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Output performance analysis for the Proton Exchange Membrane Fuel Cell hybrid power electric vehicles

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Abstract

A Proton Exchange Membrane Fuel Cell (PEMFC) vehicle system model including the hydrogen storage system is adopted and used to analysis the vehicle output performance under the different driving cycle test. This study analyzed the output performance affected parameters including the temperature, hydrogen flow required and the hydrogen storage system by compare different driving cycle simulation. Then the vehicle simulation performance including the efficiency and the fuel economy affected by different auxiliary load were studied .The results show that working temperature affected the PEM fuel cell power achieved greatly under the same auxiliary load. Different driving conditions affected the flow rate required (the hydrogen consumption)and the fuel cell power achieved, in which the aggressive cycle may need more flow rate and achieved more fuel cell power achieved by compare with the fuel economy driving cycle test. The vehicle performance varied according the different auxiliary loads, when the auxiliary loads were higher, the hydrogen delivered much more and the vehicle driving raw distance became shorter.

Keywords: Proton Exchange Membrane Fuel Cell (PEMFC), hybrid power sources, output performances , simulation analysis.

1. INTRODUCTION

Fuel cells are electrochemical devices that convert chemical energy into electricity [1]. Proton Exchange Membrane Fuel Cell is the fuel cell that combines the hydrogen and oxygen to produce energy [2]. It is an ideal form for generate power for the vehicles for its high energy density and high efficiency [3]. When the PEMFC stack system is used for the automotive, usually is combined with the hydrogen storage system to produce the hydrogen. There are often four auxiliary systems in the PEMFC vehicle system, including the hydrogen supply system, air supply system, cooling system and the humidification system [1]. Different driving conditions(Table 1-2) may affect the output performance of PEMFC vehicle system [4-7].

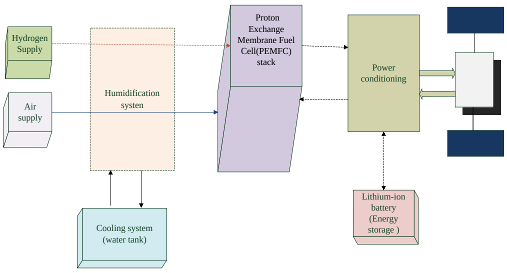

Fig.1 PEM FC hybrid power source vehicle propulsion

Table 1: Driving conditions:

Test case	Test Temperature(^{0}C)	Driving conditions
Fuel economy	24	Free-flow traffic at highway speeds
Cold cycle	-20	Low ambient temperature
Hot cycle	35	High ambient temperature
Aggressive cycle	24	Higher speed ;harder acceleration and braking

In aggressive cycle, the fuel cell power achieved max value is about 100KW, the vehicle max speed achieved 80mph.

Table 2: Output performance under different test case

Test case	Max power(kw)	Max speed(mph)
Fuel economy test	39	60
Cold cycle test	37	55
Hot cycle test	50	55
Aggressive test	100	80

In this study, the output performances of the PEM FC vehicle were tested by above four driving conditions.

2. SYSTEM CONFIGURE

The PEMFC hybrid power sources vehicle system configure is shown as Fig.1,[8]

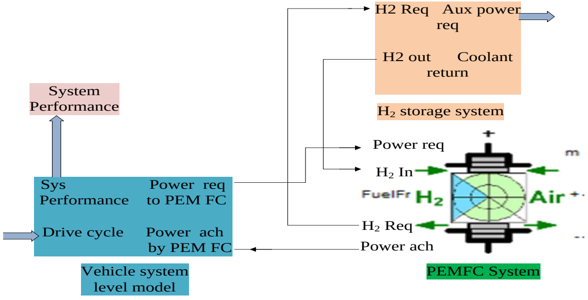

Fig.2 The PEMFC vehicle system configure

The vehicle is powered by PEMFC system, which is fueled by a hydrogen storage system [9].The power of the PEMFC stack is the function of the current and the voltage [1].

$$P=f(I,V) \qquad (1)$$

Where P is the power of the PEMFC stack,

I is the current drawn from the stack;

V is the resulting stack voltage.

2.1 PEMFC system

The PEMFC system is fueled by the hydrogen, which is the output of the Hydrogen storage system and combine the oxygen to produce the energy that provide the power needed by the vehicle. The net power of the simulation PEMFC system is 80KW, developed by the Ford company [8], and based on the model used by Pukrushpan et al[1].

