Simulation Study on Power Performance and Economy of Hydrogen Fuel Bus

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Abstract: Hydrogen energy has become the clean energy with the most development potential in the world due to its advantages of green, high efficiency and wide application range. Our country has vigorously developed new energy vehicles, and the commercialization of hydrogen fuel cell vehicles has also made great strides. In order to better promote the hydrogen fuel bus, this paper carries out simulation research on its power and economy under specific working conditions. The simulation results show that the optimized fuzzy logic control strategy makes the vehicle's power performance better, most of the fuel cell working range is in the high efficiency range, and the power battery SOC is in the ideal range, achieving the purpose of optimization.

1. Introduction

At present, the number of private cars is increasing year by year, and private cars are basically traditional internal combustion engine models, which has caused the environment to deteriorate, the smog is getting worse, and the energy crisis has also been exacerbated. On the other hand, a lot of natural gas and oil are consumed on traditional diesel locomotives every year. Practice has shown that the use of new materials and technologies for internal combustion engines cannot solve the fundamental problems of fuel consumption and environmental pollution in internal combustion engines. Only by using clean energy can fundamental problems be solved. Therefore, the promotion and application of new energy vehicles powered by clean energy is the general trend.

In recent years, our country has vigorously developed new energy vehicles, and the commercialization of hydrogen fuel cell vehicles has also made great strides. Many cities in China have trial run hydrogen fuel cell bus lines. In order to better promote the hydrogen fuel bus, it is necessary to carry out simulation research on its power and economy under specific working conditions.

2. Development Trend of Hydrogen Fuel Bus in China

At present, the new energy bus market is mainly occupied by pure electric vehicles. Hydrogen fuel cell buses are only in small-scale trial operation, and there is still a long way to go before real large-scale commercialization. In 2017, the Ministry of Industry and Information Technology listed fuel cell vehicles as a key support area, and proposed to realize the application of 50,000 vehicles, and to build 300 hydrogen refueling stations by 2025, and thus hydrogen fuel cell vehicles entered an explosive growth and large-scale development stage. On the other hand, various local governments also strongly support the operation of hydrogen energy demonstration lines and the construction of industrial parks. For example, the planned hydrogen energy and fuel cell industrial park planning project in Shanghai will continue to introduce fuel cell vehicle power system integration and key component enterprises, hydrogen energy industry supporting enterprises and other clusters to form a complete industrial chain.

Pure electric buses have the problems of long charging time, short cruising range, low battery energy density, and technical bottlenecks in the short term are difficult to break. While Hydrogen fuel cell bus hydrogenation is usually completed within 10 minutes, the battery energy density is high, the key technical problems have been solved, and the cruising range can reach about 500 kilometers. Compared with power batteries, the safety and stability of hydrogen fuel cells are greatly guaranteed. The concentration of hydrogen encountering an open flame explosion is generally 4% to 75.6%, while the hydrogen concentration used by hydrogen fuel cell vehicles is 99.99%, which is much higher than the explosion concentration range. At the same time, high-purity hydrogen is stored in high-pressure steel cylinders. Once the fire is caused by an open flame due to an accident, the system will automatically close the multi-stage valve body of the cylinder. In addition, hydrogen fuel cell vehicles are equipped with high-precision on-board detection systems that can accurately detect hydrogen leaks in steel cylinders or pipelines. Once hydrogen leaks are detected, the control system will immediately turn off the hydrogen output to avoid mixing with oxygen to ensure that it will not spontaneously ignite.

The use scenarios of hydrogen fuel cell buses with a long range of more than 300 kilometers have more advantages. From the perspective of hydrogen production, storage and refueling, it is more scientific and reasonable to distribute hydrogen refueling stations within 100 kilometers of hydrogen production sites. In other words, a hydrogen refueling station can radiate hydrogen fuel cell vehicles within 100 kilometers of the surrounding area. Compared with power battery charging piles, it will have higher utilization rate and driving effect.

