JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Hill Assist Control of Vehicle

[1]Nimisha Vilas Gajbhiye, [2]Dr Bhoopesh Chaudhari

[1]M-tech student at P.E.S college of Engineering
[1]Electrical Department of P.E.S College,
[1]P.E.S college of Engineering, Aurangabad, India.

Abstract: This paper introduces a hill-start control method designed for distributed electric vehicles, aiming to enhance the convenience of ramp starts. Traditional hill-start methods fall short for these vehicles in certain situations. Leveraging a pneumatic electronic parking brake system (EPB), the proposed method ensures a swift and stable ramp start. Analyzing force variations during ramp starts. Implementing a dynamic allocation strategy based on front and rear axle loads to optimize torque distribution. Determining the hill-start control target through force analysis on the ramp. Employing a real-time logic threshold control method to dynamically adjust actual pressure to align with the ideal pressure. Designing a driving torque correction controller based on the sliding mode algorithm. Mitigating wheel slipping on uneven roads to prevent a reduction in total driving force and avoid vehicle rollback. utilizing Mat-lab, Truck-sim, and AME-sim for co-simulation verification. Creating models for the controller, vehicle, and pneumatic EPB system. Simulation results demonstrate the effectiveness of the proposed control strategy in preventing vehicle slipping under diverse road conditions while minimizing brake wear.

***IndexTerms* - Distributed Drive, Hill Start, Sliding Mode, Coordinated Control; Moment Correction, Logical Threshold, Co-simulation.**

I. INTRODUCTION

The hill-start assist system (HAS) plays a crucial role in preventing vehicle roll-back during uphill or downhill starts, significantly impacting vehicle dynamics and safety. Unlike traditional hand-brake systems, HAS eliminates unnecessary mechanical components, providing continued braking force after releasing the brake. [1] It assesses driving force against motion resistance through sensors, releasing the brake force when needed, simplifying hill starts for the driver.

Current parking brake systems include mechanical electronic, hydraulic electronic, and pneumatic electronic brake systems. While HAS is common in traditional gasoline-fueled vehicles, its adaptation for distributed-drive electric vehicles presents challenges. [2] These vehicles, without traditional transmissions and differentials, demand advanced control strategies for hill starts.

Researchers have proposed various solutions, such as rapid control prototyping and a Hill Hold Mechanical concept, to address hill-start control. However, adapting these strategies directly to distributed-drive electric vehicles may lead to poor control and system failure. [3]

To address this, a new integrated control scheme is proposed, tailored for distributed-drive electric vehicles. The scheme incorporates a dynamic torque distribution strategy based on front and rear axle loads, acknowledging the unique characteristics of individual wheels. [4] A logic threshold control method with torque correction is designed to ensure real-time adjustment of actual brake pressure to match the ideal brake pressure during hill starts. [5]

Simulation verification using Mat-lab, Truck-sim, and AME-sim establishes the effectiveness of the proposed scheme in two road environments with a 20% slope. Evaluation indices, including starting jerk, rollback distance, and brake wear, demonstrate the superiority of the new control scheme over traditional approaches. [6]

II. CONTROL SYSTEM DESIGN

The hill start controller discussed in this study collects information from various signals such as vehicle speed, road slope, accelerator, and brake pedal. These signals are processed to determine if the braking system needs to be activated. When the analysis indicates that the vehicle is about to start on an incline, the brake force is released at the right moment. The study focuses on a hill-start control method designed for distributed driving electric vehicles on ramps, using a pneumatic electronic parking brake system. The goal is to enable a quick and stable start on uphill slopes.

