Research on Design and Control of Dual-Energy Source System for Pure Electric Vehicle

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Abstract: Based on the analysis of the structure of dual-energy source storage system and the requirements of drive motor for the power of the battery and super capacitor under different operating conditions, and according to the motor's required power and the battery and super capacitor’s SOC (State of Charge) and other parameters, a corresponding distribution fuzzy control strategy of dual-energy source power is established. A complete electric vehicle model of a dual-energy source pure electric vehicle driven by a DC (Direct Current) motor is constructed by Matlab. The system simulation results show that the battery-super capacitor dual-energy source system can simultaneously meet the dual requirements of energy and power of the pure electric vehicle. Both the economy and power have been improved. Compared with the single-battery power supply of pure electric vehicles, the electric motor drive system of pure electric vehicles with dual-energy sources is more efficient. And the mileage for a single continuous charge, the maximum speed, the shortest acceleration time of 50 km/h and maximum gradeability of 50km/h are improved. The mileage increases by 32.4%. At the same time, the charge and discharge current and temperature of the battery are significantly reduced, and the service life of the battery is effectively.

1. Introduction
The energy crisis and environmental pollution problems have promoted the rapid development of electric vehicles around the world[1]. Traditional pure electric vehicles use battery as the only energy source, which has the problems of long charging time, low specific power, and inability to meet the short-term power requirements of automobiles. The acceleration, climbing, braking performance and energy recovery efficiency of the motor are seriously affected and the motor's requirements for on-board power cannot be fully met[2-3]. In order to solve the above problems, the battery and super capacitor constitute a dual-energy source. The super capacitor has a high power density, a long service life, and the ability to withstand instantaneous high-current charge and discharge, which can effectively make up for the shortcomings of the battery, and improve the mileage of pure electric vehicles.

In addition, the drive motor and control technology are also the key technologies of electric vehicles. The application of brushless DC (Direct Current) motors with electric and electric generation functions in dual-energy sources pure electric vehicles can help solve this problem. In the operation of automobiles, the driving motor is switched and controlled between electric and power generation according to the control requirements. Energy utilization and recovery are performed between the large capacitor and the battery.

On energy distribution strategies for dual-energy sources electric vehicles, the current research mostly focuses on single energy management of dual-energy source [4-5] based on the charge and discharge characteristics of battery and capacitors. It is still not ideal in terms of energy brake recovery and driving mileage improvement of electric vehicles, etc. Therefore, combining the drive motor control technology and dual-energy source technology of electric vehicle, a fuzzy control strategy is designed,
and an overall model of the dual-energy source control system for DC motors is built, the system performances are verified by simulation.

2. The structure of dual-energy source drive control system
The structure of the dual-energy source drive control system is shown in Figure 1. The battery is the vehicle's main power source, and the super capacitor is the vehicle's auxiliary power source. The battery and the super capacitor form a parallel structure, with a DC/DC converter adjusting the terminal voltage of the super capacitor, realizing power allocation according to a certain control strategy.

3. The circuit design for motor drive and braking with dual-energy source
During the operation of a pure electric vehicle, the drive motor generally works in two operating states: electric and power generation. During the electric operation, the dual-energy source supplies power to the drive motor. And during the power generation operation, the capacitor is fully charged first, then the battery is charged by the drive motor. In this paper, we focus on studying this kind of complex power generation operation. The circuit is shown in Figure 2.

In this process, the six power tubes of the inverter bridge circuit are turned off by the control signal of the main board. When the power generation control preferentially charges the capacitor, v8 and v9 are respectively modulated by PWM (Pulse Width Modulation) \(^{13,17}\). In Figure 2, when V8 is turned on by the PWM modulation, the loop \(\text{①}\) is a BOOST boosting circuit that stores magnetic field energy for the winding coils of the brushless DC motor. When V8 is turned off by the PWM modulation and V9 is turned on, the motor winding coils store the magnetic field energy to charge the capacitor by D7, as shown in the loop \(\text{②}\).

After the capacitor is fully charged, the battery is charged. As in the case of charging the capacitor, the magnetic field energy is stored in the DC motor winding coils through the loop \(\text{①}\) in Figure 2. When V8 is turned off, the magnetic field energy stored in the motor winding coils is used to charge the battery through D7, as shown in the loop \(\text{③}\).

4. The design of fuzzy control strategy
The design of the system fuzzy control strategy is based on the premise of ensuring the dynamic performance of electric vehicles, making full use of the characteristics of high current charging and discharging of super capacitor, while reducing the impact on the battery of the frequent high current charging and discharging, extending the service life of the battery and increasing the energy recovered by the regeneration brake system. The driving mileage of the electric vehicle and the vehicle's dynamic performance are also increased \(^{8,9}\).

