# Research on braking energy feedback of intelligent electric vehicle based on fuzzy algorithm

Zhiqiang Xu
Guangdong University of Science & Technology, Guangdong, 523083, China

## ABSTRACT

The popularization of automobiles has brought convenience to people's travel. The following problem is that non-renewable energy is facing depletion, and automobile exhaust has seriously polluted the environment, which is one of the main pollution sources causing "haze". As people increasingly face up to environmental protection and health, promote green travel, and strengthen the belief in the coordinated development of human and nature. In order to improve the regenerative braking energy (BE) recovery rate of pure electric vehicles(EV), Mamdani type fuzzy controller with total braking force demand, vehicle speed and battery SOC as input and motor braking force coefficient as output is adopted to determine the proportional distribution between motor braking force and mechanical braking force; Under the premise of ensuring the good braking performance of the vehicle, the power consumption of the battery under a CYC_UDDS cycle can be reduced, the energy utilization rate can be improved, and the driving range of the electric vehicle can be effectively extended on one charge. This study provides a reference for the formulation of regenerative braking control strategy for pure electric vehicles.

**Keywords:** Fuzzy algorithm; Electric vehicles; Braking energy; Feedback research

## 1. INTRODUCTION

With the rapid pace of urbanization, the number of cars is also increasing, which has become an indispensable means of transportation for human beings. However, the large amount of energy consumption brought by cars has led to air pollution, which has greatly affected the quality of life of residents. Therefore, the development boom of new energy vehicles has swept through [1]. The oil reserves on the earth are limited, and the estimated recoverable life is only 50 years based on the current mining rate. Vehicles powered by internal combustion engines are the main body of oil consumption. Research data provided by the American Energy Foundation shows that 85% of China's total oil production (about 5.4 million barrels of oil) is consumed by motor vehicles. The increasing number of cars and the increasing demand for petroleum energy have led to a very serious petroleum energy crisis in the world [2]. The braking system of pure electric vehicles is different from that of traditional vehicles. So as to provide energy for the next start and acceleration of pure electric vehicles, thus improving the energy utilization efficiency of the whole vehicle and achieving the extension of the driving range [3]. The focus of scientific and technological development in the world is to reduce the waste of energy and resources, recycle and reuse energy, and improve the atmosphere by reducing the emission of harmful gases. In modern society, resource and environmental issues are almost related to the overall development of economic and social [4].

*450521404@qq.com

Seventh International Conference on Mechatronics and Intelligent Robotics (ICMIR 2023), edited by Srikanta Patnaik,
Tao Shen, Proc. of SPIE Vol. 12779, 127792Y · © 2023 SPIE · 0277-786X · Published under a
Creative Commons Attribution CC-BY 3.0 License · doi: 10.1117/12.2689387

In recent years, various countries are gradually increasing their investment in the development of new energy. Under the call of national science and technology, the pure electric vehicle technology has also begun to develop continuously. When the car is driving, it is in the process of constant acceleration, deceleration and braking, especially in cities, because of traffic congestion, most of the energy consumed by the car is spent on braking [5]. In contrast, regenerative braking can feed energy back to the battery instead of consuming it, which can greatly extend the driving range of electric vehicles under the condition of single battery. As a new industry with strategic significance, electric vehicle is of great significance to the development of the country, because the technical gap between the field of internal combustion engine vehicles and foreign countries is too large, and the electric vehicle technology department is on the same platform, which can vigorously develop new energy vehicles, improve competitiveness, achieve overtaking in corners, and also help to develop an environment-friendly economy, realize social sustainable development and get rid of dependence on oil imports [6]. In recent years, with the increase of national financial investment and the attention of enterprises, electric vehicles have shown a good development momentum, and made major breakthroughs in battery, motor, vehicle control, integrated technology, infrastructure and other aspects. In addition, the diversification of China's automobile market has laid an excellent foundation for the promotion of electric vehicles [7]. The system adds a DC boost conversion module between the power supply and the motor, so that the system voltage and the power supply voltage can be changed independently and with the power needs of different vehicles, which improves the energy recovery efficiency. However, the transformation ratio between the system working voltage and the power supply voltage is small, the range of motor speed adjustment is small, and the speed range of energy feedback is small. Using power battery as power supply, the maximum charging current is small and the charging efficiency is low [8].

