Fuel Cell based Vehicle Design and Performance Analysis

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Abstract: In an fuel cell vehicle, an automotive fuel cell propulsion system runs the vehicle by converting hydrogen and oxygen into electrical current through an electro-chemical reaction in the fuel cell stack. It emits just water vapor and heat, without other tailpipe pollutants. Therefore, fuel cell vehicle are considered to be zero-emission vehicles. Fuel cell vehicle can also be hybridized with a high-voltage battery, to improve vehicle performance and better optimize the cost and robustness of the fuel cell propulsion system. In fact, all of our efforts to improve high-voltage electronics, electric motors, regenerative braking and battery technology on Battery electric vehicles, hybrid electric vehicles and plug-in hybrids can be applicable to Fuel cell vehicles, if and when these vehicles become commercially viable.

Keywords: Automobile, Fuel Cell, Hydrogen, Proton electrolyte membrane

1. Introduction:

Fuel cell vehicles are running on the pure hydrogen as zero emission vehicles hence fuel cell powered vehicles can be a longer solution to the environmental problems associate with transportation system. The design of vehicle is simple with respect to a direct storage system of hydrogen, but the refueling system should need to be developed. The storage system has potentially large influence on the driving the performance. So we are focusing on the hydrogen fuel cell powered vehicles. The concerns of efficiency with energy is important in many ways in fuel cell vehicles ,the efficiency of hydrogen use affects the fuel cost per mile; and also the efficiency of energy use also determine the total greenhouse gas emissions; and the overall efficiency of converting chemical energy into electrical energy at the wheels. These factors determine the output power or requirement of infrastructure and cost of for hydrogen production. In the coming section there will be discussion about the basic fuel cell vehicle and types of fuel cells and hydrogen storage option. The hydrogen involved is also not environmentally damaging for two reasons. First the pure hydrogen will be completely contained at all times during the process, and will not come in contact with the outside world .second even if any hydrogen does leak into atmosphere; it will immediately combine with atmospheric oxygen to form water. Hydrogen vehicles have the potential to revolute the transportation industry. So all multinational vehicle developers are investing significant funds in the development of hydrogen fuelled vehicles.

A fuel cell converts chemical energy in hydrogen and oxygen directly into the electrical energy. Fuel cell is just as the battery which is rechargeable, so the fuel cells and batteries are electrochemical devices. In a fuel cell the use of hydrogen and oxygen has to been done for generating the electricity. The electricity can then be used to power the car .A fuel cell is the prime device which turn the ordinary electrical vehicles into the practical competitive alternate. The fuel cell can be operated using by the different type of fuels and oxidants. Hydrogen is most effective and recognizing fuel for practical fuel cell use since it has higher electrochemical reactivity then other fuels. Such as hydrocarbons or alcohols. Even fuel cells that operate directly on fuels other than hydrogen tend to decompose in hydrogen and other elements before the reaction takes place. Due to its high reactivity oxygen is a good choice of oxidants and its richness in air .In a fuel cell system t fuel and the oxidant gases themselves includes the anode and cathode respectively. Thus the physical structure of a fuel cell is one where the gases are directed through flow channels to either side of the electrolyte. The electrolyte is the distinguishing feature between different type of fuel cells. Different type electrolytes conducts the different ions.

2. Related Work:

Indranil Ray et al ,(2013) In this time the demand of energy is increasing, so hydrogen could be in a major role as fuel, for the vehicles. Hydrogen can use as a transportation fuel, while neither nuclear energy nor solar energy can be used directly like hydrogen.. Hydrogen very important properties as transportation fuel, with a rapid burning speed, and high octane number, with no toxicity or ozone-forming potential. A hydrogen–air mixture has a low minimum ignition energy of 0.02 MJ. The combustion product of hydrogen is clean, in which it consists of water and a little amount of oxides of nitrogen (NOx). But main problem of using hydrogen as a transportation fuel is that its needed huge on-board storage tanks. A disadvantage is that the hydrogen needed an estimated 4 times much volume than the gasoline for store the energy. The storage of the hydrogen fuel is still not much standardized condition. In this review the different type of production techniques and storage systems of hydrogen can be used as IC engine fuel. Hydrogen should be used as alternate fuel of transportation so as to negate the concept for the greenhouse effect. The greenhouse gas emission reductions should be calculated on the annual basis. And the level from year to year varies significantly so this should be also specified .

