Design and Development of Fuel Cell Electric Bicycle

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Abstract- *The design, fabrication and testing of a prototype of fuel cell electric bicycle powered by a proton exchange membrane fuel cell (PEMFC) is reported. A fuel cell electric bicycle (FCEB) is a type of electric vehicle that uses a fuel cell to power its electric motor of 350W. FCEBs are targeted to provide customers with the benefits of battery electric vehicles such as low to zero emission, high performance, and low maintenance, without compromising range and refill time. The fuel-cell system is composed of a 350W fuel cell stack, tank, solenoid valves, pressure and temperature sensors, and a microcontroller. The fuel cell system can be installed on commercial bicycles. 50 km range can be achieved in one full storage tank with a fuel consumption of 28g/hr.*

Keywords- PEM fuel cell, electric motor, storage tank, microcontroller, solenoid valve.

I. INTRODUCTION

A. Power assisted bicycle

Power-assisted bicycles (PABs) offer a cheap and efficient mode of transportation. They are becoming increasingly popular in many countries. In Asia (e.g., Taiwan), PABs are commonly used on a daily basis for commuting, while people in North America and Europe use them mainly for recreation purposes. Typically, a PAB uses a low-power source to turn a small motor attached to the wheel at the hub or at the tire. In most PABs, the rider can pedal in combination with the power source to magnify power to the wheel. Usually, electric PABs are powered by either lead–acid or nickel–cadmium batteries, with motor power ratings between 200 and 400 W, depending on the make and type. Recently, the fuel cell has been considered as a means to provide direct power to PABs, or more likely to charge the battery which, in turn, drives the motor. Mingdao University commenced the research and development of a fuel-cell, lightweight vehicle in 2000.

A FCEV uses a fuel cell and an electric motor as its propulsion system. The onboard fuel cell directly converts chemical energy to electric energy. A hydrogen fuel cell is the most popular type that has been used in fuel cell vehicles. As shown in fig 1.1 it consumes hydrogen and oxygen as fuels and only produces water vapor and heat as exhaust products. Therefore a hydrogen fuel cell vehicle produces zero tailpipe greenhouse gas (GHG) emission.

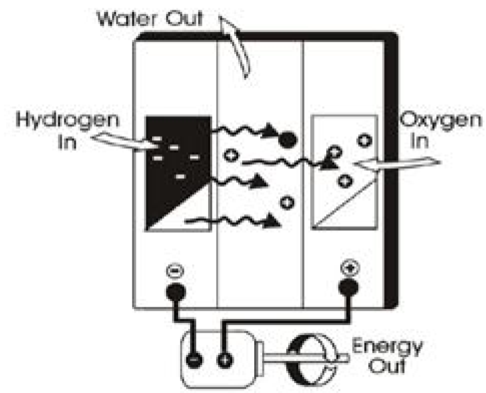

Fig. 1.1- hydrogen fuel cell

B. History hydrogen fuel cell

Since the invention in 1838, fuel cells had been used in various applications such as in spacecraft, submarine, and stationary power plants. The first fuel cell powered vehicle was produced by

General Motors (GM) in 1966, named GMC Electrovan.1 It was the result of two year development effort lead by Dr. Craig Marks and utilized 32 fuel cell modules with a continuous output of 32 kW and a peak power of 160 kW. The fuel used was pure liquid hydrogen and liquid oxygen. The Electrovan achieved a top speed of 70 MPH and had a range of 120 miles. However, the whole fuel cell system turned the 6-seat van into a 2-seater due to the large hydrogen and oxygen tanks along with the piping. After test driving in the GM facility and being shown off to journalists, the project was discontinued due to the prohibitive cost and lack of hydrogen infrastructure at that time.

In 2002, Toyota launched the world’s first limited leasing of its fuel cell hybrid vehicle (called FCHV) in the USA and Japan. Its power train comprised a 90 kW fuel cell and a nickel-metal hybrid battery. At low speed the FCHV runs on battery alone. The fuel cell and battery supplied power in tandem when higher performance was required. The combined range of the fuel cell and battery was 155 miles. Since then, eight major automakers have put in significant efforts to test the real-world performance of the fuel cell vehicles.

