REVIEW OF FUEL CELL BASED ELECTRIC VEHICLE'S PROPULSION SYSTEM

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ABSTRACT

Electric propelled vehicles can help to avoid the use of petroleum products and lead to reduction in noxious emissions. Most EVs uses battery to store the electric energy but is heavy and reduces the driving range compared to ICE vehicles. High charging time and charging significant numbers of EVs is a major challenge to the electricity grid.

In this review, an alternate to this system, power an EV using electric power generated using Fuel Cell; there will be instantaneous power generation and consumption without the inclusion of batteries. Using the most common fuel, Hydrogen, it can be ascertained that transportation becomes cleaner and load on grid can be scheduled.

Keywords: Fuel Cell, Batteries, Hydrogen, Supercapacitors, Batteries, Boost converter

I. INTRODUCTION

The last century witnessed a massive development of technology for road transportation of individuals and goods. Petroleum products are the main power source of our transportation but the crude oil reserves are fast depleting resulting in rise in cost of transportation. Apart from price rise, the use of carbon based fuels results in undesired emissions degrading the air quality in urban areas.

Fuel Cell based Electric Vehicles can be looked upon as a very feasible alternate for propulsion of road transport vehicles and can contribute to a sustainable road transport system.[1] Compared to ICE propelled vehicles, they provide local zero-emission propulsion. Using Hydrogen Fuel cell with renewable derived hydrogen, it enables complete zero-emission transportation.[3]. Compared to EVs, FCEVs put a lower burden on the electric infrastructure, i.e. if hydrogen generation is done from electrolysis of water; this process can be controlled and scheduled so to provide a way to balance the load curve, but hydrogen production during off-peak times. Compared to general EVs, FCHEVs will support an extended driving range and short fuelling times. With development of hydrogen compression & storage system, volume of fuel stored in the system can be increased drastically which will directly increase the refuelling duration.

II. A GENERAL FUEL CELL

A fuel cell hybrid propulsion system comprises of a fuel cell system, a small storage like Capacitor or battery, and an electric drive train. The ratings of the electric motor determine the maximum power and torque for traction, provided the fuel cell system and storage are capable to deliver this power. The hydrogen gas must be compressed at extremely high pressure at 5,000 to 10,000 psi to store enough fuel to obtain adequate driving range.[10] The operation of a fuel cell is based on the electrochemical oxidation of hydrogen to water. This electrochemical reaction consists of two catalytic reactions [4]. In a catalytic reaction at the anode of the fuel cell, hydrogen is reduced into protons and electrons:

$$2H_2\ (g) \rightarrow 4H^+ + 4e^-$$

The protons are transported through the water-containing electrolyte as H_3O^+ cations to the cathode. The electrons provide the external electric current. At the cathode, protons and electrons recombine in a catalytic reaction with oxygen into water:

$$O_2\ (g) + 4H^+ + 4e^- \rightarrow 2H_2O\ (g/l)$$

In totality, the fuel cell electrochemically 'burns' hydrogen as fuel, providing electric power and producing water. In practical scenario, a multiple number of fuel cells are stacked together to form a FC Stack to get the required voltage. In transportation systems, Fuel cell stacks are supplied with air source using compressors. The required compressor power depends on the air flow resistance over the channels in the stack. The power consumption of the compressor is significant with respect to the total electric power produced by the stack. Therefore, the speed of the compressor is lowered when less power is demanded from the fuel cell stack.

In automotive applications, fuel cell systems must be able to adapt to challenging operating conditions such as frequent start-up and stop and sudden change and widely varying power demand. These conditions are much easier to cope with if the fuel cell system is hybridized using batteries and or ultra-capacitors. In addition to mitigating the stress on the fuel cell via load levelling, the energy storage permits the capture of regenerative braking energy, which will benefit vehicle fuel economy and can potentially permit downsizing the fuel cell system.