Therefore, in the long run, hydrogen fuel cell buses are the ultimate solution.

3. Fuel Economy Analysis of Hydrogen Fuel Bus

3.1. Fuel Cost

With the advancement of hydrogen production technology, the cost of obtaining hydrogen fuel is getting lower and lower. The process of water electrolysis hydrogen production is simple, pollution-free, and the efficiency is as high as 75% to 85%. Moreover, water is a renewable resource and is the most promising way in the long run. The direct current consumption of hydrogen produced by water electrolysis is generally between 15.8 ~ 18 MJ/Nm3H2. The production cost of hydrogen should take into account factors such as depreciation costs of hydrogen production equipment, management and staff amortization costs, and corporate profits. Therefore, the following formula can be used to calculate the cost of hydrogen:

In the formula, C represents the cost of hydrogen use; C_1 represents the direct production cost of hydrogen production by water electrolysis; C_2 represents the amortization ratio of management and personnel; C_3 represents the depreciation ratio of equipment; C_4 represents the energy consumption ratio of purification and compression; C_5 represents the proportion of profits and other factors of hydrogen production enterprises. At present, the valley power price of power grid in major cities in China is about 0.3 Yuan/MJ; the proportion of enterprise management and personnel amortization is assumed to be 10%; equipment depreciation rate is assumed to be 20%; the proportion of purification and compression is assumed to be 10%; enterprise profit is assumed to be 10%. So, the cost of hydrogen production can be calculated 2 ~ 2.28 Yuan per Nm^3. Considering the increase of electric energy consumption in the process of hydrogen compression, it is reasonable to take 2.5 Yuan/Nm^3 as the direct production cost of hydrogen production by water electrolysis.

3.2. Development Cost

In order to reduce the development cost of the hydrogen internal combustion engine system, the development of the hydrogen internal combustion engine bus can be completed by refitting the traditional internal combustion engine bus. We have investigated the parameters of hydrogen fuel buses with good fuel economy in China, as shown in Table 1.

Table 1 Parameters of hydrogen fuel buses.

Items	Parameters
Weight	18t
Engine characteristics	Inline; supercharged
Engine capacity	10L
Number of cylinders	6
Cylinder caliber	126mm
Stroke	130mm
Compression ratio	10.5:1
Power	180 kW (2200 r/min)
Torque	850 Nm (1400-2000 r/min)
Hydrogen consumption per 100 kilometers	60 Nm^3/100km

According to the light vehicle fuel consumption test method (GB/T 19233-2008) and heavy commercial vehicle fuel consumption measurement method (GB/T 27840-2011), we measured the fuel consumption of hydrogen fuel bus is 60 Nm3/100km, and then estimated the fuel cost of hydrogen fuel bus is about 150.8 Yuan/100km.

Hydrogen internal combustion engine buses are mainly modified based on diesel buses. Considering the current vehicle scale of urban bus lines, the cost of conversion is calculated at the scale of 100 buses, and evaluate the development cost of hydrogen fuel bus is as Figure 1.