II. LITRETURE REVIEW

Hwang et all [1] (2004) presented a paper on "Development of fuel-cell-powered electric bicycle". The paper shows the design, fabrication, and testing of a prototype of electric bicycle powered by a proton exchange membrane fuel cell (PEMFC). PABs are commonly design on a daily basis for commuting. To achieve the design of fuel cell stack system and power management, fuel cell sub system, microcontroller, solenoid valves, sensors, storage tank, controller system design is reported in the paper. The fuel-cell system is composed of a 300-W fuel-cell stack. The experimental analysis shows two kinds of tests, namely, the roller-stand test and the road test. Performance of bicycle for two tests reported in paper. The result shows the efficiency of the system can reach upto 35% and the ratio of travelling distance to fuel consumption is about 1.35 km g^{-1} H2.

Roberto et all [2](2014) presented a paper on "Model based design and optimization of a fuel cell electric vehicle". Alternative power-train for a vehicle is designed to put a check on the increasing emission problem in cities. One of the promising alternatives to the conventional power-train is hydrogen fuel cell powered vehicle. The optimized design of a fuel cell powered system is done using regenerative breaking technique. Mathematical modeling method is used because virtual platform reduces time as well as expenditure. Optimum fuel cell power is obtained from WLTP cycle of a vehicle running on urban road. Other parameters such as propulsion power, energy given by the fuel cell directly to the traction motor, the energy that the battery have to provide and extra energy stored in battery are calculated by using various mathematical equations. Different braking strategies are provided to recapture the energy lost in braking. Results are graphically plotted according to which, the fuel cell provides constant power to battery. When traction power is less then fuel cell power all the requested power by motor is given by only fuel cell. When traction power is more then fuel cell power, battery provides the extra power to the motor. Battery gets charged when fuel cell power is null.

Zhang Guirong et all [3](2011) presented a paper on " propulsion control of fuel cell electric vehicle". Four methods of propulsion control are discussed. Fuel cell electric vehicle propulsion systems consist of hydrogen fuel cell, battery and super capacitor. First methods consist of only fuel cell. In this all the power requirement is full filled by fuel cell, this leads to a large fuel cell which is expensive but has advantages such as simple control and improved overload capacity. Second methods consist of fuel cell and super capacitor. Super capacitor charges and discharges quickly so regenerative braking system can be used but super capacitor provides peak power for very short time. Third methods consist of fuel cell and battery. Power required by fuel cell decreases, fuel cell system starts easily and braking energy can be recalled. Fourth systems consist of fuel cell, super capacitor and battery. It combines the advantages of all the above systems. Fourth system is efficient of all the methods but it is complicated and expensive.

Nancy et all [4] (2012) presented a paper on "Hydrogen and fuel cell technology: Progress, challenges, and future directions". Recent the hydrogen and fuel cell activity is reported in the paper. The Global view of fuel cell and need of clean energy technology to increase economy, protect the environment, and reduce dependence on foreign oil is also reported in the paper. Hydrogen and fuel cells are an integral part of the clean energy portfolio. Hydrogen can be produced from a number of diverse domestic resources, and fuel cells can generate electricity efficiently from a number of fuels, including biogas, natural gas, propane, methanol, diesel, and hydrogen. The DOE Hydrogen and Fuel Cells Program did the market survey and found big future scope in hybrid vehicles which directly reduces the pollution and protect the environment.

Sid et all [5](2014) presented a paper on "energy management and optimal control Strategies of fuel cell/super capacitors hybrid vehicle" In this paper, an energy management strategy (EMS) based on optimal control is applied to hybrid vehicle propelled by fuel cell and super capacitors pack. The EMS based on minimization of the consumption of hydrogen and effectiveness of energy management based on optimal control, which lead to improving fuel consumption and good control of the auxiliary source.HEV have hydrogen as a main energy source and super capacitors(SCs)stacks as an auxiliary power source. The FC supplies the power required for vehicle propulsion at steady regimes whereas the super capacitor supplies the peak power for transient regimes and capture the braking energy regeneration. This article focus on optimal power sharing between two electrical sources (FC and SCs).They use Two Energy management strategy, first is EMS based on optimal control theory and other is Ems based on thermostat principle. By comparing both results final conclusion is the EMS based on optimal control leads to good reduction of hydrogen consumption (allowed about 18% of fuel consumption reduction), a good control of SC and stability during the FC operation.

