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Research on Motor Speed Control Method Based on the Prevention of Vehicle Rollover

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Abstract: Vehicle driving safety is an important performance indicator for vehicles, and there is still much room for development in the active safety control of electric vehicles. Vehicles are susceptible to rollover when making sharp turns or overtaking at high speed. In order to improve the anti-rollover stability of electric vehicles (EV), this study proposes a real-time motor control strategy, mainly according to the acquisition of vehicle attitude data and real-time monitoring of the vehicle's operating state. The lateral load transfer rate was defined as the vehicle rollover evaluation index. When the real-time rollover indicator exceeded the limit safety threshold this article set, the motor speed would be reduced through active control to avoid rollover or reduce the risk of rollover. Both simulation results in Carsim and Simulink showed that the motor control strategy is highly reliable and real-time capable, and the active safety of EV was improved significantly.

Keywords: electric vehicle (EV); active rollover prevention; motor control; active safety

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1. Introduction

The safety of a vehicle on the road is an important performance indicator in the evaluation of vehicle performance. Vehicle rollover caused many serious safety accidents. Statistics from the National Highway Traffic Safety Administration (NHTSA) for 2019 showed that rollover crashes cause approximately 20% of all traffic fatalities [1].

At present, many research institutions domestic and overseas are conducting research on vehicle rollover. Rajamani and Piyabongkarn proposed an active steering reverse control algorithm to generate a reverse roll angle when the vehicle enters a curve, thereby improving the vehicle's anti-rollover capability [2]. Bai Tianyu used active steering technology to change the steering angle of the steering wheels, which effectively reduced the lateral acceleration of the vehicle and improved the anti-rollover capability of the vehicle [3]. Zhang used active pulse steering at the rear wheels to improve vehicle rollover stability [4]. Ghazali used model predictive control to solve multi-objective constrained optimization problems and designed an integrated control for active steering anti-rollover and path tracking [5]. Liu Meng combined differential braking technology and fuzzy PID control technology to control the rollover stability of a bus [6]. The simulation results under different operating conditions showed that the established anti-roll control system could significantly improve the driving attitude of the vehicle and make it less possible to roll over. Chen Lijing verified the effect of active suspension on vehicle rollover under different turning radii, different driving surfaces and emergency situations [7]. Yang Yi conducted a study on the anti-roll control of semi-active suspension vehicles, focusing on online identification of vehicle roll center, description of roll stability and its real-time prediction, and optimized control of semi-active suspension anti-roll [8]. Vu used active anti-roll bars as actuators to improve the roll stability of heavy vehicles [9]. Odenthal used a combination of steering and braking control to avoid rollover [10]. Shim and Ghike summarized four basic approaches commonly used for anti-rollover control: active steering, differential braking, active lateral stabilizer bar and active/semi-active suspension [11]. In the past, researchers have mostly concentrated on these four methods to control vehicle rollover. The above methods have a lot of research basis, and they all have their own characteristics and advantages, but there are still some shortcomings. Active steering technology can easily affect the directional control, causing the driver to deviate from the target route. It cannot be used for emergency obstacle avoidance, and there is still a certain risk factor. Differential braking technology is easily affected by road adhesion coefficient and brake performance, and high-speed braking is prone to dangers such as wheel locking. The real-time performance of active suspension technology is not high, and the delay is relatively obvious. Active stabilizer bars are mostly used to control the roll degree of vehicles while driving, and the control ability is not high in rollovers.

At the same time, there are not many related research studies on the rollover stability of electric vehicles at this stage, and the little existing research on electric vehicles is mostly focused on the control of in-wheel motors. Yuan Lin can predict the rollover risk of electric vehicles by establishing a predictive model to independently control the torque of the four in-wheel motors [12]. Ma Bin prevents electric vehicles from rolling over by actively adjusting the yaw moment control [13]. Liu designed a new type of chassis and proposed an improved anti-rollover system to effectively enhance the stability of electric vehicles [14]. Since in-wheel motors are relatively expensive, they have not been widely used in electric vehicles at this stage, and some existing electric vehicle rollover warning and control strategies are relatively complex or have high practical costs, so they are not easy to apply in practice. Therefore, based on the commonly used electric vehicles with centralized drive motors, this paper conducts research on rollover stability.

To sum up, most research institutions focus on the rollover research in static rollover, and relatively little research has been carried out on dynamic rollover issues. It is common that rollovers occurred at high speeds or under extreme working conditions. Fatal rollover crashes are more often speed-related than fatal non-rollover crashes. Approximately 40 percent of fatal rollover accidents were related to speeding. In addition, fatal rollovers occurred where the speed limit was 55 miles per hour or higher. The rollover that occurs when the car is driving dynamically can be divided into two categories [15]: one is the trip-type rollover, which occurs when the car encounters a curb or an obstacle. It is difficult to express the process of such rollover with a mathematical model for this category. The other type of rollover is the non-tripping type, when the car's steering wheel is turned substantially while the car is driving at high speed or at the limit of service, thus causing the lateral acceleration of the car to exceed the safety threshold while driving, and at the same time, the vertical reaction force on one side of the wheel is zero [16]. Emergency obstacle avoidance on highly adherent roads is a typical condition that leads to non-tripping rollover, when active safety control should ensure vehicle rollover stability [17,18]. The core of rollover control is rollover warning and anti-rollover control [19].

While for electric vehicles, where the vehicle speed was determined by the drive motor, control strategies to prevent vehicle rollover directly by controlling the drive motor speed have been less addressed in research. It is of great research significance for the development of today's electric vehicle industry to achieve the purpose of improving the active safety of electric vehicles through motor control strategies, improving the instability factors arising from the body structure of electric vehicles and improving the performance of electric vehicles.

This paper proposes a generic real-time motor control strategy to prevent vehicle non-tripped accidents at high speeds or under extreme operating conditions by controlling the speed of the electric vehicle drive motor. In this study, permanent magnet synchronous motors are chosen as the drive motors for vehicles. A high-performance field-oriented control (FOC) motor drive is used to steadily and effectively slow down the vehicle speed, reducing the generation of vehicle rollover from the root cause and effectively preventing the dangerous level of rollover accidents. Six-axis attitude sensors are used to provide real-time vehicle driving status to the main control chip, and speed sensors are used to give closed-loop feedback to the motor controller for speed control. The control strategy in this paper is safer and more reliable; it will not be affected by the adhesion coefficient and braking performance. The real-time control is better and more universal.

In this paper, a three-degree-of-freedom vehicle dynamics model is established accurately, a rollover evaluation index and a safety threshold are selected quickly, and the working principle and detailed control scheme of the motor speed control strategy are given. A joint simulation of the proposed system is carried out using Carsim and Simulink, and the results of suppressing rollover are given to verify the effectiveness and performance of the proposed strategy.