Based on the characteristics of various on-board energy storage devices, this paper compares and analyzes the advantages and disadvantages of different composite structures, comprehensively considers the cost and performance of the system, and builds a model of on-board hybrid energy storage system on the simulation platform. In the aspect of obtaining regenerative braking force, this paper designs a Sugeno fuzzy algorithm controller considering the driver's braking demand, vehicle speed, battery SOC and battery pack temperature, and optimizes the membership function and fuzzy rules of the fuzzy algorithm according to the existing theories.

# 2. RESEARCH ON BE FEEDBACK OF INTELLIGENT ELECTRIC VEHICLE

## 2.1 Analysis of BE feedback system

On the urban roads in China, the speed of most small and medium-sized cars is between 30 and 60 km/h, and the initial braking speed and the final braking speed are not necessarily the same, and some cars will reach zero. Therefore, the specific speed should be judged according to other factors [9]. In the process of driving, the purpose of the braking energy(BE) recovery system for electric vehicles is to recover as much energy generated by braking as possible to the energy storage system of electric vehicles when the vehicles need to brake and decelerate, and to release as much energy recovered from the system for the vehicles to run when the vehicles start or accelerate, so as to effectively protect the batteries from the loss caused by heavy current discharge, minimize the power consumption of the battery pack, and effectively protect the life of the batteries. The recovered energy has strong power, and the cruising range of electric vehicles is prolonged [10].

The regenerative BE recovery system mainly consists of motor, controller, power battery and other components. At the same time, the electric braking torque is generated during the motor power generation process. The regenerative BE recovery system of pure electric vehicle and the transmission of BE are shown in Figure 1.

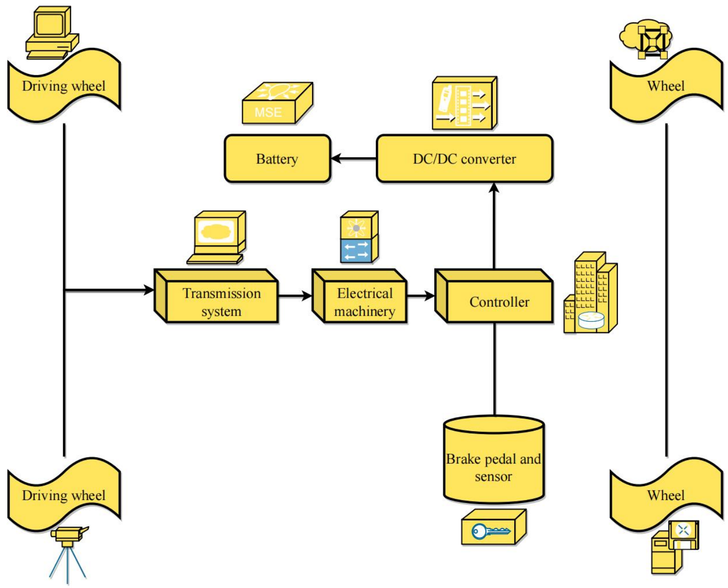

Figure 1. Regenerative braking system and BE transmission of pure electric vehicle

Under various operating conditions of electric vehicles, the main controller controls the motor of electric vehicles to realize forward acceleration and forward deceleration during operation. The combination of the two states also realizes various operating modes of vehicles. In the design of vehicle drive feedback energy, the pressure signal output by the accelerator pedal is an analog voltage signal, which is directly connected to the main controller of the vehicle control system through the adjusted voltage signal. Due to the complex road conditions, the driving conditions will change in real time. During the driving process, the vehicle has multiple operation modes of starting, accelerating, cruising and decelerating. Under these operation modes, the vehicle has power demand, and the required power will be provided by the energy management drive system. At the same time, in the process of vehicle braking, the electric energy from the generator flows to the energy storage device of the system through the frequency converter and bidirectional DC/DC converter, thus completing the recovery of BE. At present, most pure electric vehicles studied in China are made by adding motors on the basis of existing models, and the layout of vehicles can not be separated from the original models. Electric vehicles are a complex system that integrates materials, electronics and control, and there are special requirements in many places. The layout should comprehensively consider the performance and parameters of the whole vehicle, the size of parts, the proportion of axle load distribution, braking feedback and other factors. According to the market positioning requirements of Nanyang Automobile and Motorcycle Group and the research and development level at this stage, the vehicles studied in this topic.

