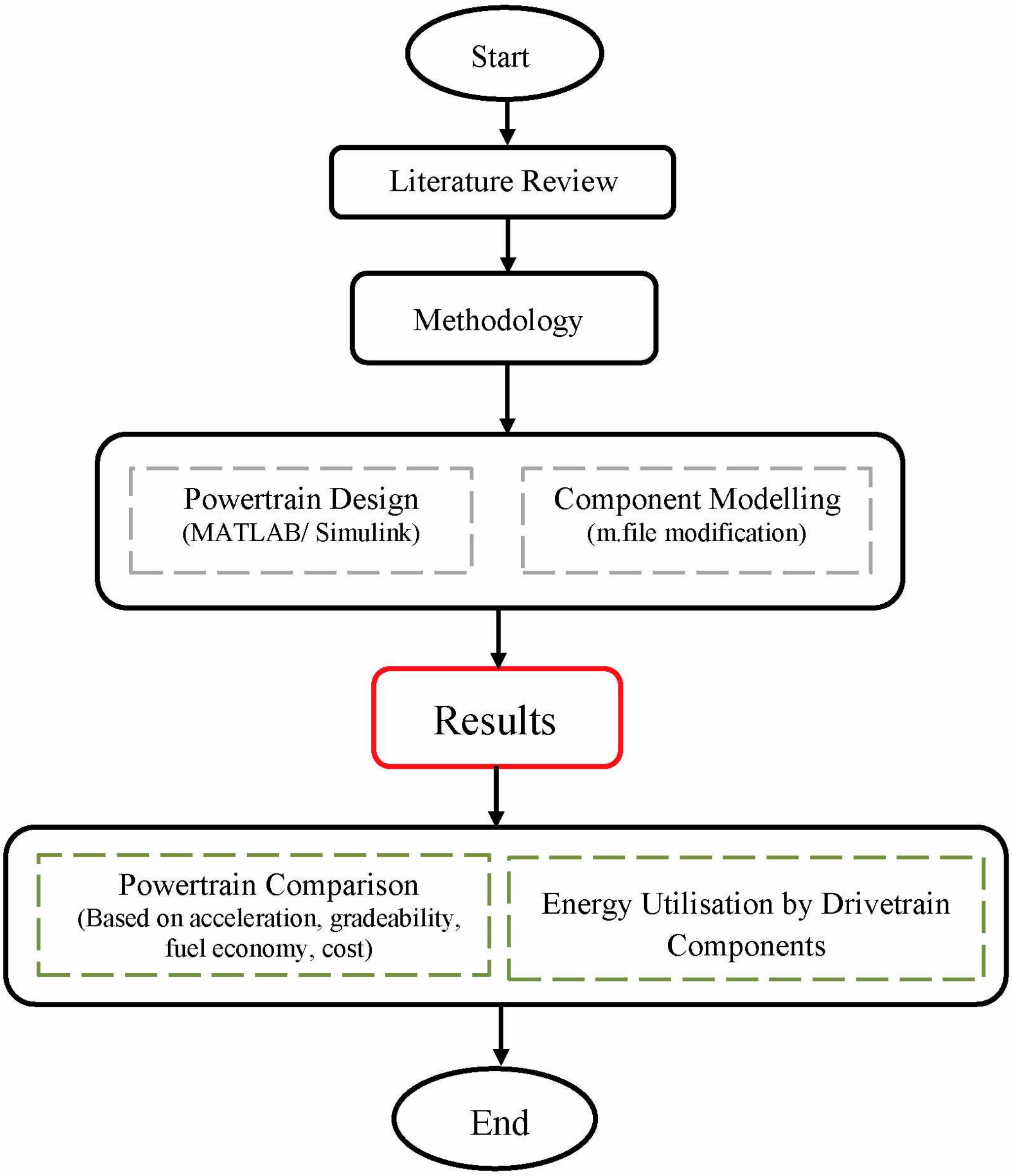

Figure 1.1 Project Flow Chart

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