Hybrid Electric Vehicle

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Hybrid Electric Vehicle (HEV) design based on the installation of a fuel cell (FC) module in the existing Daewoo Tico electric vehicle to increase its range in urban areas. Installing an FC module supplied by a 2 kg hydrogen tank would not significantly increase the mass of the electric vehicle, and the charging time of the hydrogen tank is lower than the battery charging time.

fuel cells (FC) proton exchange membrane fuel cell (PEMFC)

1. Introduction

The conversion of various forms of energy into electricity has been known for decades. Lately, hydrogen energy has often been mentioned, which is converted into electricity through a component known as a Fuel Cell (FC), and has thermal energy and technical water as a by-product. Therefore, this type of conversion is environmentally friendly concerning the use of oil and petroleum products for this purpose. Compared to gasoline engines, Proton Exchange Membrane Fuel Cells (PEMFCs) have fewer efficiency losses, zero emissions, and no thermal losses of moving parts. It is believed that a fuel cell can solve the problem of energy and car transport. FCs are one of the most promising sources of renewable energy. It is a “green energy” source because it has no nitrogen oxide and sulfur emissions and can work with exceptionally low noise levels. Fuel cell systems have the advantage of being modular and can, therefore, be built in a wide range of power requirements, from a few hundred watts up to kilowatts or megawatts. In addition, they can provide energy in a controlled way with higher efficiency than conventional power plants. In a fuel cell, the chemical energy is provided by a fuel and an oxidant stored outside the cell, in which the chemical reactions take place. If the cell is supplied with fuel and an oxidant, electrical power can be obtained. The use of fuel cells has its share of both advantages and disadvantages, compared to conventional energy converters. The main disadvantage is still the associated excessive cost.

A fuel cell, unlike a battery, generates electricity instead of storing it and continues to do so if the fuel supply is maintained. Compared to battery-powered Electric Vehicles (EVs), a fuel-powered vehicle has the advantage of a longer driving range without a long battery charging time. Compared to Internal Combustion Engine (ICE) vehicles, FCs powered vehicles have the advantages of high energy efficiency and much lower emissions, due to the direct conversion of energy from fuel to electricity without combustion.

Fuel Cell Electric Vehicles (FCEVs) are powered by hydrogen. FCEVs and the hydrogen fuel infrastructure are in the initial stages of implementation, and refueling is still a major challenge for fuel cell vehicles. The storage of hydrogen in the vehicle is a major concern. In order to refuel cells, a hydrogen tank must be attached to the vehicle. FCEVs use a propulsion system similar to electric vehicles, where energy stored as hydrogen is converted into electricity using a fuel cell. Like conventional internal combustion engine vehicles, FCEVs can refuel in less than 4 min, and have a range of over 300 miles. FCEV vehicles are equipped with advanced technologies to increase efficiency, such as a regenerative braking system that captures energy lost during braking, storing it in the battery. Large car manufacturers offer a limited but growing number of FCEV production vehicles to the public in certain markets, in line with what developing infrastructure can support.

The conversion of fossil fuel-powered vehicles into environmentally friendly battery-powered vehicles has been extensively discussed in the literature [1][2][3]. The basic principle is to remove the existing fossil fuel engine and any associated equipment not needed for the conversion. There are two cases of conversion; the first is where the existing gearbox is retained during the conversion, and the second, which is more complex, is where the existing gearbox is removed together with the engine. Each of these two conversion cases has its pros and cons. In the case of the conversion, which, was conducted within the Faculty of Transport and Traffic Engineering in Doboj, Bosnia and Herzegovina according to the project request, a small vehicle, intended for the transport of up to two people and with a small range and low maximum speed, up to 50 km/h [4], was selected. A small serial 2 kW DC motor was chosen for this, due to its robustness and large starting torque. The old gearbox was also retained, and the conversion was much easier. Absorbent Glass Mat (AGM) batteries are used, which have limited possibilities for use in electric vehicles. The redesigned vehicle was characterized by rather modest features (low maximum speed, short range, and a long battery charging time of 6–8 h). All this represented certain restrictions in the use of the modified vehicle.

