Research on control strategy of electric vehicle under braking state based on fuzzy control

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Abstract—Aiming at how to improve the efficiency of pure electric vehicles in the process of braking energy recovery and security problems, this paper takes brake laws ECER13 curve and ideal braking force distribution curve as constraint conditions, to design a kind of input is braking intensity z, battery SOC charge ratio, output for mechanical brake than kp, electric braking is larger than that of ki fuzzy control strategy, and with the fuzzy control strategy as the core to establish the model of regenerative braking, this model embedded in the ADVISOR of pure electric vehicles in the model, and the simulation under the condition of circulating CYC_UDDS. The results show that under the fuzzy control strategy, the effective recovery rate of regenerative braking energy increases by 5.4%, and the energy utilization rate of the vehicle increases by 1.9%.

1. Introduction

With the depletion of non-renewable resources and people's increasing demands on living environment, the use of new energy electric vehicles is increasing year by year. But the existing battery technology is still can't satisfy the electricity required for long-distance travel, this to a great extent, restricts the rapid development of the electric car industry, in order to improve the electric this defect, people use the power generation characteristics of the motor under braking condition, the resulting excess power to batteries, extended the range of electric cars, in this process, the motor torque can also be produced as a braking force to brake the electric cars. Therefore, the effective recovery of braking energy and rational distribution of power has become the core problem of braking energy recovery. At present, some scholars have conducted researches in this field and made certain achievements. Literature [1] proposes to obtain the optimal braking torque of the motor through particle swarm optimization algorithm, and then use the least square method to fit the optimal braking energy recovery control strategy of the motor torque curve when the effective generating power of the motor is at its maximum, ignoring the impact of braking intensity and battery charge ratio (SOC) on the braking energy recovery. Literature [2] USES MTPA control to find out the maximum feedback power torque line, and maximizes braking energy recovery by braking power distribution strategy, so as to achieve the maximum recovery of braking energy. In literature [3], the fuzzy control of braking intensity, speed (V) and battery charge ratio (SOC) as input and regenerative braking proportional coefficient (K) as output is introduced into ADVISOR.
for simulation. The results show that this control strategy can effectively improve regenerative braking energy recovery. Literature [4] established PMSM power model and power battery SOC energy feedback model, and recovered the braking energy by determining the optimal working point of regenerative braking energy recovery strategy, ignoring the impact of other factors on the braking energy recovery process. Literature [5], rear wheel braking force distribution curve before the premise condition, design the braking intensity than z, battery charge (SOC) and forecast the mechanical braking effectiveness factor Bef as the input of fuzzy control in regenerative braking force distribution coefficient fuzzy control output of the fuzzy control strategy, improve the recovery efficiency of braking energy; Literature [6-8] adopts the fuzzy control strategy, takes the key factors affecting the braking energy recovery as input and the regenerative braking distribution coefficient as output, builds the regenerative braking model, and emitters it into the ADVISOR vehicle system for simulation. The simulation results show that this control method effectively improves the regenerative braking energy recovery efficiency. This article through to the above scholars’ research results of study, analyzes the ECE regulation curve, I curve, f and M limit curve of braking force distribution, ensure the safety of the automobile braking process, on this basis, designed for braking intensity z and battery charge than the SOC for input, mechanical brake than ki, electric brake than ki for the output of fuzzy control strategy, to realize the of regenerative braking energy recovery.

2. braking power distribution scheme

In this paper, the braking power distribution safety zone is established according to the state of front and rear wheels of electric vehicles locked during braking and vehicle safety requirements. When the front and rear wheels of electric vehicles are locked at the same time, the braking power distribution curve is I curve and the curve equation is

\[ F_f = \frac{z M (b + zh)}{l} \]  
(1)

\[ F_r = \frac{1}{2} \left[ \frac{M}{h} \sqrt{b^2 + 4hl} \left( \frac{Mb}{h} + 2F_f \right) \right] \]  
(2)

Where: Ff - front wheel braking force; Fr - rear wheel braking force; Z - Braking strength; H - Height of vehicle center of mass; B - The distance between the center of mass and the rear axis; L - front and rear wheelbase; M - the total gravity of the car.

