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ENERGY SANVING ORIENTED TORQUE OPTIMAL DISTRIBUTION STRATEGY OF ONLINE SELF-LEARNING SEARCHING FOR FULL WHEEL DRIVEN ELECTRIC CAR

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ABSTRACT

Developing electric vehicles has become a common solution for the energy security problem and air pollution. In the field of electric vehicles, distributed drive is considered to be one of the cutting-edge technologies. It has advantages of flexible control, fast response and has shown great potential in terms of dynamic performance and energy saving, at the same time it has also brought some hotspot problems, such as torque distribution between drive wheels and dynamic control of each drive wheel. This research focuses on energy efficiency and dynamic response optimization of distributed drive electric vehicles.

In terms of optimizing energy efficiency, most of existing researches for torque distribution are based on models, which means the control algorithm needs either accurate models of target vehicle or large quantities of calibration data. In this research, a torque distribution method based on golden ratio search algorithm is adopted, which can realize optimized torque distribution between front and rear axles while don't need any target models. However, the main problem of this method is torque ripple in the process of searching. In order to solve this problem, an automatic calibration method of optimized torque distribution is proposed, which can solve the torque ripple problem successfully. After that, optimized torque distribution between four wheels when vehicle is turning is also studied, and its energy saving potential comparing with front and rear axle torque distribution method is analyzed.

A joint simulation platform between Matlab/Simulink and Carsim has been set up to verify the function of automatic calibration method of optimized torque distribution. Results show that with the proposed torque distribution method, up to 12.5% of energy can be saved in NEDC cycle and 7.4% of energy can be saved in China's typical cycle of city passenger cars.

To further verify the feasibility of the proposed torque control methods in real application, two kinds of HIL (hardware in the loop) simulation platforms are set up. One is based on Matlab xPC platform, the other is based on communication between two controllers. With automatic code generation technology, algorithm models in Simulink are translated into executable code and downloaded to KPV13 rapid prototyping controller. The controller is tested in both of the two HIL simulation platforms. Results show that operation and communication speed of real control systems can satisfy the requirement of real-time search algorithm, the proposed control method can be applied in real control systems.

Keywords: distributed electric driving; on-board searching method; torque optimal split; traction motor efficiency model; co-simulation

1. INTRODUCTION

At present, the Chinese automotive industry is faced with great challenges, developing new energy vehicles has been updated as state strategy[1-6]. As the largest automotive output and sale country in the world, Chinese industry is facing the challenges of energy security, urban air pollution from tailpipes, and backward core technologies. Developing electric vehicles (EVs) is assigned as an optimal technological route for solving the aforementioned problems. The Chinese government vigorously promotes EV technology advances and industry development by launching state projects, issuing fiscal subsidy policies and other comprehensive supporting policies, initiating demonstration programs and increasing infrastructure construction.

