SYSTEM DESIGN OF A HYDROGEN-POWERED FUEL CELL FOR ALL TERRAIN-VEHICLES (ATVs)

FAWAD RAHIM MALIK

UNIVERSITI TEKNOLOGI MALAYSIA

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FAWAD RAHIM MALIK

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All praises to Allah,

"To the Almighty Allah, I am grateful to the strength and inspiration You have given to me to complete this project"

"To my beloved parents, for their prayers and becoming my motivation in being able to stand to this point and to my Brother, Sister and my close Friends, thank you for your support and encouragement"

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ABSTRACT

The idea for this thesis was to design a specification of requirements for a hydrogen fuel cell system for golf cart (ATV). The fuel cell was intended to produce power requirements for ATV propulsion system and to replace existing system of golf cart and hence this system should be capable of delivering required power demand for ATV. The existing ATV powered by an internal combustion engine have conventional issues related to GHG emissions and air pollution which is making them less demandable. Hydrogen-powered fuel cell uses hydrogen as a fuel to produce electrical power. This electrical power comes out as a result of electrochemical reaction in the fuel cell where oxygen from air is used as an oxidant. In order to develop specification of requirements 4.8kW, 48V fuel cell was chosen for ATV need and hydrogen composition of 99.99% was selected. The calculations for fuel cell stack parameters and operating conditions were performed using the empirical formulas and modelling fuel cell using basic laws of conservation. Number of fuel cell in fuel stack was found to be 69. Calculations for the water and heat management was performed based on the operating temperature and pressure which in this study was chosen to be 60°C and 1.5bar respectively. Based on the findings the external humidification is required for air supply subsystem to achieve 100% humidity for exit air. The required air flow rate was achieved using low pressure blower and for humidification needs humidifiers were installed in hydrogen and air supply subsystems. The hydrogen subsystem is designed with feedback loop of hydrogen recirculation to compensate for the inert gases that move from cathode to anode. The measured parameters were than analyzed and a MATLAB Simulink model was developed to study the behaviour of fuel cell. MATLAB Simulink model developed shows that by decreasing the maximum limit of fuel flow rate from 85lpm (standard liter per min) to 70lpm the stack efficiency increases from 37% to 41% which is acceptable compared to the measured theoretical efficiency of 47%.

ABSTRAK

Idea bagi tesis ini adalah untuk membentuk keperluan sel bahan api jenis hidrogen di spesifikasikan bagi kegunaan kuasa sebuah kereta golf (ATV). Sel bahan api ini bertujuan untuk menghasilkan kuasa bagi sistem pendorongan dan keperluan ATV bagi menggantikan sistem kereta golf yang sedia ada dan seharusnya sistem ini mampu memberi keperluan kuasa yang diperlukan untuk sebuah ATV. ATV yang sedia ada sekarang dikuasakan oleh pembakaran enjin dalaman yang mempunyai kandungan konvesional yang melepaskan GHG dan menyebabkan pencemaran udara sekiranya permintaan semakin tinggi. Sel bahan api hidrogen menggunakan hidrogen sebagai sumber bahan api untuk menghasilkan tenaga elektrik. Kuasa elektrik yang keluar akibat daripada tindak balas elektrokimia di dalam sel bahan api tersebut di mana oksigen dari udara akan menghasilkan oksida. Dalam usaha untuk menjayakan spesifikasi keperluan kepada 4.8kW, 48V sel bahan api yang dipilih untuk keperluan ATV dan komposisi hidrogen 99.99%. Pengiraan bagi parameter himpunan sel bahan api dan keadaan operasi telah dilakukan menggunakan formula empirik dan model sel bahan api mengikut undang – undang asas pemuliharaan. Bilangan himpunan dalam sel bahan api di dapati 69 bahan api. Pengiraan bagi pengurusan air dan haba yang dilakukan didalam kajian ini dipilih berdasarkan kepada suhu operasi dan tekanan masing – masing 60°C dan 1.5 bar. Berdasarkan kelembapan luaran yang diperlukan untuk bekalan udara subsistem kelembapan100% udara keluar. Kadar aliran udara yang diperlukan telah dicapai dengan menggunakan blower tekanan udara rendah dan untuk kelembapan memerlukan pemasangan humidifiers hidrogen dan bekalan udara di subsistem. Hidrogen subsistem dibina dengan menggunakan gelung maklumbalas antara hidrogen edaran semula untuk memberi kepentingan kepada gas – gas lengai yang bergerak dari katod ke anod. Parameter pengukuran telah dianalisis dan model MATLAB Simulink telah dibina untuk menkaji cara kerja sel bahan api. Model MATLAB Simulink maju menunjukkan bahawa dengan mengurangkan had maksimum kadar aliran bahan api dari 851pm (liter standard per minit) untuk 701pm kecekapan tambahan himpunan daripada 37% kepada 40% yang boleh diterima berbanding kecekapan teori yang diukur 47%.