Liangfei Xu et al,(2013) A proton electrolyte membrane (PEM) fuel cell system and a Li-ion battery ,these are the two power sources in a fuel cell vehicle (FCV). The fuel cell system is component of the fuel cell stack and the subsystem for air or hydrogen supply and cooling the water. The operational procedure for the fuel cell system can be divided into several processes, as starting up, normal or abnormal working and shutting down conditions . In this review , a multi-mode real-time control strategy for a fuel cell powered vehicle has been proposed. The strategy is established on the basis of three typical processes which are (starting up, normal working and shutting down) the system of fuel cell , also the fuel economy and the system durability into the consideration. This strategy has been applied into a platform vehicle for a 5-year project named as 'the next generation technologies of fuel cell city buses'. Experiment of the 'China city bus typical cycle' on a test bench for the bus were also been taken . The Result shows that the fuel economy is 7.6 kg (100 km) into the battery charge sustainable status. In a practical situation the total mileage of driving of more than 270 km could be achieved.

Kyle Simmons et al (2013), In that review it presents the modeling and supervisory energy management design for a hybrid fuel cell or battery-powered passenger bus. With the growing concerns of petroleum usage and also the greenhouse gas emissions in transportation sector, to find out the alternative methods for vehicle propulsion is needed. Proton Exchange Membrane (PEM) fuel cell systems have good possibilities for energy converters because of their high efficiency and zero emissions. It has been described that the benefits of Proton exchange membrane fuel cell systems can greatly improved by hybridization technique . In this review the challenges for developing the on-board energy management strategy with the near optimal performance has been described by a two-step process. First is that an optimal control based on the Pontryagin's Minimum Principle (PMP) has implemented to find out the global optimal solution that can minimize the fuel consumption for the different drive cycles, with or without grade. Optimal solutions have been the analyzed in order to aid in development of a practical controller is suitable for thje on-board implementation, it is in the form of an Auto Regressive Moving Average (ARMA) regulator. The results through Simulation shows that the ARMA controller is much capable for achieving the fuel economy within 3% of PMP controller, while its being able to limit the momentary demand of the fuel cell system

Søren Juhl Andreasen et al (2013) In this work it represents the concept of the electrical traction power system through a high temperature with the polymer electrolyte membrane fuel cell range extender which is usable for the automotive electrical vehicles. The concept of hybrid system has been taken ,it consist of a power system in which the primary power has delivered through a lithium ion battery pack. For increasing the running time of the application is connected with this battery pack and a high temperature PEM fuel cell stack (HTPEM)which has been taken act as an on-board charger and it is able to charge the vehicle during the operation in a hybrid series. Just because of the high tolerance to the carbon monoxide, high temperature PEM fuel cell system can be used efficiently a liquid methanol or water mixture of the ratio of 60%/40% by its volume as a fuel instead of the compressible hydrogen and enabling potentially with the high volumetric energy density. For the test of the performance of such a system like that the experimental validation conducted use a downsize version of the battery pack which was used in Mitsubishi and it is subjected to power cycles comes through the simulations of the vehicle undergone in multiple New European Drive Cycle.

Hui Liu et al. (2012) The 'Economy of Hydrogen ' is the proposed system in which hydrogen production has been done from the sources of carbon dioxide free energy and it is used as an alternate fuel for the transportation. The utilization of hydrogen for powering the fuel cell vehicles (FCV) can decrease the air pollutants and the greenhouse gases emitted through the transportation sector. To build the future hydrogen economy a significant development in the hydrogen Infrastructure must be needed and large investments also be needed for developing of production of hydrogen , storage systems , and distribution technologies .In this review it main focus is on the analytical approach of hydrogen demands from the hydrogen powered fuel cell vehicles in Ontario (Canada) and also the cost of hydrogen.