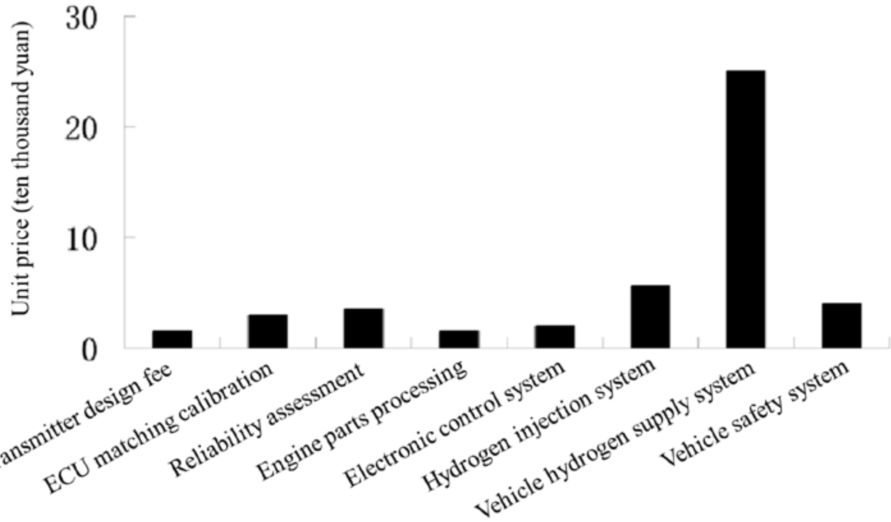

Figure 1 Development cost of hydrogen fuel bus.

It can be seen from Figure 1 that, the development cost of a hydrogen fuel bus is about 460,000 Yuan, of which the cost of the hydrogen supply system is the most significant, accounting for about 54%.

4. Simulation Analysis of Power Performance of Hydrogen Fuel Bus

4.1. Power Performance

The power performance indicators of hydrogen fuel bus usually include the maximum speed, 0-50km/h acceleration time, and the highest grade. According to the vehicle dynamics test standards and the vehicle performance indicators, the acceleration curve of the hydrogen fuel bus under the fuzzy logic control and power following control strategies is simulated, as shown in Figure 2.

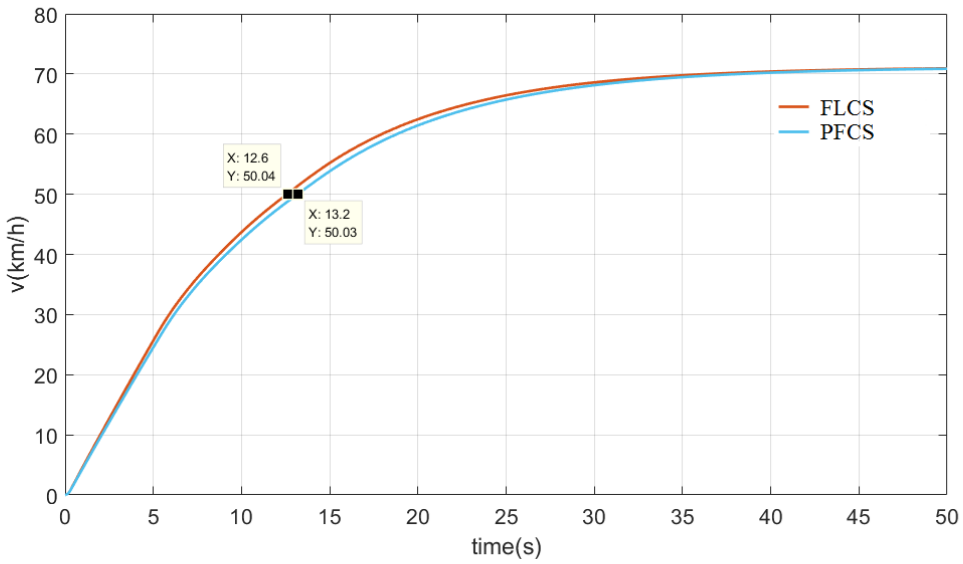

Figure 2 Acceleration curve of the hydrogen fuel bus.

As Figure 2 shows, under the power following control strategy (PFCS), the time required for the bus to accelerate from 0km/h to 50km/h is 13.2s, and the maximum speed that the vehicle can reach is 71.05km/h. Under the fuzzy logic control strategy (FLCS), the acceleration time is 12.6s, and the maximum speed is 71.1 km/h. Both control strategies can meet the technical specifications of fuel cell urban buses.