In this vehicle control system, the actual motion state is the result of collaboration among various components, with the controller being the central component. By analyzing driving signals and incorporating feedback information about the vehicle's state, the controller executes control algorithms and sends commands to actuators to correct the vehicle's motion state. [7] The key actuators in this study are four driving motors and two pneumatic EPB parking brake systems mounted on the rear axle. The four driving motors output torque to the wheels based on torque commands from the motor controllers and the current state of the motors, realizing the intended driving action. The hill-start controller proposed in the study is structured into three layers: the driving torque pre-distribution controller, the torque correction controller, and the parking control controller. These layers collaborate to ensure smooth hill starts and control the vehicle's motion state. [8]

Control Strategy Overview:

- Driver Input: The controller receives signals such as longitudinal speed, pedal signal, and gear signal as inputs.
- Vehicle Torque Distribution Controller: In the upper layer, this controller determines the reference total torque of the drive motor based on the driver's intention and pre-distributes the motor torque for the front and rear axles.
- Torque Correction Controller: In the middle layer, anti-slip control is crucial during hill starts. The controller adjusts the desired torque of each drive motor in real-time to prevent wheel slippage on low-adhesion or undulating roads. The torque distribution controller redistributes driving torque based on the corrected torque.
- Parking Control Controller: In the bottom layer, this controller manages the EPB parking brake systems to ensure vehicle stability during hill starts.
- The overall structure of the controller is divided into three layers.
- The upper layer includes the driving torque pre-distribution controller.
- The middle layer comprises the torque correction controller.
- The bottom layer involves the parking control controller.
- The driving torque pre-distribution controller determines the reference total torque based on the driver's input.
- Torque correction controller focuses on anti-slip control during hill starts, adjusting drive motor torque in real-time to prevent wheel slippage.
- Torque distribution controller redistributes driving torque based on the corrected torque to ensure vehicle stability.

In the final stages of the hill-start control system, the start judgment controller plays a crucial role in determining whether the vehicle's conditions meet the requirements for initiating hill start control. Additionally, the logic threshold controller calculates the demand pressure for the parking brake in real-time. It then controls the air pressure within the parking brake air chamber based on a logic threshold control method, ensuring it follows changes in the demand pressure. This controller assesses whether the vehicle's current conditions are suitable for activating the hill start controller. It decides based on factors such as monitored wheel speed, vehicle speed, and acceleration. If the monitored acceleration is less than 0, indicating a backward rolling trend, the system proceeds to initiate hill start control. The logic threshold controller calculates the demand pressure for the parking brake in real-time. It employs a logic threshold control method to adjust the air pressure within the parking brake air chamber in response to changes in the demand pressure. When the monitored acceleration indicates a backward trend (less than 0), the demand pressure is recalculated immediately based on the corrected torque from the middle torque correction layer. The hill start control system continues to release the parking brake force based on the logic threshold control method. If the driving torque exceeds the resistance, the inflation solenoid valve is opened until the parking brake is completely released. The EPB control unit receives the demand pressure command from the logic threshold controller. It then controls the EPB actuator, gradually releasing the brake force to accomplish the hill start control.

III. DESIGN OF HILL START CONTROLLER

When the vehicle starts on the ramp, the force of gravity generates a downward resistance to the vehicle along the ramp, and the vehicle has a downward movement tendency. By controlling the throttle and gear, the driver makes the motor generate the driving force along the ramp upward. Before the driving force overcomes the resistance, the direction of the braking force goes up along the slope to help the driving force maintain the vehicle's static state and prevent the vehicle from rolling back [22].

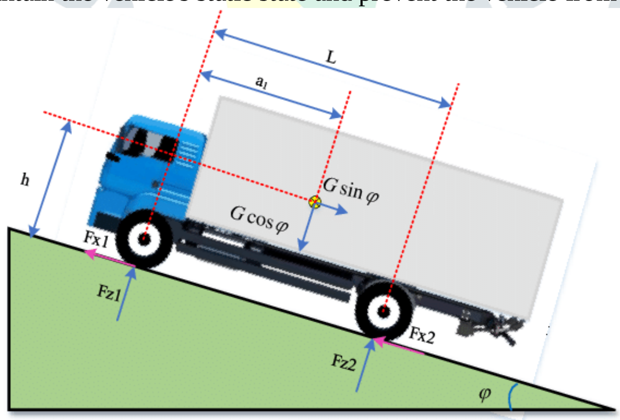


Fig.1: Force analysis of the vehicle on the ramp.

