Control Strategy for the dc-dc Converter in the Drive Train of a Fuel Cell Electric Vehicle in order to Improve its Autonomy

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Abstract: Conventional vehicles have the advantage of offering good performance and a long range, but they are polluting and emit greenhouse gases, as well as low energy efficiency. In this respect, interest in electric vehicles is growing. Fuel economy is highly dependent on the on-board energy storage system (ESS) of the fuel cell electric vehicle (FCEV). Batteries are the main energy storage devices in FCEVs. The design of the battery and the connected inverter play an important role in energy saving and state of charge (SOC), directly influencing the range of the vehicle. In this paper, the control of the Direct Current-Direct Current (DC-DC) bus feeding the electric motor taking into account the effect of the parameters on vehicle performance and energy consumption has been investigated. Following the tests, we determined the various energy consumptions of the vehicle as well as its range, according to the driving cycle used New European Driving Cycle (NEDC).

Keywords: Energy storage system, Fuel Cell Electric Vehicles (FCEV), Direct Current-Direct Current (DC-DC) Converter, New European Driving Cycle (NEDC), Dynamic parameters, Control strategy.

1. INTRODUCTION

The range of electric vehicles remains limited and they cannot reach high speeds. Today, technological advances in electric motors and batteries have enabled electric vehicles to cover longer distances, but the desired objective has still not been achieved. Studies have looked at the effect of different types of gearbox on energy consumption [1]. A fuel cell electric vehicle (FCEV) offers environmental benefits, with a greater range than other electric vehicles and the same performance as a conventional internal combustion engine vehicle [2]. Energy storage systems (ESS), such as batteries, offer important vehicle characteristics such as energy density, power density, service life, cost and maintenance [3].

The FCEV is powered by an electric motor. The power system consists of a fuel cell and a battery pack, and the DC-DC connection is provided by a three-phase inverter. The battery stores the excess energy generated by the fuel cell and the braking of the electric motor, while the fuel cell is designated as the main source [4]. The contribution of this paper lies in the choice of the DC-DC converter control method as a function of the dynamic parameters of the vehicle and the driving cycle used, with the aim of optimising battery life and increasing range. In this context, a dc/dc converter and a control strategy will be developed, which will be placed between the fuel cell and the Direct Current-Direct Current (DC-DC) block, in connection with the battery in the drive train of this vehicle [5]. In this paper, a method for controlling the output of the fuel cell system is proposed and verified.

2. VEHICLE BLOCK MODELLING

Figure 1, shows the power supply for the fuel cell/battery system, which corresponds to the fuel cell electric vehicle (FCEV) model used in this work. The two energy sources (fuel cell and battery) exchange energy with a floating DC bus [6]. To limit the effects of source ripples, filter inductors are inserted in the DC-DC converter. A three-phase inverter is connected between the DC bus and the electric traction motor, to convert the energy consumed into AC energy. Congestion caused by mechanical parts, such as the mechanical differential and drive shafts, is reduced by using just one electric traction motor instead of two. This freed-up space makes it easier to install the battery bank and

increase the capacity of the hydrogen tank [7].

The FCEV system has great stability and precision thanks to the control of a single torque at the output of the electric motor, avoiding a control chain for each wheel to stabilise the two pairs of each of the two rear wheels [8]. In FCEVs, electric traction is provided by motors with sophisticated performance features, such as small size, high power density and high efficiency [9]. The system also includes a three-phase permanent magnet synchronous machine (PMSM), fed by a three-phase Direct Current-Alternating Current (DC-AC) converter, to interface direct and alternating current and ensure bidirectional energy flow [10].

