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The Development of Hybrid Vehicle Driven by Power Battery and Ultra-capacitor

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Abstract:

The important problem to restrict the development of battery electric vehicles is that the power source of battery electric vehicles can't provide high power density and energy density at the same time. This paper gives out the hybrid power system driven by power battery and ultra-capacitor which can solve this problem and improve the performance of vehicle based on the test data.

Key word：ultra-capacitor，power battery，hybrid

1. Introduction

Nowadays the main problem to restrict the development of battery electric vehicles is battery. There is no suitable battery which can meet the energy requirement of electric vehicle. The reason is that all energies on the market can not provide high power density and energy density at the same time. Hybrid vehicle driven by power battery and ultra-capacitor can solve this problem [1].

Because the ultra-capacitor has the characteristics of the high discharge current in the short time, long cycle life, high efficiency of regenerative braking and wide working range. Hybrid power system driven by power battery and ultra-capacitor can not only take the advantage of the load balance function of ultra-capacitor, but also lower the discharge current of battery pack. So that it can increase greatly the usage efficiency of energy, extend remarkably the life of battery, and improve the power and driving range of vehicle. This paper develops the hybrid vehicle driven by power battery and ultra-capacitor on the platform of HAIMA M1 mini car.

2. Power system structure

The energy system of hybrid vehicle driven by the power battery and ultra-capacitor is shown as Fig.1.

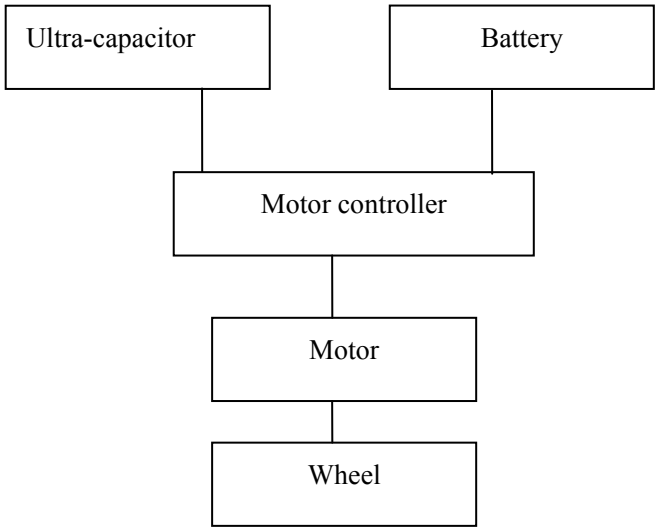

Figure 1The physics structure of power system

The control strategy of this hybrid vehicle is as follow: When the hybrid vehicle is running on the normal condition, the power battery provides the electric energy for the motor. In order to make the ultra-capacitor have the output ability anytime, when the hybrid vehicle is running at the constant speed, the power battery not only provides the electric energy for the motor, but also provides the electric energy for the ultra-capacitor. When the hybrid vehicle accelerates or climbs, the power battery and ultra-capacitor provide electric energy for the motor together. When the hybrid vehicle brakes or goes downhill, the motor work as the generator, the regenerative braking energy is charged to the ultra-capacitor. If the ultra-capacitor is full, the regenerative braking energy is charged to the battery.

The electric vehicle is running on the normal condition.

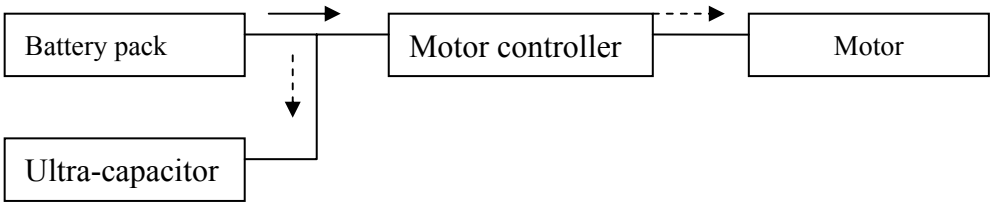

Figure 2 the vehicle energy distribution on the normal condition

The electric vehicle on acceleration or climbing condition is as follows

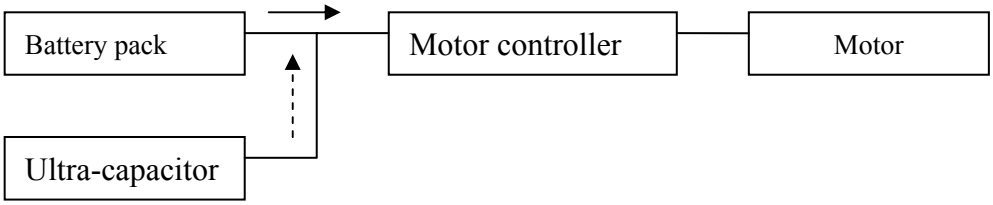

Figure 3 the vehicle energy distribution on acceleration or climbing condition

The electric vehicle brake or downhill is as follows

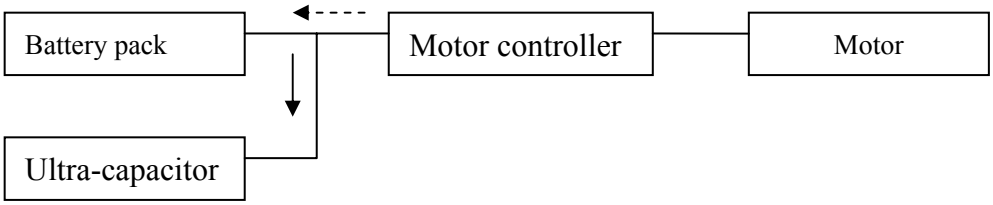

Figure 4 the vehicle energy distribution on brake or downhill condition

3. System Development

The target of vehicle power is following:

Table 1 target of vehicle

Name	parameter
Maximum speed	80km/h
Range	100km
Gradeability	》25%
0-60km/h acceleration time	〈 12S
GVW	〈 1000kg

3.1 Motor

When vehicle is driven at a constant speed from 20 to 80 km / h, the motor power corresponds to the vehicle speed in the matching relation of Table 2:

Table2 the matching relation of vehicle speed and motor power

Vehicle speed（km/h）	20	30	40	50	60	70	80
motor power（kW）	2.51	3.42	4.5	5.81	7.41	9.37	12.74

Vehicle power at the maximum speed should be less than the rated power, the motor rated power is set at 15KW and peak power is set at 35kw.
The 0-60km / h acceleration time is less than 12S, so that it meets the design requirements.
The designed vehicle has the 25% gradeability at a speed of 20km / h and at this time the running speed of motor is 2056r/min.
According to the equation of vehicle design, vehicle must be meet the equation when climbing:

$$F_t \geq F_f + F_w + F_i \qquad \text{Equation 1}$$

The result of calculation is that the motor providing the driving force required is about: 2757.6N.

By $F_t = \frac{T_{tq} i_g i_0 \eta_T}{r}$, The result of calculation is that motor torque required is 87Nm

Equation 2

By $P_e = \frac{T_{tq} n}{9550}$ when electric vehicles climb 25% slope at 20km / h, the required power is 26.18Kw, less than the peak power of 35Kw. Equation 3

To sum up, the rated power of motor is 15KW, the peak power of motor is 35KW, the rated speed of motor is 2500r/min, the maximum torque of motor is 100N.M, the rated voltage of motor is 288V.

3.2 Power batteries and ultra-capacitor

The determinacy of the number of batteries needs to consider the maximum output power of battery and battery output power in the process of traffic which are determine by control strategy ,So that ,the range and power of vehicle can meet the design requirement.
The power battery is $LiMPO_4$(Lithium Iron Phosphate). The battery cell voltage is 3.2V.The battery cell energy is 12Ah.The battery pack is made up of four battery modules in parallel. Each battery modules includes ninety-one battery cells in series. The total battery pack energy is 14Kwh.The total battery pack volume is 120L.The main parameters of battery cell are in table 3:

Table3: information of $LiMPO_4$ battery

	Model	28/82/118
1	Rated voltage	3.2V
2	Rated energy	12Ah
3	Resistance	< 5mΩ
4	The limit voltage of Discharge	2.0V

5	The limit voltage of charge	3.6V
6	Maximum sustained Discharge current	3C(50A)
7	Transient discharge current	7C(82A, 10S)
8	The Max charge Current	2C(24A), Transient 5C(60A),10S
9	Weight	0.5Kg
10	Size	28.5x 82.5 x 118 cu. mm

The determinacy of the number of ultra-capacitor is mainly affected by the ultra-capacitor charge time and discharge time, the vehicle's braking, acceleration time, as well as by output power of ultra-capacitor which is designed by control strategy. They need to satisfy the following formula:

$$\frac{1}{2} n_1 n_2 C_c (U_{c\max}^2 - U_{c\min}^2) \geq P_c t$$

Equation 4

n_1 is serial ultra-capacitor number in each group

n_2 is the number of ultra-capacitors series group

C_c is cell capacity of each ultra-capacitor

$U_{c\max}$ is the maximum working voltage of each capacitor

$U_{c\min}$ is the minimum working voltage of each capacitor

P_c is output power of the ultra-capacitor

The voltage of ultra-capacitor is 2.7V, the capacity of ultra-capacitor is 650F. The ultra-capacitor module is made up of 24 pieces in series .The ultra-capacitor group is made up of five ultra-capacitor modules in series. The whole ultra-capacitor pack is made up of three ultra-capacitor groups in parallel. The main parameters of ultra-capacitor module are in table 4.

Table4 the main parameters of ultra-capacitor module

Ultra-capacitor cell parameter	Rated capacity	650	F
	Capacity deviations	+20% / -5%	
	Rated voltage	2.7	V
	Operating temperature range	-40~+65	℃
	ACresistance	0.6	mΩ

	（1KHZ ESR）		
	DC resistance	0.8	mΩ
	Size	60.7×79.5（Diameter×Length）	sq. mm
	Weight	0.2	kg
ultra-capacitor module parameters	Rated voltage	129.6	V
	The total number of ultra-capacitor	48	piece
	Rated capacity	13.5	F
	DC resistance	≤50	mΩ
	Serial number	48	piece
	Weight	≤20	kg
	Volume	<390×260×190(length ×width ×height）	cu. mm.

