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Design and Control of a PEM Fuel Cell Electric Vehicle Drive System

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Abstract— *This paper proposes an energy management strategy for an electrical hybrid vehicle which is composed of a Proton exchange membrane (PEM) fuel cell and a supercapacitor storage device. In this paper, the mathematical model for the proposed driving chain, comprising the PEM Fuel Cell, supercapacitor, boost converter, inverter and vehicular structure, was modeled in MATLAB/Simulink. The proposed algorithm is evaluated for the Highway Fuel Economy Test (HWFET) driving cycle. The obtained results demonstrate the effectiveness of the proposed energy management strategy (EMS) in reduction of the hydrogen consumption.*

Keywords— *PEM Fuel Cell; energy management strategy; driving chain, hydrogen consumption; electric vehicle.*

I. INTRODUCTION

In recent years, the development of automotive have attracted considerable attention several constructors of vehicle due to the environmental pollution [1][2]. In this context, the fuel cell electric vehicles are the most promising in transportation area for their zero emission and environmental friendship [3][4].

In these case, the fuel cell are considered the prime preference to be used in transportation area [5] [6] due to their high power density, low operating temperature [7].However, the FC has several disadvantages and cannot respond to fast transient peak power demand [8][9].To overcome these drawbacks, the integration a secondary source can be reduces the fuel consumption[10][11]. For this reasons, the fuel cell electric vehicles are usually combined with other energy storage units such as batteries and supercapacitors [12].

In the presented work, the authors made gives an evaluation of an energy management strategy dedicated to the adopted system.

The paper is structured as follows: section II gives a general description of the studied system and its components. In Section III, we will present the energy management proposed to minimize the fuel consumption. Finally, the last section presents the obtained simulation results of our work, it serves to validate the proposed energy management.

II. POWER TRAIN DESCRIPTION

The proposed power train shown in fig. 1 consists of the primary power source based on PEM fuel cell while the second power source, based on the supercapacitor. A Boost converter is utilized to connect the PEM fuel cell to the DC bus.

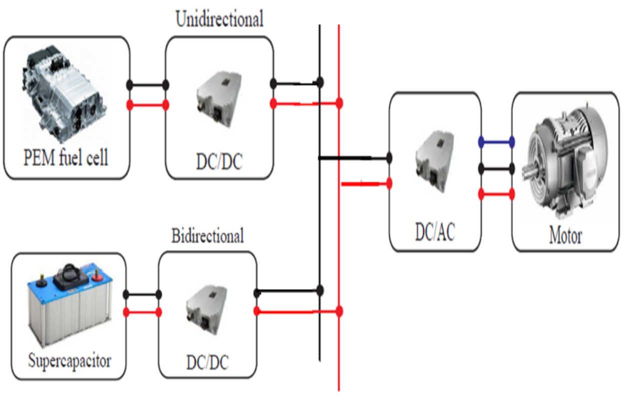

Fig. 1. The hybrid fuel cell vehicle

The vehicle components specifications are illustrated in Table I.

TABLE I. The Components Vehicle Specifications[13]

Components	Parameters	Values
PEM fuel cell	Power	85KW
	Voltage	280V
	Nominal Current	300A
Supercapacitor	Rated capacitance	63F
	Rated Voltage	125V
Boost converter	L	20e-3H
	C	100e-6F
	Duty cycle(D)	0.5
Vehicle specification	Vehicle total mass	1300
	Rolling resistance force constant	0.01
	Air density	1.2
	Aerodynamic drag coefficient	0.3
	Acceleration due to gravity	9.8

A. Modeling of the PEM Fuel Cell

The electrical circuit of PEM fuel cell is shown in fig. 2.

