# A REVIEW PAPER ON FUEL CELL HYBRID VEHICLES

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***Abstract— This paper gives a brief review about the fuel cell vehicles. The major aim of the automobile industry is to improve fuel efficiency of vehicle and performance with much lesser percentages of harmful tailpipe emissions. One of the major technologies includes fuel cell vehicles (FCV). The hydrogen is a clean fuel and finds intensive application in future in automobile industry. The different advantages of fuel cells are reliability, simplicity, quietness of operation, and zero pollution which have made them a suitable alternative option for providing automotive power. This paper aims at discussing the basic possible types of fuel cell vehicles depending on the electrolyte used along with the combination of energy storage devices with the fuel cell vehicle. PEMFC has found certain advantages in the field of vehicle application.This paper gives a brief about the energy management control strategies for proper distribution of power flow among different components of fuel cell hybrid vehicles. The major issues that need to be overcome in order to make them practically viable depends upon the selection of proper energy management control strategy.***

***Index Terms— Fuel Cell Vehicles, Energy Storage Devices, Energy Management Strategies.(keywords)***

## I. Introduction

Automobiles release a number of different harmful gases into the air that causes respiratory diseases, including bronchitis, emphysema, pulmonary fibrosis, and asthma. The concentration of carbon dioxide released from the vehicles has been increased in the air by about 25 percent. Decreasing carbon dioxide and other greenhouse gas emissions is becoming a major issue. Global oil reserves are only sufficient for around 40 years with the current level of oil production and consumption [1]. Thus, it is necessary to promote the development of new energy technologies. In order to reduce the emissions, several alternative technologies need to be explored. Most prominent of these technologies are electric vehicles, hybrid vehicles, dual fuel engines, and fuel cell vehicles. Fuel cell vehicles are one of the most prominent and emerging technology which can overcome the internal combustion engine (ICE) fully. The cost and reliability of fuel cells are major obstructions preventing fuel cell vehicle from entering the mainstream market. This fuel cell technology was first invented in 19th century by Sir William Grove, a Welsh judge and scientist who assembled the first fuel cell vehicle in 1839. But at that time this technology was not able to develop due to various reasons. At present, the hybridization of the fuel cell system with peak power sources like battery and super capacitor is an effective technology to overcome the disadvantages of the fuel cell alone powered vehicles. The fuel cell hybrid electric vehicle is fully different from the ICE vehicles and ICE-based battery vehicles. Moreover, with the implementation of a driving condition based efficient EMS, minimum fuel consumption and maximum power utilization can be achieved. Impressive progress has been made in the past few years in the advancement of technology of fuel cells.

## II. HYDROGEN AS A FUEL

Hydrogen has a very high energy-density, higher than conventional fuels and substantially higher than the batteries. However, volumetric energy densities are much lower so hydrogen is compressed, either to 350 bar or more commonly to 700 bar for filling in the cars as per availability of space. Hydrogen can be manufactured from a wide number of sources, which help many countries to reduce their dependence on imported energy. The researchers are working hard for manufacturing, storing, distributing and dispensing hydrogen.

One of the oldest and easiest methods for production of hydrogen is the electrolysis of water: using electricity to split water into hydrogen and oxygen. This technique is particularly suitable for small-scale production, and many hydrogen refueling stations make their own hydrogen on site by this method. If the electricity is provided from a renewable source, such as wind or solar power, then the production of the fuel releases no carbon and other gases, hence the emissions are reduced to zero. The large scale production of hydrogen used in industries at present is the steam reforming of methane, which can yield conversion efficiencies of up to 80%. A further sustainable technology, which is to be applied at an industrial scale, is the gasification of biomass and waste [2].

The major issue is the storage and dispensing of the hydrogen for automobile use.