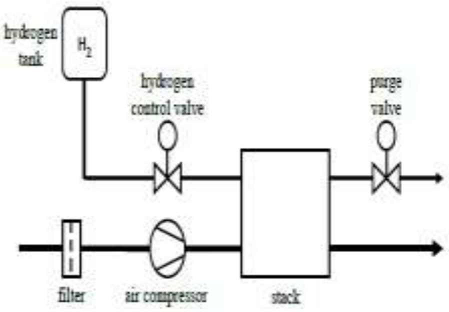

Fig 1 : Basic Fuel Cell System [5]

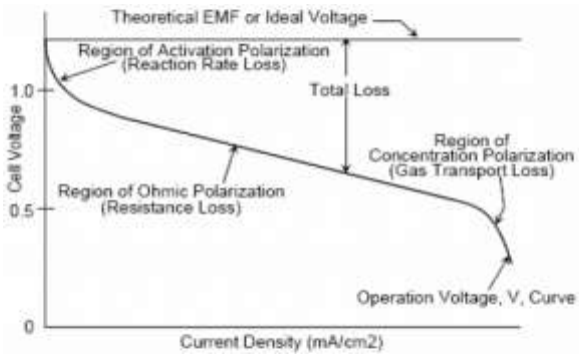

Fig 2:Typical Voltage vs. Current Curve for Fuel Cell [7]

Consider a fuel cell stack based on hydrogen fuel. Hydrogen delivers two electrons, the mass flow of hydrogen as fuel is directly proportional to the stack current [9], and neglecting losses. The fuel efficiency therefore depends on the stack voltage. The relation between stack voltage and stack current is presented in figure 3.

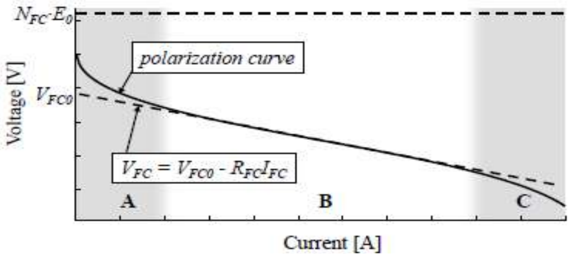

Fig 3 : Fuel cell stack polarisation curve

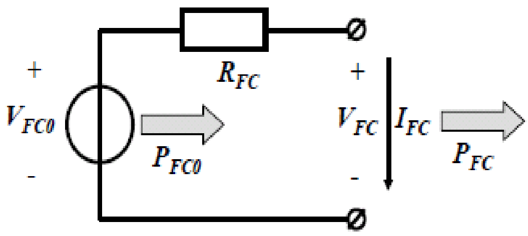

Fig 4 : Fuel Cell Stack Model

For a stack without internal losses, the stack voltage is defined by the reversible cell potential E0 times the number of cells. This ideal potential is reduced by activation losses, ohmic losses and concentration losses. For small currents, the activation losses dominate the voltage reduction (area A). In the normal operating range, an ohmic relation dominates (area B), and for high current densities, concentration losses reduce the voltage to unpractical low values (area C). The relation between stack current and stack voltage is standing on ohmic relation; the fuel cell stack is modelled as an ideal voltage source with an internal resistance in series. This leads to the following relation between stack voltage V_{FC} and stack current I_{FC}.

$$V_{FC} = V_{FC0} - R_{FC}I_{FC}$$

The power PFC delivered at the terminals of the fuel cell stack relates to the stack current IFC as:

$$P_{FC} = V_{FC}I_{FC} = V_{FC0}I_{FC} - R_{FC}I^2_{FC}$$

The power range for normal operation is bounded by a maximum and minimum. $P_{FCmin} < P_{FC} < P_{FCmax}$. Here, P_{FCmin} and P_{FCmax} denote the minimum and maximum rated operating power of the fuel cell stack. Typically, P_{FCmin} is 10-20% of P_{FCmax}.

