A Performance Analysis of Electric Vehicles

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Abstract: ***The revolution in the automobile industry is made by electric vehicles, hybrid electric vehicles, etc. In the next few years, these technologies will replace conventional vehicle systems completely. As technology evolves very rapidly, research and development in this area are very much required. This paper presents a detailed review of a variety of electric vehicles. The technological performance review discussed here will help researchers to move the research rapidly. In this paper, the author outlines and formulates a structural framework for understanding the optimality in the case of electric vehicles and hybrid electric vehicles.***

Keywords: Electric vehicle (EV); Fuel Cell Vehicle (FCV); Hybrid Electric Vehicle; HEV; Plug-in HEV.

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1. Introduction

The increase of population directly increases the mobility of people or transportation drastically. Moreover, these days there are a huge number of rules and regulations implemented by different governments of the world in the automobile industry towards fuel consumption and air pollution. On the other side, people want more comfort, advanced technology, luxury, and more safety to be present in their vehicles.

To meet both the criteria, i.e., reduce fuel consumption and air pollution without compromising the customer needs, the automobile industry is entering into the electrical environment more. Most of the mechanical and hydraulic components are replaced by electrical components. This reduces the weight of the vehicle and also improves the efficiency of the vehicle [1]. More focus is given to the aerodynamics of the vehicle to reduce the energy needed for the propulsion of the vehicle.

Electric vehicles are a very old technology/concept. It was first made around 1890 with a speed of 14 miles per hour. But the invention of motor vehicles running on gas and steam was the main reason for the fall of the electric vehicle because electric vehicles were having very little speed. In this article, the author represents the latest research done in the last 10 years particularly in the area of electric vehicles.

2. Electric vehicles and configurations

Electric vehicles normally come with battery technologies to improve their performance of electric vehicles. Battery electric vehicles are classified into 3 different types based on their range, speed, and acceleration performance, etc.

Table 1: Electric Vehicle Configuration

Name of vehicle	Speed
Neighbourhood electric vehicles	Less than 25 Km
City electric vehicles	Less than 50 Km
Full performance BEV	150-600 Km

Depending upon the performance, there are the following types of electric vehicles as shown in table 2.

Table 2: Electric Vehicle Types

Type of Vehicle	Hybrid Electric Vehicle	Battery Electric Vehicle	Plug-in Hybrid Electric Vehicle	Fuel Cell Vehicle
Topology	1) Series 2) Parallel 3) Series-Parallel 4) Complex hybrid	None	None	None

Components	- Electric motors - Internal Combustion Engines	Electrical motors	- Electric motors - Internal Combustion Engines	Fuel Cell
Power source	- Electrical Grid - Gasoline stations	Electrical grid	- Electric motors - Internal Combustion Engines	Hydrogen

2.1 Series Configuration

In this type of configuration, a battery serves as the primary power source, while an Internal Combustion Engine (ICE) serves as the optimum power source, acting as a generator.

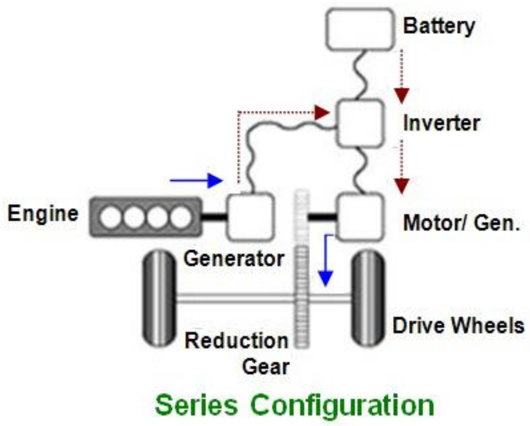

Figure 1: Series configuration of Hybrid Electric Vehicle (HEV) [9]

The electrical energy thus converted can be used to charge the battery or it can be transferred to the wheels by compassing the battery [3]. When the battery's state of charge falls below the manufacturer's recommended minimum contained value, the ICE is turned ON. This type of configuration involves three types of systems for propulsion such as electric motor, generator, and ICE. Hence, the sizing of series HEVs is difficult.