The optimal distribution of torque for drive electric vehicles is mainly concentrated in two aspects, one is based on the target of the stability control optimization, the other is based on the torque distribution of optimal energy efficiency. For the torque distribution of optimal energy efficiency, some of the existing studies suggest that the four-wheel torque average distribution mode is optimal for energy efficiency. Yuan and Wang et al.[7] derive the analytical expressions of the power loss characteristics of electric motor drives. The conclusion is that a 50:50 front-to-rear wheel torque distribution should be the most efficient solution for the case of identical drivetrains on the two axles. J. KIM et al. [8] investigated a optimal power distribution of the front and rear motors for minimizing energy consumption of a 4WD EV. The optimal torque distribution maps of the front and rear motors can be obtained for all vehicle driving force and velocity ranges. In Ref. [9], a novel operation strategy for electric vehicles with axle-individual electric machines to improve their energy efficiency is proposed and the control policy is indirectly confirmed by the experimental tests. Similarly, the approach in [10] is generating the requested torque for a wheel-individually propelled BEV either by the two front or all four EMs. Another part of the studies suggest that the use of uniaxial drive energy efficiency is optimal when the total torque requirements in a lower case. Rongrong Wang et al. [11] proposed a torque distribution method to show the potentials of optimizing the FIAIWM EGV operational energy efficiency by utilizing the actuation flexibility and the characterized in-wheel motor efficiency and torque response The preceding results show that by appropriately utilizing the actuation flexibility of the FIAIWM EGV and distributing the torque among the four in-wheel motors with respect to their energy efficiency characteristics, the battery power in the driving and regenerative braking modes can be either reduced or increased in comparison with the cases of equally distributed torque. Chen et al. [12, 13] based on motor efficiency characteristics maps, believe that the optimal torque allocation strategy should be switched between the four-wheel average distribution mode and the two-wheel mode: when the total torque demand is low, the two front wheels or two rear wheels output torque, the other two motors do not work; when the total torque demand is high, the torque of the four wheels is distributed evenly. The above studies are based on the mathematical model of the motor or the motor efficiency characteristic diagram has known and applies only to the same configuration between front and rear axles. However, it does not adapt to configurations where the front and rear axle motors are not consistent, which configuration has a great potential for development. For the configuration of front and rear axle motors are not consistent, the combination of high-speed motor and low-speed motor can ensure the driving ability at the same time broadening the motor-driven integrated high efficiency area; from the point of view of space arrangement, due to the existence of the steering system, the existing car front axle space is generally more compact than the rear axle space, so the front axle suitable for the layout of small motor, rear axle suitable for large motor. Hiroshi Fujimoto et al. [14, 15] through theoretical deduction and gold proportion search algorithm, estimated the influence of yaw torque for vehicle side slip angle. When the car is bent, the yaw torque is added to the car by assigning the torque between the two rear drive wheels. The front wheel steering angle can be reduced while maintaining the running path of the vehicle, thereby reducing the running resistance. Arash M. et al. [16] formulated the optimal torque distribution as the solution of a parametric optimization problem, depending on the vehicle speed. And provided an analytical solution for the case of equal drivetrains, under the experimentally confirmed hypothesis that the drivetrain power losses are strictly monotonically increasing with the torque demand. Song ZY. et al. [17] proposed a fuzzy logic torque control system to suppress the oscillation in the driveline. Simulation results demonstrate the effectiveness and robustness of the proposed control system. S. KO et al. [18] proposed a cooperative control algorithm for an in-wheel motor and an electric booster brake to improve the stability of an in-wheel electric vehicle. Through a hardware-in-the-loop simulation, the braking time was shorter 1.9 s than the anti-lock braking system (ABS) braking.

Through the above analysis we can see that most of the studies are based on the model algorithm to achieve optimal torque distribution, or the average distribution of the torque distribution method to achieve optimal torque distribution. The disadvantage of based on the model algorithm to achieve optimal torque distribution is that it is necessary to obtain a large number of control items in the efficiency of the test data to establish the calibration model, usually only consider the efficiency of the motor itself with the conditions of change, while ignoring the inverter and other components of the efficiency of change characteristics. In addition, the existing research is mainly aimed at matching the same motor to drive the electric drive. Through the literature review, we can see that there is little research on the optimization strategy of electric vehicle torque optimization for front and rear axles matching different motors. The electric drive is the main part of the driving condition, so the driving efficiency optimization algorithm under the condition is the main research content. In this paper, a torque distribution method based on golden ratio search algorithm is adopted, which can realize optimized torque distribution between front and rear axles while don't need any target models. An automatic calibration method of optimized torque distribution is proposed, which can solve the torque ripple problem successfully. After that, optimized torque distribution between four wheels when vehicle is turning is also studied, and its energy saving potential comparing with front and method of rear axle torque distribution is analyzed.

This paper is organized as follows. In Section 2, we analyze feasibility of search algorithm. In Section 3, the effectiveness of the optimization control method is verified. In Section 4, we present Self-studying ability. In Section 5, the energy efficiency of the driving system is analyzed.