3. Methodology:

The issue of hydrogen production, storage and distribution needs careful consideration. Hydrogen is an energy carrier and not an energy source and consequently has to be production by means of energy source, A majority of the hydrogen production today is used in chemical industry and the dominant production method is stream reforming of natural gas. In the long run, fossil fuels based hydrogen production method is steam reforming of natural gas. In the long run fossil fuel based hydrogen production will require CO_2 capture and sequestration. Alternative productions methods include gasification and reforming of other fuels, electrolysis and biological process. Both centralized, where the logistics is provided by trucks or hydrogen pipelines radiating from a centre source, as well as de- centralized production, e.g. on site-reforming are considered viable supply options.Large-scale, industrial hydrogen production from all fossil energy sources can be considered a commercial technology for industrial purposes, Through not yet for utilities. Hydrogen production at a large scale has the potential for relatively low unit costs, although the hydrogen production cost from natural bus in medium sized plants may be reduced towards to the cost of large scale production .An important challenge is to decarbonise the hydrogen production processes.CO_2 capture and storage options are not fully technically and commercially proven. It is also important to increase plant efficiency, reduce capital costs and enhance reliability and operating flexibility. A principle sketch of hydrogen distribution from natural gas based centralized hydrogen production plant is in the figure.

Further R&D is particularly needed on hydrogen purification (to produce hydrogen suitable for fuel cells) and on gas separation (to separate hydrogen or CO_2 from gas mixtures). This involves the development of catalysts ,adsorption materials and gas separation membranes of the production and purification of hydrogen. Hydrogen and power can be co-produced in integral gasification combined cycle plants. The IGCC plants is the most advanced and efficient solution in which the carbon in the fuel is removed and hydrogen is produced in a pre-combustion processes. However successful centralized hydrogen production requires large market demand as well as the construction of a new hydrogen transmission and distribution infrastructure and pipeline for the CO_2 storage .In the future , centralized hydrogen production from high-temperature processes based on renewable energy and waste heat can be an option to enhance sustainability and remove the need for capture and storage .

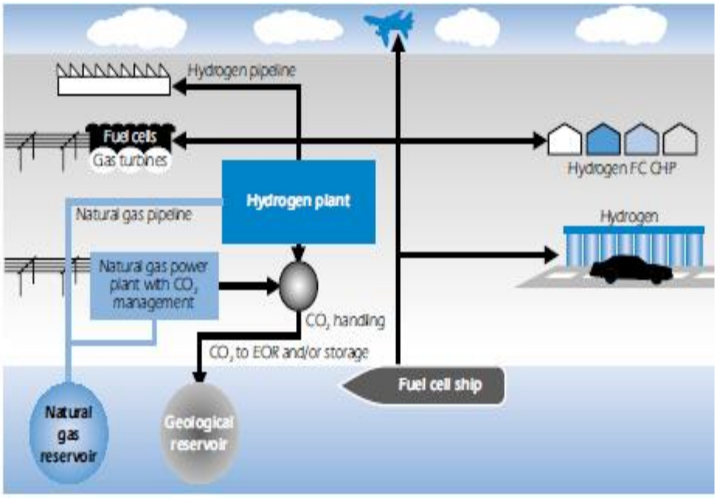

Fig. 1. Centralized hydrogen Production

Fig. 2. Hydrogen Storage Tank

The Hydrogen Storage Tanks:
A hydrogen vehicle needs hydrogen, obviously. The vehicle is powered by the given off by the combination of hydrogen and oxygen into water .Oxygen is readily available from the air, but hydrogen must be supplied by a separate source. The traditional method for storing hydrogen (or any other gas) is an pressurized tank. This is the storage method which is opted but it has some of disadvantages .Hydrogen is a very low density gas , and so to store the necessary quantity to provide adequate driving range to a car. Very large or high pressure tanks are required. This is obviously not all the desirable because high pressure can be dangerous and difficult to use the larger tanks consume a lot of vehicle space and weight. However, as hydrogen storage tanks increase in pressure ,the latest are available at pressure up to 10.000 psi-vehicle range rivals that of conventional gasoline vehicles . there are several of other methods of storing hydrogen. The first option involves storing hydrogen by binding it in a metal .The metal compound is heated, and it absorbs hydrogen. Done correctly, this allows for storage of more hydrogen molecules per volume then with pressurized tanks. However the total weight per molecule of hydrogen is more than with conventional pressurized tanks. . The process is also more complicated: the metal had to be heated when hydrogen is being pumped in, and heated again to get her hydrogen out. This would create an additional drain on a fuel cell in a car, decreasing the overall efficiency slightly .This system also has another advantage: even if the tank is broken open , hydrogen cannot leak out because it is bound to the metal .The car becomes even safer in an accident because a hydrogen fire would be extremely unlikely.Another option is to store hydrogen as a liquid instead of a gas. However to liquefy hydrogen must decrease to a temperature only 20 k above absolute zero.This requires a quite a lot of energy , and difficult to maintain such a low temperature in a car . While a few prototype vehicles exist that store hydrogen as a liquid, it is unlikely this technique will become a practical option given in current technology.

