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Fuel optimization strategy for hydrogen fuel cell range extender vehicles applying genetic algorithms

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ABSTRACT

Whether or not alternative fuel vehicles (AFVs) will finally find a place in the global mass-market or even will dominate the vehicle segment will depend on several success factors: reduction of customer anxiety, fast recharging, better charging infrastructure, environmental justice policies and some others. Current technological advances in battery electric vehicles and hydrogen fuelled electric vehicles could represent a hopefully option in the near future. Nevertheless, and until electric/hydrogen technological barriers are not torn down, both power architecture do not have an opportunity to be fully introduced in the vehicle market. In this paper, the authors present a powertrain architecture concept based in current fossil fuel extender range, but changing it to a hydrogen fuel cell stack system that works as range extender. The objective is to probe how optimization techniques, by the inclusion of genetic algorithms, could be a crucial help when planning the fuel consumption/selection. The paper ambition is to highlight the possibilities of this powertrain and its appropriated management to allow hydrogen become an energy carrier feasible today in the automotive world.

1. Introduction

Environmental conditions does not only change naturally across days, seasons and years. Human greenhouse gases (GHGs) traps are the greater responsible of the continuous growth trend of earth warming. The most important greenhouse gases directly emitted by humans include CO_2, CH_4, NO_x and several other fluorine-containing halogenated substances. Although the direct greenhouse gases CO_2, CH_4, and NO_x exist naturally in the atmosphere, human activities have a dramatic influence on the unstoppable growth of their atmospheric concentrations. Recent annual Conference of Parties COP21 (Paris, 2015) has revealed world global concern about the extreme climate changes in the near future if no action is taken today. The agreements reached in that Conference are also a reference of the commitments undertaken by all the nations. There are many relevant questions included in that agreement but, thinking about those ones concerning to alternative fuel vehicles and their benefits to avoid global warming, the most relevant ones are the strengthening of the emission reduction ensuring policies aiming to keep global temperatures to a maximum increase of 1.5 °C, or failing that, less than 2 °C [1]. A new paradigm has to be developed in order to reduce and control GHG emissions (recent air pollution crises in China has revealed the need to accelerate such efforts [2]) focusing, not only on the most pollutant activities, but also on the common day to day activities: burning of fossil fuels in electricity generation, transport and households.

The transport sector contributes significantly to society and economy, but it also leads to emissions of greenhouse gases and air pollutants, causing adverse impacts on the environment, global climate and human health. This is the only main European economic sector for which GHG emissions have increased since 1990, while all other sectors have reduced their carbon emissions, transport figures increased by 19.4% over the period [3]. A progressive decarbonisation process (based on low carbon power sources that therefore has a minimal output of greenhouse gas emissions) of the transport sector, based on improvements in fuel efficiency and a reduction of carbon intensity of fuels, will not be able if just only technological solutions are applied, but also policies that promote significant changes in human life and behavior. Renewable Directive 2009/28/EC, i.e. tries to reach a 10% of transport fuel from renewal sources target. Thereby it will be necessary new approaches that would eliminate the current barriers that are slowing down the market penetration of alternative fuel vehicle technologies: battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV) and extended-range electric vehicle (EREV). However, adopting these alternative, lower

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carbon fuels and powertrains is a beginning, these well-known non-polluting vehicle technologies cannot be the sole solution to the problems of carbon emissions, so long as the electricity they run is clear in the place of use, but typically it pollutes the environment during production as it is primarily generated from carbon-emitting coal-fired power plants [4]. Obviously, there exists other zero emissions' future releases; it is the case of fuel cell electric vehicles (FCEV) and hydrogen as an attractive alternative to fossil fuels, mainly if it is produced from renewable (hydro, wind, solar, biomass, geothermal) [5]. The fuel cells themselves have achieved dramatic improvements in efficiency and cost in recent years, but the infrastructure needed to support them remains a weak point. In fact, is a chicken and egg problem: there exists a feasible hydrogen fuel cell vehicle, technologically suitable for driving, but it is not salable because there is lack of infrastructure for its charge and vice versa.

The authors of this work consider that the solution to the problem will not be fast or abrupt, but the one derived from an evolutionary process in which different fuels and powertrains will coexist. This is the case of the vehicle here analyzed, in which two powertrains and two fuels are combined. The study proposes an analysis of the improvements in fuel consumption, range and usability of the different strategies aiming to improve current usability for the consumer and allowing an extension to the development of new/future fuel recharging networks.