The input parameters of the PEM fuel cell system are: [Design parameters; H2 stream in; signals from the vehicle; wasted heat stream in].

The output results include: design results; max power achievable; power achieved; H2 requested; wasted heat stream out.

2.2 H storage system

One of the critical elements of the PEMFC vehicle is the on-board hydrogen storage system [10].It is responsible for providing H_2 stream to the PEMFC to satisfy the DOE constraints such as the purity et al. There are six storage

2.3 vehicle system

The vehicle system is powered by the PEMFC achieved and provides the power required by the PEMFC. The vehicle system runs according to different driving conditions associated by the standard driving cycles such as the cold and the hot cycle test. The vehicle system model is established by the power-based approach to calculate all components ahead to simplify the power demand of each component from the wheel to storage system.

3. SIMULATION TEST

We made the simulation test under different test cases by the constant auxiliary load.

3.1 Effect of temperature

When the vehicle system runs at auxiliary load 0.2KW, the cold cycle test and hot cycle test results are shown as follows (Fig.3-10).

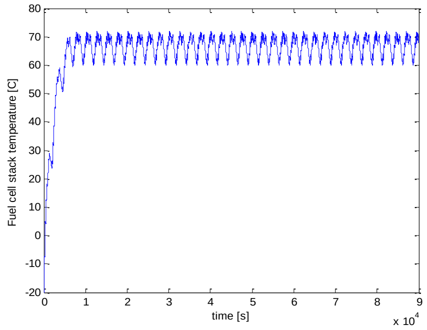

Fig.3 PEMFC Stack Temperature (Cold cycle test)

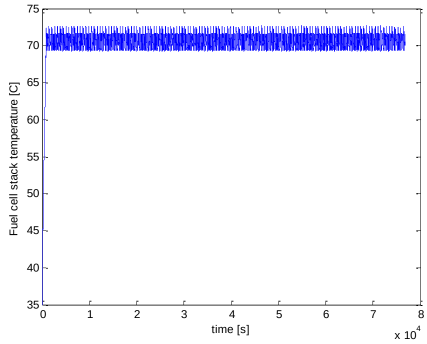

Fig.4 PEMFC Stack Temperature (Hot cycle test)

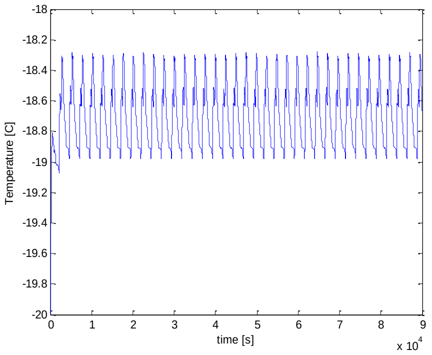

Fig.5 Test Temperature (Cold cycle test)

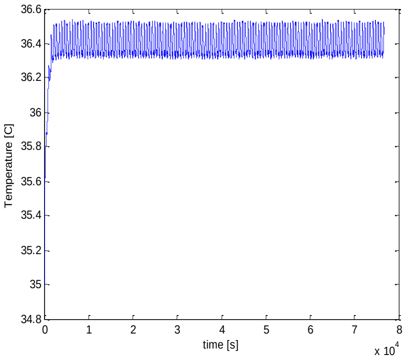

Fig.6 Test Temperature (Hot cycle test)

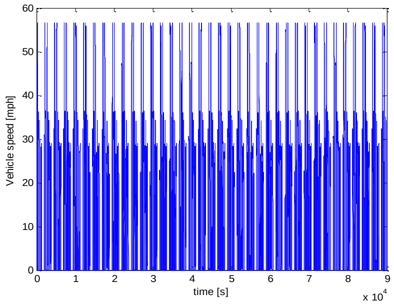

Fig.7 Vehicle speed (Cold cycle test)

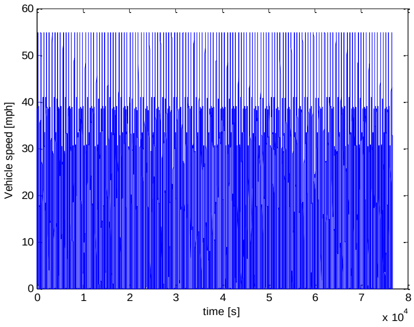

Fig .8 Vehicle speed (Hot cycle test)