Lorenzo et all [6](2012) presented a paper on "Reva electric vehicle conversion to a hydrogen fuel cell powered vehicle". The main problems in electric vehicle are the autonomy and recharge time. Using a hydrogen fuel cell, able to increase autonomy and reduce the time to recharge electric vehicles. The fuel cell is responsible for recharging the battery (REEV) or directly from the electric motor power (FCEV). We studied the two technologies of vehicle (FCEV and REEV) by testing and stimulation, which stimulate urban and road driving. Data is collected from various resources like conventional medias: magazine scientific, internet and related article to this field. Once collected data analyzed all this information, proceed to comparison between the different alternatives by using the software Matlab / Simulink. The main advantage offered by electric vehicle compared to vehicle fuel (gasoline or diesel), is the lower cost of fuel and emission released into the atmosphere is null. It conclude that the best power train configuration of electric vehicle I.e. that obtained in greater economy are those in which the addition of hydrogen fuel cell to train power. The best configuration is the REEV (Range Extended Electric Vehicle) and obtained a range slightly higher than FCEV (Fuel Cell Electric Vehicle).

Mathe et all [7](2012) present paper on "Electrocatalysis research for fuel cells and hydrogen production." This paper shows that The CSIR undertakes research in the Electrocatalysis of fuel cells and for hydrogen production. The Hydrogen South Africa (HySA) strategy supports research on electrocatalysts due to their importance to the national beneficiation strategy. The work reported here presents choice methods for the production of Platinum Group Metals (PGM) electrocatalysts, which are characterized for their performance. Investigations on the commercial feasibility of such electrocatalysts in the fuel cells including hydrogen production continue to be subject of global interest, to ensure energy security of supply. The paper aims to present possible synthesis routes for PGM electrocatalysts for commercial gains.

Scott et all [8](2015) present paper on "Changing the fate of Fuel Cell Vehicles: Can lessons be learnt from Tesla Motors?".this paper shows the Fuel Cell Vehicles (FCVs) are a disruptive innovation and are currently looking towards niche market entry. However, commercialisation has been unsuccessful thus far and there is a limited amount of literature that can guide their market entry. In this paper a historical case study is undertaken which looks at Tesla Motors high-end encroachment market entry strategy. FCVs have been compared to Tesla vehicles due to their similarities; both are disruptive innovations, both are high cost and both are zero emission vehicles. Therefore this paper looks at what can be learned form Tesla Motors successful market entry strategy and proposes a market entry strategy for FCVs. It was found that FCVs need to enact a paradigm shift from their current market entry strategy to one of high-end encroachment. When this has been achieved FCVs will have greater potential for market penetration.

III. DESIGN OF SYSTEM

The conceptual process and instrument design of the fuel-cell system is shown in fig. 3.1

A. Electric motor

Case 1:

Assume power: 350w
Weight: 100 kgs
Motor shaft diameter: 0.214m
Maximum speed (rpm): 300rpm (assumed as standard motors available)

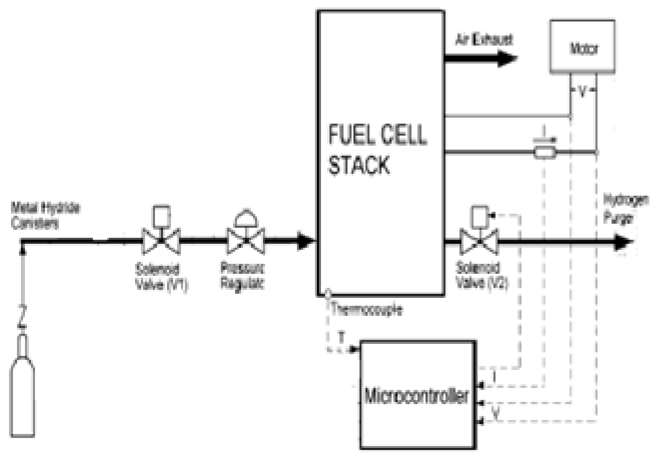

Fig.3.1 fuel cell system design

Torque Calculations:

Angular Velocity (ω) = (2 π N)/60 rad/sec
N= Maximum speed of motor in rpm
Power (P) = Torque (T) x Angular Velocity (ω)
ω = (2 π 300)/60 = 31.4 rad/sec
P = T x ω
350 = T x 31.4
T = 350/31.4 =11.4 Nm

Velocity Calculations:

Let's calculate the speed the bike can do with above power and torque.