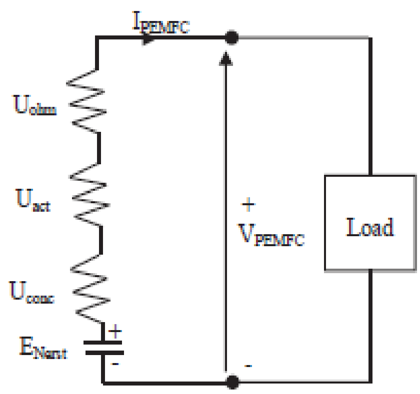

Fig. 2. The electrical circuit of PEM fuel cell

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According to the electrical circuit given in Fig. 2, the fuel cell output voltage can be expressed as in (1): [14][15][16]

$$V_{PEMFC} = E_{nerst} - U_{act} - U_{ohm} \quad (1)$$

V_{act} is activation Voltage losses, V_{ohm} is Ohmic Voltage losses, V_{con} is Concentration Voltage losses.

B. Inverter

A three phase inverter shown in fig. 4 is generally composed of three arms; each one is composed of two electronic IGBTs.

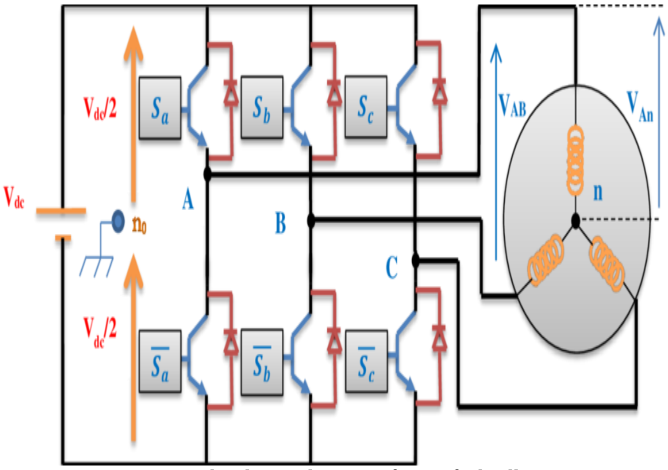

Fig. 4. The electrical circuit of PEM fuel cell

Based on the electrical circuit shown in fig.4 the three voltages are given by the following equations:

$$V_{an} = \frac{VDC}{3}(2.sa - sb - sc) \quad (5)$$

$$V_{bn} = \frac{VDC}{3}(2.sb - sc - s_a) \quad (6)$$

$$V_{cn} = \frac{VDC}{3}(2.s_c - sa - sb) \quad (7)$$

Where,

sa, sb, sc are the controlled switches of the IGBTs of the inverter

C. Supercapacitor

The power and the output voltage of supercapacitor are detailed by the following equations: [17][18][19][20]

$$U_{sc} = V_s - RI_{sc} \quad (8)$$

$$P_{sc} = U_{sc} I_{sc} \quad (9)$$

The state of charge (SOC) is estimated as:

$$SOC = \frac{E}{E_{max}} \quad (10)$$

The energy of supercapacitor can be written as

$$E = \frac{1}{2} c_{SC} u_{sc}^2 \quad (11)$$

$$E_{max} = \frac{1}{2} c_{sc} u_{sc-max}^2 \quad (12)$$

D. Vehicle Modeling

The vehicle is subjected to forces along the longitudinal axis. We have three forces [7] [23][24]:

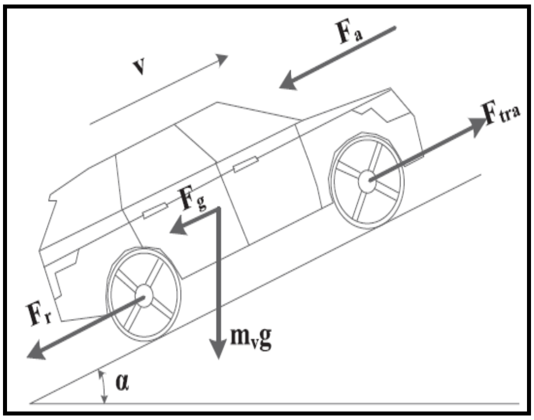

Fig. 5. Forces applied to the electric vehicle

The rolling resistance force F_{tire} is given as follow [23]:

$$F_r = mgc_r\cos(\beta) \quad (13)$$

The aerodynamic force F_{aero} given by the following expression [23]:

$$F_a = \frac{1}{2} \rho_{air} A_f c_d v^2 \quad (14)$$

The inclination force F_{slope} is [23]:

$$F_i = mgsin(\beta) \quad (15)$$

The total the total tractive effort is given as follow [23]:

$$F_t = F_r + F_i + F_a \quad (16)$$

Where: β is Road slope angle, ρ_{air} *is* Air density, F_{aero} is Effort of aerodynamic resistance, A_f is Front area of the vehicle, C_d is Aerodynamic drag coefficient.