2. Roll Dynamic Model

To achieve active rollover control of the vehicle, a three-degree-of-freedom rollover dynamics model of the electric vehicle including lateral, yaw and roll was developed, as shown in Figure 1.

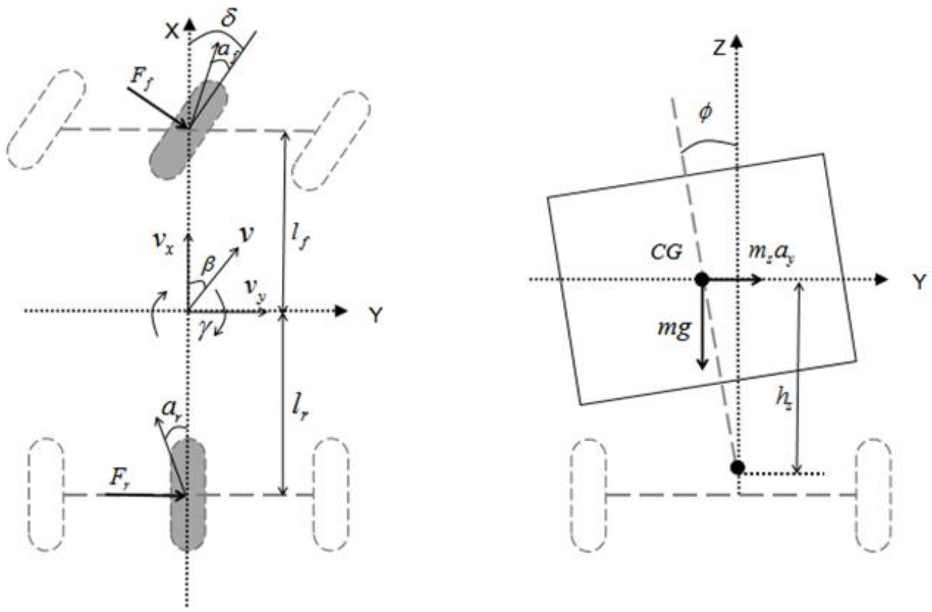

Figure 1. Three-degree-of-freedom rollover dynamics model.

In order to make the model easy to solve, the following simplification of the vehicle dynamics characteristics is required [20] (p. 10).

(1) The kinematics of the left and right wheels of the model are symmetrical about the X-axis.
(2) The model ignores motion in the Z-axis direction and motion around the Y-axis.
(3) The model ignores changes in tire characteristics due to changes in load and the effect of tire return moments.
(4) The model ignores the non-linearity of the suspension and tires that interferes with the rollover of electric vehicles.
(5) The model ignores the effect of different front and rear axle characteristics and unsprung mass on the rollover characteristics of the vehicle.
(6) The model ignores aerodynamic forces.

According to D'Alembert's principle, the motion of the above model is as follows.

Lateral motion:

$$ma_y - m_s h_s \ddot{\phi} = 2(F_f + F_r) \tag{1}$$

Yaw motion:

$$I_z \dot{\gamma} = 2\left(l_f F_f - l_r F_r\right) \tag{2}$$

Roll motion:

$$I_x \ddot{\phi} - m h_s a_y = m g h_s - c \ddot{\phi} - k_s \phi \quad (3)$$

where the lateral acceleration of the whole vehicle center of mass is:

$$a_y = \dot{v} + u \dot{\gamma} \quad (4)$$

and

$$F_f = k_f \alpha_f \quad (5)$$

$$F_r = k_r \alpha_r \quad (6)$$

$$\alpha_f = \beta + \frac{l_f}{v_x}\gamma - \delta \quad (7)$$

$$\alpha_r = \beta - \frac{l_r}{v_x}\gamma \quad (8)$$

In the above equation. m is the overall vehicle mass; a_y is the vehicle center of mass lateral acceleration; m_s is the sprung mass; h_s is the distance from the center of mass to the center of lateral inclination; φ is the roll angle; F_f is the lateral force of the front wheel; F_r is the lateral force of the rear wheel; I_z is the inertia of the spring loaded mass about the Z-axis; γ is the yaw angular velocity; l_f is the distance from the front axis to the center of mass; l_r is the distance from the rear axis to the center of mass; I_x is the rotational inertia of the spring-loaded mass about the X-axis past the center of lateral tilt; g is the acceleration of gravity; c is the is the suspension damping factor; k_s is the suspension torsional stiffness; v is the lateral vehicle speed; and u is the longitudinal vehicle speed.k_f is the front wheel lateral deflection stiffness and k_r is the rear wheel lateral deflection stiffness; α_f is the front wheel slip angle; α_r is the slip angle of rear wheel; β is the angle between v and the x-axis; v_x is the component of v on the x-axis; and δ is the angle between the front wheel and the x-axis.

3. Vehicle Rollover Evaluation Indicator

Accurate and real-time rollover indices are essential to prevent vehicle rollover. A dynamic indicator can show the transient nature and response of the vehicle state. Current indicators, which are used for rollover determination, are usually maximum rollover angle, lateral acceleration and lateral load transfer rate. As the lateral load transfer rate is simple and portable, the threshold value was not restricted by the vehicle model, and the generality has good performance, and has been shown to have better real-time warning performance as a rollover indicator, it is used as the rollover indicator of the control algorithm.

The conventional lateral load transfer rate (*LTR*) is defined as the ratio of the difference between the vertical loads of the left and right wheels compared to their sum and is a dimensionless indicator. This indicator is simple, portable and has good generality, as the threshold is not limited by the vehicle type, and it has been shown to have good real-time warning performance as a rollover indicator [21,22]. So, it is used as the rollover indicator in the control algorithm [23].

$$LTR = \frac{F_l - F_r}{F_l + F_r} \quad (9)$$

where: F_l is the sum of the vertical loads on the left-hand wheel and F_r is the sum of the vertical loads on the right-hand wheel.

The value of *LTR* ranges from -1 to 1. When *LTR* = -1 or 1, it means that all the wheels on the left or right side of the vehicle are off the ground. It is difficult to obtain tire loads directly from sensors in real time and with accuracy. According to the literature, the following equation is proposed for the calculation of the dynamic lateral load transfer rate, which is the moment balance equation containing the vertical tire force and the suspension lateral sway moment [20] (p. 11).

$$-F_r\frac{T}{2}+F_l\frac{T}{2}-k_s\varphi-c\omega=0 \tag{10}$$

From Equations (9) and (10), the dynamic lateral load transfer rate expression is obtained as

$$LTR=-\frac{2(c\omega+k_s\varphi)}{mgT} \tag{11}$$

where m is the vehicle mass, T is the wheelbase, g is the gravitational acceleration, c is the suspension equivalent damping factor, k_s is the suspension lateral sway stiffness, ϕ is the lateral sway angle and ω is the lateral sway angular velocity [24].

