Design and Simulation of FC Plug-in Hybrid Bus with Ultracapacitors

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Abstract

The plug-in hybrid vehicle has been taken as one of the main streams of electric vehicles world wide with the development of battery technology and the remaining obstacles by the fuel cell to be broken through. Fuel cell plug-in vehicle will follow the engine plug-in vehicle because of the more and more strict control of green house gas emission. At this moment, lithium battery is still expensive and safety problem remains. The performance of ultra capacitor has been significantly improved and the price goes down rapidly because of being used on harbor vehicle and mechanical facilities such like container/cargo cranes in-small-batch. It has become a popular ESS for energy regeneration such like the transit buses. The paper will present the advantage and the performance of a FC plug-in hybrid transit bus with ultracapacitors and NiMH batteries. The design and simulation will be covered in the paper.

Keywords

simulation, FCEV, plug-in, hybrid bus, ultracapacitor

1. INTRODUCTION

The research and development of plug-in hybrid vehicle has become a main stream in EV circle world wide. No zero emission can be achieved if the ICE engine is not used and the relay on renewable energy can not be changed ultimately. The fuel cell technology is getting mature and the price is still expensive. The battery technology worldwide has been developing quickly and traction battery with large capacity is available for EV production. Especially in China, the traction battery with large capacity leads the world and has gained worldwide focus on the technology development. While at the same time, the oil price is climbing continuously and the china's oil consumption depend at over 57% on the importation from overseas countries. The energy security and strategy force us to develop renewable energy vehicles at full strength. The involvement of State Electric Power Grid Corporation (SEPG) in field of power source, charging stations and battery have greatly accelerated the EV industry in China. The two hydrogen infrastructures available in Beijing and Shanghai, the EV drive by SEPG and battery technology of China are the basis of the development of FC plug-in hybrid bus with ultracapacitors. [Szumanowski, 2000, 2007]

2. WHY FC PLUG-IN HYBRID BUS WITH ULTRACAPACITORS

If the energy and power are all depend on on-board fuel cell during operation, the power, volume and weight of on-board fuel cell will be larger than any other battery to meet the same power performance and range to one charge requirements, which leads to difficult structural design and layout of bus design. Especially the life of fuel cell module will be shortened if the entire load is burden by it and the discharge current is large. Further more, the price of such a fuel cell stack is too expensive to be sold commercially. [Electric & Hybrid, 2005]

The fuel cell used on-board cannot be charged on-board and no braking energy regenerated if only the fuel cell is used for power system. While the effects of regenerative braking by lead acid battery, nickel hydride battery or lithium-ion battery need improving. For the electric transit buses with frequent starts and stops, regenerative braking should not be neglected as statistics, more than 10% range can be extended with regenerative braking for transit buses.

Besides the function of regeneration, the ultracapapcitor can improve the system performance as well as the efficiency of the whole system especially it will improve their battey life. Experimental results have shown that the battery life with the help of the ultracapapcitor can be significantly improved. The ultracapacitor pack should have high power density to ensure the discharge capability with large current while starting, accelerating and climbing as well as overloading. It also should have long life, no memory effect, no pollution and low price.

The rectangular in Table 1 stands for ICE plug-in hybrid vehicle. It combines the advantages of both HEV and EV, it features low price, long range, need not stop

Table 1 The comparisons of HEV, battery vehicle and FC hybrid vehicle

	Hybrid Vehicle (with ICE engine)	Battery Vehicle	Fuel Cell Hybrid Vehicle
Advantage	low price	Zero emission	Zero emission
	long range	high energy efficiency	high energy efficiency
	need not stop when battery energy is out	low noise	need not stop when battery energy is out
			low noise
Disadvantage	Non zero emission	High battery price	High fuel cell price
	medium energy efficiency	long charging time	
	noise	special charger	
		short range	
		need stop if battery energy is out	