The following equation can be obtained by using the force and moment balance equation:

$$\begin{cases} F_{x1} + F_{x2} - \frac{1}{2}C_d\rho_a SV^2 + Mg(sin\varphi + \mu_a cos\varphi) = Ma \\ F_{z1} + F_{z2} - Mgcos\varphi = 0 \\ -F_{z1}a_1 + F_{z2}(L - a_1) - (F_{x1} + F_{x2}) \cdot h = 0 \end{cases} \tag{5}$$

By eliminating $Fx1$ and $Fx2$, the normal force $Fz1$ and $Fz2$ based on vehicle dynamics can be obtained.

$$\begin{cases} F_{z1} = \frac{M\cdot g\cdot cos\varphi(L-a_1-\mu_a h)-M\cdot g\cdot sin\varphi\cdot h-Ma-\frac{1}{2}C_d\rho_a SV^2}{L} \\ F_{z2} = \frac{M\cdot g\cdot sin\varphi\cdot h+M\cdot g\cdot cos\varphi(a_1+\mu_a h)+\frac{1}{2}C_d\rho_a SV^2+Ma}{L} \end{cases} \tag{6}$$

Therefore, the demand torque of each driving motor is:

$$T_{refi} = \frac{F_{zi}}{2\sum_{i=1}^{2} F_{zi}} T_{tot} \tag{7}$$

Where M,g,$R\omega$,φ,V,Cd,ρa, S represent the total mass of the vehicle, the acceleration of gravity, the effective radius of the wheel, the road slope, the vehicle speed, the air drag coefficient, the air density, and the effective windward area respectively ; $Fx1$ and $Fx2$ respectively represent the road driving force of the front and rear axles of the vehicle; $Fz1$ and $Fz2$ refer to the normal forces on the front and rear axles respectively; $Ttot$ is the total moment required at the moment; μa is the rolling friction coefficient of the tire; h is the height of the centroid; $a1$ and L are refer to the distance from the center of mass to the front axis and the wheelbase respectively; a is the acceleration of the vehicle. The longitudinal dynamic equation of the vehicle [23]： are the final effective driving torque of the vehicle and the driving torque acting on the wheels; $Tbrk$ is the braking torque of a single wheel generated by the static friction of the tire and the pneumatic brake system and meets:

A hill-start control system, the accuracy of estimating the longitudinal speed is crucial for the effectiveness of the driving torque correction module. To achieve this, real-time and accurate vehicle speed information is essential. There are two primary methods for obtaining the longitudinal speed of a distributed driving vehicle, and the paper opts for an estimation method based on common on-board sensors. One approach to obtaining longitudinal speed is through the use of high-precision GPS speedometers or optical sensors. However, these methods are often expensive and may not be suitable for large-scale production or general research due to cost constraints. The more common and practical approach is to use an estimation method based on on-board sensors. This method relies on the information provided by sensors already present in the vehicle. In this paper, the chosen method for estimating driving state parameters, including longitudinal speed, is the Kalman filter method. The Kalman filter is a recursive algorithm that provides estimates of the state of a dynamic system based on a series of noisy measurements. In this case, the wheel speed signals from all four wheels serve as the observed quantities, and an acceleration sensor is strategically placed at the center of mass of the vehicle to capture acceleration information.

$$\begin{cases} W^-(k) = W(k-1) + Q \\ K(k) = P^-(k)H^T[(HW^-(k))H^T + R(k)]^{-1} \\ \hat{v}(k+1) = v(k) + \sigma a(k) \\ \hat{\omega}(k+1) = H\hat{v}(k+1) \\ v(k+1) = \hat{v}(k+1) + K(k+1)(\omega(k+1) - \hat{\omega}(k+1)) \\ P(k) = (I - K(k)H)P^-(k) \end{cases} \tag{8}$$

Where, $W(k)$ is the error covariance matrix; $a(k)$ is the acceleration at time $t(k)$; $R(k)$ is the variance of the measurement noise Q ; $v(k)$ and $\hat{v}(k+1)$ are the estimated value and the prior estimate value of the vehicle speed at time $t(k+1)$; ω $(k+1)$ and $\hat{\omega}(k+1)$ are the measured value and the predictive value of wheel speed at time $t(k+1)$; $K(k)$ is the Kalman filter gain matrix at time $t(k)$ and its expression is: $K = [kfl\ kfr\ krl\ krr]$. ki， $i = fl$、fr、rl、rr represent the gain values of the left front wheel, left rear wheel, right front wheel, and right rear wheel respectively. When a wheel is slipping, the parameter in the gain matrix is adjusted so that the element value corresponding to the wheel is reset to zero. If the wheels do not slip, the element values obtained from the recursive formula of the Kalman filter are used to calculate, so as to obtain a more accurate vehicle speed estimate.

