2021-01-0783 Published 06 Apr 2021

Energy-Efficient Braking Torque Distribution Strategy of Rear-Axle Drive Commercial EV Based on Fuzzy Neural Network

Guoxue Ge, Tao Wang, and Yiheng Lv Nanjing University of Science & Technology

Xiaojun Zou, Wei Song, and Guofang Zhang Nanjing Iveco Automobile Co., Ltd.

Citation: Ge, G., Wang, T., Lv, Y., Zou, X. et al., "Energy-Efficient Braking Torque Distribution Strategy of Rear-Axle Drive Commercial EV Based on Fuzzy Neural Network," *SAE Int. J. Advances & Curr. Prac. in Mobility* 3(4):2136-2145, 2021, doi:10.4271/2021-01-0783.

This article was presented at the WCX World Congress Experience Digital Summit, April 13-15, 2021.

Abstract

Regenerative braking is identified as an essential step toward extending cruising mileage for electric vehicle (EV). Braking energy recovery strategies usually focus on passenger EV and commercial EV is ignored. In this paper, an energy-efficient braking torque distribution strategy is proposed for a rear-axle drive commercial EV to improve braking energy recovery and safety. Firstly, the braking force distribution curve is determined referring to the EU braking law for commercial vehicle and the ideal braking distribution curve. Secondly, a novel braking torque distribution strategy is established adopting fuzzy control algorithm, where the ratio between hydraulic braking torque and regenerative braking torque is updated instantaneously according to vehicle velocity, braking strength and state of charge of battery. Then, the corresponding controller is synthesized on ideal braking condition and several classic cycles. To further enhance the performance of the controller, a neural network based framework is established to optimize the membership function in fuzzy controller. Simulations on ideal braking condition demonstrate the controller can always meet emergency braking needs. For the standard cycles, including NEDC and WLTC, the energy-efficient strategy based on fuzzy control can recover up to 18.88% and 16.56% of energy under NEDC and WLTC cycles, and on this basis, the optimized strategy based on adaptive neuro-fuzzy control can improve energy recovery by 2.84% and 3.6% under these two cycles. The developed braking torque distribution strategy can potentially be embedded in real-time supervisory systems to realize the energy saving and increase the cruising mileage for commercial EV.

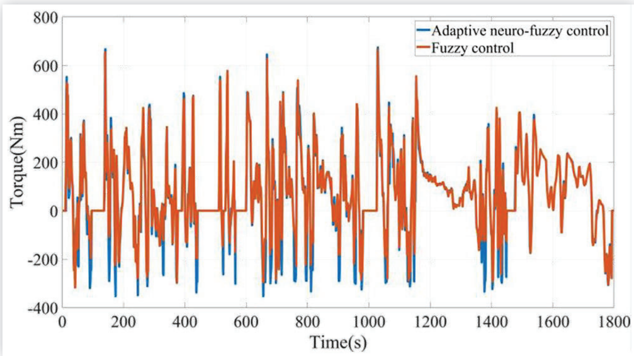
Introduction

With the rapid development of the automobile industry, the energy crisis and environmental degradation have become two major problems that plague the world today. The vigorous development of pure electric vehicles has become a solution to the problem, and it is also a trend of current automobile development. When a pure electric vehicle is running, the motor can not only be used as an electric motor to provide power, but also as a generator during braking. It can also charge the battery while generating braking torque, thereby increasing the driving range of the pure electric vehicle and reducing the brake wear [1, 2].

When a pure electric vehicle recovers braking energy, it will cause changes in the braking force distribution of the front and rear axles, and changes in the distribution of hydraulic braking force and regenerative braking force. On the premise of ensuring that the braking performance is not affected, how to maximize the recovery of braking energy under the premise of ensuring braking safety and stability has become the research of regenerative braking key points and difficulties [3]. At present, compound braking is mainly divided into series and parallel. Because the parallel braking energy recovery strategy is relatively simple and low in cost, the current mass-produced pure electric vehicle braking energy recovery strategy mostly adopts the parallel strategy. Parallel braking is the superposition of hydraulic braking and regenerative braking, and the braking force is generated at the same time, without affecting each other, the braking energy recovery effect of the motor is not ideal [4]. Gong, X., et al. studied the braking force distribution of pure electric cars based on braking stability requirements and ECE braking regulations. While ensuring braking stability, it also significantly improved the braking energy recovery of the vehicle [5]. Based on the characteristics of the electric compound braking system of electric commercial vehicles, a best-feeling braking control strategy has been proposed, which greatly improves the economy of the vehicle while ensuring the braking feeling [6]. A self-learning strategy using the braking habits of the driver was proposed and by Di Zhu and Ewan Pritchard. The self-learning strategy records the brake pedal travel and analyzes the braking habits of the driver. The strategy involves several iterations to adapt to the particular driver and provides the maximum available torque when the driver brakes to a maximum [7].