III. OPTIONS FOR ENERGY STORAGE

With system hybridisation, energy storage technology for FCVs has been searched. The system is tested in terms of performance, lifetime and cost. Comparison of technologies is done in terms of energy storage and power handling capacity. The Ragone plot of these technologies gives an idea of current status and estimated future potentials and their relative charging and discharging times, which can be concluded into following:

- Supercapacitors can deliver very high power and be charged in a few seconds but have limited energy storage capacity.
- Lithium batteries can store 10-30 kWh and be completely charged and discharged in 10-20 minutes and can provide high pulse power for a few seconds much like capacitors, but with greater losses.
- The fuel cell system has a very high system energy density due primarily to the characteristics of the hydrogen fuel and can deliver high power for long periods, but has relatively poor dynamic response due to the compressor needed to provide the air at the cathode of the fuel cell.[6]

Hence none of the technologies meets all of the needs of electric drive vehicles alone but the combination of fuel cells and supercapacitors or batteries can take advantage of the strengths of each of the technologies and achieve performance in automotive application.

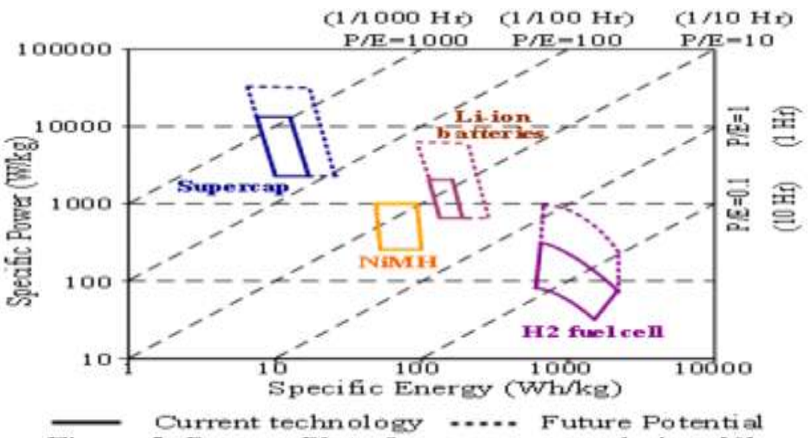

Figure 5- Ragone Plot of energy storage devices [6]

IV. POWER DELIVARY SYSTEM IN FUEL CELL VEHICLES

The proper operation of FCEVs requires maintaining the ratio of back pressure and air flow with the change in power demand. The conditions in which the fuel cell stack needs to operate can significantly increase or decrease the life of the FC arrangement due to stresses on the system. One option to critically balance the stresses on the system is to use a system containing two energy sources i.e. a Fuel Cell stack and an energy storing device. Considering hybridization of fuel cell vehicles much architecture have been thought off including physical arrangement of the power sources, selection of the energy storage technology and devices, and the control strategy for splitting power between two power sources. There are many options relative to operating conditions, control complexity, development cost, vehicle performance, and fuel economy potential.

The following fuel cell power arrangements are known to be applicable to a vehicle power system arrangement:[5]

4.1 Direct hydrogen fuel cell vehicles (FCVs) without energy storage

No DC/DC converter is employed. The dependency of FCs output current on the reactant flow rate limits its response to load transients. It requires large fuel cell stack and fast reactant supply. The DC-link voltage has a large swing due to the slow response of the fuel cell system.