In order to ensure the security in the braking process of electric vehicle and braking force distribution at the same time also have to meet the laws ECER13 brake curve: when the tire-road friction coefficient \( \phi \) between interval 0.2 to 0.8, the braking intensity \( z \geq 1.0 + 0.85(\phi - 0.2) \). At this point, the braking force distribution curve is M curve, and its equation is

\[ F_f = \frac{z + 0.07M}{0.85l} (b + zh) \]  
(3)

\[ F_r = Mz - F_f \]  
(4)

Current when the wheel lock the rear wheels do not lock the front and the relation curve of the ground adhesion f curve, this paper select tire-road friction coefficient \( \phi \) is 0.7, the equation for

\[ F_r = \frac{l - \phi h}{\phi h} F_f - \frac{Mb}{h} \]  
(5)

According to the above analysis, in order to ensure the stability and safety of electric vehicles in the braking process, braking force of front and rear wheels must be distributed according to the area
enclosed by I curve, M curve, x-coordinate and F curve. This is the safe area of braking force distribution that we want to establish, as shown in Fig. 1.

Figure 1  Braking force distribution curve

In order to improve the efficiency of regenerative braking energy recovery, under the premise of electric vehicle safety braking force must be reasonable allocation, maximize more braking and electrical braking, this paper machine braking and electrical braking is allocated according to the following rules: when \( 0 \leq z \leq 0.21 \), because braking intensity is small, all the braking force are provided by electric braking, so the braking force distribution by AB; when \( 0.21 \leq z \leq 0.53 \), braking force according to the BC line distribution; when \( 0.53 \leq z \leq 0.7 \), the braking force by the CD line distribution; when \( z \geq 0.7 \), braking force is larger, the electric car is in emergency braking, in order to ensure the safety brake, brake force all provided by the mechanical braking, braking force distribution according to the AD line.

3. regenerative braking fuzzy control

Fuzzy control is an important branch of intelligent control, it through the accurate input fuzzy, and then according to the expert experience and human reasoning summary to establish fuzzy rules, the input through the fuzzy rules to get fuzzy output, after the output can be de-fuzzy accurate output value. Therefore, fuzzy control is widely used in systems where precise models are difficult or impossible to be obtained, and has good applicability.

For the regenerative braking control charts, the fuzzy controller as the core, to the electric car braking intensity \( z \), battery charge (SOC) as the control object, the mechanical brake than kp, electric brake than ki for controlled object, according to kp, ki and actually the product of the electric car braking force required to get the mechanical braking and electrical braking force, and then press brake force distribution safety rules for braking force distribution. If the braking force required is less than the electric braking force, the electric vehicle braking is all provided by the electric braking; If the braking force is greater than the electrical braking force, electric braking and mechanical braking are required to participate in the ev braking; When the braking force is large and emergency braking is needed, the braking of electric vehicle is completed by mechanical braking, which ensures the safety of automobile braking.

Braking intensity \( z \): fuzzy controller based on expert knowledge and experience, when the \( 0 \leq z \leq 0.7 \), electric braking in brake, when \( z \geq 0.7 \), considering the electric car braking security, electric braking is not involved in the brake, therefore, a braking intensity theory of domain of \([0, 1]\), and divided into \{L (low), M (middle), H (high)\}, braking former \( z \) membership degree function is shown in Fig. 2.
Battery as energy storage equipment, charge ratio (SOC) as an important parameter to reflect battery power, its size directly affects the efficiency of braking energy recovery. When SOC is too low, the stability of the electric vehicle is reduced and energy recovery is unsuitable. When SOC is too high, energy recovery efficiency is reduced, which easily leads to overcharge of the battery and reduces the battery life. Suppose the battery (SOC) field is \([0, 1]\), divided into \{L (low), M(middle), H(high)\}, and the membership function is shown in Fig. 3.