2.2 Parallel Configuration

In this type of configuration, both battery and ICE act as the main power source. Both electric motors and ICE are directly connected to the wheel for propulsion. Unlike series configuration, the sizing of parallel hybrid electric vehicles is simple because it requires only two propulsion systems such as electric motors and ICE.

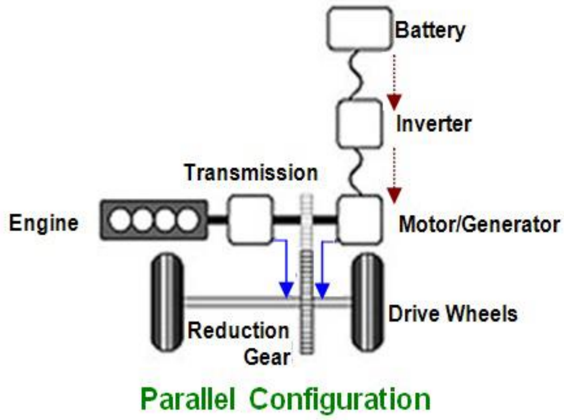

Figure 2: Parallel configuration of Hybrid Electric Vehicle [9]

2.3 Series - Parallel Configuration

In this case, there are two compound types of operations like electric intensive configuration and engine intensive configuration in which ICE acts as the main power source. As it is the combination of both series and parallel connection, there is a different mechanical connection between ICE and wheels for series connection and a separate generator for parallel connection. Due to various propulsion systems, the sizing is quite complicated.

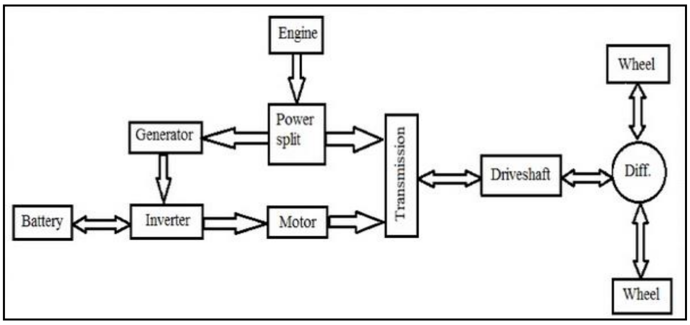

Figure 3: Series-Parallel configuration of Hybrid Electric Vehicle

Beyond these three configurations, there is another configuration called complex configuration. This is almost the same as that of series-parallel configuration but the only difference is its bidirectional power flow.

2.4 Fuel Cell Technologies

There are mainly four types of fuel cell technologies as follows:

- **Direct Methanol Fuel Cell (DMFC)** was developed by Prof. Narayan as a collaborative effort between his team at NASA-JPL and Prof. Surya Prakash's group at USC under programs sponsored by DARPA [2]. The concept was commercialized by Smart Fuel Inc., and portable power generators can be readily purchased.

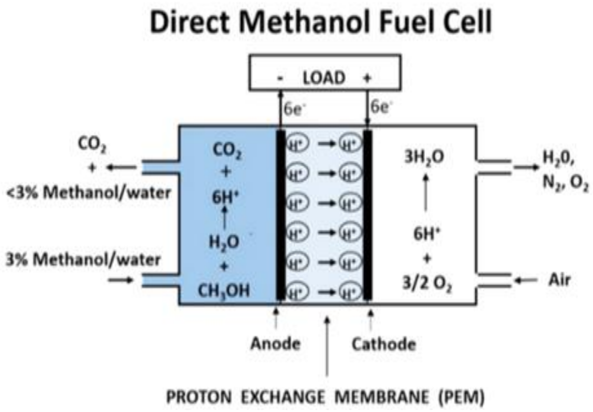

Figure 4: Direct Methanol Fuel Cell [10]

Methanol in presence of oxygen produces a huge amount of energy i.e., around 4800Wh of heat per kg of methanol. A solution of methanol dissolved in water is circulated past the negative electrode in the case of DMFC while oxygen is flown past the positive electrode. As electricity is generated, the methanol is oxidized to carbon dioxide at the negative electrode while oxygen is reduced to water at the positive electrode. The protons are conducted across the membrane. The DMFC works with high energy density but low power density.

