Energy Management Strategy of Hybrid Power Supply for Pure Electric Vehicle Based on Fuzzy Control

Xiaokan Wang*, Liang Wang, Qiong Wang
Henan Mechanical and Electrical Vocational College, XinZheng, China

*Corresponding author e-mail: wxkbbg@163.com

Abstract. Principle of electric vehicles composite power structure are analyzed and introduced, according to the characteristics of super capacitor and power battery to establish simulation model of vehicular composite power using fuzzy control theory to establish the composite power energy management system control strategy and bring new composite power supply model of electric vehicle driving cycle in different road conditions are simulated, the simulation results show that the control strategy of fuzzy control can significantly improve the working efficiency of the super capacitor and power battery, play the role of the super capacitor peak "cut", extend the service life of the battery; Under the same conditions, the vehicle's power performance and range are improved.

1. Introduction

Electric vehicles, driven by on-board power supply, have incomparable advantages in energy conservation and environmental protection, and are the main development direction of new energy vehicles in the future[1,2]. Power battery is higher than energy, lower than power, and high current charge-discharge seriously affects battery life. The ultracapacitors have low specific energy and high specific power, which can meet the power demand of electric vehicles in short time. The power battery and supercapacitor are combined into a composite power supply, and reasonable topology structure and control strategy are selected to make them complement each other, which can obtain good specific power and specific energy characteristics, which not only greatly improve the power performance of electric vehicles, but also play a role in energy conservation and environmental protection[3,4].

The control topology and control strategy of the composite power supply is a hot topic at present[5]. Due to different components, arrangements and control strategies, the supercapacitor-battery drive system has various structures. In China, Fengchun Sun et al. used speed control and current constraint control to establish the control strategy model of the electric bus energy management system, which can avoid the over-current charging and discharging of power batteries, but reduce the power performance of the whole vehicle. Lichao Chen et al. used the power distribution control strategy to limit the output power of the battery and the improvement of power efficiency was limited. Moreover, the determination of the positive and negative average power demand of the composite power supply was complicated[6].The paper[7] used fuzzy PID algorithm to control the dc-dc in the composite power supply. Caux S et al. analyzed and established the composite power supply with different topology structure, adopted real-time online control and adopted different optimization algorithms to optimize the control strategy, which greatly improved the efficiency of the composite power supply.

In this paper, two modes of motor operation are considered. A new fuzzy control strategy is designed according to the vehicle demand power Preq, battery charging state BSOC and supercapacitor charging state CSOC. The control strategy is simulated and analyzed in matlab.
2. Composite power supply structure for electric vehicle
The composite power supply system is composed of power batteries, supercapacitors and bi-directional DC/DC converters. The topology of the vehicle composite power supply is shown in figure 1. Supercapacitors are connected in series with bi-directional DC/DC and connected with the power battery pack. This kind of structure form is directly output power from the power battery with high energy conversion efficiency. As the auxiliary energy, the super capacitor can track and detect the power battery terminal voltage through two-way DC/DC, and adjust the voltage of itself and the power battery to work, so as to protect the power battery.

3. Formulation of composite power control strategy
Electric motors in electric vehicles have two working modes: electric motor and power generation. In both working modes[8], system demand power $P_{req}$, battery charge state BSOC and ultracapacitor charge state CSOC are input of the fuzzy controller, and power distribution factor $K$ of the composite power supply is output. The structure diagram of the fuzzy controller is shown in Figure 2. The size and fluctuation range of the required power $P_{req}$ of the system in the two working modes are quite different, and the emphasis of control is different. Therefore, the composite power control strategy should be formulated in the two working modes of normal driving and braking.

3.1. Normal driving mode
When the electric vehicle is running normally, the motor is in an electric state, and the required power of the motor is $P_{req} > 0$. Output power distribution strategy of composite power supply system:

1) When the system demand power $P_{req}$ is very small; At this point, if the power battery BSOC is high or moderate, all power required by the system is provided by the power battery; When the power battery BSOC is low and the supercapacitor can output power to the external, the power required by the system shall be provided by both or the supercapacitor separately.

2) When the system demand power $P_{req}$ is small; At this point, if the power battery BSOC is high or moderate, all power required by the system is provided by the power battery; If the power battery BSOC is low, when the ultracapacitor CSOC is high, all power required by the system is provided by the ultracapacitor. When the power of the supercapacitor is moderate or low, the power required by the system is provided by both the supercapacitor and the power battery.

3) When the system needs moderate power $P_{req}$; At this point, if the power battery BSOC is high, all power required by the system is provided by the power battery. If the power cell BSOC is moderate, when the ultracapacitor CSOC is high, the system power is provided by both of them, otherwise, it is provided by the power battery alone. If the power battery BSOC is low, when the ultracapacitor CSOC is high, the power required by the system is provided separately by the ultracapacitor. When the power
of the supercapacitor is moderate or low, the power required by the system is provided by both the supercapacitor and the power battery.

(4) When the system needs a larger power $P_{req}$; At this point, if the ultracapacitor CSOC is higher, the power required by the system is provided separately by the ultracapacitor. If the ultracapacitor CSOC is moderate and the power battery BSOC is large or moderate, the system power is provided by both. When the ultracapacitor CSOC is low, all power required by the system is provided by the power battery.

(5) When the system demand power $P_{req}$ is very large; At this point, if the ultracapacitor CSOC is high or moderate, the power required by the system is provided by the ultracapacitor alone. When the ultracapacitor CSOC is low, all power required by the system is provided by the power battery.

Based on the above strategy of output power allocation of composite power supply, the language values of the three input variables of the fuzzy logic controller of composite power supply system are respectively set as $P_{req} = \{TS, S, M, B, TB\}$, $BSOC = \{L, M, H\}$, and $CSOC = \{L, M, H\}$, and the language values of output variables are $K_{cap} = \{TS, S, M, B, TB\}$, and their subordinate functions are shown in Figure 3, and the corresponding fuzzy rules are shown in table 1.