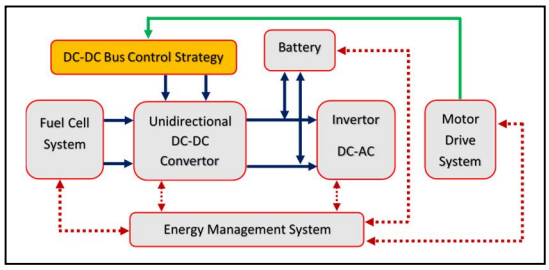


Fig. 1 Global scheme of the Fuel Cell Electric Vehicle.

2.1. DYNAMIC MODELLING OF THE PEMFC

To establish a general, zero-dimensional model of the Proton Exchange Membrane Fuel Cell (PEMFC), a semi-empirical solution was applied to reproduce the experimental polarisation curve of the fuel cell [11]. The mean cell voltage can be expressed analytically by the following expression :

$$V_{cell} = E - \eta_{act} - \eta_{ohmic} - \eta_{conc} \quad (1)$$

Where : E is the open circuit voltage, η_{act} , η_{ohmic} , η_{conc} are respectively activation, ohmic and concentration losses.

The parameters of the FC model are given in Table 1 [12]. Numerous equations have been proposed in the literature to predict the above terms, which are developed below [8] :

$$V_{stack} = \upsilon_{cell} . \eta_{cell} \quad (2)$$

Where the stack tension V_{stack} is simply the cell voltage multiplied by the number of cells η_{cell} [13].

$$P_e = i.\upsilon_{cell} . \eta_{cell} = i.V_{stack} \quad (3)$$

Where P_e is the output power of the fuel cell stack (W) [13].

Table 1 Parameters of the fuel cell model [12]

Parameters	Symbol	Values	Units
Activation over voltage constants	B	0.0477	V
Hydrogen valve constant	K_{H_2}	4.22 10^{-5}	k.mol.atm/s
Oxygen valve constant	K_{O_2}	2.11 10^{-5}	k.mol.atm/s
Number of cells in series in the stack	N_0	375	-
Fuel cell internal resistance	R_{FC}	0.003	Ω
Absolute temperature	T_{FC}	343	K
Nominal power	$P_{nominal}$	30	Kw

3. CONTROL SYSTEMS

This article deals with energy management in a fuel cell electric vehicle (FCEV). The proposed method consists of finding the best distribution of battery power in order to increase its range, in addition to the energy management system with the fuel cell (FC). The main objective is to minimise hydrogen consumption by prioritising braking energy during downhill gradients and the various braking phases of the FCEV.

3.1. DC-DC CONVERTER CONTROL

The contribution of this document lies in the control of the DC-DC bus as a function of the reference and instantaneous currents of the fuel cell and also in our use of a parameter denoted Pv, which represents the dynamic parameters of the vehicle. The aim is to maintain the battery's state of charge within the specified range. In this way, the fuel cell will extend the vehicle's range and prevent battery ageing.

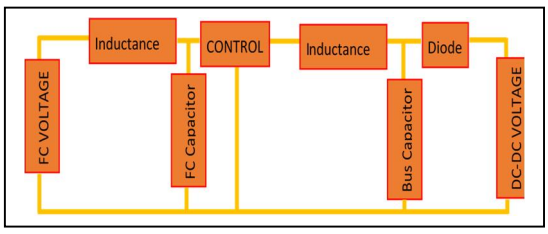


Fig. 2 Diagram illustrating the control of the DC-DC converter.

The dc-dc converter control method is based on the fuel cell currents [14]. A current is obtained and then compared with a measured value to control the boost converter using a regulator. The reference current is also used to define hydrogen and oxygen consumption and to regulate their flow rates [15].

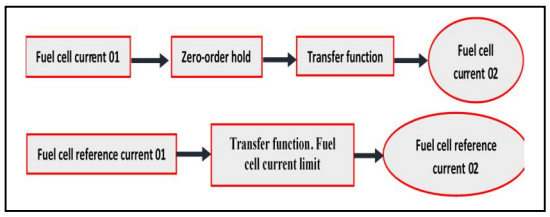


Fig. 3 Determination of instantaneous and reference fuel cell currents.