IV. RESULTS AND DISCUSSION

Represents the duration of the hill climb in fig.2,3 and 4. Usually measured in seconds. Indicates the speed of the vehicle. Typically measured in units such as meters per second (m/s) or kilometers per hour (km/h). Initial Phase (t=0 to t1): The vehicle starts climbing the hill. The ABS system is active, monitoring wheel speed continuously. ABS Engagement (t1 to t2): As the vehicle encounters an incline, the ABS engages. ABS intervene to prevent wheel lock-up during braking on the slope. Vehicle speed may slightly decrease, but ABS maintains control. Stabilization (t2 onward): The ABS helps stabilize the vehicle speed during uphill braking. The graph shows a controlled decrease or stabilization of speed. The graph shows a more controlled and stabilized decrease in vehicle speed during hill climbing. The ABS system prevents wheel lock-up, enhancing vehicle control and maintaining stability.

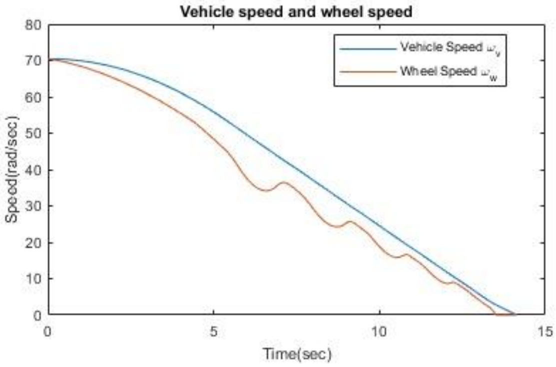