**Figure 3.** Membership function of the input and output ($P_{req} > 0$)

**Table 1.** Fuzzy rule of hybrid power system ($P_{req} > 0$)

| $K_p$ | $P_{req}$ |
|-------|-----------|
|       | TS | S | M | B | TB |
| BSOC (CSOC=L) | L | TS | TS | S | B | M |
|          | M | TS | TS | TS | S | B |
|          | H | TS | TS | TS | TS | S |
| BSOC (CSOC=M) | L | TS | TS | TS | S | M |
|          | M | TS | S | M | B | B |
|          | H | TS | S | M | B |
| BSOC (CSOC=H) | L | S | M | B | TB | TB |
|          | M | TS | S | M | B | B |
|          | H | TS | S | M | B |

3.2. Regenerative braking feedback mode

When the electric vehicle is in the braking state, the motor is in the generating state, and the system needs power $P_{req}<0$. Allocation strategies for energy feedback to composite systems:

(1) When the energy received by the composite power system is large; At this point, if the ultracapacitor CSOC is too low, it will only charge the ultracapacitor. When the power battery BSOC is low, it will charge the battery appropriately. If the ultracapacitor CSOC is low or moderate, both the ultracapacitor and the power battery are charged, and the ultracapacitor is charged multiple times. If the ultracapacitor CSOC is higher, both the ultracapacitor and the power battery are charged, and the ultracapacitor is charged less.
When the energy received by the composite power supply system is moderate, if the ultracapacitor CSOC is too low, only the ultracapacitor is charged; If the supercapacitor CSOC is moderate, both the supercapacitor and the power battery are charged, and the supercapacitor is charged multiple times. If the supercapacitor CSOC is large, both the supercapacitor and the power battery are charged, and the supercapacitor is charged less.

When the energy received by the composite power supply system is small, if the ultracapacitor CSOC is too low or low, only the ultracapacitor is charged; If the supercapacitor CSOC is moderate or large, both charge.

The language values of the three input variables of the fuzzy logic controller of the composite power supply system are respectively set as $P_{req} = \{S, M, B\}$, $BSOC = \{L, M, H\}$, and $CSOC = \{L, M, H\}$, and the language values of the output variables are $K_{sup} = \{TS, S, M, B\}$, and their subordinate functions are shown in figure 4, and the corresponding fuzzy rules are shown in table 2.

Finally, the output control quantity of the fuzzy controller is a fuzzy quantity, which should be transformed into a precise value by proper method. In this paper, combined with practical experience, and through simulation calculation, the method of solving fuzzy problem is MOM. The method of solving fuzzy problem only considers the membership function (MF) of output effective action, and the height of the maximum component center. If there are multiple maximum values, the formula of solving fuzzy problem is as follows:

$$Z = \sum_{m=1}^{M} Z_m$$  \hspace{1cm} (1)

![Figure 4. Membership function of the input and output (P_{req}<0)](image)

| K_p | P_{req} |
|-----|---------|
|     | S       | M       | B       |
| BSOC (CSOC=TL) | L | S | M | M |
|       | M | S | M | M |
|       | H | M | M | B |
| BSOC (CSOC=L) | L | B | B | M |
|       | M | B | M | M |
|       | H | M | M | B |
| BSOC (CSOC=M) | L | M | S | TS |
|       | M | B | M | S |
|       | H | B | M | M |
| BSOC (CSOC=B) | L | TS | TS | S |
|       | M | TS | S | S |
|       | H | S | M | B |

Table 2. Fuzzy rule of hybrid power system (P_{req}<0)
4. Vehicle model establishment and simulation

In order to verify the effectiveness of the above-mentioned fuzzy control strategy for composite power supply, the simulation is carried out under the conditions of CYC-UDDS and CYC-US06 in MATLAB/SIMULINK[9,10]. Among them, CYC-UDDS tests light vehicles with high acceleration under typical urban road dynamic driving conditions, and CYC-US06 tests and simulates suburban areas with higher speed and acceleration. The initial SOC of power battery is 0.93 and the initial SOC of supercapacitor is 0.93. The simulation results of the hybrid power electric vehicle model are compared and analyzed. The comparison of the simulation results is shown in Fig. 5 and Fig. 6.

Obtained from the simulation result: in the urban road, the main energy source in composite power supply power battery SOC drop more gently, super capacitor, relatively frequent severe fluctuations of SOC by output power contrast figure, you can see that provides the main output power battery power, speed, super capacitor assistance provides output power, super capacitor full braking energy recycling; In the suburban roads, the current fluctuates violently. The power battery and the supercapacitor jointly output large power to the outside world. When braking, the supercapacitor will recover most of the energy, and the power battery will recover some of the energy.

5. Conclusion

This article expounds the all-electric composite power system, the structure and principle of establishing the all-electric vehicle model with composite power supply system, design the compound fuzzy control power system energy management strategy, a study on the simulation in MATLAB/SIMULINK platform, the simulation results show that compared with the single power battery system, composite power system can give full play to the power battery and super capacitor, respectively, in the specific energy and specific power performance advantages, can provide high instantaneous power, in order to meet the electric car acceleration. The proposed control strategy can significantly improve the working efficiency of power batteries and supercapacitors, reduce the impact of large current on power batteries, extend the service life of power batteries, and play the role of "peak cutting and valley filling". In the braking energy feedback process of electric vehicles, the composite power supply system can recover the braking energy to the maximum extent, which not
only extends the driving distance of electric vehicles, but also plays a role of energy conservation and environmental protection.

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