ICE plug-in hybrid vehicle

Fuel cell plug-in hybrid vehicle

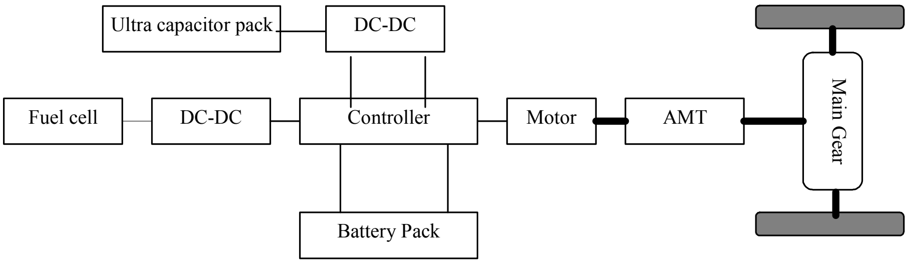

Fig. 1 The configuration of FC plug-in hybrid bus with ultracapacitors

even though the battery energy is out and zero emission, high energy efficiency and low noise. While the other rectangular stands for Fuel Cell plug-in hybrid vehicle. It combines the advantages of HEV, EV and FCEV.

3. SYSTEM CONFIGURATION

The configuration of the plug-in hybrid bus with ultracapacitors consists of an AC motor and controller system, an AMT, a NiMH battery pack with medium capacity, high power density and energy density, an ultracapacitor pack with DC-DC converter and a fuel cell system with DC-DC converter is shown in Figure 1.

4. PARAMETER MATCH

After a serial of calculation and analysis the main system parameters are fixed and the requirements of the vehicle performance are shown in Table 2.

5. PERFORMANCE SIMULATION

As depicted in Figure 2, the maximum speed of the FC plug-in hybrid bus with ultracapacitors is over 75Km/h and the maximum climbing capability is over 20%. The system match can fully meet the requirements.

6. CONCLUSION

The configuration of the FC plug-in hybrid bus with ultracapacitors mentioned in the paper can greatly meet the current needs of zero emission vehicles. The price is also reduced by adopting only half of the power as the fuel cell hybrid bus. The system is expected to save oil consumption with on-board charger to charge NiMH battery pack during operation intervals, usually a fast charge in daytime and a normal charge at grid valley during night.

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Table 2 Parameters required to constract the FC plug-in hybrid electric bus with ultracapacitors

Item	Data	
Overall length /mm	11,500~12,000	
Overall width /mm	2,450~2,550	
Overall height /mm	<3,800	
Min. ground clearance /mm	>160	
Ceiling height from floor /mm	>2,100	
Front approach angle	≥7°	
Rear departure angle	≥7°	
Wheelbase /mm	5,800~6,200	
Floor height at entrance /mm	<400 (from ground)	
Min. turning radius /mm	<24,000	
Curb weight /kg	<14,000	
Gross weight/kg	<19,000	
Max. front axle load /kg	<7,000	
Max. real axle load /kg	<13,000	
Passenger seat number	>35	
Max. passenger number	≥70	
Allowed max. overload	≥10%	
io	5.8	
AMT(2 shifts)	Ig1=1.6, ig2=3.5	
Road condition	Paved cement or asphalt road	
Duty Cycle	Typical urbane drive cycle in China	
Max. speed(km/h)	≥75 with AC operating	
Acceleration	0-50 km·h^{-1} in less than 20 sec.	
Gradability (Gradient)	≥15%	
Range per fueling/km	≥350 (fully fueled and after PLUG IN at night)	
Fuel economy	Price of Fuel consumption per 100km (with gross weight and constant speed 40km·h^{-1})<the price of 15kg of hydrogen, per Chinese standard GB/T 18386-2001 "Electric Vehicle Reference Energy Consumption and Range Test Procedures".	
Outside noise	<80dB (A) in acceleration measured using GB 1495-2002 Standard "Limits and measurement methods for noise emitted by acceleration motor vehicles" or equivalent International, European and USA Standards.	
Inside noise	≤75 dB (A) during driving at constant speed of 50km·h^{-1} using GB 18697-2002 Standard "Acoustics – Measurement of noise inside motor vehicles" or equivalent International, European and USA Standards.	
Motor and controller	Rated power (kW) (60min)	100
	Rated rotation speed (r/min)	1800
	Rated torque (N.m)	531
	Peak power (kW) (5min)	185
	Maximum torque (N.m)	1100
	Maximum speed (r/min)	6000
	Speed range at constant power (r/min)	1600-3500
	Temperature range (℃)	-30～85
	Rated inlet DC Voltage (V)	345
	Cooling means	Water
	Inlet temperature of motor	≤65℃
	Inlet temperature of controller	≤65℃
	Weight of motor (kg)	395
	Weight of controller (kg)	82
	Protection rate	Motor: IP44, Controller: IP54
	Rated Efficiency	Rated: ≥90%
	High efficiency zone (>80%)	≥50%
	Noise	<85dB(A);