2. THE FEASIBLITY OF ONLINE SEARCHING METHOD

2.1 Overview of golden section search method

2.2 The construction of electric full wheel driven powertrain and the control theory

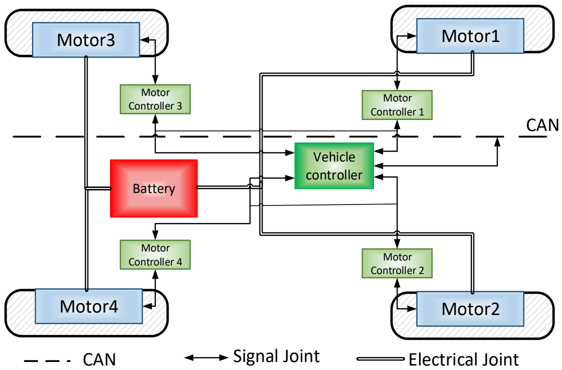

Fig.1 The configuration of four wheel driving electric vehicle

2.3 The verification of convex characteristic for electric driving system

3. ALGORITHM VALIDATION

3.1 physical models of full wheel electric powertrain

3.1.1 Vehicle model

3.1.2 Traction battery model

3.1.3 Electric motor model

3.2 Co-simulation model

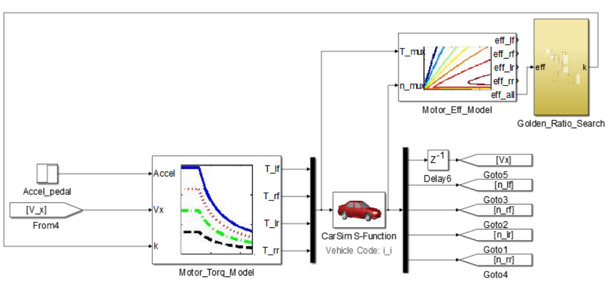

Fig.2 The diagram of the co-simulation model

3.3 Simulation results

4. THE SELF-LEARNING METHOD

4.1 The concept of self-learning method

4.2 Initial validation of self-learning method

4.2.1 The verification of stability of the algorithm

4.2.2 The verification of real time of the algorithm

5. ENERGY EFFICIENCY ANALYSIS

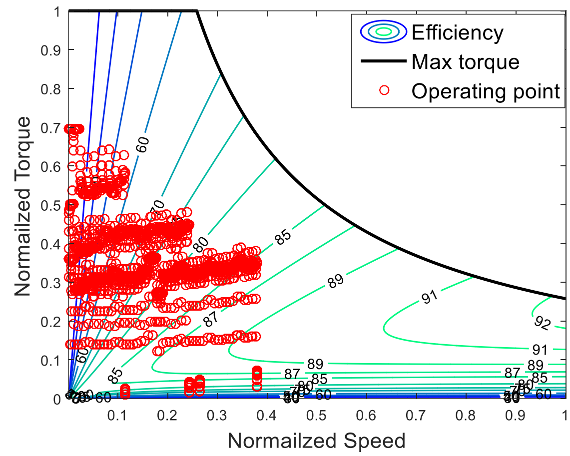

Fig.3 The operation point distribution of front wheel

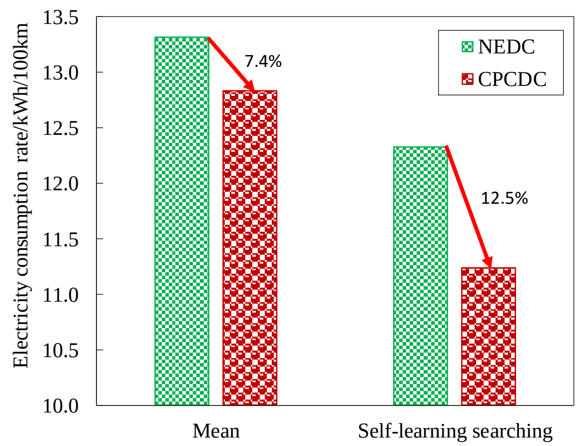

Fig.4 The energy saving effect by self-learning searching method

6. CONCLUSIONS

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