In the simulation of maximum climbing degree, under the power-following control strategy, the maximum climb rate that the bus can reach at 20km/h is 19%; under fuzzy logic control strategy, the maximum climb that can be achieved is 18%. The fuzzy logic control controlled the power output of the fuel cell in the optimal working range, which caused the vehicle's grade to decrease at a speed of 20km/h, but it still met the technical specifications of the fuel cell city bus, so it has little effect on vehicle performance.

The power performance simulation results of hydrogen fuel buses under the two control strategies are shown in Table 2.

Table 2 Power performance simulation results of hydrogen fuel bus.

Power performance test items	Fuzzy logic control strategy	Power follow control strategy
Acceleration time (s) from 0 to 50 km/h	13.1	12.5
Maximum speed (km/h)	71.03	70.92
Maximum creeping gradient (%)	19	18

It can be seen from Table 2 the acceleration time and maximum speed of the bus are improved under the fuzzy logic control strategy. Since the power output of fuel cell is controlled in the optimal working range by fuzzy logic control, the climbing gradient of bus decreases at the speed of 20km/h, but it still met the technical specifications of the fuel cell city bus, so it has little effect on vehicle performance.

4.2. Fuel Economy

The economic performance of the whole vehicle of the hydrogen fuel cell bus studied in this paper mainly focuses on the hydrogen consumption of 100 km and the maximum driving range of the whole vehicle.

In the simulation analysis of hydrogen consumption in 100 km, for urban buses, a typical urban bus cycle in China is adopted under 65% (11250kg) load. The hydrogen consumption under the fuzzy logic control strategy and power follow control strategy is shown in Figure 3.

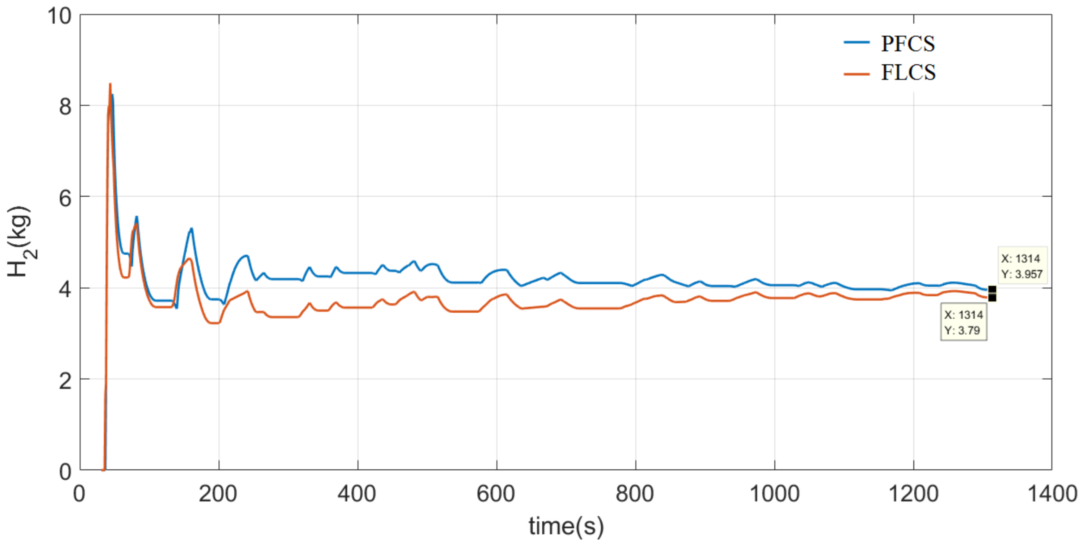

Figure 3 Hydrogen consumption of the hydrogen fuel bus.

The SOC curve of power battery under two control strategies is shown in Figure 4.