## 2.2 Regenerative braking system of electric vehicle

The internal resistance, charge-discharge curve, energy density, power density and cycle life of different energy storage devices have a direct impact on the performance of the hybrid energy storage system of electric vehicles. Therefore, it is necessary to deeply analyze the characteristics of various energy storage devices, understand the relationship between their various characteristics, and find the best hybrid energy storage system structure and matching parameters by comparing the advantages and disadvantages of the performance indicators of each energy storage device, According to the characteristics of the energy storage device and the structure of the system, the optimal energy distribution and control strategy is designed to meet the requirements of the electric vehicle for the energy storage system. According to the structural characteristics and working principle of the AC motor, it can realize the mutual conversion of mechanical energy and electrical energy. It has many advantages: wide range of applications, simple structure, reliable operation, low price, durability and long life. It can widely drive various metal cutting machines, forging machines, casting machines, conveyor belts, poppies, etc. The essence of feedback braking is the auxiliary braking of electric vehicles. The braking system of pure electric vehicles is a combination of electric braking and hydraulic braking, which results in its braking process different from that of traditional gasoline vehicles. The regenerative braking system of electric vehicle is shown in Figure 2.

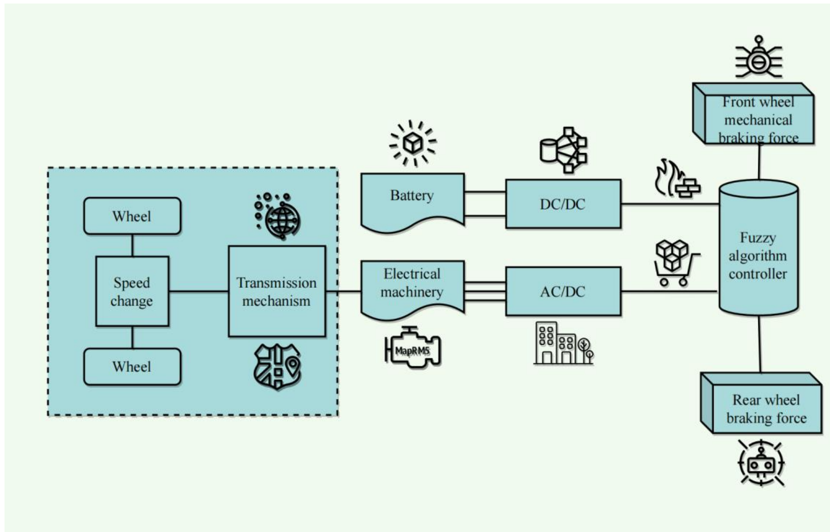


Figure 2. Electric vehicle regenerative braking system

The driver decides the angle and speed of stepping on the brake pedal according to the driving condition of the vehicle. When the angle of the driver stepping on the brake pedal is relatively large, it means that the braking demand of the vehicle is relatively large, and the vehicle needs to stop as soon as possible. At this time, the proportion of mechanical braking force should be increased as much as possible.

The energy drive system is the control system that provides kinetic energy for the motor when the vehicle starts and runs normally, and it is also very important in the regeneration process of BE, which can control the coordinated work of various components to recover energy. In order to give full play to the use value of the motor in the regenerative braking system and maximize the BE recovery, after analysis and consideration of the most efficient operation of the motor and the maximum area of energy conversion, the output of the bidirectional BDC converter is controlled and regulated by the main controller, so that the DC bus voltage is always maintained near the linear area of the motor power generation, which can maximize the efficiency of the motor.

# 3. RESEARCH ON BE FEEDBACK OF INTELLIGENT ELECTRIC VEHICLE BASED ON FUZZY ALGORITHM

## 3.1 Fuzzy algorithm model

The hybrid energy storage system of electric vehicle is connected by different energy storage devices through a specific topology. The connection structure will not only directly affect the performance of each device, but also have a great impact on the formulation of control strategy. Therefore, the connection of system structure is also an important part of system design. The optimal topology of the hybrid structure of supercapacitors and batteries has caused fierce debate, focusing on its flexibility and cost.