## III. FUEL CELL VEHICLES

Fuel cell vehicles are at an early stage of development as compared to electric vehicles. They have the advantages of battery driven vehicles and can be refueled quickly, and can be used for longer range. In addition, fuel cell cars, depending on the fuel used, releases few greenhouse gases. Fuel cells are electrochemical devices that convert the energy of a chemical reaction directly into electrical energy. Fuel cells have the capability of producing electrical energy as long as the fuel is supplied to the electrodes. **Advantages of Fuel Cell Vehicles**

**over Internal Combustion Engine (ICE) vehicles:**

- No moving parts in the energy converter and hence quiet.
- Direct energy conversion (no combustion).
- The use of fuel cell vehicles can reduce the air pollution to a large extent.
- If the ICE is replaced by fuel cell vehicles it can save up to 60% of the petrol and diesel consumption, and the CO2 emissions can also be reduced by about 75%.

**Advantages of fuel cell vehicles over battery driven electric vehicles:**

• The energy density of a fuel cell is greater than that of a battery. Taking into account the efficiency, the methanol with tank in a fuel cell vehicle corresponds to 1900 Wh/kg. The lead acid batteries are about 40 Wh/kg.

• A fuel cell can be refueled much faster than a battery. It is similar to filling the tank in an ICE vehicle. Fuel cell vehicles do not need much charging time like the battery driven vehicles.

• A liquid fuel distribution network could easily be established based on the present gasoline stations. These stations could be converted to handle methanol or a different grade gasoline. The battery recharging stations may need much more work.

For automotive applications, fuel cell systems are not yet competitive with the ICE for performance, packaging, cost, fuel storage, and high volume manufacturability. In addition, it is still a developing technology with no infrastructure for refueling

FCs produce dc voltage outputs and they are always connected to electric power networks through power conditioning units such as dc/dc and dc/ac converters. Power conversion and control functions form the basis of what has come to be known as the field of power electronics. In recent years, power electronics technology has been spurred by needs for efficient control of industrial applications and the development of more reliable lightweight switching power supplies for a sophisticated system [3].

TYPES OF FUEL CELLS : Various types of fuel cells are in the development stage. The most common classification of fuel cells is by the type of the electrolyte used [4-7]. They are:

1. Proton Exchange Membrane (PEM, also called polymer electrolyte) fuel cell with an operating temperature of about 80 $^oC$
2. Alkaline fuel cell with an operating temperature of about 100 $^oC$
3. Phosphoric Acid fuel cell with an operating temperature of about 200 $^oC$
4. Molten Carbonate fuel cell with an operating temperature of about 650 $^oC$
5. Solid Oxide fuel cell with an operating temperature of 800 $^oC$ to 1000 $^oC$.

Hydrogen, methanol, natural gas and gasoline can be used as fuels in fuel cell vehicles, but the best option is hydrogen in a polymer electrolyte membrane fuel cell (PEMFC). Because such fuels, except hydrogen, contain carbon and it is impossible to avoid exhaust gas of carbon dioxide. When hydrogen is used, the exhaust is pure water only and there is no need for a fuel processor [8].

PEMFC are gaining importance as the fuel cell for vehicular applications because of their low operating temperature, higher power density, specific power, longevity, efficiency, relatively high durability, and the ability to rapidly adjust to changes in power demand. The PEM is more suitable for automotive applications for the following reasons.

- PEM can be started easily at normal temperatures and can operate at relatively low temperatures, below 100 $^oC$ also.
- Since they have relatively high power density, the size can be made smaller and can be easily packaged in the vehicles.
- Because of the simple structure compared to other types of fuel cells, their maintenance is also easy.
- They can withstand the shock and vibrations of the automotive environment because of their composite structure.

One problem in PEM is that the CO concentration in fuel should be reduced to less than 10 ppm, because even small amounts of CO in fuels cause deterioration of the cell performance. Another problem is that they typically require expensive precious-metal catalysts.

DRIVE TRAIN CONFIGURATIONS

There are different drive train configurations used by vehicle developers and energy storage technology in their vehicles. Four practical arrangements of power sources are possible.

a. Fuel cell vehicles (FCVs) without ESS.
b. FCVs with super capacitors directly connected to FCV.
c. FCVs with batteries or super capacitors coupled to fuel cells via a DC/DC converter.
d. Fuel cells coupling to batteries or super capacitors via a DC/DC converter (battery/super capacitor).