III. Proposed Enerfy Management System

The objective of this work is to develop an energy management for the fuel cell/supercapacitor vehicular system which considers the fuel economy during the various driving phases such as: acceleration, deceleration, stopping phases and the behavior of power storage element [23].

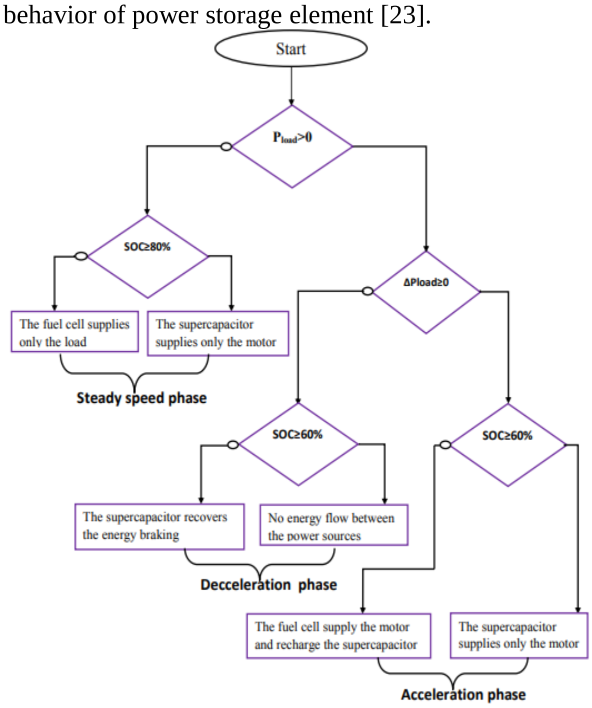

Fig. 6. Proposed energy management

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IV. Simulation Results and Disccusion

In this section, we present the analysis results of the energy management control which is illustrated previously in Fig. 6.

Figure 7 illustrates the simulation results of a HWFET driving cycle.

Fig. 8 represents the hydrogen consumed by the PEM fuel cell during the HWFET driving cycle is around 83g/s.

However, Fig. 9 illustrate the simulations results of the hydrogen consumed that is minimized by 35g when the proposed energy management algorithm is implented.

The performance of the developed power train is validated and illustrated in fig. 10. The developed energy management has guaranteed a 41%.