Fig.2: Vehicle and wheel speed with Anti-lock

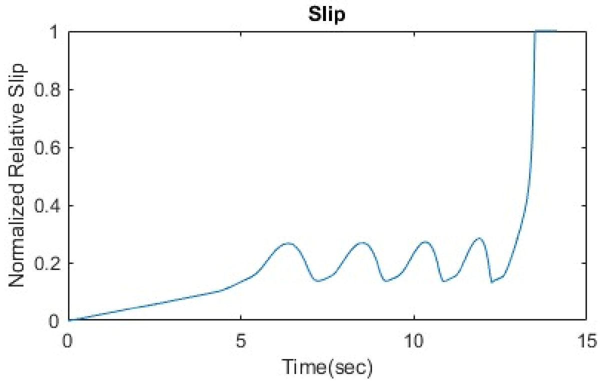


Fig.3: Slip with Anti-lock hill climbing

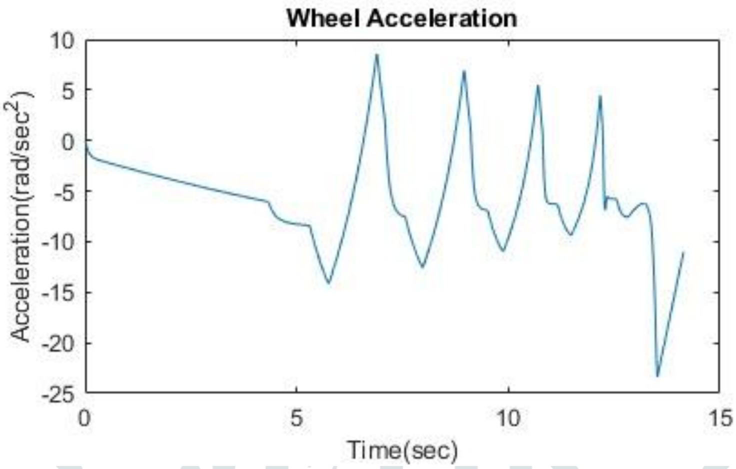


Fig.4: Wheel acceleration with Anti-lock hill climbing

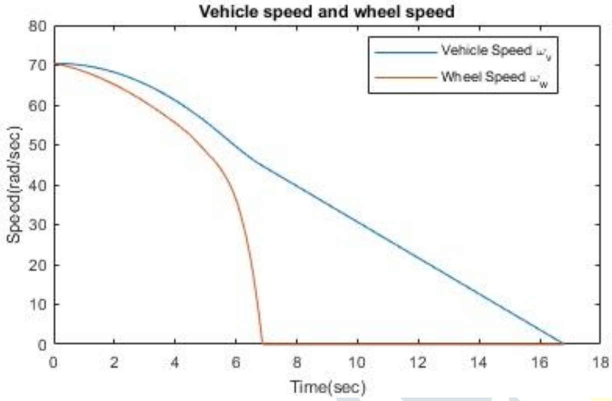


Fig.5: Vehicle and wheel speed without Anti-lock

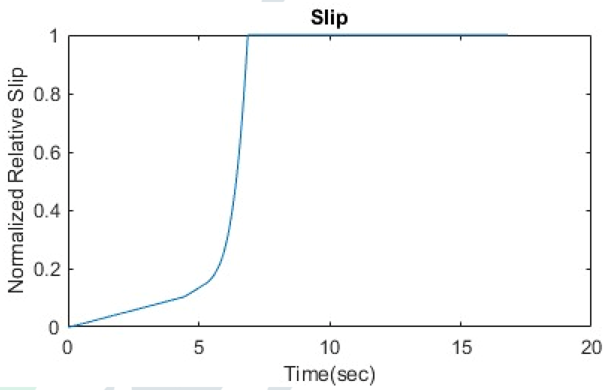


Fig.6: Slip without Anti-lock hill climbing

Initial Phase (t=0 to t1): The vehicle starts climbing the hill. Brakes are applied without ABS intervention. Potential Wheel Lock-up (t1 to t2): As the vehicle ascends, there is a risk of wheel lock-up during braking. Without ABS, wheel lock-up could lead to loss of steering control. Uncontrolled Speed Reduction (t2 onward): The absence of ABS may result in uncontrolled speed reduction. Wheel lock-up might cause a significant decrease in speed. The graph may indicate a less controlled speed reduction. Wheel lock-up, if it occurs, could lead to a sudden and uncontrolled decrease in speed.