Each of the power sources arrangements has its advantages and disadvantages on the basis of operating conditions, control complexity, development cost, vehicle performance, and fuel economy potential.

Several conditions need to be considered to connect the ESS and the FCS to the load, depending on the following issues:

1) Characteristics of the load (dc or ac voltage, single-phase or three-phase, and range of the voltage);
2) Possibility of energy recovering from the load (e.g., regenerative braking);
3) range of the voltage in the ESS;
4) Output voltage of the FCS.

## IV. FUEL CELL HYBRID SYSTEMS

The major components of a typical Fuel Cell Hybrid System [9] include:

• Fuel Cell System
• Power Electronics Converter
• Electric Machines
• Energy Storage Devices
• Hydrogen Storage System.

The fuel cell system consists of a fuel cell stack, fuel processor, inverters and conditioners, and a heat recovery system that uses hydrogen and oxygen to produce electricity.

Fuel Cell Hybrid Systems (FCHS) are combination of a primary power source i.e. the fuel cell and an energy storage system, a battery or super capacitor bank that supports to supply the load power demand. Hence, the load power Pload(t) is supplied from the fuel cell system, Pfcs(t) and the energy storage system, Pess(t), in such a way that:

Pload (t) = Pfcs (t)+ Pess (t) for all t .

The Figure. 1 shown below indicates the power flow in a FCHS.

Power electronics converters include a motor controller, DC/DC converter, and inverter that process and controls the electrical power flow between the fuel cell, battery, super capacitors and the electric machine. The motor controller regulates the power to the motor whereas the DC/DC converter converts the high DC voltage to low DC voltage. This voltage is then used to power the vehicle’s auxiliary loads such as lighting, windshield wipers, and the radio. Lastly, inverters convert DC power from the fuel cell, battery or super capacitor to alternating current to power the electric machine. The FCS is connected to the DC bus through a step-up power converter (Boost converter), whereas the

ESS is connected to the DC bus through a bi-directional power converter (Buck-Boost converter). This converter acts as a "switch" that allows the regulation of the energy flow between the ESS and the dc bus. The load is fed through a DC-AC inverter.

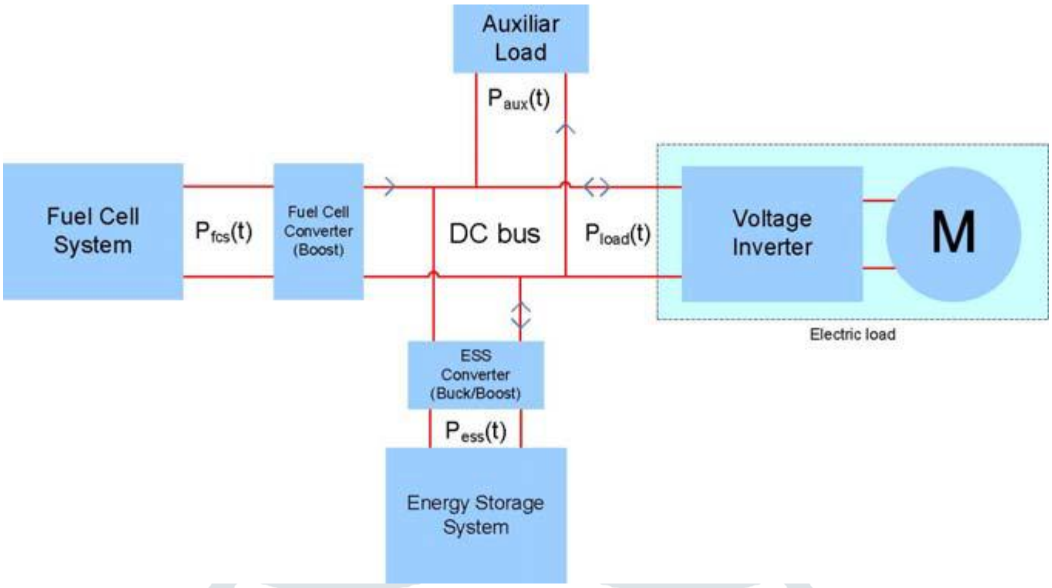


Fig.1 Diagram showing the electrical topology and the power flow in a FCHS

The power converter that connects the ESS to the dc bus is fundamental in implementing the energy management strategy in the hybrid system: In the same way, the converter that connects the FCS to the dc bus allows the regulation of the power flow from the FCS and, in addition, has to cope with the variations in the FCS output voltage since the FCS does not act as an ideal voltage source [9].