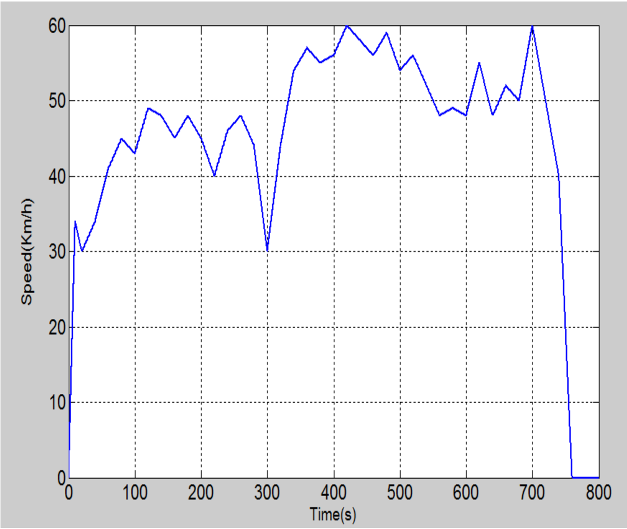

Fig. 7. The HWFET profile

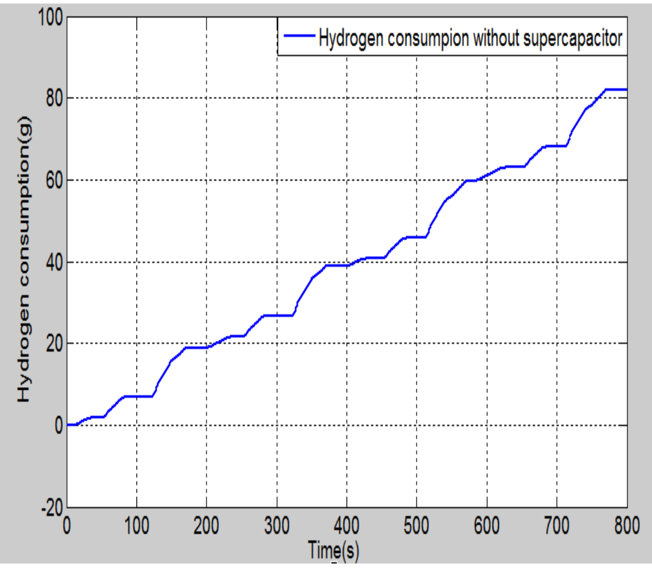

Fig. 8. Hydrogen consumption without supercapacitor

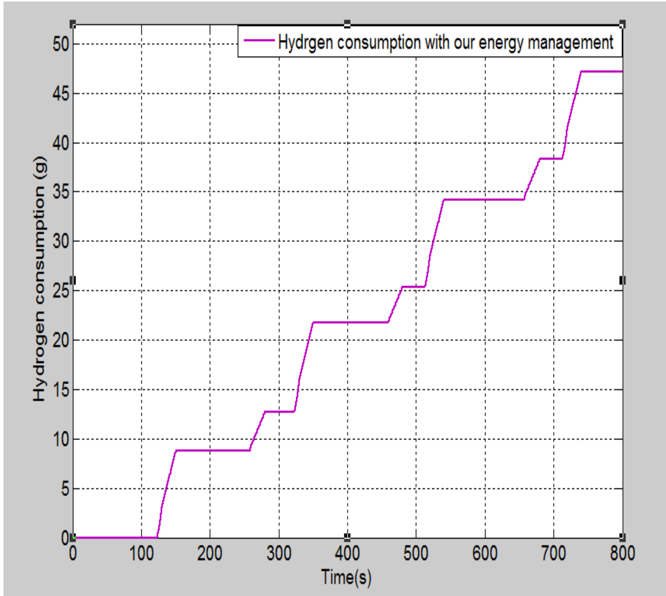

Fig. 9. Hydrogen consumption with our energy management algorithm

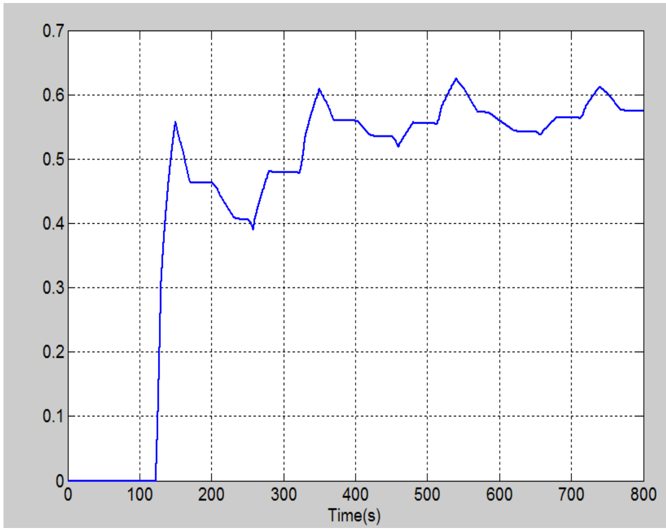

Fig. 10. Gain in hydrogen consumption in pu

V. Conclusion

In this paper, the model of a hybrid electric system has been presented. Thus, we have proposed a simplified energy management while assessed by HWFET driving cycle. This strategy system has been evaluated and developed using MATLAB/Simulink software .We have evaluated and shown the effectiveness of the proposed approach. It has been clearly concluded that the adopted control proved a gain in hydrogen consumption.

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