The resulting calculated lateral load transfer rate was related to the vehicle's real-time dynamic parameters, allowing for improved real-time performance. When the vehicle parameters were determined, the dynamic lateral load transfer rate at that moment can be found by simply obtaining the rollover angle and rollover velocity for each sampling instantly. When LTR = ±1, it means that the wheel on one side of the vehicle leaves the road surface in this instantaneous state. In theory, the moment when one side of the wheel leaves the ground is generally called the rollover critical point; that is, the moment when $|LTR|$ = 1. In fact, due to the driving inertia, an unavoidable rollover accident will occur in most vehicles once one wheel leaves the ground at high speed. Therefore, from the perspective of this practical application, this design cannot integrate the active control of the anti-rollover system. The safety threshold is set to the rollover critical value ±1. At this time, it is difficult to avoid accidents with active control. For the selection of the safety threshold, most of the research literature using LTR for rollover control select the LTR value with a 20% safety margin reserved; that is, $|LTR_{\max}| = 0.8$.

4. Control Principle of PMSM

The basic idea of FOC is similar to the control method of a DC motor for control, based on linear transformation and the principle of constant magneto-dynamic potential and power before and after transformation [25]. The mathematical model in a, b and c-phase stationary coordinates is transformed into a model of the a-b two-phase stationary coordinate system by means of the Clarke transformation, and then the model of the a-b two-phase stationary coordinate system is transformed into a model of the d-q two-phase rotating coordinate system by means of the park transformation. Under the $\alpha-\beta/d-q$ conversion, the stator current vector is decomposed into two tributary components i_d and i_q (where i_d is the excitation current component and i_q is the torque current component) oriented according to the rotor magnetic field and controlled separately, control i_d being equivalent to control of flux and control i_q to control of torque.

The voltage equation for a permanent magnet synchronous motor can be expressed as:

$$u_d=Ri_d+\frac{d\psi_d}{dt}-\omega_r\psi_q \tag{12}$$

$$u_q=Ri_q+\frac{d\psi_q}{dt}+\omega_r\psi_d \tag{13}$$

$$\psi_d=L_di_d+\psi_f \tag{14}$$

$$\psi_q=L_qi_q \tag{15}$$

$$T_e=\frac{3}{2}kp(\psi_di_q-\psi_qi_d)=\frac{3}{2}kpi_q\left[\psi_f+(L_d-L_q)i_d\right] \tag{16}$$

where u_d, u_q, i_d, i_q, ψ_d, ψ_q, is the voltage, current and stator magnetic chain on the d and q axes, L_d and L_q is the stator inductance on the d and q axes; ψ_f is the magnetic chain of the permanent magnet rotor; ω_r is the angular speed of rotor rotation; R is the stator resistance;

p is the number of pole pairs of the permanent magnet synchronous motor; and k is the electromagnetic torque coefficient [26].

5. Driving Motor Control-Strategy-Based Anti-Rollover

According to the vehicle dynamics model, the lateral acceleration of the vehicle's center of mass is determined by the longitudinal driving speed, the lateral driving acceleration and the yaw rate. If the longitudinal driving speed of the vehicle decreases, the lateral acceleration of the center of mass of the whole vehicle can be directly reduced from the source, so as to achieve the purpose of restraining the roll or avoiding the vehicle rollover. The safety threshold is set according to the determined rollover evaluation index, and the dynamic evaluation index is calculated through the dynamic input data obtained by the sensor, and the current vehicle driving state is judged, so as to carry out timely early warning and active control.

This strategy includes two parts: rollover warning and active rollover prevention control. The six-axis attitude sensor is used to obtain the raw data values of the gyroscope and accelerometer, and the dynamic roll angle and roll angular velocity are obtained by calculation. According to the calculation formula of Equation (11), the absolute value of the real-time rollover evaluation index can be obtained. 0.75, the safety threshold of active anti-rollover control is 0.8. When $|LTR| \geq 0.75$, the buzzer alarm will be triggered to remind the driver to pay attention to the rollover tendency of the vehicle and operate in time. When $|LTR| \geq 0.8$, the drive motor is directly controlled to decelerate. If it does not exceed the safety threshold, it will directly return to the load without alarm and control. The speed sensor monitors the change in the motor speed in real time as negative feedback for the drive motor speed control.

A block diagram of the rollover control strategy is shown in Figure 2.

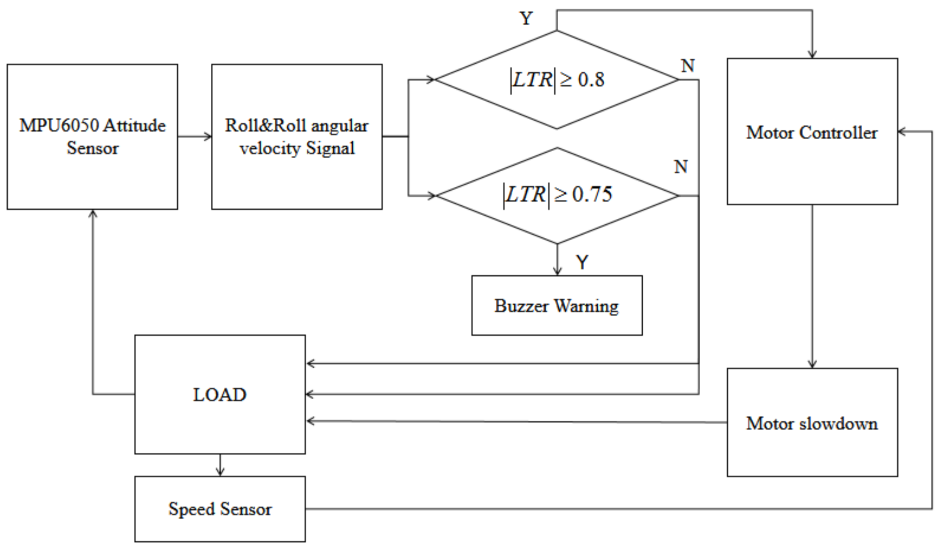

Figure 2. Rollover control strategies.