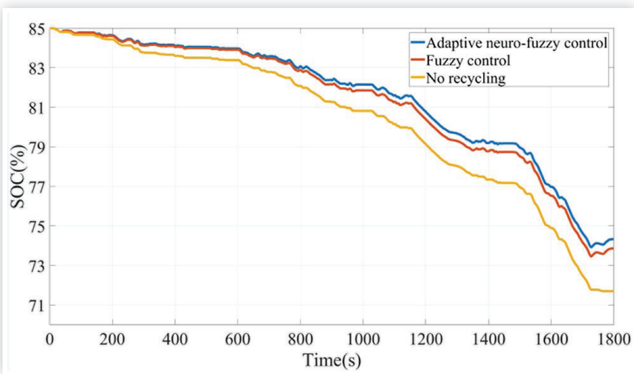
The rear-axle drive commercial EV studied in this paper is an electric vehicle for urban transportation, so good

FIGURE 18 Motor torque curve before and after optimization.



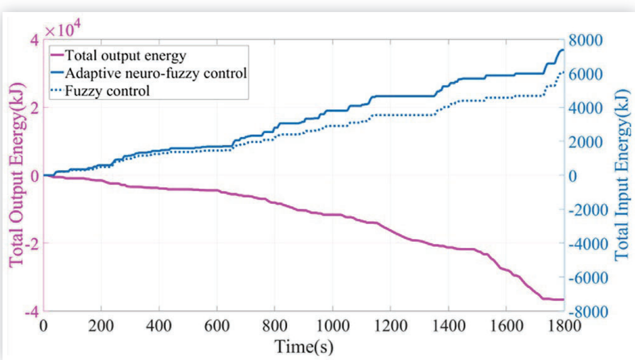
© SAE International.

FIGURE 19 SOC comparison curve.



© SAE International.

FIGURE 20 Energy consumption and recovery curve.



© SAE International.

10.67%; the SOC of the fuzzy control is reduced from 85% to 73.86%, which is a decrease of 11.14%; the SOC of no recycling is reduced from 85% to 71.68%, which is a decrease of 13.32%. The simulation results of WLTC cycle conditions are shown in Table 6.

In Tables 5 and Table 6, the effective energy recovery rate is equal to the recovered energy divided by the energy consumed by the vehicle. It can be seen from the comparison that both of the two control strategies in this paper have good effect of braking energy recovery, and the control strategy based on neural network optimization is compared with the fuzzy control strategy

TABLE 6 WLTC cycle simulation results.

	Fuzzy control	Adaptive neuro-fuzzy control	Increase(%)
Total energy consumption (kJ)	36597.73	36597.73	
Recovery of braking energy (kJ)	6059.14	7376.45	21.74%
Effective energy recovery rate (%)	16.56%	20.16%	3.60%

© SAE International.

under NEDC and WLTC cycle conditions, the effective energy recovery rate has increased by 2.84% and 3.60%, the correctness of the braking control strategy can be verified and the optimization has a certain effect.

Conclusion

This paper researches a rear-axle drive commercial EV. The front and rear axle braking force distribution is performed according to the I curve and the ECE curve to ensure the braking stability and braking efficiency of the vehicle. At the same time, considering the constraints of the motor and the battery, we use fuzzy control to redistribute the braking force of the rear axle, and then use the neural network to optimize the fuzzy controller to get the energy-efficient braking torque distribution strategy of rear-axle drive commercial EV based on fuzzy neural network, and maximizes the recovery of regenerative braking energy.

The control strategy studied in this paper has verified the feasibility of the control strategy through the joint simulation of CRUISE and SIMULINK. First, under typical braking conditions, the safety of the strategy and the effectiveness of energy recovery are verified, the braking time and braking distance of the vehicle have been reduced after optimization, and the efficiency of braking energy recovery has been improved. The NEDC and WLTC simulation results show that the torque distribution strategy proposed in the paper can effectively recover braking energy, and the use of neural network for optimization improves the energy recovery rate of the strategy, which verifies the performance of this strategy.