The storage battery with this structure is directly connected with the load, and the energy conversion rate is high; Moreover, the supercapacitor can provide instantaneous power for the DC bus through the DC/DC converter, and can recover the energy fed back by braking. Due to the introduction of bidirectional DC/DC converter, the system has greater flexibility in capacity design. However, this structure requires the power converter to have a large output power, and it can not give full play to the advantages of instantaneous large current charging and discharging of supercapacitors. In the motor braking distribution control of pure electric vehicle, it is difficult to calculate its distribution ratio with accurate mathematical expression, but fuzzy control can express the rules that are difficult to express accurately and quantitatively through experimental experience, and at the same time, it can easily reflect the influence of influencing factors on BE recovery.

It is found that the brake pedal can basically experience the braking strength z from 0.1 to 0.7 when rotating at a constant speed under low-intensity braking conditions. The angular displacement of the brake pedal represents the braking strength required by the driver when braking, thus determining the braking force required by the drive shaft. According to different braking conditions, the relationship between brake master cylinder pressure $p_m$ and brake pedal displacement x is as follows:

$$1np_m = -1.542 + 0.1432x \tag{1}$$

During braking, the relationship between the pressure of the master cylinder $p_m$ and the pressure of the wheel cylinder $p_w$ is as follows:

$$\frac{dp_w}{dt} = 36.48(p_m - p_w)^{0.66} \tag{2}$$

When the vehicle does not slip when braking, only the driving axle braking is considered, then the braking force of the brake is reduced to I; The relationship between the braking force in pairs and the brake wheel cylinder pressure is as follows:

$$F_{xbl} = (p_w - p_0)\sum_{i=1}^{2}\frac{\pi D_i^2 R_i}{4r_i}\mu_i \tag{3}$$

Where, $p_0$ is the pressure converted from the static friction of the wheel cylinder, D is the wheel cylinder diameter, I represents each wheel of the front axle, R is the equivalent action radius of braking force, R is the wheel radius, and it is the friction coefficient of the friction pair.

When the car does not slip when braking, there are:

$$\frac{zG(b + zh_g)}{L} = (p_w - p_0)\sum_{i=1}^{2}\frac{\pi D_i^2 R_i}{4r_i}\mu_i \tag{4}$$

From formula (4), we can know the relationship between the angular displacement of the brake pedal and the vehicle braking strength required by the driving axle.

**3.2 Analysis of experimental results**

For traditional fuel vehicles, the design of the brake pedal is completely from the consideration of friction braking, and the depth of the brake pedal is directly proportional to the braking torque. Although the energy feedback braking of electric vehicles can be achieved through different control strategies (maximum regenerative feedback power; maximum regenerative feedback efficiency; constant braking current and constant feedback current), considering that the energy feedback must be used in conjunction with friction braking and should conform to the driver's braking habits, the control strategy of "constant braking current" (the braking current directly corresponds to the braking torque) is mostly adopted. The control object is the motor winding current (braking current). During the braking process, the braking current is always kept to follow the change of the command value, and the braking torque is adjusted. In recent years, it has also been widely used in the simulation analysis of electric vehicles. The software can build various vehicle models, such as concept vehicles, motorcycles, trailers, etc., and can perform static calculation, semi-static calculation and simulation. The calculation items are rich, and users can set different simulation tasks according to their needs. It has online monitoring function and calculation result manager, which can find the simulation data of each step and provide users with rich analysis results.

In view of the diversification of new energy vehicle layout and the complexity of control strategy, through simple modeling methods and advanced modeling concepts, vehicles with various layout forms can be simulated, and control strategies can be studied, optimized and combined. The software divides all parts of the car into discrete modules, and designers can combine them into any car model, such as different types of generators, motors, clutches, wheels, brakes, etc. It is easy to build with or without trailers, single-axle trailers or double-axle trailers, front-drive or rear-drive electric vehicles, parallel, series and series electric vehicles, etc. In the process of energy feedback, the regenerative braking force is converted into current command through the relationship between torque and current. The error between the current and the actual feedback current is adjusted and controlled by PID to control the duty cycle, so as to control the on-off state of

IGBT in the power module. The energy is fed back to the battery through the freewheeling diode, realizing the function of converting mechanical energy into electrical energy and charging the battery.