6. Simulation Results

In this section, to test and validate the control strategy, a model is built in MATLAB/Simulink and the vehicle parameters and the fishhook and double lane-change conditions are set up in Carsim, which is used in conjunction with Simulink for joint simulation testing; the specific vehicle parameters are shown in Figure 3. In the fishhook procedure test, the steering wheel is turned twice in quick reversal to simulate the vehicle avoiding an obstacle; the second turn is in the opposite direction to the first turn, and the angle of the second turn is twice the angle of the first turn, while the double lane-change procedure test simulates the vehicle overtaking at high speed. The fishhook and double lane-change tests are often used to evaluate the rollover performance of a vehicle because it is most likely to flip in the fishhook and double lane-change tests. The simulation is an ideal test simulation, i.e., a fishhook test at a constant speed of 50 km/h and a double shift test at a constant speed of 120 km/h. The fishhook test is a path with two steering wheel turns after constant acceleration from standstill to 50 km/h. The double shift test is a target speed of 120 km/h before starting the double shift path. Under the condition of no anti-rollover control, the vehicle travels at a fixed target speed for the test condition and the speed does not change during travel. Under the condition of anti-rollover control, when the *LTR* exceeds the safety threshold, a controlled deceleration will be performed by the system, thus forming two control curves. The control strategy of this study is analyzed according to the comparison of the simulation results under different operating conditions. The Simulink simulation model is shown in Figure 4.

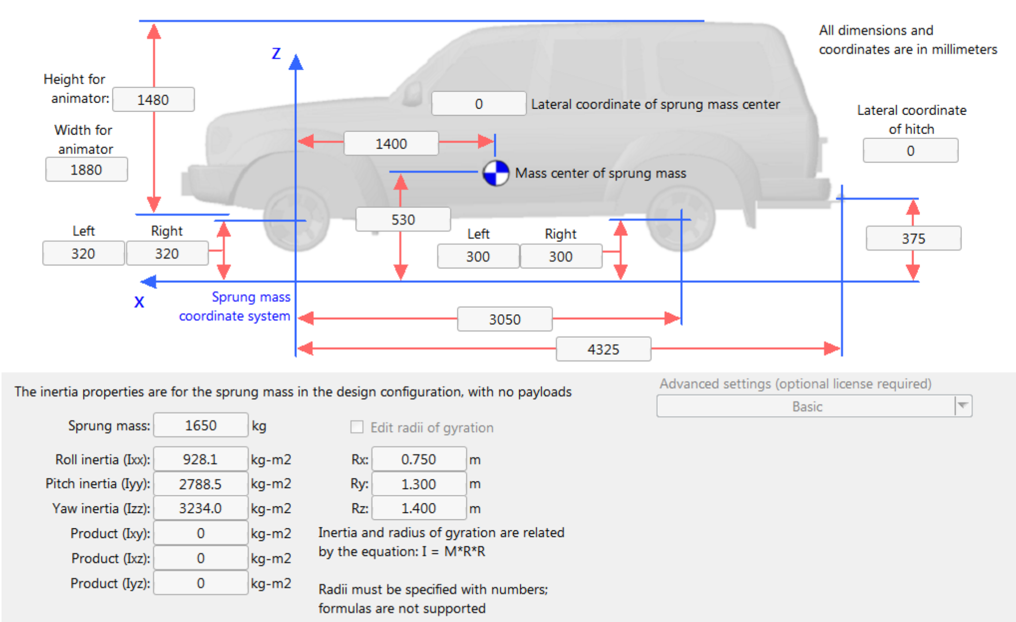

Figure 3. The vehicle parameters settings.

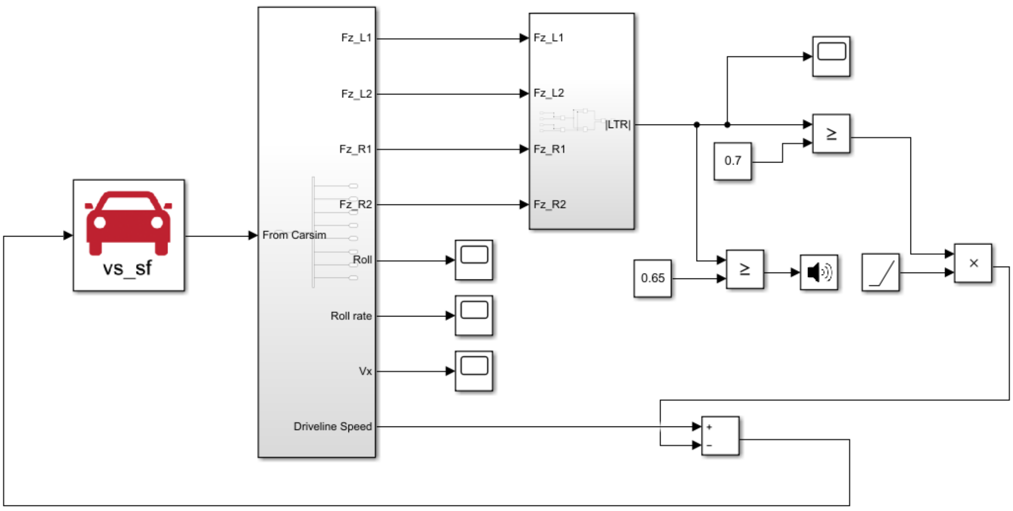

Figure 4. Simulink simulation model.

6.1. Fishhook Procedure

A medium-sized car at 50 km/h under the fishhook working conditions simulation test can be seen in 23.85 s when the absolute value of *LTR* reaches 0.8. The car for the side of the dangerous driving state, according to the control strategy, reduces the motor speed. At this time, the car's speed gradually declines. The value of *LTR* drops back to 0.8 below the car driving-state's safety. The absolute value of the *LTR* change curve is shown in Figure 5; the car longitudinal driving speed change curve is shown in Figure 6.

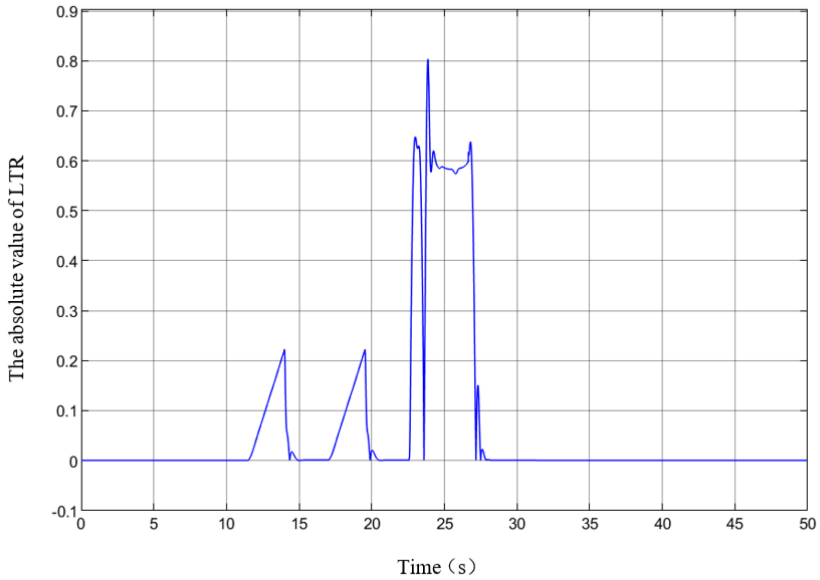

Figure 5. Absolute value change curve of *LTR* for fishhook test.