It is worth noting that a necessary step toward practical application of the novel braking torque distribution strategy based on fuzzy neural network is to conduct simulation in a real vehicle environment. Thus, safety of the strategy and actual effect of braking energy recovery will be validated and simulated in the future work.

References

1. Zhang, L., Liang, L., Cheng, L., Chong, W. et al., “Coaxial-Coupling Traction Control for a Four-Wheel-Independent-Drive Electric Vehicle on a Complex Road,” *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 228(12):1398–1414, October 2014, doi:https://doi.org/10.1177/0954407014529941.

2. Maeda, K., Fujimoto, H., and Hori, Y., "Four-Wheel Driving-Force Distribution Method Based on Driving Stiffness and Slip Ratio Estimation for Electric Vehicle with In-Wheel Motors," in *2012 IEEE Vehicle Power and Propulsion Conference, VPPC 2012,* pp. 1286–1291, doi:https://doi.org/10.1109/VPPC.2012.6422490.
3. Wen, Y. and Niu, Z., "Research on Regenerative Energy Recovery Control of Pure Electric Logistics Vehicle," *Computer Simulation* 35(1):136–140, 213, 2018, doi:10.3969/j.issn.1006-9348.2018.01.029.
4. Chu, L., He, Q., Fu, Z., Liu, Z., and Pan, Y., "Research on Regenerative Braking Control Strategy for Pure Electric Vehicles," *Chinese Journal of Automotive Engineering* 6(4):2095–1469, 244–251, 2016, doi:10.3969/j.issn.2095-1469.2016.04.02.
5. Gong, X., Zhang, L., and Ma, J., "Braking Force Distribution of Electric Vehicles Based on Braking Stability," *Journal of Chang' an University (Natural Science Edition)* 34(1), Xi'an Highway University: 103-8, doi:10.3969/j.issn.1671-8879.2014.01.017.
6. Xu, S., Tang, Z., Wang, D., and Zhao, X., "Series Braking Control Strategy for Electric Commercial Vehicles," *Journal of Gansu Agricultural University* 51(4):1003–4315, 113–120, 2016, doi:10.3969/j.issn.1003-4315.2016.04.018.
7. Zhu, D. and Ewan, P., "NCSU Year Three Final Technical Report," SAE Technical Paper 2014-01-2907, 2014. https://doi.org/10.4271/2014-01-2907.
8. Zhang, L., Yu, L., Pan, N., Zhang, Y. et al., "Cooperative Control of Regenerative Braking and Friction Braking in the Transient Process of Anti-Lock Braking Activation in Electric Vehicles," *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 230(11):1459–1476, September 2016, doi:https://doi.org/10.1177/0954407015613193.
9. Zhang, H., Wei, H., Lu, X., and Xu, S., "Design and Research on Hydraulic Control Unit for a Novel Integrated-Electro-Hydraulic Braking System," in *2016 IEEE Transportation Electrification Conference and Expo, Asia-Pacific, ITEC Asia-Pacific 2016*, 139–144, Institute of Electrical and Electronics Engineers Inc., doi:10.1109/ITEC-AP.2016.7512937.
10. Xin, Y., Zhang, T., Zhang, H. et al., "Fuzzy Logic Optimization of Composite Brake Control Strategy for Load-Isolated Electric Bus," Mathematical Problems in Engineering, 2019, Hindawi Limited, doi:10.1155/2019/9735368.
11. Wang, Q., Sun, Y., and Huang, Y., "Research on the Control Strategy of Hybrid Energy Storage for Hybrid Electric Vehicles Based on Grid Partition and Adaptive Fuzzy Neural Network," *Applied Mechanics and Materials* 448–453:3123–3128, doi:10.4028/www.scientific.net/AMM.448-453.3123.
12. Wai, R., Chen, M., and Liu, Y., "Design of Adaptive Control and Fuzzy Neural Network Control for Single-Stage Boost Inverter," *IEEE Transactions on Industrial Electronics* 62(9), Institute of Electrical and Electronics Engineers Inc., 5434–45, doi:10.1109/TIE.2015.2408571.
13. Qiao, J., Ying, H., Zhang, L., and Han, H., "Adaptive Fuzzy Neural Network Control of Wastewater Treatment Process with Multi objective Operation," *Neuro Computing* 275, (January), Elsevier B.V., 383–93, doi:10.1016/j.neucom.2017.08.059.

Contact Information

Guoxue Ge
Master Candidate., School of Mechanical Engineering
Nanjing University of Science & Technology
geguoxue@njust.edu.cn
+86-158-9589-2821.