According to the parameter setting, cycle condition selection and simulation model of pure electric vehicle, the comparison of SOC values of the remaining battery with ADVISOR's own scheme, fuzzy control scheme and improved fuzzy control in this paper is shown in Table 1 and Figure 3, and its energy usage is shown in Table 1.

Table 1. UDDS Cycle Condition Data

| **Worry time /s** | | **Driving distance /km** | | **Speed /(km.h-1)** | |
|---|---|---|---|---|---|
| | | | | **Maximum** | **Average** |
| 1365 | | 11.52 | | 99.85 | 32.25 |
| Acceleration | | Deceleration | | Stop | |
| Maximum | Average | Maximum | Average | Time | Frequency |
| 1.25 | 0.20 | -1.22 | -0.25 | 283 | 17 |

In the result manager of CRUISE software, the change curve of vehicle speed and acceleration under the NEDC cycle condition is shown in Figure 3. It can be seen that the vehicle speed and acceleration curve follow well. The output power and efficiency curve of the motor is shown in Figure 4. It can be seen that the motor works in the high efficiency zone, and the efficiency of the motor is concentrated in 82%~92% most of the time, but it is not greater than the maximum power of the motor during the whole cycle.

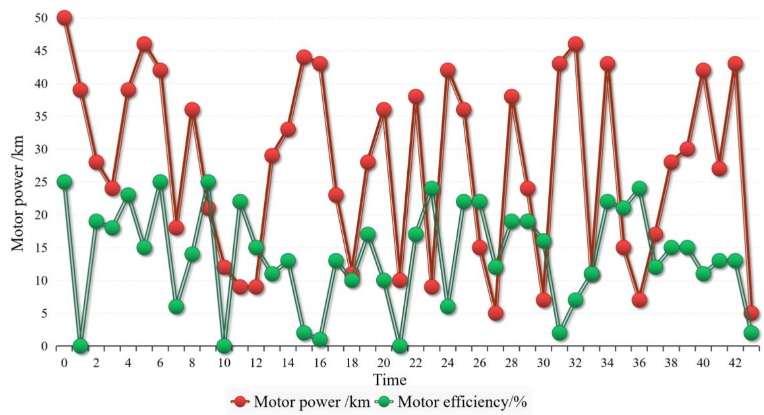


Figure 3. Curve of simulated vehicle speed and acceleration with time

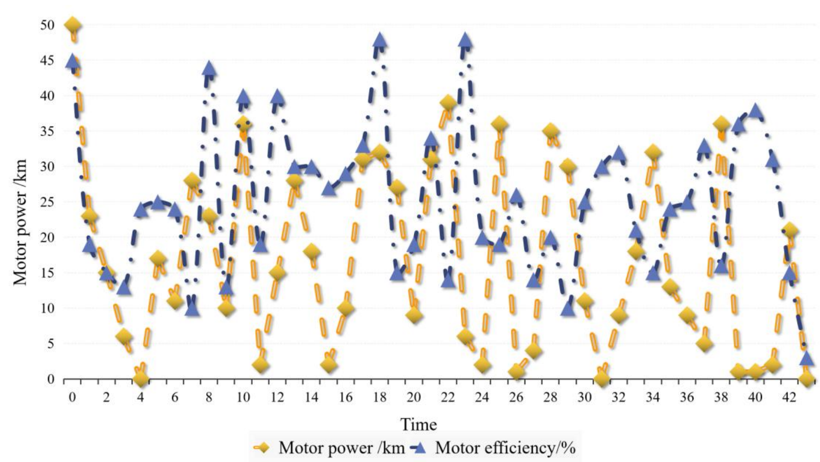


Figure 4. Motor Efficiency and Output Power Curve

The simulation results and their comparative analysis show that the energy feedback efficiency of choosing super capacitor bank is greatly improved compared with choosing battery as power supply when using conventional braking method. Using the new system in this paper, compared with the conventional braking method, the power supply selects the super capacitor bank, which not only reduces the volume and cost of the power supply, but also increases the speed range of energy feedback and improves the energy feedback efficiency. Using the new system proposed in this paper, when the power supply is switched in series and parallel with the super capacitor bank, the speed range that can realize energy feedback is further increased, and the efficiency of energy feedback is improved. It is especially suitable for the BE feedback of the city bus with frequent braking and the occasions where the low speed feedback energy is required.

