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A new approach to battery powered electric vehicles: A hydrogen fuel-cell-based range extender system

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ABSTRACT

Sometimes technology and development of society run slightly different roads. This situation is now happening in the case of hydrogen as an energy carrier in the automotive world. In the article presented here, the authors propose a change in the structure of the power plant of Battery Electric Vehicles (BEV). The objective is that these vehicles can be presently used until the development of an electric and/or hydrogen recharge/refuel network allows being useful with the current status. In this paper a new concept of Extended Range Electric Vehicle (EREV) based in a Fuel Cell Electric Vehicle (FCEV) set model is presented. A study is then developed in order to determine the working conditions that will lead to better efficiency and performance, referring to capacity of both energy sources: electricity stored in a Lithium-Ion battery and hydrogen gas in high pressure tanks. The possibilities here shown open the door to strategic advantages and innovation for car designers in the future.

Introduction

Nowadays, when the traditional transport model has become to its depletion, manufacturers and governments are betting hard on newer and greener technologies as a solution. Not only the progressive depletion of fuel reserves, but also the environment evolution indicate that the mobile fleet must probably change in no more than the next twenty – thirty years [1,2]. Many manufacturer companies agree that the Battery Electric Vehicle (BEV) is the one to beat [3,4], but differ on the specific way [5]. This has much to do with the characteristics of the different technologies of energy storage available. It is known that batteries offer a good dynamic response, while their discharge time, shorter than desired, and the recharge time, longer than desired, makes consequently that BEVs available in the market today are not suitable for many customers.

Abbreviations: BEV, Battery Electric Vehicle; EREV, Extended Range Electric Vehicle; FCEV, Fuel Cell Electric Vehicle; PHEV, Plug-in Hybrid Electric Vehicle; RE, Range Extender; ICE, Internal Combustion Engine; PDU, Power Distribution System; AFV, Alternative Fuel Vehicles; SoC, State of Charge; PEM, Proton Exchange Membrane; NEDC, New European Driving Cycle.

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A temporary solution may be the Plug in Hybrid Electric Vehicle (PHEV), as it can be charged with electricity like BEVs, run on gasoline with an Internal Combustion Engine (ICE) and use batteries to improve fuel efficiency [6]. The combination offers increased driving range with potential large fuel cost savings and emission reductions. There are two main PHEV technologies: parallel hybrids, in which both, the electric motor and the combustion engine, are mechanically coupled to the wheels through a transmission (i.e. Toyota Prius), and series hybrids, also known as Extended Range Electric Vehicles (EREV), in which the electric motor is directly coupled to the wheels and the combustion engine is only used to charge the batteries (i.e. BMW i3). Although PHEVs possess many advantages, they also have certain limitations. The main concerns include increased cost due to the introduction of engines, energy storage systems, and power converters [7], and also, fossil fuels are used. At best, a 2 to 2.5 fold fuel efficiency gain can be hoped for the world car fleet out to 2030. Most of this gain would be the result of a switch to hybrid technologies [8], and depending on the percentage of electricity derived from renewable energy that could replace most petroleum-based fuels.

On the other hand, Fuel Cell Electric Vehicles (FCEVs) are powered by gaseous hydrogen, stored onboard in high pressure tanks, which is converted into electricity by multiple individual cells serial connected (fuel cell stack). A small battery pack is still used. It is typically smaller than BEV's one and it is charged by an excess of energy from the hydrogen fuel cell or through regenerative braking techniques (also often available on BEVs) which returns energy from the kinetic force when braking, by switching the motor to operate in reverse, flipping the route of the electricity and charging the battery. Hyundai Tucson ix35 Fuel Cell and Toyota Mirai are two examples of FCEVs: both are zero tailpipe emissions and enjoy good characteristics when it comes to range, as it is determined by the capacity of the tank, which can be refilled as simply and fast as a gasoline tank.

Several policy initiatives have been adopted in order to promote the development of a hydrogen refuelling network: i.e. California State has committed funding for the development of 100 hydrogen fuelling stations, Japan's government proposed $71 million to build hydrogen fuelling stations, the U.K. announced over $752 million of new capital investment between 2015 and 2020 in support of ultra-low emission vehicles, including FCEVs [9]. Germany, alone, expects to have 400 hydrogen fuelling stations in 2020. Norway, Sweden and Denmark are developing the Scandinavian Hydrogen Highway to make the Scandinavian region the first in Europe where hydrogen is commercially available in a network of refuelling stations [10]. Italy is establishing a similar highway, designed to connect the country in a hydrogen way to Germany and Scandinavia. Nevertheless the slow development of refuelling infrastructure and current vehicle cost are clearly the most important hurdles keeping FCEVs from storming the market *en masse* [11].

In the present paper the authors have started to combine both vehicle concepts, EREV and FCEV, in order to solve these particular problems and obtain a mixed response and an improved vehicle range with easy refill.

Problem statement

A configuration scheme for an EREV and a FCEV is very similar. An EREV is characterized by a powertrain composed by an electric engine, a power converter and an energy storage battery pack, that compound the vehicle propulsion subsystem (see Fig. 1). It also has a second subsystem, Range Extender (RE), composed by an Internal Combustion Engine (ICE), a fuel tank and an electric generator. That subsystem it is exclusively used to charge the batteries [7].

FCEV configuration is that similar. Like Battery Electric Vehicles, Fuel Cell Electric Vehicles use electricity to power an electric engine, but in contrast to other electric vehicles, FCEVs produce their primary electricity using the fuel cell powered by hydrogen. The vehicle uses the fuel cell as a generator to power what is otherwise a battery electric car (see Fig. 2). The power plant has also a small battery pack that helps the fuel cell to boost and also to recover energy during regenerative braking periods. Energy flow is controlled by a Power Electronic Distributor Unit (PDU). See the arrows inside the box in Fig. 2: when the vehicle is in a transient of hard acceleration, the PDU distributes the power generated from the onboard fuel cell and the battery to cover the power demand. When this transient finishes, the PDU allows the energy flowing from the fuel cell stack to the primary motor through the power converter and, at the same time, the battery could be recharged. In case of braking, the PDU manages the regenerative braking. This recovered electricity is stored in the battery.

There are few models of FCEV available currently in the market but with limited distribution. Details of these models' specifications, shown in Table 1, illustrate the efficiency of FCEVs. The models are: Midsize Car Honda FCX Clarity, Mercedes B Class FCell, Toyota Mirai and Hyundai Tucson (ix35 Fuel Cell in Europe) respectively. All these vehicles have similar characteristics. Similar power levels (about 100 kW) and hydrogen gas/electrical energy storage systems technologies are similar too, fuel tank and battery technologies. Nickel Metal Hydride and Lithium-Ion battery packs, two hydrogen pressures: 350 bar and 700 bar with fibre wrapped composite tanks. But the most important common characteristic is that all of them use a very low capacity battery storage and also that no one of them is plug-in. This is obvious, as the batteries have capacities lower than 2 kWh, and it creates an auto-generated product design drawback to commercialize these vehicles, as consumers will not feel comfortable without the availability of a full refuelling infrastructure before purchasing a hydrogen fuel cell vehicle.

Refuelling has been a historical problem for Alternative Fuel Vehicles (AFV) [11], but this problem is more pronounced for those AFVs that operate exclusively on a single alternative fuel, such as hydrogen fuel cell vehicles or battery electric vehicles [12].

EREVs were born as one possible solution to cope with some of the BEV limitations in this sense. Some studies have explored and compared different EREVs taking into account their energy consumption [13] or the different range