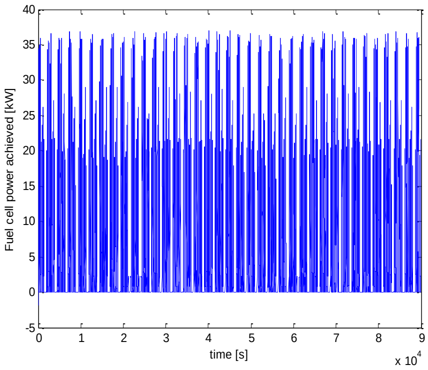

Fig .9 PEM FC power achieved (Cold cycle test)

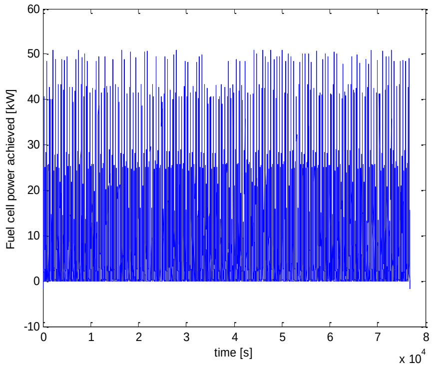

Fig .10 PEM FC power achieved (Hot cycle test)

Table 3 shows the working condition temperature and the running time for the two test case.

Table 3: The run time of the vehicle system

Test case	Run time(s)
Cold cycle	89973.2
Hot cycle	76844

From Table 3, we may see that the run time in cold cycle of the hybrid sources vehicle is longer that the hot cycle. The high temperature is more suitable for the vehicle system.

From Fig.3-10, we may see that in cold cycle test, the fuel cell power achieved max value is about 37KW, the vehicle max speed achieved 55mph. The vehicle working temperature is under -18C.

In hot cycle, the fuel cell power achieved max value is about 50KW, the vehicle max speed achieved 55mph. The fuel cell stack working temperature is around 73C.

It may be seen from above figure and table, the vehicle driving temperature affect the fuel cell stack working temperature, but not affect the max speed of the vehicle. In the cold cycle test, the speed of the vehicle changes frequently while in the hot cycle, the speed of the vehicle may run relatively constant. In the hot cycle, the fuel cell stack may runs quickly achieve the max temperature that maintain the fuel cell stack to work constant.

3.2 Effect of flow rate required (H2 hydrogen)

When the auxiliary load is 0.2 kw, the test results are shown as follows.

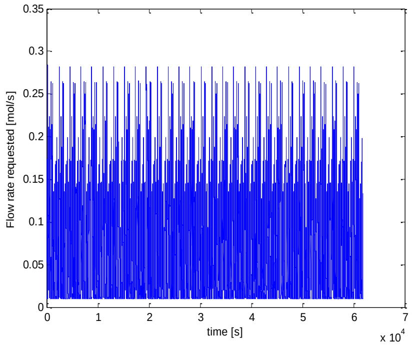

Fig .11 Flow rate required Fuel economy test)

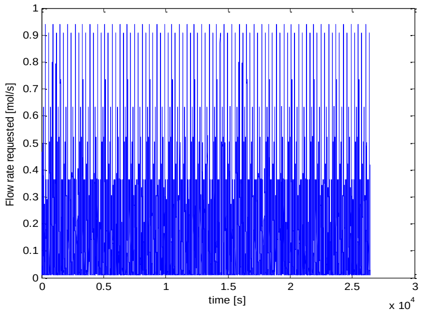

Fig .12 Flow rate required (Aggressive cycle test)

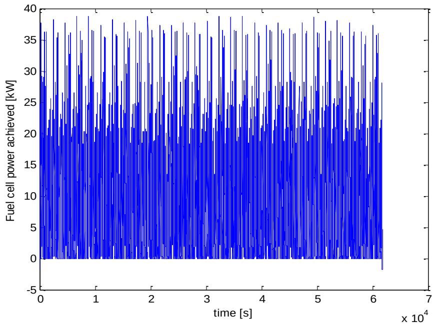

Fig.13 PEM FC power achieved (Fuel economy test)