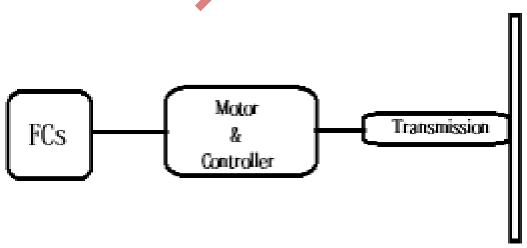

Fig 6: FC-HEV Configuration 1

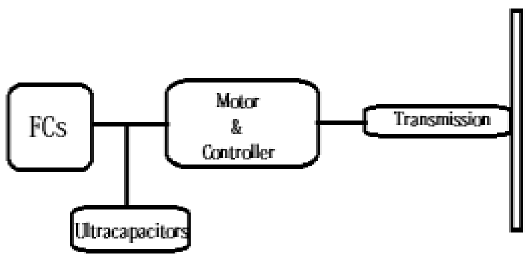

Fig 7: FC-HEV Configuration 2

4.2 FCVs with super capacitors directly connected in parallel with the fuel cell

The supercapacitors are directly connected in parallel with the DC-link. The relatively soft voltage-current characteristics of fuel cells allow supercapacitors to operate over a fairly wide range of voltage and to self regulate the DC-link voltage fluctuation. The supercapacitors will absorb the excess power from the stack and the regenerative braking energy and provide a fraction of transient power for vehicle acceleration.

4.3 FCVs with supercapacitors coupled in parallel with the fuel cell through a DC/DC converter

The fuel cell voltage is the DC-link voltage. The transient power provided by the energy storage is regulated by a DC/DC converter. The introduction of the DC/DC converter can maximize the utilization of supercapacitors or batteries during acceleration and cruise and regenerative braking. This configuration permits controlling the transient power from the fuel cell by applying different power split strategies such as power-assist or load-levelling control to mitigate the stress on the fuel cell stack [8]. The state of charge (SOC) of supercapacitors or batteries can be directly controlled within appropriate levels.

4.4 FCVs with the fuel cell connected to supercapacitor dc-link via a DC/DC converter

The energy storage voltage is the DC-link voltage. The steady power provided by the fuel cell passes through the DC/DC converter. The converter regulates the fuel cell power to avoid large fluctuation of the DC-link voltage. The SOC can be controlled indirectly.

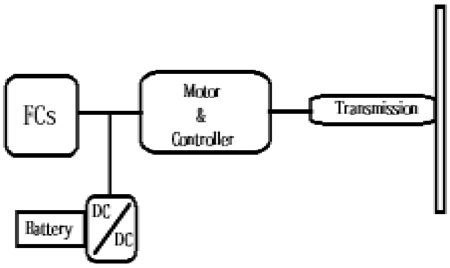

Fig 8: FC-EHV Configuration 3

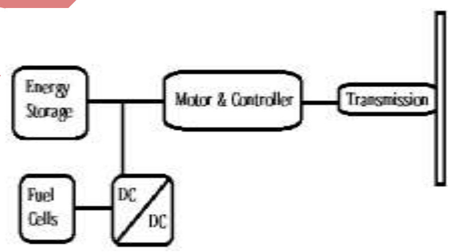

Fig 9: FC-EHV Configuration 4

V. FUEL CELL VEHICLE CONFIGURATIONS

A Fuel Cell Hybrid vehicle has a battery or an ultracapacitor in parallel with the fuel cell system. Fuel Cell Hybrid operation enables most efficient use of the inherently high energy density of the fuel cell and the high power density of the battery. When power demand is high, such as during acceleration, batteries will provide the required power. When the power demand is low, the fuel cell provides the required power. Batteries will be recharged during the periods of low power operation. Thus, depending on the power and energy requirements, the fuel cell could be designed to provide cruising power and the battery could be designed to provide peak power. The selection of the battery pack would also depend on factors such as cost and performance of the fuel cell and the battery, the battery technology, and the driving cycle.

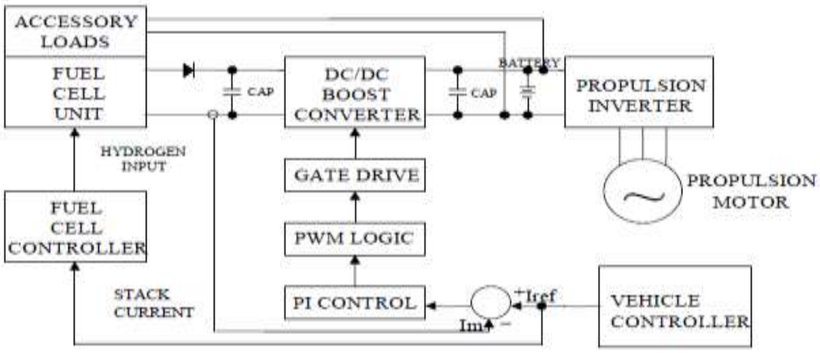

Figure 10 –Fuel Cell Converter Control System [13]