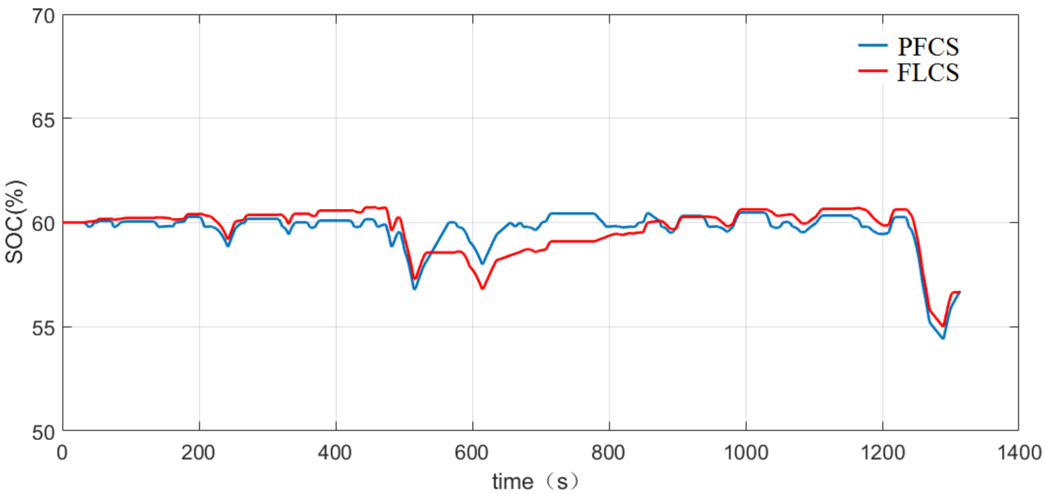

Figure 4 SOC curve of power battery.

And then, the simulation results of fuel economy of hydrogen fuel bus under two control strategies are shown in Table 3.

Table 3 Simulation results of fuel economy of hydrogen fuel bus.

Fuel economy	Power follow control strategy	Fuzzy logic control strategy	Energy saving rate (%)
Energy consumption (kw/h)	61.53	58.96	4.17
Hydrogen consumption (kg)	3.94	3.80	
Hydrogen consumption (L)	188.50	188.53	

It can be seen from Table 3 the simulation results show that the optimal control strategy is 4.17 percentage points higher than the power follow control strategy. As show in Figure 4, the SOC of power battery is initially set at 60%. After one cycle of operation, the SOC residual of power follow control strategy is 56.65%, and that of fuzzy logic control strategy is 56.72%. The SOC variation range is between 50% - 70%, which meets the design requirements of SOC in high charge discharge efficiency range. The SOC residual value under the two control strategies is close, and meanwhile, the improvement of energy saving rate also reflects the improvement of vehicle fuel economy.

In hydrogen fuel bus driving range simulation, the initial value of SOC is set to 100%, and the simulation speed is set to a constant speed of 40km/h. When the hydrogen consumption is completed and the SOC of the power battery is reduced from 100% to 5%, the driving range of the bus under the two control strategies is shown in Table 4.

Table 4 Simulation results of driving range of hydrogen fuel bus.

Working condition	Initial hydrogen content	Residual hydrogen content	Initial SOC	Residual SOC	Driving range under PFCS	Driving range under FLCS	Increase rate (%)
40 km/h	100%	0	100%	5%	410	424	3.4%

In can be seen from Table 4, the driving range under the both control strategies can meet the design requirements of fuel cell city bus technical indicators. When the bus is driving at a constant speed of 40km/h, the driving range can reach 400km under both control strategies. And the driving range under fuzzy logic control strategy is improved by 3.4% compared with the original control strategy, which achieves the purpose of optimal control.

5. Conclusion

In this paper, simulation study of power performance and economy of hydrogen fuel bus under power following control strategy and fuzzy logic control strategy is conducted. The simulation results show that the optimized control strategy improves the power and economy of the vehicle and meets the design performance requirements of the vehicle. The optimized fuzzy logic control strategy makes the vehicle's power performance better, most of the fuel cell working range is in the high efficiency range, and the power battery SOC is in the ideal range, achieving the purpose of optimization.

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