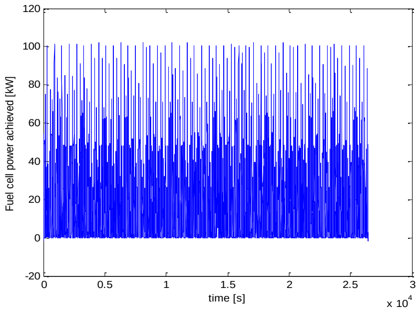

Fig .14 PEM FC power achieved (Aggressive cycle test)

From above figures (**Fig.11-14)**, when the vehicle runs at the fuel economy cycle test, the flow rate requested is 0.2mol/s, and when it runs at the aggressive cycle test, the flow rate requested is achieved around 0.6mol/s. While when the vehicle runs at the fuel economy cycle test, the fuel cell power achieved around 25KW, but when it runs at aggressive cycle test, the fuel cell power may achieve around 60 KW. That means when the system flow rate requested is higher, the fuel cell power achieved may be improved.

3.3 Effect of tank status

When the auxiliary load is 2 kw, the test results are shown as follows.

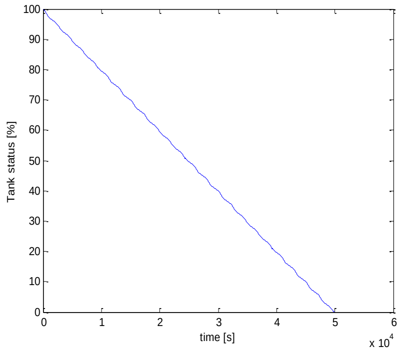

Fig.15 Hydrogen tank status (Fuel economy test)

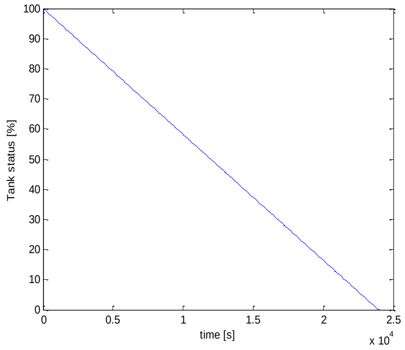

Fig.16 Hydrogen tank status (Aggressive test)

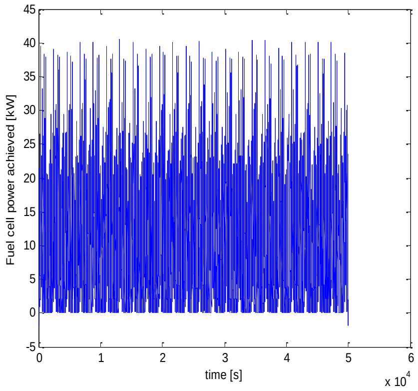

Fig.17 PEM FC power achieved (Fuel economy test)

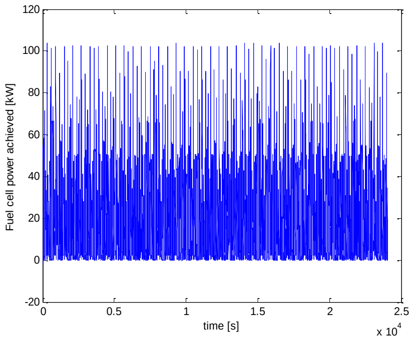

Fig.18 PEM FC power achieved (Fuel economy test)

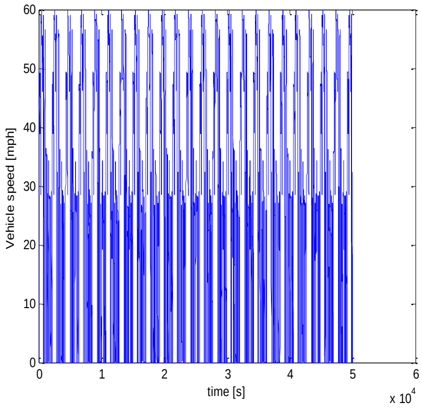

Fig.19 Vehicle driving speed (Fuel economy test)

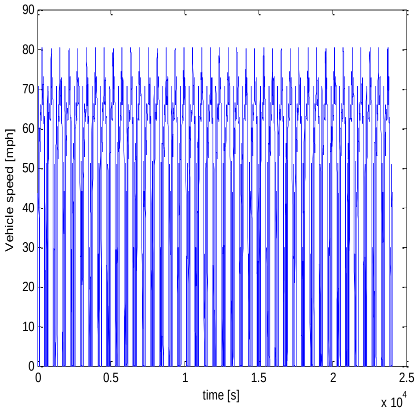

Fig.20 Vehicle speed (Aggressive test)

In fuel economy test, the H_2 consumption completed in about 5*10^{4}s (Fig.15), while in the aggressive test, the time for the H_2 consumption is about half of the fuel economy test, almost in about 2.4*10^{4}s (Fig.16).But the maximium value of the fuel cell power achieved in the fuel economy test may reach only 4KW(Fig.17), while the same value in the aggressive test can reach 10kw(Fig.18).