Ultracapacitor pack	Working voltage (V)	240-380
	Maximum charge voltage (V)	460
	Static capacity (F)	3500F
	Power density (kW/kg)	2000
	Energy density (Wh/kg)	6
	Storage energy (Wh)	1000
	Maximum charging rate	20-200C
	Maximum Discharging Rate	20-200C
	Maximum charge and discharge current(A)	300
	Internal resistance (Ω)	0.3
	Temperature range (°C)	-25-60
	Life cycle	150000
	Weight (kg)	<200
	Price (RMB/Wh)	<150
Fuel cell engine	Rated Power (kW)	50 (1h)
	Overload power	60kw (3min)
	Starting time	≤6s
	Working voltage	336v (over load)～460v (idle)
	Power weight ratio	≥0.08kw/kg
	Power volume density	≥0.08kw/kg
	Loss of hydrogen	<4% (G/S)
	FC stack efficiency	≥47%
	Noise	≤78dB
	Outlet temperature of FC	65°C
	Power ration of FC engine	≥120w/kg
	Power density	≥0.42w/cm2 (area of membrane)
	Isolation performance	≥1MΩ
Battery pack	Battery Type	NiMH
	Capcity(Ah)	240
	Single	12V80Ah
	Number	96
	Total Voltage(V)	384
	Total Energy (kWh)	92.16
Range	Battery only (Km)	100@80%DOD
	Fuel cell only (Km)	250
	Total (Km)	350

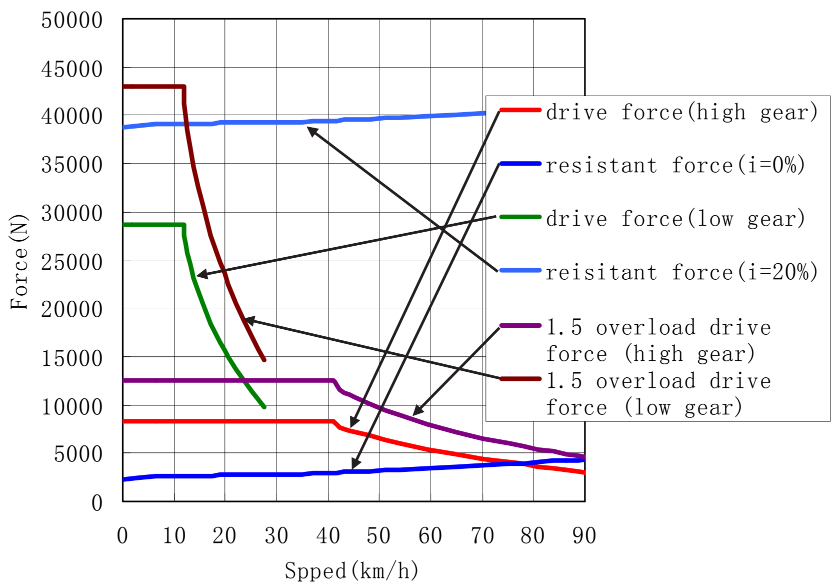

Fig. 2 Performance simulation of the FC plug-in hybrid bus

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(Received November 2, 2007; accepted December 17, 2007)