- **Alkaline Fuel Cell (AFC)** is one of the first extensively researched fuel cell types. It is used by NASA in the case of Apollo, Gemini, and space shuttle missions. In AFC, depending upon the electrolyte composition the oxygen reacts at the cathode to produce either hydroxide or carbonate ions. The ion travels through the electrolyte to react with hydrogen at the cathode. AFCs use lower-cost materials compared with other fuel cells.

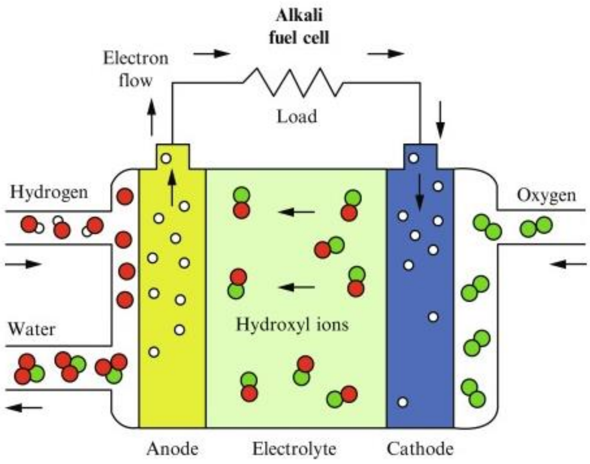

Figure 5: Alkali Fuel Cell [11]

- **Solid Oxide Fuel Cell** uses calcium or zirconium oxide as electrolytes. The operating temperature is around 1800º F. The main demerit of this type of cell is its large starting time. The efficiency is 60% and the output is 100kW. It is normally used as a secondary power source as air conditioning in cars and heaters.

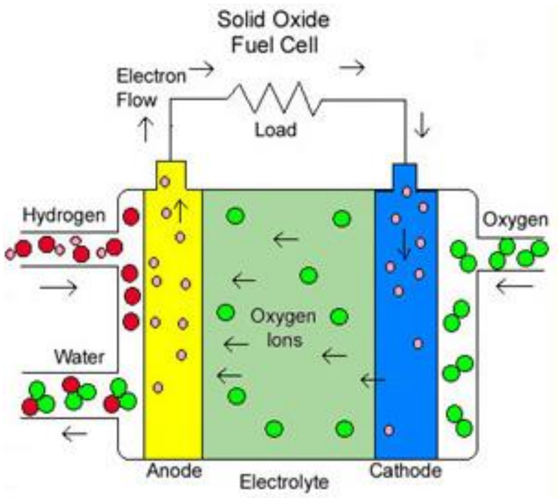

Figure 6: Solid Oxide Fuel Cell [11]

- **Proton Exchange Membrane Fuel Cell (PEMFC)** works with a polymer electrolyte in the form of a thin, permeable sheet. The operating temperature is around 175º F. The efficiency is a little lesser than SOFC i.e., about 40-50%. The output generally ranges from 50-250 kW. The design is compact and the quick output can be obtained. The presence of carbon monoxide impurities reduces the efficiency of the vehicle. This is the main demerit of this type of fuel cell.