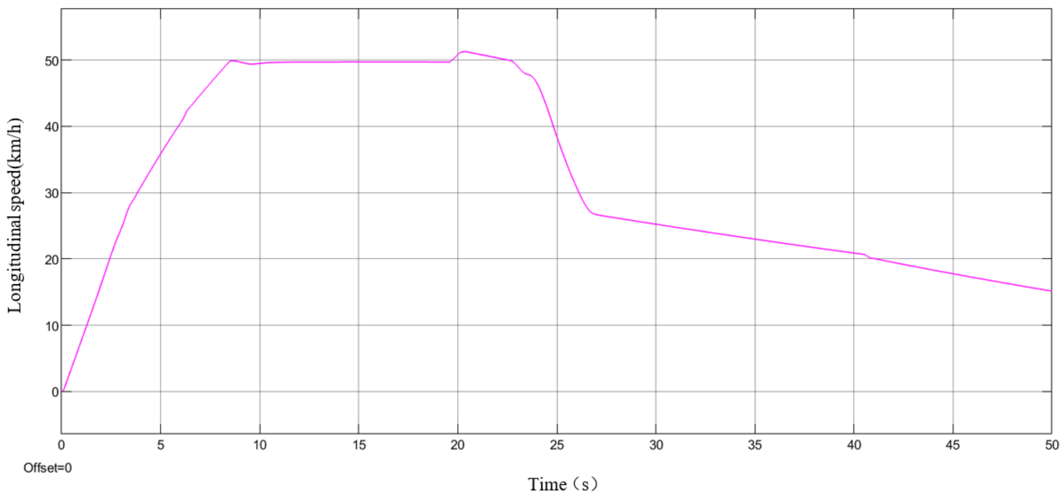

Figure 6. Longitudinal speed variation curve for fishhook test.

The Rollover Steer Input: Unstable model in the dataset in Carsim is a vehicle motion model without rollover stability control. Additionally, the Batch function of Libraries in Carsim allows the comparison of two or more models at the same time. The Rollover Steer Input: Unstable model and the EV Rollover Control model of this research strategy are selected to compare the rollover angle, rollover rate and vertical load on the left and right tires under the fishhook test conditions.

As seen in Figure 7, the car motion model without rollover control starts to increase the roll angle after 1.2 s, reaching a positive maximum of 18 deg at 2.3 s, then the roll angle drops sharply, reaching a negative maximum of 78 deg at 3.4 s. The car driving state is extremely unstable, and rollover will occur. In this control strategy, the rollover angle of the car is almost stable at zero during the driving process, and after 5 s there is a small up and down fluctuation, but the car is still driving stably.

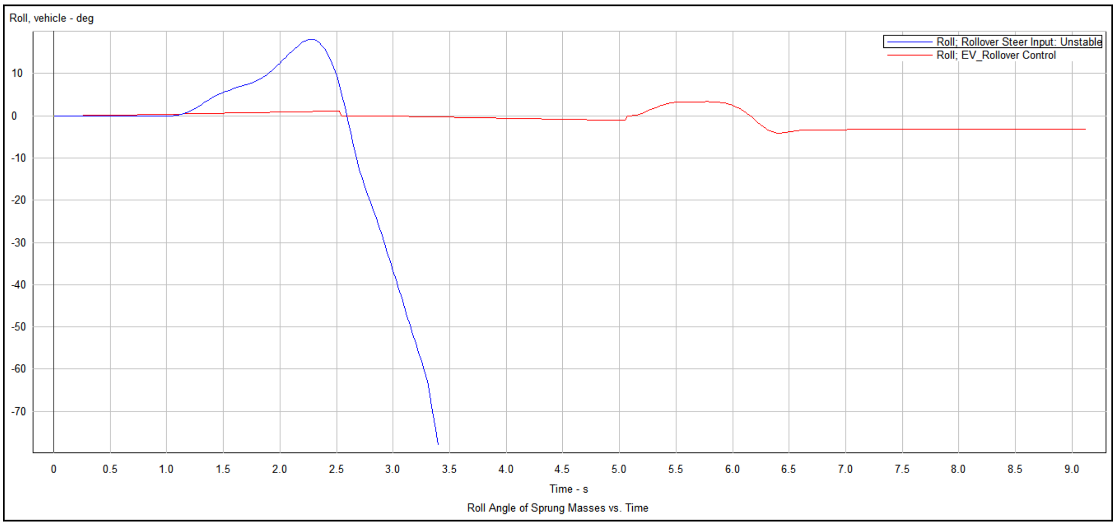

Figure 7. Roll angle comparison curve for fishhook test.

As can be seen from Figure 8, the car motion model without rollover control starts to increase in rollover angular velocity after 1 s, reaching a positive maximum of 27.4 deg/s at 2.1 s. Next, the rollover angular velocity drops sharply, with a small reduction at 2.6 s, but then becomes a larger angular velocity at 2.8 s, with a maximum negative rollover angular velocity of 160 deg/s, and the car rolls over. The lateral tilt angle speed of the car motion model under this control strategy is stable at zero until 5 s, and after 5 s there is a small up and down fluctuation. After 6.5 s it continues to remain at zero, so the car is driving stably.