We use the error calculated by the algorithm used in the DC bus control system.

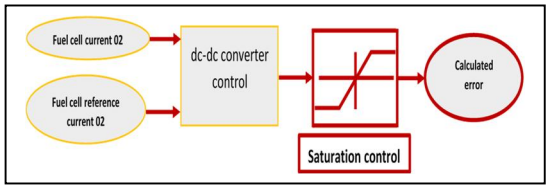


Fig. 4 Calculation of dc-dc bus control error.

Figure 5 shows the use of two IGBT switches.

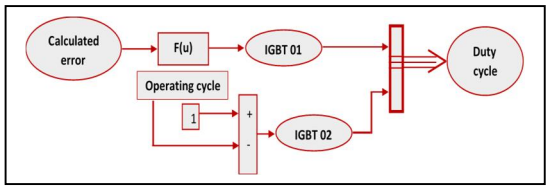


Fig. 5 Dc-dc bus duty cycle.

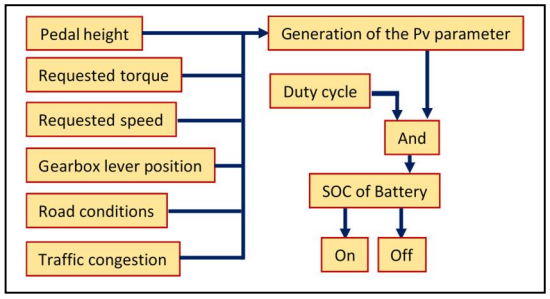


Fig. 6 Method for using the vehicle's dynamic parameters to increase battery range.

4. SIMULATION RESULTS AND DISCUSSION

In this article, a numerical simulation was carried out using the Matlab/Simulink environment in order to show the performance of the proposed energy management for a fuel cell electric vehicle (FCEV) application. The simulation results of the system studied represent the objective of this work, where the vehicle deceleration phase was tested during model simulation where we confirmed battery recharging. Also, depending on the dynamic parameters of the FCEV, using a block containing the Pv parameter, in the control of the DC-DC bus block, we reduced unnecessary battery calls in order to gain autonomy, at the start of the acceleration phases at low speeds and average torque values.
We used an NEDC-type driving cycle, as shown in Fig. 7. Figure 8 shows the comparison between the two vehicle speeds: reference and measured, where the control is verified during tracking. The power graph for the fuel cell and the vehicle is shown in Fig. 9. The battery states of charge are shown in Fig. 10 and Fig. 11.

From these figures, we can see that the model is well dimensioned, in particular the secondary source as a function of range and the required speed profile (NEDC). The battery comes into play during the acceleration phase, while it is recharged continuously as a function of braking phases, and of the predefined parameter Pv, during energy loss phases such as unnecessary acceleration, poor road conditions and shifting gears in poor driving regimes.

In the three ranges chosen, namely [50-60S], [120-130S] and [240-250S], the battery is not discharged, where the state of charge is higher after the intervention of the Pv parameter, and therefore a gain in energy is recorded (in Fig. 11, it is as if the battery is recharged, but to read that the battery is not unnecessarily discharged). These three regions are the most important in our study where the Pv parameter intervenes to put the battery in the ‘off’ position in cases where the overall vehicle management system requires the intervention of the primary and secondary sources, which confirms the interest of the proposed strategy.

In Fig. 9, we have simulated poor road conditions and traffic congestion, as well as the pedal pressure available. This leads us to calculate the power required and reach a limit value for the Pv parameter in the ‘on’ position.

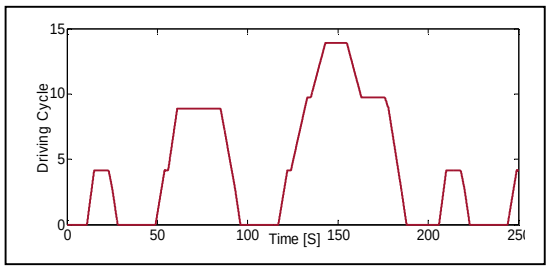


Fig. 7 NEDC Driving Cycle.

