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Design of a hybrid electric fuel cell power train for an urban bus

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ABSTRACT

With the requirements for reducing emissions and improving fuel economy, new markets have become attractive for automotive companies that are developing electric, hybrid, and plug-in vehicles using new technologies candidates to be implemented in the next generations of vehicles. Most of all, hybrid vehicles are attracting interest due to great potential to achieve higher fuel economy and a longer range with respect to pure electric mode but often this solution is not petroleum free. Within a national project CNR TAE Institute is involved in the development of a zero emission hybrid electric city bus based on PEM fuel cell technology able to increase the range at least 30% with respect to the same vehicle in pure electric configuration. Design, control and preliminary results are reported in this paper.

1. Introduction

Transport sector is responsible for more than 30% of greenhouse gases and contrary to all other sources of emissions, those from transport grew during the period from 1990 to 2007. The EU-27's transport sector contributed 982.5 million tonnes of CO_2 equivalents in 2007, with transport emissions increasing, on average, by 1.4 % per annum from 1990 [1]. For this reason European politic is addressed toward the development of zero/low emissions vehicles characterized by installation of clean innovative devices. The automotive industry has also brought real solutions, and manufacturers have yielded significant improvements in vehicle safety and sustainability. Trend in automotive market shows that, in the last years, all carmakers are investing in emerging sector of electric traction [2–4]. Annually, the industry invests €20 billion in R&D, more than any other private sector. The need for its drive toward sustainable mobility remains an ongoing commitment. Electric vehicles (EVs), are more energy efficient and have zero emissions but cost, weight, time required to recharge the battery and limited range represents undoubted drawbacks [5,6]. Hybrid vehicles (HVs) offer improved fuel economy and take the advantage of existing fuel infrastructure but still depend entirely on petroleum to charge the battery pack [7–10]. On the other hand, vehicles totally based on fuel cell (FC) have been proposed, but still face significant improvement above all for high cost that limit market penetration [11–14]. Hybrid electric vehicles (HEVs) based on batteries and fuel cell give the possibility to merge the advantages of both technologies and avoid some disadvantages. If the cost of FCs remains high, hybridization can reduce the life-cycle cost of fuel cell vehicles, increasing thus their growth option value and their combination with other technologies creates better scenario for their market introduction [15]. This explains the growing orientation of car manufacturers toward HEV based on batteries and FCs [16–20].

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Recently, several prototypes in which the *range extender* function is performed by FCs have been developed. Such a hybrid concept, overcoming the limits of batteries, makes the growth of FCs in the automotive sector, easier since they use lower power and lower cost FCs. Furthermore in this type of systems the quantity of hydrogen carried on board the vehicle remains quite low facilitating refueling and a low weight for the hydrogen tanks. A small FC used as on board batteries charger in a *range extender* approach allows to reduce costs, weight and recharge time of batteries and, at the same time, to increase the range with respect to the equivalent electric vehicle. To obtain benefits from the operation of a hybrid system, the flow of power within the system must be carefully planned and regulated in accordance with an appropriate energetic strategy to optimize the total efficiency and to preserve the devices from stress that may reduce their lifecycle.

The paper is organized as follows. After this introductory section, the description of the system (vehicle, powertrain, FC and batteries) is reported in Section 2. Management strategies of powertrain control are presented in Section 3. Simulation results are discussed in Section 4. Finally, the main points and significant results of the paper are summarized in conclusions.

2. Description of the system

2.1. *Powertrain*

The bus selected for the prototype realization is an electric vehicle having an electric drive motor of 85 kW as rated power (Model: Siemens Drive Motor 1PV5138-4WS24) and a capacity of 44 passengers (Fig. 1). In Table 1 the technical characteristics are reported. The same city bus equipped with 8 ZEBRA® (Zero Emission Battery Research Activities) batteries was previously tested in EV configuration (Fig. 2). The main aim was to control the energy transfer from battery and FC to the electric motor with minimum loss of energy. The selected HEV include in fact more electrical apparatus as compared to the same EV or the conventional internal combustion engine vehicles [21]. The drive train, is driven by an AC Induction Motor and supplied from an IGBT Mono Inverter via 6 Zebra battery module providing a DC bus voltage of 557 V (upto 670 V by regenerative voltage). In the proposed solution the electrochemical batteries are connected in parallel to the FC system (Fig. 3). In order to maximize energy efficiency and to preserve the FC system from continuous changes in the operating point, that could reduce its lifetime, FC system operates at constant power every time the boundary conditions allow it. The DC/DC converter allows the control of the maximum input current, fixing the nominal operating point of the FC system and thus setting the maximum power expressed by the device. If the power required by the electric motor should be less than the reference power (low load/deceleration/braking/bus stop), the FC system works as battery charger.

2.2. *FC system and hydrogen storage system*

The chosen FC system is a 5 kW Nuvera® Fuel cells product composed by a PEM FC based on XDS-900 stack and the linked ancillaries: a blower for the air, a pump for the water and a fan for the cooling circuit. Voltage of DC output is unregulated. A dedicated micro-computer and a software drive the entire system for operations and safety. The stack is based on self-humidifying technology, so the water circuit works both for cooling and humidification. Many of the hydrogen and air components are attached directly to the fuel cell stack. They include the air compressor, silencer, filter, solenoid valves, pressure transducer, hydrogen recycle tank and recycle tank water drain level switch. The power components (fuses, relays, converters and a current sensor) regulate external power during start-up and shutdown. Heat and water management system dissipates heat and reclaims water by use of a condensing radiator and water reservoir. This subsystem also contains a de-ionized water filter and water flow sensor. The PEM FC system is fed by hydrogen stored in 2 tanks (compressed at 200 bar) containing about 4.8 kg of hydrogen each. The management and control for hydrogen system is done using 2 multi-functional solenoid valves for use in high pressure mobile storage cylinders installed one for each tank and 1 hydrogen supply valve. Each tank valve has 2 inlet/outlet ports, inlet and withdrawal filters, manual valve for isolation, solenoid, bleed valve, thermally activated pressure relief device, excess flow valve and in-tank temperature thermistor. The hydrogen system is also equipped with three pressure transmitters that detect the value of the pressure inside the cylinders and on the medium and low pressure line. In addition a sensor for detecting the temperature inside the tank is installed. In Fig. 4 the FC and hydrogen systems with

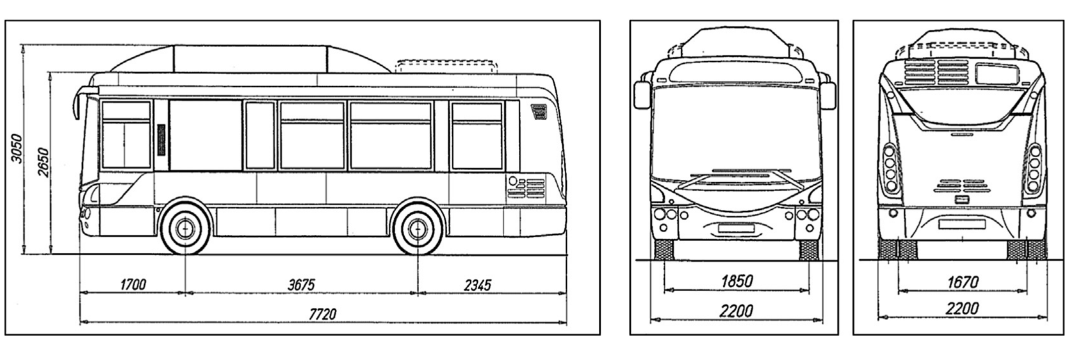

Fig. 1 – City bus.