Other schemes are also in development .One of the more promising options involves storing hydrogen carbon nano-tubes. Like metal storage , this increase the number of hydrogen molecules per volume, thus creating similar fuel tanks and longer vehicle range. This option is still too new to be considered at this point.

Vehicular Hydrogen Requirement:
The size of the tanks used will depend on the amount of hydrogen the vehicle needs. The car requires a range of around 250 miles per tank to be competitive .

250 miles = about 400 kilometers

It would be extremely difficult to calculate the average number of joules of a car expands going 250 miles .However a rough estimate can be done by calculating air resistance of a vehicle going 60 mph for 250 miles. Rolling resistance is less significant than air resistance, and can vary widely depending on a number of factors concerning the vehicle, tires and road resistance. I will be left out this estimate because of the regenerative braking takes place, much of excess energy used in acceleration during this braking. It will be assumed that the car begins end ends the 250 mile trip going 60 mph. These assumptions will doubtlessly cause the estimation to be optimistically low.
The proposed vehicle loses approximates 6.3 k W of power to air resistance during a 250 mile trip at 60 mph

250 miles / 60 mph = 4.17 hours

6.3 kW× 4.17 hours = 26.271 kWh (9.5× 10^7 joules)

Therefore it takes 9.5× 10^7 joules to move a car 250 miles at 60 mph.
Hydrogen holds 118.800 kJ (33 kWh) of energy per kilogram. This turns to be remarkably similar to the amount of energy per gallon of gas. Like a combustion engine, however a fuel cell is not 100% efficient. Some of energy is converted into heat. Then of course, there are further in efficiencies within the vehicle which need to be taken into account.
50% Fuel cell* 90% Controller * 90% Motor * 90% Drive train= 36% total efficiency
These estimates are slightly conservative ,a well designed AC motor can reach efficiencies of over 95 % and the drive train , a fixed gear box is used instead of a transmission, should be also better . PEM fuel cells theoretically max out at efficiency of 83 %, a number of yielding from calculating the resulting energy from the combustion of oxygen and hydrogen. In future there will no reason to suspect fuel cells will not move closer their maximum theoretical efficiency. For the record ,

gasoline engines are about 15 % efficient with those larger SUVs and trucks obviously even less.

118,800 J * 36% = 42 J of usable energy / kg of H_2

9.5×10^7 J / 4.28×10^4 J /kg = 2.2 kg. of hydrogen.

Prototype vehicle	**Range**	**Hydrogen (kg)**
Honda FCX	220 miles	3.75 kg
Toyota FCHV-4	155 miles	~ 3 kg
GM Hy-Wire	80 miles	2 kg
Ford Focus FCV-Hybrid	160-200 miles	4 kg

4. Result and Discussion:

In this section we will discuss about the performance of our hydrogen powered fuel cell vehicle (HFCV). The vehicle model consists of the fuel cell stack, electric drive ,dc motor and mechanically coupled vehicle drive. The complete model and its block diagram is shown in the figure 1.(a) and(b). The model is designed using matlab Simulink software tool named as matlab R2010a. The complete model mainly uses the Simulink tool boxes known as sim power system and sim drive line. Sim power system consists of block related to the electrical power systems. It has blocks like electric sources ,battery ,power electronic semiconductor devices ,ac/dc motors etc. Sim driveline consists of block that can be use to design a vehicle drive .The different blocks are gears, mechanical couplings, inertia blocks ,IC engines etc.

In this subsystem there are the three main blocks are used named as-

(1) H_2 (hydrogen) gas flow rate regulator
(2) Air flow rate regulator
(3) Fuel cell stack

H_2 gas flow rate regulator controls the flow of hydrogen gas at the input of fuel cell stack. It has been assumed that the gas varies from 1 to ∞. Similarly air flow rate is considered to varies from 60 to ∞ as shown in the figure 1 the fuel cell stack take the fuel and air as the input.