The electric machines use the alternating current to provide traction to the wheels of the vehicle, thus enabling propulsion. Manufactures of current FCVs commonly use one of two electric machine technologies: permanent magnet (PM) or induction. Switched reluctance motors, although not commonly used as FCV drives today, are also being explored by researchers [10].

The ESS in the FCHS can be implemented either by a high specific energy device such as battery or by a high specific power device such as super capacitors (SC). There is also the possibility of a combined solution using batteries and SCs [11]. The batteries have a very high energy density approximately 10 times more than super capacitor whereas the super capacitor has approximately 3 times high power density than the battery.

Lastly, an onboard hydrogen storage system is required. The development of a suitable onboard system to store hydrogen fuel remains one of the key challenges inhibiting the widespread commercialization of hydrogen FCVs. The issue lies in developing safe, reliable, and cost-effective systems within the mass and volume constraints of a vehicle.

On vehicle driving, there are power losses in many vehicle components. The required power of the fuel cell and ESS includes these component losses as well as the auxiliary power for cooling, air supply, fuel supply, head lights etc. The main losses in a fuel cell hybrid vehicle are largely motor and controller losses, transmission losses, breaking losses, and dc–dc boost converter losses.

**Energy storage devices**

In order to operate the FC in vehicle application, the fuel starvation problem needs to be eliminated. The fast energy demand causes high voltage drop in short time which is being treated as fuel starvation phenomenon and results in degradation of the performance of fuel cell. Therefore, we need an energy buffer to improve the vehicle performance when the dc bus demands high power in short time i.e. during acceleration. The two different types of energy storage devices that can be used are batteries and super capacitor.

**Batteries**

The role of the battery in a fuel cell hybrid vehicle can be summarized as follows:

1. Acts as a source of energy electric vehicular devices.
2. An energy storage device during regenerative braking.
3. Electrical energy storage device that is generated from the fuel cell at low load.
4. Assists the fuel cell power at higher load.
5. Main energy supplier when fuel cell system operates at low load.

Various types of battery are under development. The factors in selecting a battery for vehicles are specific power, specific energy, life-cycle and cost.

**Supercapacitors**

Electric double-layer capacitors, also known as super capacitors, electrochemical double layer capacitors (EDLCs) or ultra capacitors are electrochemical capacitors that have a very high energy density as compared to common capacitors. An ultra capacitor is an innovation in the field of capacitors. The main difference between a capacitor and an ultra capacitor is that- it uses a very small charge separation distance that is literally equivalent to the dimensions of the ions within the electrolyte. Due to the carbon technology, these capacitors are able to create a very large surface area. Thus, it has a very high capacitance than an ordinary capacitor. They are quite beneficial for hybrid vehicles.

The advantages of super capacitors as an energy storage device in fuel cell vehicles are:

- High energy storage compared to conventional capacitor technologies.
- Low Equivalent Series Resistance (ESR) compared to batteries hence providing high power density capability.
- Low Temperature performance
- Fast charge/discharge since they achieve charging and discharging through the absorption and release of ions.

**Energy management strategies**

To guarantee the efficiency and performance of FCHEVs, a relevant Energy Management Strategy (EMS) plays an important role. An EMS defines the power sharing between the different energy sources in the system to fulfill the power demand. In order to maximize the fuel economy a supervisory control strategy needs to be developed on the basis of the driving cycles. It has to ensure that constraints on the operation of the fuel cell system and storage are not violated, without compromising on the drivability of the vehicle.

The EMS are the algorithms which determine at each sampling time the power generation split between the Fuel Cell System (FCS) and the Energy Storage System (ESS) in order to fulfill the power balance between the load power and the power sources. Depending on how the power split is done minimization of the hydrogen consumption can be obtained. To find a global optimal solution, control techniques where a minimization problem is resolved needs to be studied. The energy management control strategies are basically divided in two categories: Rule based control strategy and Optimization control strategy.