Velocity in km/h (V) = (2 x π x r x N x 60)/1000
V = (2 x π x 0.74 x N x 60)/1000
r = Radius of Motor Shaft = 148/ (2x1000)
N = Speed of motor in rpm
Values of N = 50, 100, 150, 200, 250, 300 rpm
V = (2 x π x 0.74 x 50 x 60)/1000 = 13.9416 km/h

V = (2 x π x 0.74 x 100 x 60)/1000 = 27.8832 km/h
V = (2 x π x 0.74 x 150 x 60)/1000 = 41.8248 km/h
V = (2 x π x 0.74 x 200 x 60)/1000 = 55.7664 km/h
V = (2 x π x 0.74 x 250 x 60)/1000 = 69.7080 km/h
V = (2 x π x 0.74 x 300 x 60)/1000 = 83.6496 km/h

Thus 350 watt motor seems compatible, let's verify it again in further cases.

Note that the above speeds obtained are at no load and 1:1 Gear ratios of the motor alone.

Case 2

F=m x a with m being the mass of the bicycle of 100kg and a the acceleration you desire to be

a=dv/dt= [18km/h]/[10s]. $=0.5m/s^2$

F=50N

diameter r calculate the torque T needed at the tire's centre from

T= r x F.

T=0.66x50Nm

T=32.94Nm

Considering a motor that can operate at constant torque mode from 0 to 25km/h, the power delivered would be

P=2πnT/60

P= (2x3.14x100x32.94)/60

P=344 OR

p=350watts

This approach neglects the power added from the bicycle's driver, usually considered to be in the range of 100W.

Case 3

Electric Bicycles or e-bikes have a power rating of 750W and carry a payload of about 200kgs

Power: 750W

Weight: 120kgs (Vehicle) + 80kgs (Human)

Hence Power to Weight ratio= $\frac{750}{200}$

=3.75

Our mini electric bicycle is designed for much smaller payload and less speeds. Hence a power to weight ratio of 3.5 is maintained

Weight: 20kgs (Vehicle) + 80kgs (Human)

Hence find the required power maintaining a power to weight ratio of 3.5

$$3.5 = \frac{\text{Power}}{100}$$

Required Power = 350W

Hence based on availability in the market a suitable high toque motor was selected with the following specifications

Validation of the selection

Radius of Driven Wheel = 0.6604m = 660mm
Gearing ratio = 2:1
Max speed required v = 25kmph

$= 25 * \frac{1000}{3600}$

=6.94m/s

$$v = \frac{2 * \pi * r * N}{60}$$

N_{wheel} = 100prm

$$G = \frac{N_{Motor}}{N_{Wheel}}$$

$2 \times N_{wheel} = N_{motor}$

N_{motor} = 2 x 100

N_{motor} = 200rpm

$$P = \frac{2 \times \pi \times N_{Motor} \times T}{60}$$

Where

T = Torque at the given rpm

N = Motor rpm

Hence calculating

Torque @ 200prm. Substituting the values in the above formula:

T = 16.71 Nm @200rpm

B. Hydrogen storage

For 50km at speed of 20km/hr

Operation time = 2.5hrs

350W x 2.5hrs = 875Wh

Provided that 80gm/hr of hydrogen produces 1KWh of power, therefore for 0.875 KWh the quantity of hydrogen required will be 70gm.

IV. CONCLUSION

The Project has been completed with the development of a fuel-cell-powered electric bicycle. The information and experience obtained with the design, fabrication, and testing of this prototype will assist further advancement of the fuel-cell technology. The bicycle may also prove useful for enhancing public acceptance of hydrogen fuel, and for facilitating the licensing processes of this technology. The final goal of this project is to promote proton exchange membrane fuel cell (PEMFC) technology and accelerate it to commercialization, thus making it accessible to all applications that require a clean and efficient source of energy.

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