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Fuel cell/battery passive hybrid power source for electric powertrains

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ABSTRACT

The concept of passive hybrid, i.e. the direct electrical coupling between a fuel cell system and a battery without using a power converter, is presented as a feasible solution for powertrain applications. As there are no DC/DC converters, the passive hybrid is a cheap and simple solution and the power losses in the electronic hardware are eliminated. In such a powertrain topology where the two devices always have the same voltage, the active power sharing between the two energy sources can not be done in the conventional way. As an alternative, control of the fuel cell power by adjusting its operating pressure is elaborated. Only pure H_2/O_2 fuel cell systems are considered in this approach. Simulation and hardware in the loop (HIL) results for the powertrain show that this hybrid power source is able to satisfy the power demand of an electric vehicle while sustaining the battery state of charge.

1. Introduction

In a fuel cell hybrid vehicle, the electric propulsion motor(s) is powered by a fuel cell system coupled to a battery. A polymer electrolyte fuel cell (PEFC) [1–3] converts hydrogen and oxygen into electrical power with only water and heat as the byproducts. The battery is used as an energy buffer [4,5]: it power assists the fuel cell system during peak power demands (vehicle acceleration), recovers partially the kinetic energy of the vehicle during braking phases, and allows shifting to a certain degree the fuel cell operating point for optimizing the efficiency. Generally, the battery is used in a charge sustaining mode, i.e. the state of charge evolutes around a prescribed value and no external charger is used.

There are two categories of fuel cell hybrid power sources: active and passive hybrids [6] (Fig. 1). In an active hybrid architecture (Fig. 1a), there is at least one DC/DC converter between the fuel cell and the battery. The DC/DC converter(s) adapts the voltage of each device to the bus voltage and permits to actively control the power sharing between each source. A power management strategy is needed to determine this power sharing according to a certain objective (for example the fuel consumption) while respecting constraints (battery state of charge limits, power limits, etc.) [7–9].

In a passive hybrid architecture (Fig. 1b), the fuel cell and the battery are directly connected to the bus without DC/DC converter(s). Only a switch may be present to connect or disconnect the fuel cell from the bus. As long as the switch is closed, the two components operate at the same voltage [10]. This causes disadvantages [11–13]: (1) the sizing is highly constrained because the voltages deviations of the sources have to match, (2) such an architecture reduces the overall specific power of the hybrid power source as highlighted in Figs. 2 and 3) the bus voltage and the currents regulate themselves according to the impedance of the fuel cell system and the battery. This last point reveals that the system variables (currents, voltage, powers, state of charge) are uncontrolled (no power management strategy is possible) and can therefore reach or exceed their limits, leading eventually to system breakdown.

Therefore the active hybrid has been established as the preferred topology since it has less constraints in comparison to the passive hybrid topology. However, as there are no DC/DC converters, the passive hybrid is the cheaper and the simpler solution, and the power losses in the electronic hardware are eliminated. This paper, addressing only fuel cell systems operated with pure oxygen, shows that also a passive hybrid can become a suitable solution for powertrain applications when the power sharing becomes actively controlled. One solution to achieve an active power sharing is to vary the internal impedance of the fuel cell by controlling its operating pressure.

In the first part of this paper, the characteristics of the hydrogen/oxygen fuel cell system are presented. Then in the next section the concept of the passive hybrid is exposed in details. Section 4

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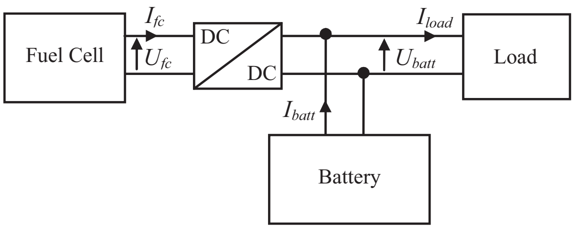
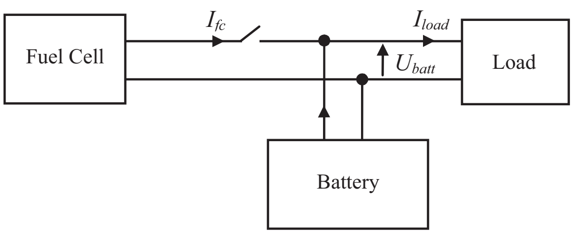


a Active hybrid with DC/DC converter between the FC and the battery.



b Passive hybrid with direct connection between the FC and the battery.

Fig. 1. Passive (a) and active (b) FC/battery hybrid powertrain architectures.

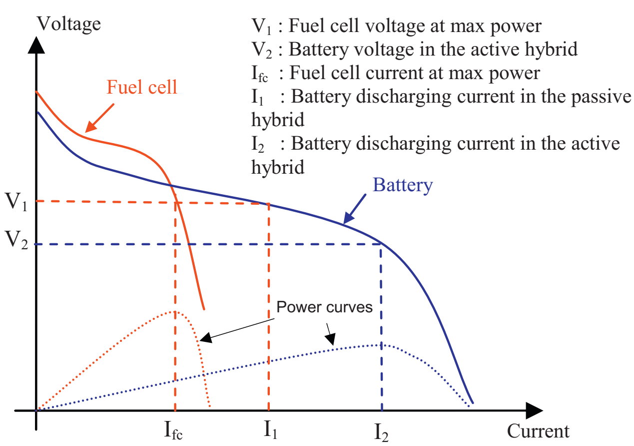


Fig. 2. Passive and active maximum power [13]. The voltage–current curves of the fuel cell and the battery show that the output power in the active hybrid is higher than in the passive hybrid.

provides simulation results of a vehicle under different driving conditions. The last part of the paper discusses the advantages and the drawbacks of the passive hybrid solution.