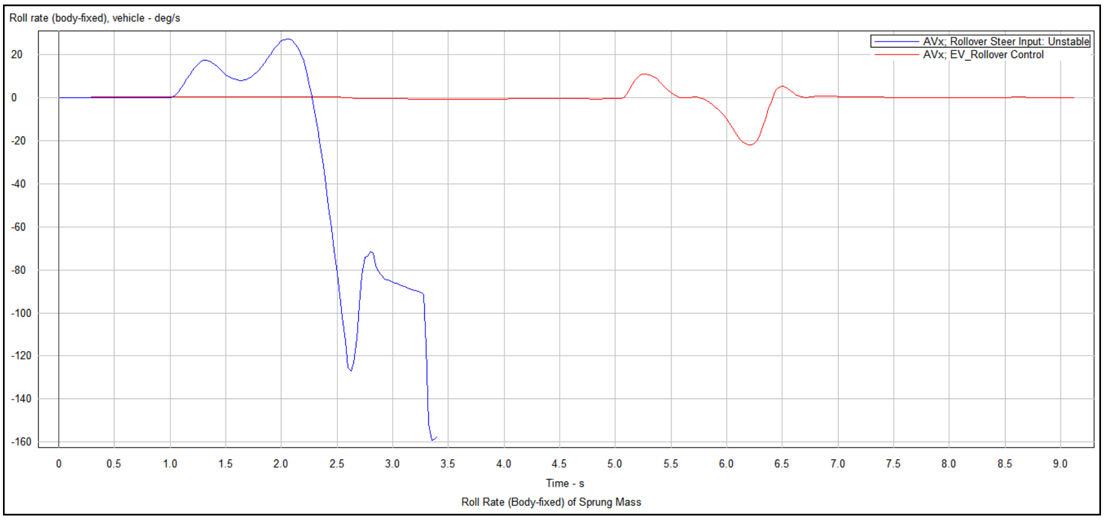

Figure 8. Roll angle comparison curve for fishhook test.

As can be seen from Figure 9, the car motion model without rollover control, after 1 s, the vertical load of the left wheel drops to 0 KN, while the vertical load of the right wheel is raised to 12 KN and 11 KN. At this time, all the wheels on the left side of the car leave the ground, and the car is about to roll over. At 2.5 s, when the left side of the front and rear of the two wheels of the vertical load is quickly increased to 53 KN and 50 KN, while the right side of the front and rear of the two wheels of the vertical load is quickly felled to 0 KN, it can be seen that the car and the right side of the wheel all off the ground. It can be seen that at this time that there is a large side-angle speed, and the car overturns. While in the car motion model under this control strategy, before 5 s the vertical load of the left- and right-side wheels are kept at about 5 KN, after 5 s, the vertical load of the right-side wheels has a small increase to a maximum of 7.5 KN, and the vertical load of the left-side wheels has a small decrease. The minimum vertical load on the left front wheel is 2.5 KN and the minimum vertical load on the left rear wheel is 0.5 KN. At this time, according to the *LTR* calculation formula, the car is still in a safe driving condition. Around 6.1 s, the vertical load on the right wheel of the car drops to 2.5 KN and 0.5 KN, and the left wheel is raised to 7.5 KN. At this time, the car is still in a safe driving condition.

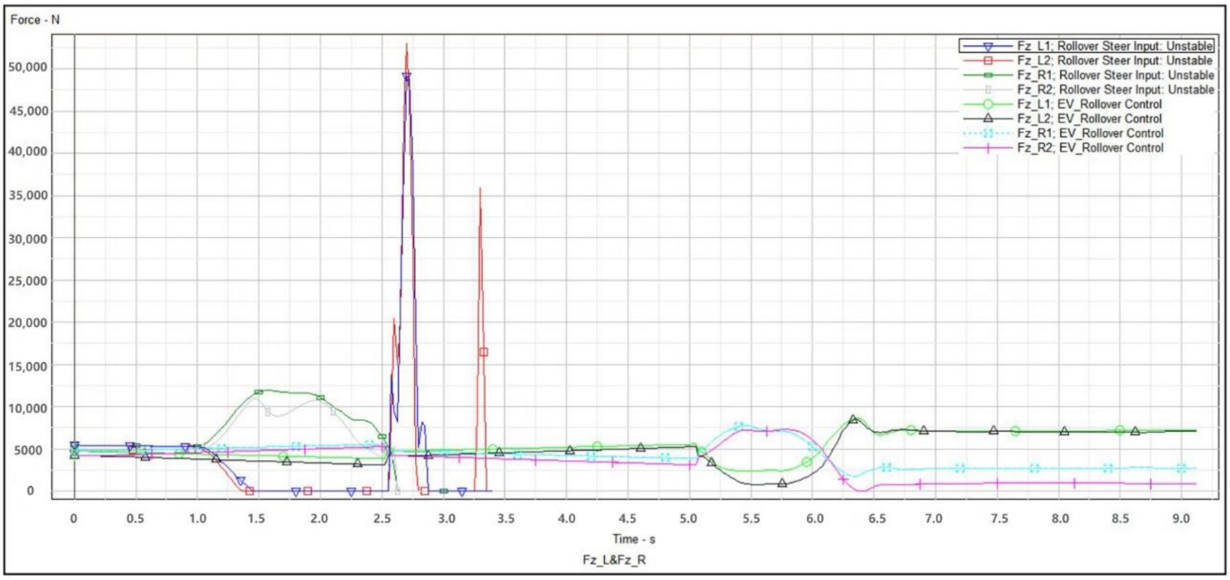

Figure 9. Wheel vertical load comparison curve for fishhook test.

6.2. Double Lane-change Procedure

In the results for the medium-sized car at 120 km/h in the double-shift-line working conditions simulation test, the absolute value of the Double Lane Change Procedure of *LTR* reached 0.8—the trigger value for the car's rollover dangerous driving state—for the first time in 5.38 s. According to the control strategy, the motor speed should be reduced; therefore, at this time, the car speed gradually decreased, the *LTR* value returned to below 0.8, and the car driving state was once again safe. Then, the *LTR* absolute value exceeded 0.8 after, respectively, 7.34 and 9.03 s, and the motor reduced the speed according to the control strategy. The absolute value of the *LTR* change curve is shown in Figure 10. The car longitudinal driving speed change curve is shown Figure 11.

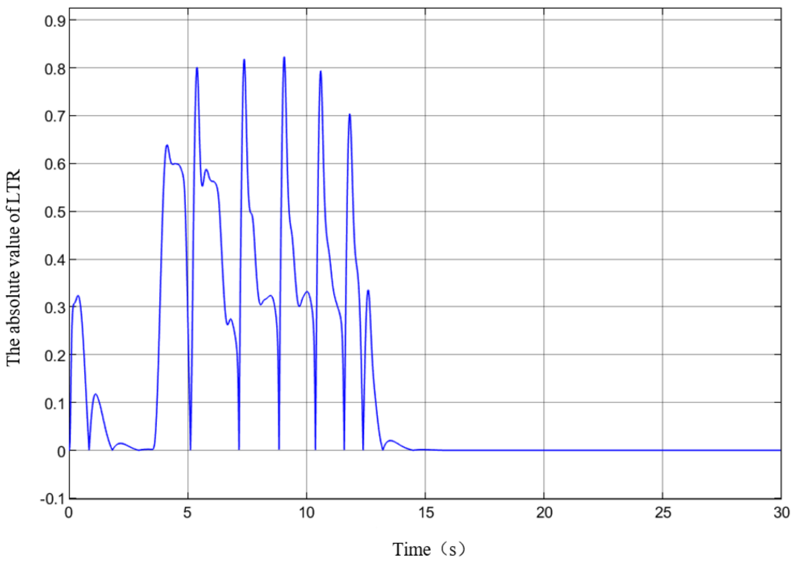

Figure 10. Absolute value change curve of *LTR* for double lane-change test.