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LIST OF ABBREVIATIONS

λ_a	-	Anode stoichiometry
λ_c	-	Cathode stoichiometry
η_{Fuel}	-	Fuel Efficiency
η_{stack}	-	Stack Efficiency
$\dot{m}_{H_2}$	-	Mass flow rate of hydrogen, kg s^{-1}
$\dot{m}_{air,in}$	-	Mass flow rate of air, kg s^{-1}
$\dot{n_{O_2}}$	-	Number of moles of oxygen leaving cell per second
$\dot{n_{rest}}$	-	Number of moles of non-oxygen component of air per second
$\dot{n_w}$	-	Number of Moles of Water Leaving cell per second
$\dot{h}$	-	Heating rate in terms of electrical power, W
∇	-	Differential Operator
A_{cell}	-	Cell Active Area, cm^2
ATVs	-	All-Terrain Vehicles
c_p	-	Mixture Averaged specific heat capacity, J kg^{-1} K^{-1}
E^0	-	Open circuit Voltage, V
F	-	Faraday's Constant, C mol^{-1}
FCV	-	Fuel Cell Vehicle
GDL	-	Gas Diffusion Layer
H^+	-	Hydrogen Protons
HHV	-	Higher Heating Value
I	-	Required Current, A
i	-	Current Density, A/cm^2
k	-	Thermal Conductivity, W m^{-1} K^{-1}
LHV	-	Lower Heating Value
N	-	Number of Cells

n	-	Amount of Exchanged Electrons
P	-	Required Power, kW
PEMFC	-	Proton Exchange Membrane Fuel Cell
P_{exist}	-	Air Exist Pressure, bar
PFSA	-	Perfluoroshulfonic Acid
P_{in}	-	Inlet Pressure of air, bar
P_{sat}	-	Saturated Vapour Pressure of Water, kPa
P_w	-	Partial Pressure of Water, kPa
P_{win}	-	Inlet partial pressure of water, kPa
r	-	Internal Resistance, Ω cm^{-2}
R	-	Universal Gas Constant, J mol^{-1} K^{-1}
RH	-	Relative Humidity
V	-	Required Voltage, V
v	-	Velocity, ms^{-1}
V_c	-	Average cell voltage, V
μ_{mix}	-	Mixture Average Viscosity, $kgm^{-1}s^{-1}$
ρ	-	Density, kg m^{-3}

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CHAPTER 1

INTRODUCTION

1.1 Background

Conventional power production techniques use hydrocarbon based fossil fuels. The hydrocarbon based fossil fuel besides being in limited quantity available, is producing toxic emissions causing global warming and other environmental and air related pollutions. Most of these emissions are being caused by transport sector. According to key world energy statistics 2014 published by International Energy Agency (IEA), out of the total CO_2 emissions in 2012, 35.3% is from oil consumption. And out of the total oil consumption 63.7% is from transport sector in the same year. This statistic highlights the need for the alternative fuel or alternative drive-train mechanism, which could be defined as clean technology.

Hydrogen fuel cells can be considered as the potential candidate for the transport sector to use a clean energy technology. Fuel cell can use pure hydrogen as a fuel along with air, and the only by product is thermal heat and water along with electricity. Developing fuel cell vehicle will not only be able to reduce air and environmental related pollution but also will decrease the dependency on petroleum products. Hydrogen fuel cell vehicles is also a key factor in hydrogen economy-an economy with the determination of clean and sustainable future power [1].