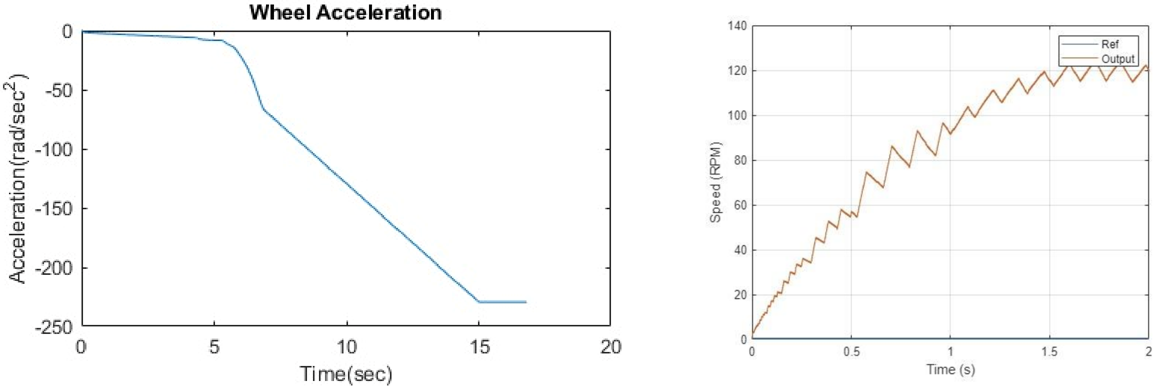


Fig.7: this is without anti-lock for car hill climbing

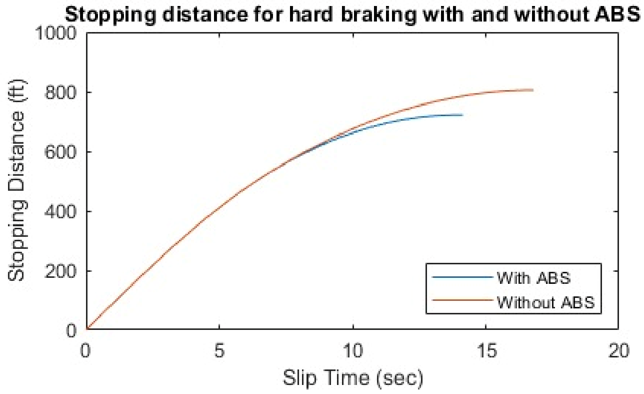
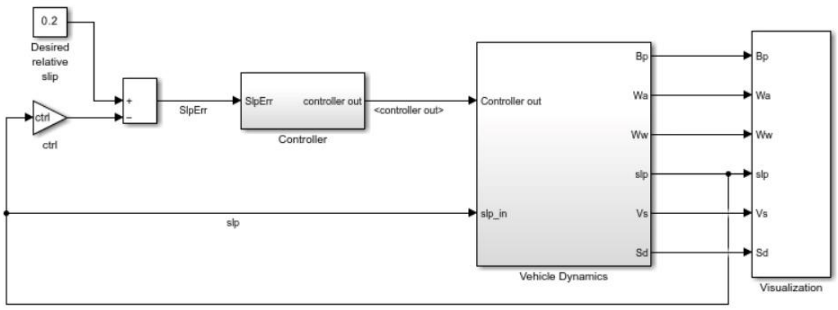


Fig.8: Stopping distance for hard braking with and without ABS

- Stopping Distance Axis (Y-axis): Represents the distance traveled by the vehicle while coming to a complete stop. Usually measured in units such as meters or feet.
- Braking Scenario Axis (X-axis): Indicates different braking scenarios, specifically comparing hard braking situations.
- Stopping Distance Scenarios: With ABS: ABS actively prevents wheel lock-up during hard braking. The graph shows a relatively shorter stopping distance compared to the scenario without ABS. ABS optimizes brake force to maintain steering control with stabilized braking. The line on the graph might show a relatively consistent and shorter distance. The stopping distance is generally shorter due to ABS preventing wheel lock-up. ABS help maintain steering control during hard braking, contributing to a more controlled stop. Without ABS: Longer Stopping Distance: In the absence of ABS, there's a risk of wheel lock-up during hard braking. The graph shows a longer stopping distance, as the vehicle may slide during braking. Without ABS, the vehicle may experience less control over the braking process. The line on the graph might indicate a less consistent and longer distance. The stopping distance tends to be longer without ABS, as wheel lock-up may lead to sliding. Less control over the braking process can result in a less predictable and longer stopping distance.



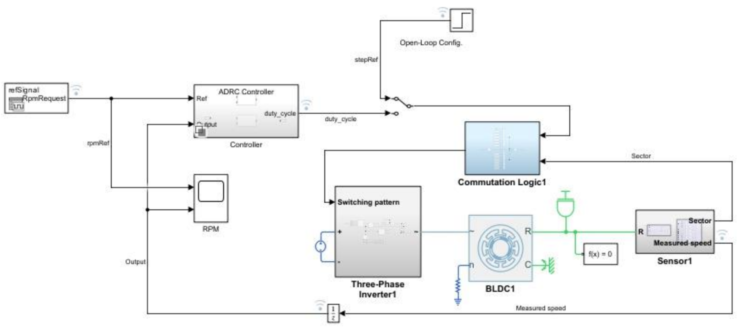


Fig.9: Block diagram of overall controller.