4.1. Structure of fuzzy controller
The three-input and single-output fuzzy controllers have the input variables as the required power \(P_{\text{req}}\) of the motor drive system, the battery \(SOC_b\) (State of Charge), and Super capacitor \(SOC_{uc}\). The output variable is the power factor \(K_{uc}\) of the super capacitor.
4.2. Design of fuzzy control rules

The number of fuzzy controller language values is related to the accuracy of the fuzzy control and the calculation workload. Considering the overall situation, the language value of each variable of the controller is shown in Table 1.

| mode        | Input / output variable | Language value |
|-------------|-------------------------|----------------|
| Discharge   | $p_{req}$               | TS, S, M, B, TB |
| (p_{req} > 0)| $SOC_b$                 | L, M, H        |
|             | $SOC_{uc}$              | L, M, H        |
|             | $K_{uc}$                | TS, S, M, B, TB |
| Charging    | $SOC_b$                 | L, M, H        |
| (p_{req} < 0)| $SOC_{uc}$              | TL, L, M, H   |
|             | $K_{uc}$                | TS, S, M, B   |

Combined with the dual-energy source working mode and various driving conditions of electric vehicles, the fuzzy control rules in the discharge mode and charge mode are analyzed.

When the required power of the drive motor is $p_{req} > 0$, the dual-energy source is in the discharge mode, and the pure electric vehicle is in the driving state. According to the different characteristics of the battery and the super capacitor, the power battery should be at low current and low power at this time. The super capacitor should provide large peak power to ensure the maximum efficiency of the dual-energy source system.

If $p_{req} > 0$ and the power increase $\Delta p_{req} > 0$ is large, the motor is in an emergency acceleration state (starting, accelerating or overtaking), and it is likely to decelerate. At this time, $K_{uc}$, at least, should be large. If $p_{req} > 0$ and the power increase $\Delta p_{req} > 0$ is small, it means that the motor is driving at a constant or low speed, and the required power is mainly provided by the battery, and the super capacitor is used as an auxiliary power source to supplement. At this time, $K_{uc}$ should be smaller.

When the required power of the drive motor is $p_{req} < 0$, the dual-energy source is in charging mode, and the pure electric vehicle is in the brake feedback state.

If $p_{req} < 0$ and the remaining battery quantity is small, that is, $SOC_b$ is small, the feedback energy of the drive motor is preferentially used to charge the battery. At this time, the power ratio $K_{uc}$ of the super capacitor is smaller.

If $p_{req} < 0$ and a speed increase is required after braking, in order to provide the instantaneous power required for speed increase, the feedback energy of the drive motor is used to charge the super capacitor first. At this time, the power ratio $K_{uc}$ of the super capacitor is higher.

Finally, overcharge phenomenon should be prevented. That is, if the battery's remaining power $SOC_b$ is high, the battery's proportion of power is small, while $K_{uc}$ is high. The fuzzy rules of the fuzzy controller for the discharge and charge mode are shown in Figures 3 and 4 respectively.
The structure of the dual-energy source control strategy model built on the Matlab/Simulink platform is shown in Figure 5.

**Figure 5 Structure diagram of dual-energy source control strategy model**

5. **System Modeling**

Under the Matlab environment, the fuzzy controller, motor, composite-energy, DC/DC converter and other component models are constructed. Then they are integrated into the advisor simulation software. The dual-energy source electric vehicle model interface is shown in Figure 6.

**Figure 6 interface of dual-energy source**
6. System Simulation and Analysis

Figure 7 Simulation results of a single-battery source

The number of battery and super capacitors (only dual-energy sources), the peak power of the drive motor, the test load quality and so on, are set in the simulation system interface. While the type of cycle conditions, the number of cycles, the acceleration performance test, the climbing performance test and other functions are selected.

Simulation experiments were performed under NEDC typical operating conditions. The simulation results of a single-battery and a dual-energy source pure electric vehicle are shown in figures 7 and 8 respectively. The comparison results are shown in Table 2.
Table 2 Comparison of dynamic performance results

|                  | Single- power supply | Dual-energy source | Compared |
|------------------|----------------------|--------------------|----------|
| Driving mileage  | 123.2Km              | 163.2Km            | Up 32.47%|
| Maximum speed    | 148.0Km/h            | 156.9Km/h          | Up 6.01% |
| Minimum acceleration time of 50Km / h  | 2.9 s                | 2.8 s              | Up 3.57% |
| Maximum gradeability of 50Km / h      | 17.5%                | 18.2%              | Up 4%     |

It can be seen from the simulation results that under the same operating conditions, the pure electric vehicles based on dual-energy sources are compared with those based on single-battery power. The continuous mileage has increased significantly by 32.47%, and the maximum vehicle speed, the shortest acceleration time of 50Km/h and the maximum gradeability of 50Km/h are also increased slightly. From the analysis of current changes, the battery current in the dual-energy source system is relatively stable, avoiding large current shocks. Analyzing the temperature changes, super capacitor ease the interior heat accumulation of the battery during driving, extending the service life of the battery.

7. Conclusion

Aiming at current problems of the low energy utilization and recovery efficiency of pure electric vehicles’ composite-energy technology, combining the control technology of electric vehicle drive motor and dual-energy source technology, a fuzzy control strategy is designed. And an overall model of composite-energy control system is constructed for DC motors. The simulation results show that with the system energy control strategy, the power distribution and energy management can be reasonably
performed, and the driving mileage, the maximum speed, the climbing performance and the acceleration performance on a single charge are improved to different degrees compared to the single-power pure electric vehicle. The charge and discharge current and temperature are significantly reduced, which prolongs the service life of the battery.

Acknowledgments
This work was supported by the Key Research Program of Shaanxi Province, China (Grant No. 2018GY-181).

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