The EMS of a hybrid vehicle should perform following functions:

•Provide the power demanded by the system and the driver.
•Control and maintain the State of Charge of Battery and Super Capacitor.
•Recover the braking energy during regenerative braking as much as possible.
•To operate each component of the vehicle with its optimum efficiency.

Different approaches for EMS were found in literature. In [12], the proposed strategy was based on the regulation of the DC link voltage by controlling two power converters, and, thus, the fuel cell operates in almost steady state conditions. In [13], it was proposed a control strategy with two objectives: obtaining high efficiency in the hybrid system and maintaining the state of charge in the batteries above a minimum value. If both objectives cannot be fulfilled simultaneously, the priority is given to the battery state of charge. In [14], three heuristic strategies were compared using a Fuel Cell Hybrid Vehicle model. In contrast, other publications propose the strategies based on optimization techniques. One of the most relevant was the method presented in [15], based on a control strategy called Equivalent Consumption Minimization Strategy (ECMS). The base of this strategy consists in converting all the power flows in equivalent hydrogen consumptions. Using the same concept, in [16], a real time control was implemented on a real fuel cell-super capacitor-powered vehicle with good results. But the practical implementation of the fuel cell technology in the vehicular technology is still not commercialized and lot of efforts is required.

**Vehicle performance**

The performance of a vehicle depends on its maximum cruising speed, gradeability, and acceleration. The predication of vehicle performance is based on the relationship between tractive effort and vehicle speed [17].

**Maximum speed of a vehicle:**

The maximum speed of a vehicle is defined as the constant cruising speed that the vehicle can develop with full power plant load (full throttle of the engine or full power of the motor) on a flat road. The maximum speed of a vehicle is determined by the equilibrium between the tractive effort of the vehicle and the resistance or the maximum speed of the power plant and gear ratios of the transmission.

**Gradeability:**

Gradeability is usually defined as the grade (or grade angle) that the vehicle can overcome at a certain constant speed. For heavy commercial vehicles or off-road vehicles, the gradeability is defined as the maximum grade or grade angle in the whole speed range.

**Acceleration performance:**

The acceleration performance of a vehicle is defined by the acceleration time and the distance covered from zero speed to a certain high speed (zero to 96 km/h or 60 mph, for example) on ground level.

**Basic techniques to improve vehicle fuel economy**

The efforts are made in the automobile industry to improve the fuel economy of vehicles. Following techniques are used that cover these aspects:

(1)Reducing vehicle resistance
(2)Improving engine operation efficiency
(3)Properly matched transmission
(4)Advanced drive trains

## V. CONCLUSION

The protection of environment and energy conservation are the growing concerns and the development of hybrid fuel cell and fuel-cell vehicles has been accelerated. The dream of having commercially viable the fuel cell vehicles is currently becoming a reality. The use of hydrogen as a fuel is inherently very clean because the hydrogen consumed by either combustion or a fuel cell produces only water as a product. However the cost of hydrogen is very high as compared to other fuel options, so it is likely to play a major role in the economy if the cost comes down by making improvements in the technology. For vehicle applications, fuel cells have higher efficiency than ICE, since it is not restricted with Carnot efficiency, quieter than ICEs; and reduce environmental pollution. Among different types of fuel cells, PEMFC, also known as Polymer Electrolyte Membrane Fuel Cells has proven to be the most attractive option. Also, the various heads were studied on which the performance of vehicle depends and how it can be improved. There are many challenges that still have to be met before a fuel cell power system can achieve the cost, performance and reliability in order to guarantee successful commercialization of fuel cell vehicles. Two things are needed for the market introduction of FCEV: the cars themselves and hydrogen refueling stations to support them. In any market, a minimum number of each is necessary to support demand for the other. Fuel cell research will provide improvements in both performance and cost. The list of shortcomings of FCVs has been reduced in recent years. Power density range and cold start capability cannot be seen as show-stoppers anymore.

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