2. Fuel cell system

The fuel cell system considered is a H_2/O_2 PEFC system. Such a system using pure oxygen as the oxidant is not commonly used for powertrain applications where the H_2/air fuel cell systems are dominating. A H_2/O_2 PEFC system brings yet several advantages such as higher specific power, higher efficiency, higher system dynamics and easier water management [14]. The main disadvantages are the need of oxygen production and it's on board storage, but this can be balanced by the higher efficiencies achieved by such powertrains [15].

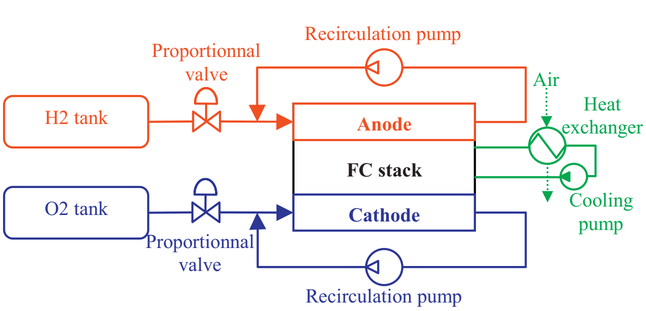


Fig. 3. Simplified scheme of a H_2/O_2 fuel cell system.

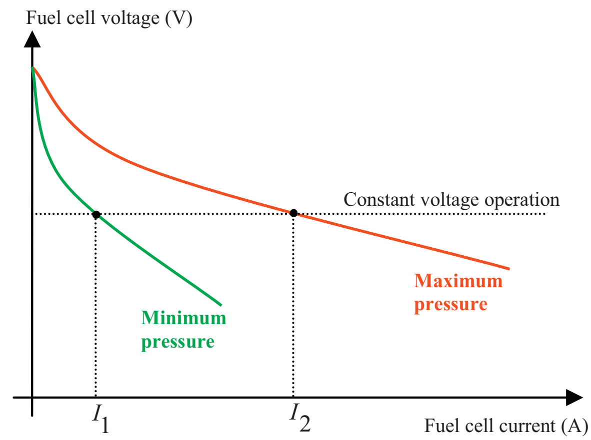


Fig. 4. Example of polarization curves of a fuel cell stack at different operating pressures.

Fig. 3 shows a simplified scheme of a H_2/O_2 PEFC system. It is composed from a PEFC stack surrounded by auxiliary components. The auxiliaries are grouped into three main circuits (Fig. 3): (1) the hydrogen circuit on the anode side, (2) the oxygen circuit on the cathode side and (3) the cooling circuit. The cathode and anode pressures are controlled by means of proportional valves. The hydrogen and oxygen gases are re-circulated from stack outlet to stack inlet by means of recirculation pumps. The recirculation loops contain also water separators and purge valves which are not shown in Fig. 3.

The electrical characteristics of a fuel cell are described by its polarization curve (Fig. 4). This polarization curve is pressure and temperature dependent. For instance, at a constant temperature and a constant voltage, the fuel cell current decreases when decreasing the gas pressures (Fig. 4). For example, at a given voltage, the fuel cell current is minimal at the lowest pressure (Fig. 4, current I_1) and reaches it's maximum at the highest operating pressure (Fig. 4, current I_2).

Further experimental result is shown in Fig. 5. This measurement was performed with a 10 kW fuel cell stack operated in a

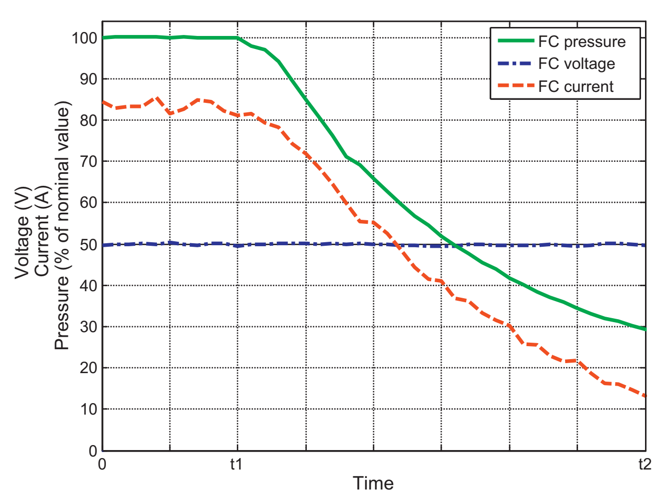


Fig. 5. Current and pressure variation of a PEFC stack operated at constant voltage.