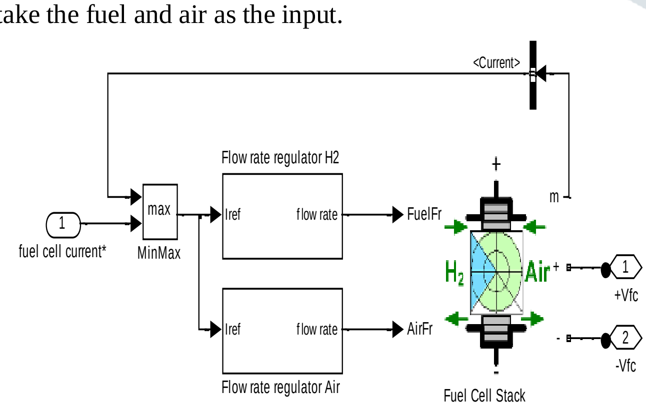

Fig. 3. Flow regulator of fuel cell

The specification in the table is given below –

Voltage limit	380-400 volts
Nominal operating point	285 amp. At 300 volts
No. of cells	400
Nominal Stack efficiency	57%
Operating temperature	95°C
Nominal air flow rate	1698 lpm
Fuel pressure	3 bar
Air Pressure	3 bar
Nominal Composition	99.95% H_2

The fuel cell voltage vs current and power vs current graphs are shown for the above mentioned fuel cell –

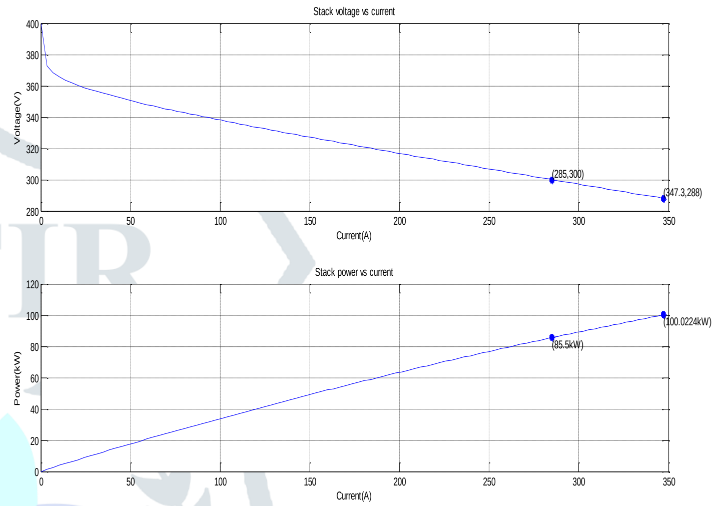

Fig. 4. Voltage and Power response

The output voltage of fuel cell is taken as ± (…..). This input terminal of this block is fuel cell current. This reference current is provided by the power management system as per the requirement of our accelerator speed. According to the fuel cell current the flow rate of H_2 and air are regulated by the flow rate regulator to provide a desired voltage.

The "m" is the measurement terminal of the fuel cell. The data's are generated from this terminal are voltage ,current, fuel cell stack efficiency , flow rate , stack consumption etc. but we are only selecting current signal of fuel cell . In this way the "m" terminal gives actual current that is presently generated by the fuel cell and input current is the current required to run the vehicle at desired speed. Min-max block select the any one of the input which is higher. As per the input current named as 'i_{ref}' ,hydrogen and air flow rates are controlled.

5. Conclusion:

Hydrogen Fuel cell vehicles are currently being researched for their feasibility of widespread usage in automobiles and other forms of transportation. Many companies are working to develop technologies that might efficiently exploit the potential of hydrogen energy for. The attraction of using hydrogen as an energy currency is that, if hydrogen is prepared without using fossil fuel inputs, vehicle propulsion would not contribute to carbon dioxide emissions. The drawbacks of hydrogen use are low energy content per unit volume, high tankage weights, very high storage vessel pressures, the storage, transportation and filling of gaseous or liquid hydrogen in vehicles, the large investment in infrastructure that would be required to fuel vehicles, and the inefficiency of production processes. The fuel cell technology is one approach of many to reduce the energy demand of the transportation sector. To be accepted by end-users, fuel cell vehicles need to perform the same, or better, than corresponding ICE vehicles.

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