1.1. Problem statement

In the present paper the authors will study a method needed to optimize the two power sources (electricity and hydrogen) energy consumption when driving a passenger vehicle whose power plant architecture is a plug-in, extended range electric vehicle, powered with the electric energy stored in the battery and also using a range extender system powered by a fuel cell stack, which is fuelled with hydrogen. This alternative drivetrain has been tested in vans and fleets of public transport buses in the same way that it happened with biodiesel (diesel fuel generated from biological sources, such as soybeans) as an approach to clean air without replacing the vehicle fleets [6], but in this paper the authors have focused on passenger vehicles due to the volume and the social impact of this mode of transport.

1.1.1. Hydrogen vs electricity: FCEVs vs BEVs

Transformations will require global vision, commitment and actions. Policy makers, automobile manufacturers and even oil companies agree that the world's transportation infrastructure needs to be upgraded. The future solutions to mitigate carbon emissions by motorized transport and particularly passenger cars will need a new paradigm, including new aspects covering the different stages of vehicle conception and use, involving the consumers, urban planners and policy makers.

These aspects could be resumed in two main categories:

- New zero emission powertrain technologies: with no fossil fuels combustion and zero tailpipe emissions, a driving range in the hundreds of kilometers, and fast and easy refuel.
- Fuel consumption/emissions optimization: Apart from other considerations, an accurate energy optimization along a chosen route before the start of the trip is relevant to avoid problems such us range anxiety or greenhouse gas emissions. Better developed and practical route planners, able to report on the characteristics of the route and able to learn and optimize the management of the different fuels that could propel the vehicle.

Beginning with the first, it perfectly fits with the case of fuel cell electric vehicles. Several authors have emphasized [7–9] that, in the future, zero-emissions (ZE) powertrains will be powered by stored electricity and/or hydrogen. In a previous paper [5], the authors have explained the benefits of using the fuel cell as a range extender system to improve the mix of both, FCEV and PHEV powertrains. Power plant architecture mixing a plug-in battery, ER fuel management (extended range), fuel cell stack and BEV concepts, combining them into a Plug-in ERFCEV vehicle that could also be customized to meet customer's range requirements.

Why is this alternative so necessary? To answer this question it is imperative to put on the table the present and the future challenges of hydrogen employment in the area of automotive propulsion systems and to stablish a comparative with the other energy vector: electricity.

According to the US Department of Energy [10], there are currently 15,553 electric vehicle's public charging stations (2017 February data) and 40,819 charging outlets across the United States. On the other hand the number of hydrogen refuelling stations (HRS) is 64 (most of them are located in California). European data are not better, only 79 public access hydrogen stations are available while the number of public electric charging stations is near 114,000. Compared with hydrogen stations, public electric charging devices are cheaper and easier to construct. Nevertheless, 92 new HRS have been put into operation throughout the world in 2016, the largest number of new stations ever.

Several policy initiatives in several countries all over the world are promoting the development of a hydrogen refuelling network. A summary of the plans that speed up the development of hydrogen infrastructure through targets, incentives and regulations per country, including subsidies for FCEV purchase is:

- The Energy Commission and other California state agencies implement the actions set forth in the ZEV Action Plan that ensures that 1.5 million zero-emissions vehicles (ZEVs) are on California roadways by 2025 [11], including a provision to fund hydrogen refuel network [12].
- Hydrogen Mobility Europe (projects H2ME1 and H2ME2) is a flagship project giving fuel cell electric vehicle drivers access to the first truly pan-European network of hydrogen refuelling stations (€68 million demonstration project co-funded with €32 million from the European Union's Horizon 2020 programme) [13].
- United Kingdom's UKH2Mobility program, whose focus will be to build an infrastructure serving metropolitan areas and the major routes which link them from 2015, progressing to nationwide coverage by 2030. Over $752 million of new capital investment between 2015 and 2020 in zero emission vehicles, including plans for 65 h and 20,000 FCEVs by 2020 growing to 1150 h and 1.5 million FCEVs by 2030 [14].
- Germany´s NIP, national innovation programme, expects to have 400 hydrogen fuelling stations by 2023. There were 18 h currently operational in 2015, with plans for 100 h by 2018 and a 400 h strong network by 2023, that will cover the refuelling of the expected target fleet of 1.8 million fuel cell vehicles [15].
- Norway, Iceland, 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 HRS. H2moves-scandinavia planned development of 150 stations by 2020 across Denmark, Iceland, Norway and Sweden [16].
- Hydrogen Mobility Italy (MH2IT) aims to provide Italy with the infrastructure allowing for a full development of hydrogen fuel cell mobility by 2025 [17].
- France (Mobilité Hydrogène France). A twenty partner member's consortium created to boost the potential deployment of hydrogen fuel cell electric vehicles, while strengthening renewable energy production capacities in regional France. The partners share a vision to produce an economically competitive and supported deployment plan for a public-private hydrogen refuelling infrastructure (620 h) in France between 2015 and 2030 covering the 800,000 FCVEs on the road target [18].

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