To maintain the demand for an environmentally friendly vehicle, it was necessary to choose a new technology that provides the ability to solve some of the mentioned shortcomings, including the vehicle range and charging speed. As a logical choice, the solution that uses fuel cells was adopted, primarily because it represents an environmentally friendly technology and solves some additional problems that are otherwise related to electric vehicles (e.g., the problem of heating the vehicle cabin in winter) [5][6]. A system using PEM-type fuel cells was chosen as an additional energy source due to its cost and simple implementation [6]. The operating temperature of these cells is in the range of 80 °C–90 °C, which is quite enough to solve the problem of heating the passenger cabin in the winter.

2. Design of a Hybrid Electric Vehicle with Dual Energy Sources

The goal of the research is a model of concrete hybrid electric vehicle with dual energy sources, namely, a battery source and a hydrogen source. The battery-powered energy source is provided by the AGM battery pack, and the hydrogen-powered is provided by the FC system. In the event of an AGM battery failure, the FC system takes over the role of supplying the vehicle with energy, and vice versa. The result of the research is a model designed with two AGM/PEMFC power supplies.

The Daewoo Tico electric vehicle was made in the laboratory of the Faculty of Transport and Traffic Engineering in Doboj, Bosnia and Herzegovina, in 2019. The Daewoo Tico is a prototype vehicle for experimental research with the possibility of registration and uses in urban areas, **Figure 1**.

Figure 1. Laboratory production of EV Daewoo Tico with the AGM battery pack.

The Daewoo Tico is a lightweight vehicle (approximately 640 kg, maximum permissible mass: 1025 kg). The vehicle has a propulsion motor manufactured in the factory ("Rade Končar", Zagreb, Croatia) with the following characteristics: power—2 kW, supply voltage—40 V, current—72 A, speed—1650 rpm. The battery-powered energy source is an AGM (absorbent glass mat) battery pack.

The Daewoo Tico electric vehicle has the following characteristics:

(a) Maximum vehicle velocity up to 50 km/h;

(b) Range of 15–20 km with one charge.

The vehicle is intended for the transport of goods and passengers, i.e., for the transport of the driver plus one passenger (150 kg), which would make the total mass of the vehicle with the planned passengers 790 kg.

The vehicle speeds in different gears—for a maximum engine speed of 1980 rpm with a connected voltage of 48 V—are:

- First gear: 12 km/h;
- Second gear: 20.8 km/h;

- Third gear: 32.29 km/h;
- Fourth gear: 47.37 km/h;
- Fifth gear: 54.8 km/h.

The entry proposes the improvement of the Daewoo Tico electric vehicle with a hydrogen-powered energy source. Accordingly, the Daewoo Tico EV is converted into an HEV with two energy sources. The hydrogen-powered energy source is provided by the FC system, the fuel tank (2 kg), and the fuel filter. The FC system consists of a PEMFC stack and a fuel controller that controls the operation of this system. The PEMFC control system is connected to a battery controller which regulates the operation and charging of the AGM battery pack [7]. The PEMFC stack is composed of PEMFCs that are connected in series and in parallel to obtain higher output voltages and currents compared to individual cells, whose operating output voltage is approximately 0.6 V. The operation of each PEMFC is important for the operation of the complete system for the purpose of the optimal and efficient use of hydrogen as a propellant. PEMFCs with optimal characteristics and low failure rates are of great importance for HEVs. The AGM battery pack has a capacity of 3.84 kWh, while the PEMFC pack consists of 80 individual fuel cells with a total voltage of 48 V. **Figure 2** shows the proposed design of the HEV with two energy sources.