3.4 Effect of H_2 storage system

Different H_2 storage systems were tested at the auxiliary load is 0.7kw, hot cycle.

When it is adopted the CH-AB Slurry Exothermic storage system the vehicle variables were:

Mass in feed tank [kg]:	77.5623
Ballast volume [m^3]:	0.014068
Fraction CH in feed [-]:	0.5
Pressure setpoint [bar]:	25
Length reactor [m]:	0.403
Length liquid radiator [m]:	1.5347
Length gas radiator [m]:	0.70881

The effect of the different H_2 storage systems are shown in Table 4. From the table 4, we may that the vehicle on-board efficiency when the storage system adopts the compressed 350 bar, is higher than it is adopted the CH-AB Slurry Exothermic storage system, which can be reached 100%.

Table 4: Effect of different storage system

Storage system	Run time(h)	Stack Temperature(^{0}c)	Distance (miles)	Fuel economy [mpgge]	On-board efficiency	H2 used [kg]	Storage system volume [L]	Pressure (bar)
CH-AB Slurry Exothermic	1:19:19.9	36.4	425	71	95.9%	6.01	135.8	5
Compressed 350 bar	1:09:27.5	25.7	406	72	100%	5.62	329.0	6

4. RESULTS AND DISCUSSION

The tests are carried out at different auxiliary loads from 0.2kw to 2kw by fixing the same hydrogen storage system. Performance was studied of the PEMFC electric vehicle by given different auxiliary loads.

The test results are shown as the **Table 5-7.**

Table 5: PEM FC hybrid power sources vehicle output performances when auxiliary loads (0.2 KW)

Test case	Run time (S)	Raw Distance (miles)	On-board efficiency	Fuel economy (mpgge)	Temperature (^{0}C)	H2 delivered (Kg)
Fuel economy test	61759.0	513/343(cal)	95.8%	57	25.6	6.01
Cold cycle test	89973.2	403/403	90.4	79	-18.7	5.01
Hot cycle test	76844	458	94.3%	76	36.5	6.01
Aggressive test	26450	353	97.9%	59	37.8	6.01

Table 6: PEM FC hybrid power sources vehicle output performances when auxiliary loads (0.7 KW)

Test case	Run time (S)	Raw Distance(miles)	On-board efficiency	Fuel economy (mpgge)	Temperature(^{0}C)
Fuel economy test	58028.8	483/324(cal)	96.9%	54	25.9
Cold cycle test	89957.6	403	92.6	73	-18.6
Hot cycle test	71189.8	425/425	95.9%	71	36.4
Aggressive test	25703.8	344/344	98.2%	57	53.2

Table 7: PEM FC hybrid power sources vehicle output performances when auxiliary loads (2KW)

Test case	Run time (S)	Raw Distance(miles)	On-board efficiency	Fuel economy (mpgge)	Temperature(^{0}C)
Fuel economy test	49965.8	418/284(cal)	97.8%	47	31.3
Cold cycle test	81908.8	366/367	94.5%	61	-17.9
Hot cycle test	60044.2	358/358	97.1%	60	37.1
Aggressive test	24016.4	321/321	98.5%	53	40.6

From Fig.5-7, we may see that the raw driving distance became shorter when the auxiliary loads higher.

5. CONCLUSION AND PROSPECTION

The output performance of the PEMFC electric vehicles was compared under different operating parameters by keeping the other parameters constant. Simulation results show that the driving temperature affected the PEM fuel cell power achieved greatly under the same auxiliary load. The aggressive cycle may need more flow rate and achieved more fuel cell power by compare with the fuel economy driving cycle test under the same auxiliary load and the same hydrogen storage system. When the auxiliary loads were higher, the hydrogen delivered by the vehicle much more and the vehicle driving raw distance became shorter. The output running performance analysis may be useful for the designer and driver of the PEMFC hybrid power source electric vehicles.

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