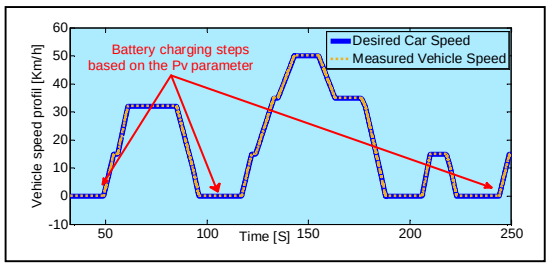


Fig. 8 Comparison between the two speeds of the vehicle: reference and measured.

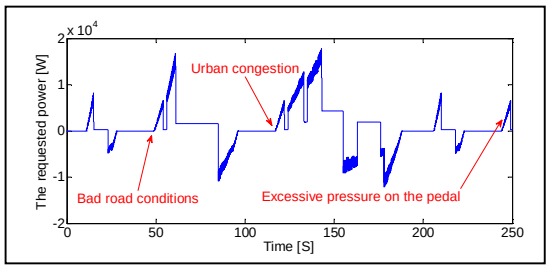


Fig. 9 The requested power.

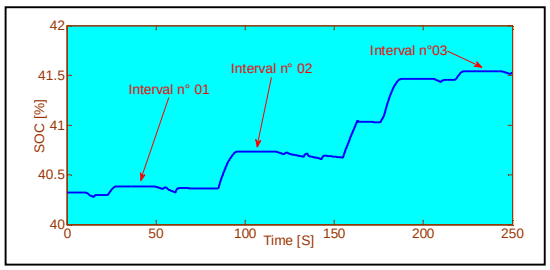


Fig. 10 The requested power.

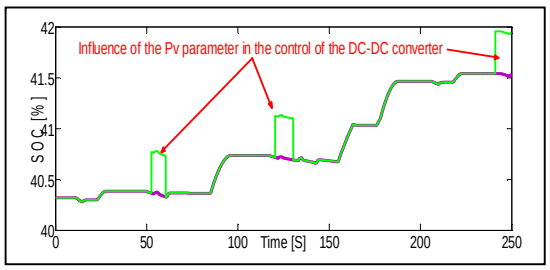


Fig. 11 The three stops of battery discharges in the "ON" position of the Pv parameter.

5. CONCLUSION

Energy management has been proposed as a solution for a fuel cell electric vehicle, with a battery used as a secondary source and energy storage device. A supplementary control method at the dc-dc bus level can improve the storage device according to the characteristics of vehicle demands and main sources, providing an optimal solution to respond to changes during vehicle driving phases.

In this paper, a strategy is presented aimed at improving energy management in a fuel cell electric vehicle, during the acceleration phases of the vehicle, with the main source providing the necessary energy balance during these periods, but associating the secondary source which is the battery. The method's contribution is to disconnect the battery's energy call to avoid unnecessary losses, while the main source provides the energy supply. In terms of vehicle range and battery life, this control strategy will contribute continuously and assist the overall vehicle energy management system by adding an optimal level of energy storage, improving supply quality and efficiency.

The simplicity of the control, where we have exploited the advantages of control by integrating regulators, as well as the modelling of the photovoltaic source, is the main advantage of this technique presented. We have saved in terms of space and cost for the dc-dc bus control unit. Not to mention a considerable gain in the amount of energy not consumed during acceleration phases, given the limited load on the battery. Validation of the dc-dc bus control model, while checking the power supply and storage phases, demonstrated the excellent performance of the system as a whole and validated the principle of the proposed dc-dc converter control, while respecting the compatibility of the connections with other sub-systems such as the battery, the hydrogen fuel cell, as well as the dynamic model of the vehicle.

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