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Design and development of a multipurpose utility AWD electric vehicle with a hybrid powertrain based on PEM fuel cells and batteries

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ABSTRACT

This paper presents the results obtained on the research project *CIT-370000-2008-11*, entitled "Multi-purpose remote-controlled all-wheel-drive tool-vehicle powered by fuel cells" funded by the Spanish Ministry of Science and Technology. A new concept multipurpose electric vehicle has been designed and manufactured, based on three basic features: a hybrid power system consisting in PEM fuel cells + batteries, an all-wheel-drive traction system, and the capability of being either on-site driven or remote-controlled. The vehicle is formed by two frames connected by a two-degree of freedom joint, and is powered by two 2.5 kW DC motors, one in each axle. All the electric circuits for the suitable control of the power hybrid system have been developed in our Laboratory, allowing a large flexibility. After the different tests performed, it has been verified that the vehicle presents good maneuverability, a good traction performance in off-road driving, as well as a good slope-climbing capability. Under the experimental conditions tested, the vehicle reached a maximum speed of 11 km/h on flat surface, keeping the maximum power consumption always around 3 kW.

1. Introduction

Production of energy worldwide is mainly based on combustion of hydrocarbons, and it is expected to rise by 60% in the next 20 years [1]. Unfortunately, hydrocarbon combustion has a major impact on the global environment because it is responsible for 80% of the greenhouse gas emissions, which are the principal cause of climate warming and air pollution. On the other hand, energy is also essential to guarantee the growth of both the economy of the Countries and the social welfare, facing up to an increase in the price due to the shortage of fossil fuels. However, our current standard of living is closely related to electric power consumption and with a raise in the use of cars, which is contradictory with the control of greenhouse effect, local pollution and with the use of renewable and local source of energy criteria. Today, about 60 million internal combustion engine vehicles (ICEVs) are manufactured every year, and about a billion ICEVs are circulating on the roads of our planet, representing one car for each seven people [2]. They are responsible for the emission of

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Nomenclature

AWD	all-wheel-drive traction system
BSF	back-up side fans
CFS	cathode channels fan system
CCM	catalyst coated membrane
CHP	combined heat and power unit
ECU	electronic control unit
ESD	energy storage device
EEV	exit electrovalve at the H_2 pipe of the stacks
EV	electric vehicles
FPGA	field-programmable gate array
ICEV	internal combustion engine vehicle
IEV	inlet electrovalve at the H_2 pipe of the stacks
I/O	input/output ports of electric boards
LFS	lateral fan system
MEV	electrovalve placed in the main line of the H_2 supply system
PEM	polymer electrolyte membrane
PCB	printed circuit board
PLC	programmable logic controller
PSW	power switch of the stacks
PWM	pulse-width modulation
RL-1	100 Ω resistance load
RL-2	1 kΩ resistance load
UGV	unmanned ground vehicle
UPS	uninterruptible power supply
ZEV	zero-emission vehicles

a very large part of the total amount of pollutants contained in the air, namely 40% of solid particles, 25% of CO_2, 65% of NO_x, 70% of CO, 45% of OVC and 5% of the SO_2. So, the development of new zero-emission vehicles (ZEVs) to gradually substitute the ICEVs in transportation is becoming urgent, in order to fulfill the strict emission legislation established in the Kyoto Protocol.

Most of the commercial ZEVs available today are pure electric vehicles (EVs) powered with batteries, with the main drawback of their limited range. To overcome this problem, vehicle manufacturers have introduced two solutions based on hybrid powertrain. On the one hand, they are combining ICEs and electric motors, to extend the operational range with lower average pollutant emission than classic ICE-based vehicles. As combustion products are still emitted, this configuration can only be considered as an intermediate stage toward the final ZEV objective. On the other hand, other solutions are based on hybrid electric architectures (actually ZEVs), which are fed by batteries (or capacitors) and fuel cells, also extending the EV range. This paper analyses a solution that integrates a battery pack that can be charged either from the electricity grid or from the energy produced by an embarked fuel cell system, which can also be used to power the vehicle.

Among the different types of fuel cells, polymer electrolyte membrane (PEM) fuel cells have several advantages when used for car powertrain because of the low operating temperature, the fast start-up time and response to load changes, and the robustness of the construction. Hybrid systems using PEM fuel cells have been used in different applications in transportation such as lightweight cars, electric forklifts, mini-trains, electric toy vehicles, and bicycles [3–10], using either active or passive hybrid architectures. In general, it has been demonstrated that PEM fuel cell systems respond to very fast and large power transients, and the needed current ramp rate can be reduced by using a hybrid system. When the vehicle runs in both steady and dynamic conditions, a management strategy for the ancillary components can also be defined for different power–temperature optimal working regions. Some other studies have been performed analyzing the behavior of hybrid systems including a PEM fuel cell using modeling techniques [11–16]. Research has been focused on the analysis of the relationship between cost and performance of automotive PEM fuel cell systems, the durability and lifetime of hybrid systems, as well as the definition of high- and low-level control algorithms for hybrid systems. It has also been concluded that the use of passive or active hybrid configurations could be determined by the driving conditions and vehicle specifications. Finally, automatic control for PEM fuel cells power systems has also been developed for stationary applications such as CHP units [17,18], and UPS [19,20]. In summary, big efforts are being devoted to fully understand and optimize the different alternatives for hybrid systems, especially in the automotive sector.

The research presented in this paper deals on the design and development of the hybrid powertrain for a new concept multipurpose electric vehicle, based on PEM fuel cells and lead-acid batteries. The all-wheel drive (AWD) configuration, its articulated-type architecture, as well as the use of two DC motors in both front and rear axles are some of the novelties of the vehicle, because neither commercial units nor a scaled prototype of such kind of low power electric car are currently available. An *ad-hoc* dual-control design has been performed, allowing its operation either on-site or remote-controlled ensuring its maximum versatility. The vehicle can be used for transportation (persons or payload), as well as to carry special tools to develop very specific tasks as, for example, crane or drilling booms, and robotic arms among others. Although this is a specific configuration, many of the results obtained are general and can be extended to other automobile types (buses, tourism cars, forklifts, etc.). In particular, both the hybridization control and the operation procedures, including the start-up and shut-off protocols and the stack temperature regulation, can be directly applied, and are relevant, to other PEM powered devices.

2. System description

2.1. *Vehicle configuration*

In order to fulfill the main specifications of the vehicle, i.e. electric hybrid architecture, AWD traction system, and capability to be on-site or remotely driven, the vehicle is formed by two frames connected by a two-degree of freedom joint, as