This is the desired reference signal, possibly representing a target speed or position for the BLDC motor. It sets the goal for the motor's performance. The Speed Reference represents the desired speed setpoint for the BLDC motor, indicating the target speed the system should achieve. The Active Disturbance Rejection Controller (ADRC) is a control strategy designed to enhance the system's ability to reject external disturbances and uncertainties. It processes signals, possibly including the reference signal and feedback, to generate a control output. The Raf Controller adjusts the duty cycle, which is the ratio of time a signal is ON to the total time of the signal period. In the context of motor control, the duty cycle often controls the power supplied to the motor. This logic is responsible for determining the switching pattern for the three-phase inverter based on the rotor position of the BLDC motor. It plays a crucial role in controlling the motor's rotation. The output of the sector commutation logic represents the determined switching pattern. It decides how the inverter will switch the phases to control the BLDC motor. The Three-Phase Inverter converts DC power to AC power to drive the BLDC motor. It executes the switching pattern determined by the sector commutation logic. This block represents the actual speed of the BLDC motor as measured by a sensor. It provides feedback on the motor's current speed. This sensor measures the RPM (Revolutions Per Minute) of the motor. The RPM measurement is likely used for feedback to compare the actual motor speed with the desired speed. This might represent the measured speed specifically in the context of the sector commutation logic, indicating the motor's speed relevant to the commutation process. This term may represent a disturbance function or signal (f(x)) with a disturbance term (D). It could be part of the inputs to the ADRC controller, representing external factors affecting the motor that the controller aims to reject. The Output represents the final result of the system, possibly the actual speed or position of the BLDC motor after the control process.

CONCLUSION

The paper introduces a hill-start control method tailored for distributed electric vehicles, focusing on improving the convenience and safety of ramp starts. Traditional hill-start methods, while effective for conventional vehicles, face challenges when applied to distributed-drive electric vehicles due to the absence of traditional transmissions and differentials. To address this, the proposed method utilizes a pneumatic electronic parking brake system (EPB) and employs a dynamic torque distribution strategy based on front and rear axle loads. The control strategy involves three main layers: the driving torque pre-distribution controller, the torque correction controller, and the parking control controller. These layers work collaboratively to achieve a swift and stable hill start on uphill slopes. The driving torque pre-distribution controller determines the reference total torque, while the torque correction controller focuses on anti-slip control during hill starts. The parking control controller manages the EPB system to ensure vehicle stability. The proposed control strategy is simulated and verified using MatLab, Truck-sim, and AME-sim for co-simulation. The simulation results demonstrate the effectiveness of the strategy in preventing vehicle slipping under diverse road conditions and minimizing brake wear. The hill-start control system incorporates a logic threshold control method with torque correction, ensuring real-time adjustment of actual brake pressure to match the ideal pressure during hill starts. The paper emphasizes the importance of accurate longitudinal speed estimation, achieved through a Kalman filter-based method using on-board sensors. The results and discussion section present simulations depicting the hill climb duration, vehicle and wheel speed with and without Anti-lock Braking System (ABS), slip with and without ABS during hill climbing, wheel acceleration with and without ABS during hill climbing, and stopping distance for hard braking with and without ABS. The comparison highlights the superiority of the proposed control scheme, particularly with ABS, in terms of controlled speed reduction and shorter stopping distances.

REFERENCES

[1] B. Peng et al, “Research on the Stability Control Strategy of Four-Wheel Independent Driving Electric Vehicle,” Engineering, vol. 9, no. 3, pp. 338-350, Mar, 2017, DOI.10.4236/eng.2017.93018.

[2] A. Nair, R. Sreedharan and M. Rajesh, “Intelligent motion control of bots using hill hold assistance mechanism,” Conference: 2017 International Conference on Smart Technologies for Smart Nation (SmartTechCon)., Bengaluru., India, 2017, pp. 618-621.

[3] A. Sharma, H. K. Gangwar, and D. Dabhole, “Hill start assistance developed for buses equipped with AMT,” SAE Technical Paper., DOI: 10.4271/2016-01-1111.

[4] M. Paul, K. Baidya, and R. Deepak, “Electro-Magnetic Parking Brake System for Electric Vehicles,” SAE Technical Paper., DOI: 10.4271/2019-26-0119.

[5] I. Mohd, A. Rahim and B. Ali, “Brake torque analysis of fully mechanical parking brake system: Theoretical and experimental approach,” IngenIería InvestIgacIón ytecnología, vol. 19, no. 1, pp. 37-49, Mar, 2018, DOI. 10.22201/fi.25940732 e. 2018.19n1.004.

[6] X. Zhang, D. Göhlich and J Li, “Energy-efficient toque allocation design of traction and regenerative braking for distributed drive electric vehicles,” IEEE Transactions on Vehicular Technology, vol. 67, no. 1, pp. 285-295, July, 2018, DOI. 10.1109/TVT.2017.2731525.