5.1 Fuel Cell System with Battery and DC/DC Converter

A fuel cell propulsion system with a battery pack and DC/ DC converter is shown in Fig 11. In this system, the propulsion unit is designed at a higher voltage than the fuel cell voltage. Hence a boost type DC/DC converter is required to boost the fuel cell stack voltage to the required battery voltage of about 300 V. The boost converter is also required to charge the batteries. The power required for propulsion is supplied by the batteries and the fuel cell stack. The DC/DC converter has to be sized based on the maximum power capability of the fuel cell stack. The diode at the output of the fuel cell stack is necessary to prevent the negative current going into the stack.[13]

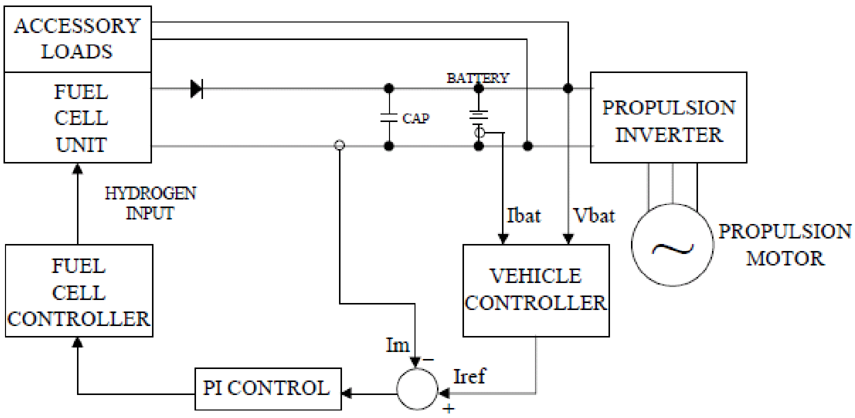

Fig 11: Fuel Cell System without a DC/DC Converter [13]

5.2 Fuel Cell System without a DC/DC Converter

If the characteristics of the fuel cell stack and the battery are matched, it is possible to eliminate the DC/DC converter. In the system shown in Fig. 10b, the load is shared by the fuel cell and the battery. By controlling the hydrogen input to the stack, it is possible to adjust the power supplied by the battery and by the fuel cell. The fuel cell also can be operated to fully supply the load and to charge the batteries. If it is a smaller battery, it can be used to provide mainly the peak and transient power. The power command from the vehicle controller is divided by the fuel cell voltage to derive the reference current command. This current reference is compared with the actual current to derive a signal to control the amount hydrogen input to the stack.[13]

VI. SAFETY & ACCEPTANCE

Safety concerns include the pressurized storage of hydrogen on-board vehicles. Hydrogen gas is odourless, colourless, and tasteless, and thus unable to be detected by human senses. Unlike natural gas, hydrogen cannot be odorized to aid human detection; furthermore, current odorants contaminate fuel cells and impair cell functioning. It is also more combustible than gasoline; although flames produce lower radiant heat which limits the chance of secondary fires.[11] Improved on-board storage will reduce safety concerns. Consumers will have to become familiar with and embrace fuel cell technology before FCVs can become widespread.[12] In addition, the durability and reliability of fuel cells will need to be comparable to the lifetime of a conventional passenger vehicle.

VII. CONCLUSION

The technological development on FCEVs will certainly give a new dimension to road transportation based on non-fossil fuel systems. The cost and mass acceptance of the vehicle will depend on the government policies and fuel availability. Improvement in energy storage system and cheap & efficient hydrogen generation methods will certainly help in improvement of vehicle popularity.

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