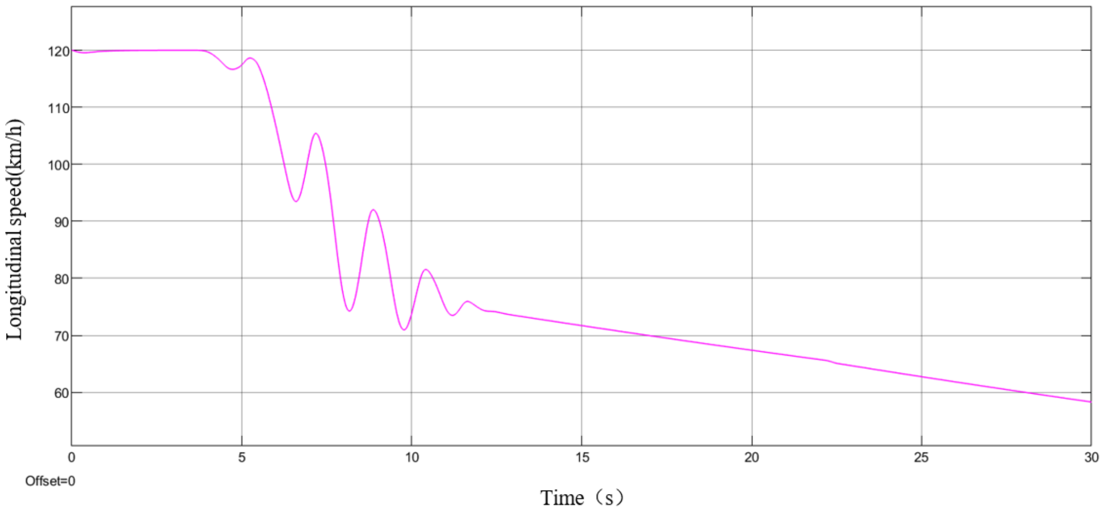

Figure 11. Longitudinal speed variation curve for double lane-change test.

The Carsim model in the previous section is still selected for simulation with this control strategy model under double shift conditions, comparing the rollover angle, rollover rate and vertical loads on the left and right tires.

As seen in Figure 12, the car motion model without rollover control starts to increase the roll angle after 1.2 s, reaching a positive maximum of 18 deg at 2.3 s, then the roll angle drops sharply, reaching a negative maximum of 78 deg at 3.4 s. The car driving state is extremely unstable, and rollover will occur. Under this control strategy, the rollover angle of the car fluctuates between (−5 deg, 5 deg) before 13.6 s, after which it is stable at zero and the car is driving steadily.

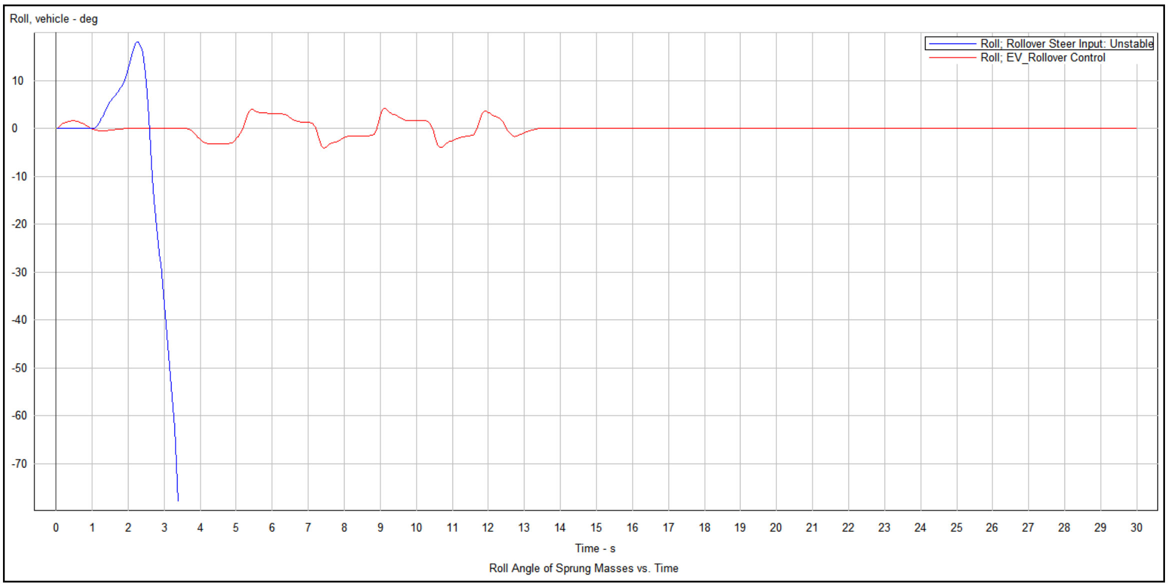

Figure 12. Roll angle comparison curve for double lane-change test.

As can be seen from Figure 13, the car motion model without rollover control starts to increase in rollover angular velocity after 1 s, reaching a positive maximum of 27.4 deg/s at 2.1 s, followed by a sharp drop in rollover angular velocity, with a small reduction at 2.6 s. This then becomes a larger angular velocity at 2.8 s, with a maximum negative rollover angular velocity of 160 deg/s, and the car rolls over. Under this control strategy, the rollover angle speed of the car fluctuates up and down in the range (−27.2 deg/s, 27.2 deg/s) until 15 s. However, 15 s after stable to zero, the car is driving stably.

Figure 14 shows the car motion model without rollover control after 1 s. The vertical load of the left wheel is dropped to 0 KN, while the vertical load of the right wheel is increasing to 12 KN and 11 KN. At this time, all the wheels on the left side of the car are off the ground, and the car is about to roll over. Then, 2.5 s later, the vertical load of the left front and rear two wheels is rapidly increased to 53 KN and 50 KN, while the right front and rear two wheels are quickly dropped to 0 KN. In this control strategy, the vertical load of the left and right wheels of the car before 14.6 s is floated in the range of (0.25 KN, 8.74 KN), and after 14.6 s, the vertical load of the left and right front wheels of the car is stabilized at 4.8 KN. After 14.6 s, the vertical load on the left and right rear wheels is stabilized at 4.1 KN, and the car reaches a safe driving condition.