[7] L. Xiong, G. Teng and Z. Yu, “Novel stability control strategy for distributed drive electric vehicle based on driver operation intention,” International journal of automotive technology, vol. 17, no. 4, pp. 651-663, Aug, 2016, DOI. 10. 1007/s12239-016-0064-3.

[8] K. Shi, X. Yuan and L. Liu, “Model predictive controllerbased multi-model control system for longitudinal stability of distributed drive electric vehicle,” ISA transactions, vol. 72, pp. 44-55, Jan, 2018, DOI. 10.1016/j.isatra.2017.10.013.

[9] N. Bagheri and H. Alipour, “Yaw Rate Control and Actuator Fault Detection and Isolation for a Four Wheel Independent Drive Electric Vehicle,” Journal of Operation and Automation in Power Engineering, vol. 5, no. 1, pp. 83-95, Abbrev. June, 2017, DOI. 10. 22098/joape.2017.551.

[10] S. Subramanian et al, “Development and testing of a control algorithm to assist drive-off in the gradient-a rapid control prototyping approach,” SAE Technical Paper., DOI: 10.4271/2015-26-0002.

[11] R. Iyer et al, “Safety and Comfort for All: An affordable HillHold and Automated Parking Brake System,” SAE Technical Paper., DOI: 10.4271/2019-26-0005.

[12] X. Zhao et al, “Cooperative Control of Clutch and Hydraulic Control Unit,” IEEE Transactions on Industrial Electronics, vol. 66, no. 9, pp. 7209-7218, Oct, 2018, DOI. 10.1109/TIE.2018.2874615.

[13] H. L. Wang et al, “Research on bang-bang control of EPB system in vehicle hill start,” Transactions of Beijing Institute of Technology, vol. 37, no. 1, pp. 46-49, Jan, 2017, DOI. 10.15918/j.tbit1001-0645.2017.01.010.

[14] P. Peng et al, “Research on the Hill Start Assist of Commercial Vehicles Based on Electronic Parking Brake System,” Strojniski Vestnik/Journal of Mechanical Engineering, vol. 65, no. 1, Jan, 2019, DOI. 10.5545/svjme.2018.5422.

[15] P. Peng et al, “Two-layer mass-adaptive hill start assist control method for commercial vehicles,” Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering, vol. 234, no. 2, June, 2019, DOI. 10. 1177/0954407019859802.

[16] E. V. Belousov, M. A. Grigor’ev and A. A. Gryzlov, “An electric traction drive for electric vehicles,” Abbrev. Russian Electrical Engineering, vol. 88, no. 4, pp. 185-188, Apr, 2017, DOI. 10.3103/S1068371217040034.

[17] N. K. Saxena, S. Gebrehiwot and D. Mena, “Controller Design for Electric Motor Derived Vehicle,” Indonesian Journal of Electrical Engineering and Informatics (IJEEI), vol. 6, no. 2, pp. 125-131, June, 2018, DOI.10.11591/ijeei.v6i2.282.

[18] M. Song et al, “Design and Research of Intelligent Vehicle EPB Controller Based on ISO26262 Standard,” SAE Technical Paper., DOI: 10.4271/2019-26-0005.

[19] Q. Zhang, H. Wang and W. Gu, “Design and Research of Pneumatic Control Solenoid Valve of Hill Start Assist System of the Medium and Heavy-Duty Vehicles,” Chinese Hydraulics & Pneumatics, vol. 0, no. 11, pp. 15-19, Nov, 2016, DOI. 10. 11832/j.issn.1000-4858.2016.11.003.

[20] Y. Chen et al, “Optimized handling stability control strategy for a four in-wheel motor independent-drive electric vehicle,” IEEE Access, vol. 7, pp. 17017-17032, Jan, 2019, DOI. 10.1109/ACCESS.2019.2893894.

[21] C. Zhang et al, “Research of smoothness on torque coordination of two-wheel independently driven hub electric,” Noise & Vibration Worldwide, vol. 50, no. 7, pp. 205-216, July, 2019, DOI. 10.1177/0957456519860841.