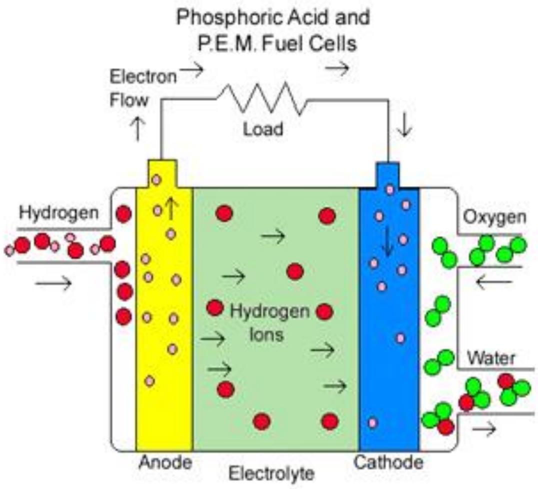

Figure 7: Proton Exchange Membrane Fuel Cell [11]

Fuel Cells and battery configurations are the most important in HEVs. Battery maintenance here is very expensive. The demand for the battery and electric motor is low. But there is also another type of configuration known as a *Fuel cell with battery and supercapacitor configuration*, in which supercapacitors are used for range extenders. Supercapacitors are having high power density and batteries are having high energy density. The combination of both results in high charging/discharging capacity with very good battery life.

2.5 Plug-in HEV Configuration

The mode of operation is the same as that of the Hybrid Electric Vehicles (HEV). The only additional feature is known as All-Electric Range (AER). It uses an electric powertrain which acts as the main power source. Hence, the advantage is that the user can get the fuel and emission-free operation for a few kilometers before the State of Charge of the battery falls below the minimum level. After that, the Plug HEV switches to the HEV mode of operation [4,5]. Based on the level of electric power and function of electric motor, HEV's are classified into the following categories [7,8]:

Micro-Hybrid: It is the very simplest type of electrical technology. The most important feature is the Start-stop function. In this technology, the vehicle starts and stops the engine automatically without producing noise and vibrations. In case of frequent start-stop during city driving, the energy-saving may be around 5-10%.

Mild Hybrid: The electric motor used in this vehicle is of power 10-20kW at 100-200V. The electric motor used here is of flat shape and is directly connected to the engine. The ratio of the diameter to the length of the motor is very high. This helps the motor to have high inertia such that the original flywheel of the motor is removed. Although the efficiency is 20-30%, the cost also increases 20-30%.

Full Hybrid: The electric motor of this vehicle is about 50kW and the voltage is 200-300V. The motor, generator, and engine are all connected in series-parallel or complex form. A full hybrid can have an efficiency from 30-50% but the cost can increase from 30-50%.

3. Key Parameters of EV, HEV and FCV

Propulsion motor: Normally motors and drives play an important role in the case of any type of electric vehicle. There are varieties of motors used in such vehicles. Induction motor switched reluctance motor and permanent magnet synchronous motor or permanent magnet brushless motor.

The permanent magnet (PM) machines normally have very high efficiency, high torque, and high power-density. But, the back emf may be an issue during high speed. During stator winding short circuit fault, the system may come into a problem due to the existence of the rotor PM field.

Due to its simple and rugged construction, simple control, and the ability to have a very high speed, switched reluctance motor is more popular in the propulsion system of EV, HEV and Fuel Cell Vehicles (FCV) [6]. The higher cost is its main drawback.

Similarly, Induction motors are also used in the field of EV, HEV, and FCVs due to their simplicity, robustness, and wide speed range. The induction machines do not entertain the back emf in case of high speed. The efficiency is generally lower than permanent magnet machines due to inherent rotor loss.

Power Converters- Rectifiers, inverters, and DC/DC converters are normally involved in the design of HEVs.

4. Conclusion

In this article, the authors have tried to present an analysis of the performances of EV, HEV and FCVs. The authors have discussed various configurations, topologies of EV, HEV, and FCVs. Furthermore, the authors have discussed how these technologies can be used based on the application in which they are adopted, also how these technologies are used to optimize the performance of these vehicles as compared to conventional vehicles. Due to superior fuel economy and vehicle performance, the HEVs will increase their popularity in recent future. Researches are going on for further improvement of the performance of the HEV depending on the demand of the requirement. Modelling and simulation play important role in the development of the HEVs.

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