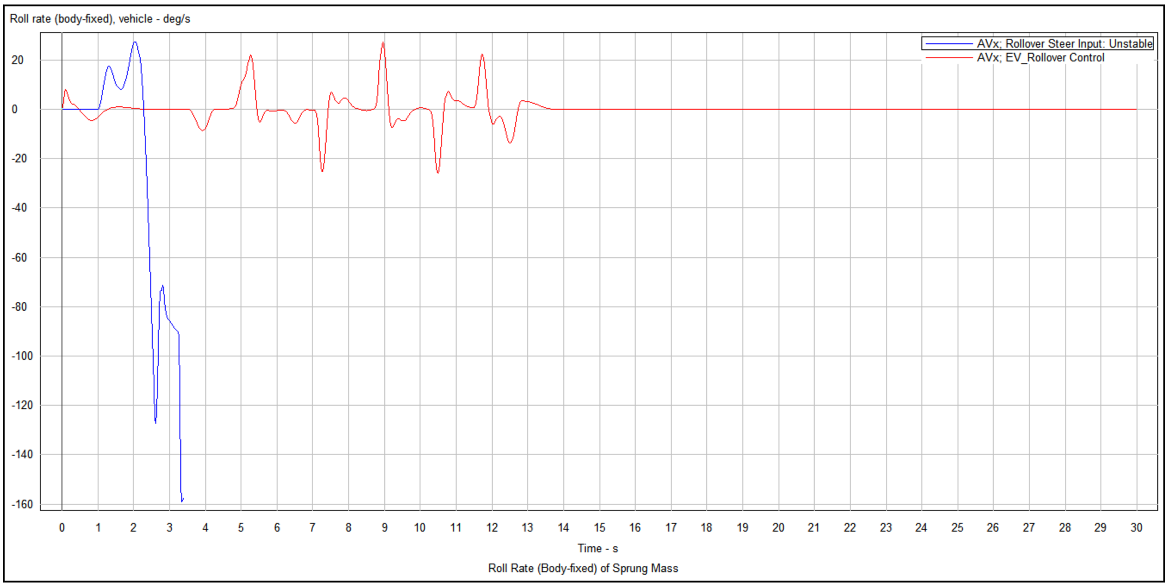

Figure 13. Roll rate comparison curve for double lane-change test.

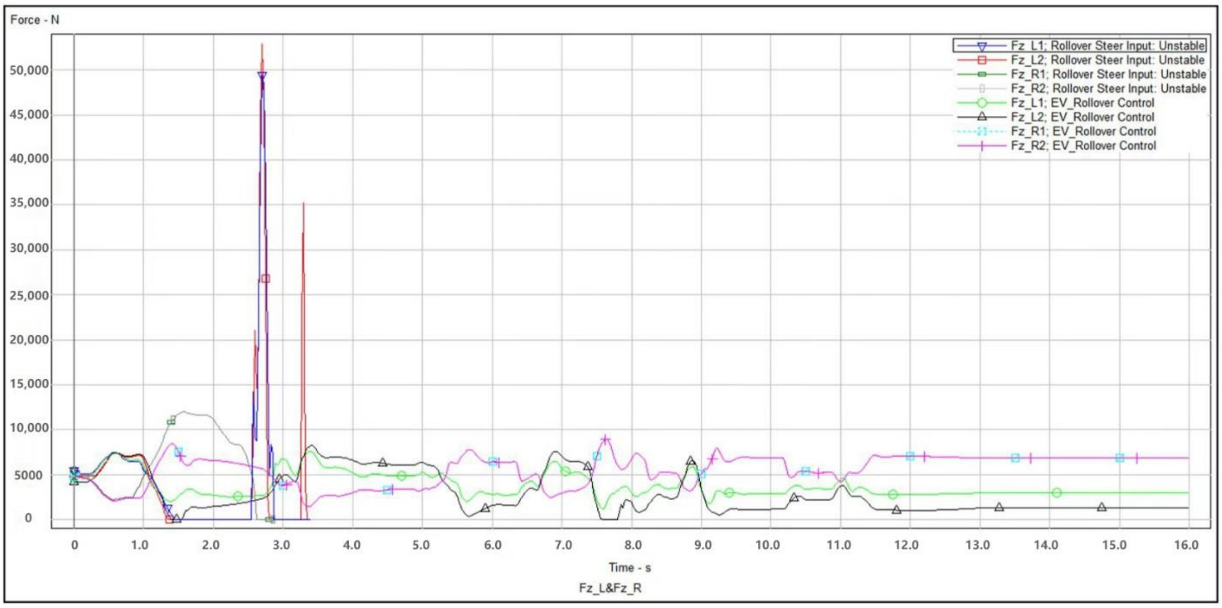

Figure 14. Wheel vertical load comparison curve for double lane-change test.

7. Conclusions

A generic real-time rollover control strategy was presented to reduce the risk of electric vehicle rollover through electric vehicle drive motor speed control. The vehicle motion state was obtained through attitude sensors and high-performance field-oriented control (FOC) was used to control the drive motor speed reduction when the vehicle had a tendency to roll over in order to significantly reduce the likelihood of the vehicle rolling over. The feasibility of the proposed strategy was demonstrated by the joint simulation curve results of Carsim and Simulink. The real-time anti-rollover control strategy proposed in this paper showed excellent stability under two different operating conditions and driving speeds in both the fishhook test and the double lane-change test.

Based on the research on the motor speed control method of vehicle rollover, this paper combined the drive motor speed control with vehicle rollover for the first time, which is also a research idea to realize the response control of vehicle body structure through automotive electronic control technology. The proposal and verification of this method provide a new technical support route for the future technical research and development of electric vehicle active safety. In today's automobile industry, electronic control has become important technology. In the comprehensive technological innovation and development of automatic driving, automatic assisted driving and intelligent cockpit, automobile electronic control will be used as the main technology to control various structural responses of vehicles. When the driver cannot safely operate the vehicle or when a more dangerous driving condition occurs, the electronic active safety control of the vehicle will greatly reduce the occurrence of traffic accidents, reducing casualties and economic losses.

Although this research has achieved the research purpose of the anti-rollover control method for electric vehicles, and verified its feasibility through simulation, there are still some deficiencies and challenges due to the limitations of time and objective conditions. The model is simplified to ignore some effects, including tire positioning torque, suspension, air resistance, etc. In the follow-up research, the model should continue to be optimized to consider more non-linear effects and improve the control accuracy; this research only focuses on the control design of the DC motor of the test vehicle. However, this control method can be widely applied to different types of drive motors of electric vehicles and used as an automatic driving assistance function. As long as different motor control methods are modified for different drive motors, the overall strategy has good generality and can improve the active safety performance and driving stability of various electric vehicles.

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