3.3 Other Parts

3.3.1 DC-DC Parameters Design

The total power of low-voltage electric in this electric vehicle is shown in table 6 to8. In the calculation process of electric power load of low voltage electric .The coefficient of frequency is added which reflects the frequency of electric when the vehicle is in the operation. For different vehicle manufacturers and different models, this coefficient is different.

The actual power multiplied by the coefficient of frequency is calculated power. The total calculated power is the optimized power supplied by DC / DC converters of fuel vehicles or electric vehicles which supplies power to 12V low-voltage electric. Electrical components are in table 6-8.

Table 6 Electrical components in continuous job

Name of electrical components	Actual power（W）	Coefficient of frequency	Calculated Power（W）
Position lights	20	1	20
License light	10	1	10
Instrument lights	13.2	1	13.2
The charge of battery	54	0.4	21.6
Power steering System	360	1	360
Power vacuum	100	1	100

pump			
Electric pump	40	1	40
Electronics Fan	180	0.6	108
Total（P_{W1}）			672.8

Table 7 Electrical components in short job

Name of electrical Components	Actual power（W）	Coefficient of Frequency	Calculated Power（W）
Headlight near light	110	0.6	66
Headlight far light	120	0.4	48
Wiper in the front	50	0.4	20
Wiper in the rear	30	0.05	1.5
Sound system	20	1	20
Air-conditioning systems	200	0.6	120
Total（P_{W2}）			275.5

Table 8 Electrical components at random

Name of electrical components	Actual power（W）	Coefficient of frequency	Calculated Power（W）
Electric horn	42	0.01	0.42
Turn lights	94	0.05	4.7
Brake lights	42	0.03	1.26
Back-up lights	21	0.02	0.42
Front fog lights	110	0.7	77
behind fog lights	21	0.7	14.7
Interior lights	10	0.1	1
Suitcases lights	5	0.1	0.5
High level brake light	21	0.03	0.63
Cigarette lighter	120	0.01	1.2
Glass Lifter	90	0.01	0.9
Defrost System	160	0.7	112
Airbag	20	0.01	0.2
Scrubber	43	0.01	0.43

Total（P_{W3}）	215.36

The total power :$P=P_{W1}+P_{W2}+P_{W3}=672.8+275.5+215.36=1193.66\approx1200$（W)
The optimized power of DC / DC converter is 1200W. Technical parameters of DC / DC converter are in table 9.

Table 9 Technical parameters of DC / DC converter

Output voltage	DC13.5V
Input voltage	DC180V～360V
Output power	1200W
Power efficiency	﹥85%
Output ripple	＜100mv
Over-temperature protection temperature	75℃
Insulation resistance	≧200MΩ
Operating temperature	-20°C ～70°C
Cooling method	Natural air-cooled
Relative humidity	＜90%

3.3.2 The parameters design of vehicle charger

Main technical parameters of electric vehicle charger are in table 10.

Table 10 Main technical parameters of electric vehicle charger

Name	parameter
Input voltage	AC220V±15%;50Hz
the range of output power	180V～335V
Output current	8A
power	3000W
the rate of voltage regulation	stabilized voltage≦0.5%
digital display	Output voltage accuracy is ± 1%, output current is ± 1%, showed a decimal
Output ripple	＜1%
Charging phase	Constant current→Constant voltage
Insulation Resistance	between input and output≧200MΩ
Over-temperature protection temperature	75℃
Insulation strength	between input and output，AC1500V，10mA，1 Minutes
Cooling method	Cooling fan
Operating temperature	-20°C ～65°C
Operating humidity	＜90%
Operating efficiency	＞90%

Other Function	CAN Bus Interface
Size	300width)¡78(height)¡370deepth) cu. mm

4 Vehicle Test

4.1 Sliding test

Electric cars sliding test data is in table 11.

Table 11 Electric cars sliding test data

Sliding speed（km/h）	Direction	Sliding distance(m)	The average sliding distance(m)
50	To	567.3	589.8
	Back	612.2	

4.2 Range

Electric range test data is in table 12.

table12: Electric range test data

Test sections	range（km）	Continued driving time（min）	Driving speed（km/h）	Whether or not open the ultra-capacitor
high-speed runway	110	138	48.6	not open
high-speed runway	117	145	49.4	open

4.3 0-60km / h acceleration time

Acceleration time test data is in table 13.

table13: acceleration time test data

Test sections	acceleration time	Whether or not open the ultra-capacitor
high-speed runway	10.8	not open
high-speed runway	10.4	open

5 Conclusions

Ultra-capacitor and battery power hybrid vehicles compared to ordinary battery electric vehicles, the vehicle power is significantly strengthened and the range is extended. Because ultra-capacitor and battery power cost is too high, it is still the important problem to restrict the industrialization of battery electric vehicle.

References

[1] Quanshi Chen, <advanced electric vehicle technology>, chemistry industry publishing company, 2007

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