Many automobile companies have been developing fuel cell vehicles for a long time, and has been able to produce at least one prototype vehicle. Some examples

include General Motors, Toyota, Honda, Ford, Mazda, DaimlerChrysler, Hyundai, Fiat, and Volkswagen. Many utility vehicle have also been developed by these companies. The major reasons for developing automotive fuel cell technology are their efficiency, low or zero emissions, and fuel that could be reproduced from local sources rather than imported [2]. For use in automobiles compressed hydrogen is used, whether using reformer or on board storage. The alternative fuel used beside hydrogen is methanol, which is used with reformer.

Fuel cell is basically a device that converts chemical energy to electrical energy through electrochemical process. Main components of fuel cell include electrodes (anode and cathode), electrolyte, catalyst, and gas diffusion layer. The hydrogen or fuel is supplied to the anode and the oxidant is supplied to the cathode. The electrolyte is sandwiched in between the anode and cathode catalyst layers. The most common type of fuel cell used in fuel cell vehicles (FCV) is proton exchange membrane fuel cell (PEMFC) [2]. In PEMFC the membrane is the proton exchange medium, which is in solid form.

PEMFCs are being developed for use in transportation applications as well as in a variety of portable and stationary applications. Proton exchange membrane (PEM) fuel cells are simple, operate at considerably low temperature (up to 80 C), have quick start-up and fast response to change of load, they have high efficiency and high power density, and when hydrogen is used as fuel, they produce almost zero emissions [3]. The best-known membrane material is Nafion made by Dupont, which uses perfluoro sulfonylfluoride ethyl-propyl-vinyl ether (PSEPVE).

For all terrain-vehicles (ATV), the power requirement is usually less, and hence vehicles are not required to perform under heavy duty loads. ATV’s are light weight vehicles with light duty purposes. ATV’s can come under a wide range of vehicles and applications. They purpose of ATV varies as it can be used for recreational, military, agriculture and as passenger vehicle. Golf cart is simple type of ATV, which can be used in Golf course, in shopping malls, in supermarkets for carrying loads and on airports. In this study a PEMFC system design is proposed to provide transmission power to golf cart (ATV).

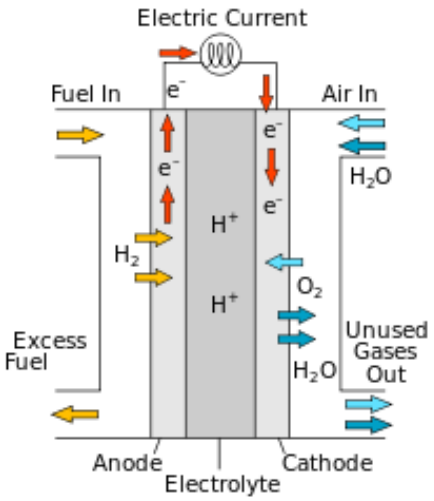

Figure 1.1 Basic Fuel Cell Working Principle [2]

1.2 Problem Statement

Internal combustion engine based propulsion system of ATV have their issues regarding the sustainable environment and GHGs emissions, causing air pollution. Beside this, the achievable efficiency of IC engine is 35% to 37%. The proposed study of fuel cell based propulsion system is effective in terms of efficiency and sustainability. From fuel cell, we can get efficiencies of up to 53% and the only by product is water, giving almost zero GHGs emissions. As compared to IC engines fuel cells are not able to produce desired power with a standalone fuel cell. So, the concept of hybridization of fuel cell with battery is necessary. For the ATVs working on pure electrical system have the issue related with charging and discharging of battery. The incorporation of fuel cell system in existing EV based ATVs can reduce the dependency of battery charging from external source. So, a hybridized system of fuel cell and battery is proposed in this study with design specification requirements of fuel cell system of 4.8kW which will give better efficiency than IC engine.

1.3 Objective(s)

The objective(s) of the proposed study is to:

i. To produce a hydrogen powered mini fuel-cell system design for adaptation in a commercial/recreational All Terrain-Vehicles (ATVs). Taking into consideration, water management while designing fuel cell system for the need of ATVs segment.

1.4 Work Scope

The scope of the work is defined in following areas:

i. Literature review-Extensive

ii. Design and analysis of fuel cell

iii. Components identification

iv. Fuel cell sub-systems integration

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