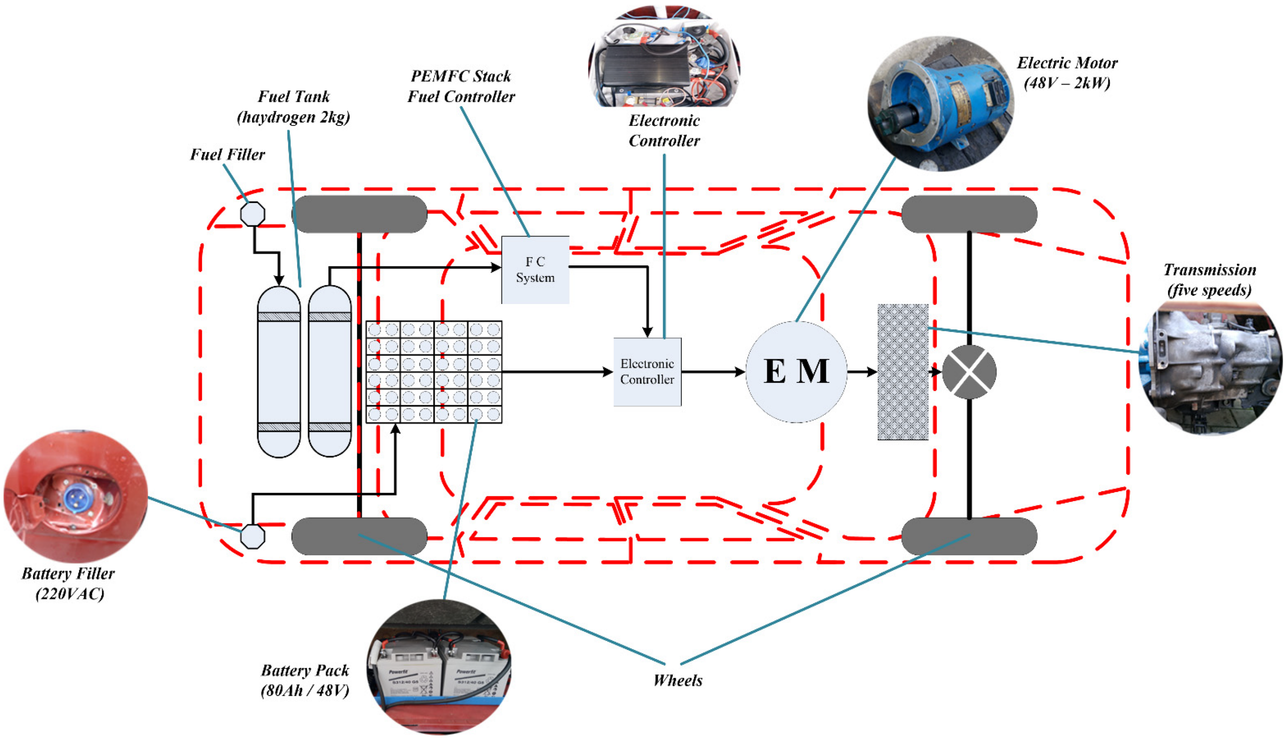

Figure 2. Design of the HEV with dual energy sources.

The calculation of the HEV motor power, for a maximum velocity of 50 km/h, can be calculated approximately using the following formula:

$$P = (m \cdot 9.81 \cdot v \cdot f) + \left(0.6465 \cdot cd \cdot A \cdot v^3\right) = 2193\ \mathrm{W} \quad (1)$$

In Equation (1), *m* = 790 kg—vehicle mass (with two passengers), *v* = 14 m/s = 50.4 km/h—velocity in m/s, *f* = 0.0081—rolling resistance coefficient, *cd* = 0.38—aerodynamic drag coefficient, *A* = 1.95 m^2—surface height * vehicle width.

Based on the motor power, the series DC motor was selected as the vehicle's drive motor. The proposed design of the HEV has at least two power sources, a fuel cell (FC) system as a power source [8][9], and an AGM (absorbent glass mat) battery package [10]. The drive batteries are 48 V with a capacity of 80 Ah (3.84 kWh). The PEMFC package consists of 80 PEMFCs connected in series. The hydrogen and battery powered supplies provide power of HEV [5][6][11].

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