Mechanical braking ratio \(k_p\), electrical braking ratio \(k_i\) mechanical braking ratio and electrical braking ratio all have theoretical domains of \([0, 1]\) and are divided into \{L(low), M(middle) and H(high)\}. Their membership functions are shown in Fig. 4.
Fuzzy control rules Take braking strength $Z$ and battery (SOC) as the input of fuzzy control, mechanical braking ratio $PK$ and electrical braking ratio $IK$ as the input of fuzzy control, and establish fuzzy control rules with the fuzzy language of "IF AandBTHENCandD". The control rules are shown in Table 1. In order to maximize the recovery of regenerative braking energy and ensure the stability and safety of the electric vehicle, the fuzzy control rules follow the following principles: when the input braking strength is small, the braking force of the electric vehicle is provided by the electric brake; When the input braking intensity is large, the braking force of the electric vehicle is mainly provided by electrical braking force, supplemented by mechanical braking. When the input braking strength is high, in order to ensure the stability and safety of electric vehicles, braking power is provided by mechanical braking. At the same time, when the input battery (SOC) is small, it is mainly electric braking; when the battery (SOC) is large, the electric braking does not participate in the braking of electric vehicles.

| The serial number | Braking strength $Z$ | Battery SOC | $k_p$ | $k_i$ |
|-------------------|---------------------|-------------|-------|-------|
| 1                 | L                   | L           | L     | H     |
| 2                 | L                   | M           | L     | H     |
| 3                 | L                   | H           | H     | L     |
| 4                 | M                   | L           | L     | H     |
| 5                 | M                   | M           | M     | H     |
| 6                 | M                   | H           | H     | L     |
| 7                 | H                   | L           | H     | L     |
| 8                 | H                   | M           | H     | L     |
| 9                 | H                   | H           | H     | L     |

According to the fuzzy control rules in Table 1 and the membership function of braking intensity $Z$, accumulator battery (SOC), mechanical braking proportional coefficient $k_p$ and regenerative braking proportional coefficient $k_i$, the relationship between regenerative braking proportional coefficient $k_i$ and braking intensity $Z$ and accumulator battery (SOC) is shown in Fig. 5.

Figure 5 The relation diagram of regenerative braking proportional coefficient $k_i$ braking strength $Z$ and battery (SOC)

4. ADVISOR 2002/Simulink simulation and result analysis
Set up a fuzzy control-based regenerative braking energy recovery control module in Simulink. The control module was embedded into ADVISOR 2002 automobile software, and the CYC_UDDS cycle vehicle as shown in Fig. 6 was selected for simulation. The time was 1369s, the maximum speed was 90.73km/h, and the average speed was 31.33km/h.
Through the simulation, obtained is shown in Fig. 7 (SOC) of battery, the changes of red curve for regenerative braking control strategy based on fuzzy control in CYC_UDDS circulation conditions change curve of the SOC, blue curve for the change of SOC under the original control strategy in ADVISOR curve, can be intuitive to see the red curve in the figure above the blue curve, and the red curve in the SOC decline than the blue curve is relatively flat, so in this paper, the design based on the fuzzy control strategy can improve the efficiency of regenerative braking energy recovery, but overall the two curves in close, The fuzzy control strategy designed in this paper still has defects and needs further optimization.

Compares the energy use of the fuzzy control strategy and the ADVISOR control strategy under the CYC_UDDS cycle. It can be seen from the table that the fuzzy control strategy recovers 367KJ more than the ADVISOR control strategy, with an effective energy recovery of 5.4%, but the energy utilization rate of the vehicle only increases by 1.9%.

5. Conclusion
In order to extend the range of electric vehicles and improve the energy recovery efficiency of pure electric vehicles, this paper designs a regenerative braking energy recovery strategy based on fuzzy control on the premise of the safety zone of braking force distribution surrounded by ECER13 braking regulation curve, I curve and M curve.

This paper designs a fuzzy controller with braking intensity Z and battery (SOC) as input, mechanical braking proportional coefficient kp and electrical braking proportional coefficient ki as output, and establishes a regenerative braking energy recovery module based on fuzzy control.

Establish the regenerative braking energy recovery module embedded ADVISOR2002, under the CYC_UDDS cycle conditions are simulated, the simulation results show that under the fuzzy control strategy, the effective recycling braking energy efficiency by 5.4% higher than that of under the control strategy of ADVISOR, (SOC) of battery performance has also improved, but there is still a lot of room for improvement, need to be further optimized.

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