# 4. CONCLUSION

With the increasing shortage of global energy and environmental pollution, people have increasingly higher requirements for energy conservation and environmental protection. Electric vehicle is one of the ideal models in the future that can meet the requirements of energy conservation and environmental protection at the same time. Governments, academia and industry are increasing their efforts to develop and invest in electric vehicles. The power supply adopts the super capacitor bank, and uses the novel series-parallel switching technology of the super capacitor bank to fully utilize the large current charging and discharging characteristics of the super capacitor bank, high charging and discharging efficiency and the characteristics of maintaining stable performance under fast charging and discharging conditions, which improves the system efficiency and realizes the design of the variable voltage power supply system. According to the characteristics and constraints of regenerative braking of electric vehicles, this paper designs a Sugeno fuzzy controller with braking, vehicle speed, battery SOC and battery pack temperature as inputs and regenerative braking as outputs. The simulation results show that the energy recovery efficiency is effectively improved on the premise of ensuring braking safety, and the effectiveness of the high-efficiency BE recovery control strategy is verified.

## ACKNOWLEDGMENTS

1.Key project of the school-level scientific research project (natural science) of Guangdong University of Science and Technology in 2021: Research on the core technology of electric vehicle feedback braking based on road condition recognition (project number: GKY-2021KYZDK-3)

2. The characteristic innovation project of ordinary colleges and universities in Guangdong Province in 2022: Research on the core technology of electric vehicle feedback braking based on intelligent road condition recognition algorithm (project approval number: 2022KTSCX161)

## REFERENCES

[1] Zhang, L., He, R., Research on multi-mode regenerative BE recovery of electric vehicle with double rotor hub motor. International Journal of Vehicle Design, vol.33, no.8, pp.24 (2020).
[2] Liu, D., Zhu, S. Q., Bi, Y. R., et al., Research on the Utilization of Metro Regenerative Braking Energy Based on an Improved Differential Evolution Algorithm. Journal of Advanced Transportation, vol.11, no.1, pp.4 (2020).
[3] Zhang, L., Research on path tracking of intelligent vehicle based on optimal deviation control. Integrated Ferroelectrics, vol.19, no.8, pp.20 (2018).
[4] Yu, Z., Feng, H., Meng, Y., et al., Braking energy management strategy for electric vehicles based on working condition prediction. AIP Advances, vol.12, no.6, pp.27 (2022).
[5] Ji, F., Pan, Y., Zhou, Y., et al., Energy recovery based on pedal situation for regenerative braking system of electric vehicle. Vehicle System Dynamics, vol.58, no.2, pp.30 (2019).
[6] Singh, K. V., Bansal, H. O., Singh, D., Feed-forward modeling and real-time implementation of an intelligent fuzzy logic-based energy management strategy in a series–parallel hybrid electric vehicle to improve fuel economy. Electrical Engineering, vol.102, no.4, pp.37(2020).
[7] Cui, W., Xu, X. L., Model Research of Vehicle Intelligent Scheduling Problem in Distribution Center Based on Improved Differential Evolution Algorithm. Journal of Interconnection Networks, vol.22, pp.5, pp.68 (2022).

[8] Sepehrzad, R., Moridi, A. R., Hassanzadeh, M. E., et al., Intelligent Energy Management and Multi-Objective Power Distribution Control in Hybrid Micro-grids based on the Advanced Fuzzy-PSO Method. ISA Transactions, vol.22, no.12, pp.44 (2021).
[9] Guo, Q., Zhao, Z., Shen, P., et al., Adaptive optimal control based on driving style recognition for plug- in hybrid electric vehicle. Energy, vol.18, no.5, pp.40 (2019).
[10] Zhang, R., Tao, J., Zhou, H., Fuzzy Optimal Energy Management for Fuel Cell and Supercapacitor Systems Using Neural Network Based Driving Pattern Recognition. IEEE Transactions on Fuzzy Systems, vol.55, no.9, pp.30 (2018).