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**Research Article**

# Dynamic Stability of Electric Vehicles under Slippery Conditions: Contribution of Fuzzy Logic in Anti-Slip Control

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**ABSTRACT**

**Introduction**: In electric traction systems, the efficient conversion of electrical energy into mechanical energy is a key requirement for ensuring vehicle propulsion. This process relies on a powertrain composed of essential components such as electric motors, mechanical transmissions, and wheels in direct contact with the road surface. However, these systems are subject to significant mechanical disturbances, particularly the loss of wheel adhesion, which can adversely affect both vehicle stability and overall performance. To overcome this challenge, the development of robust control strategies is crucial, including advanced observation and regulation techniques. In this context, intelligent approaches such as fuzzy logic control offer a promising solution to enhance system performance under varying adhesion conditions.

**Objectives**: The objective of this study is to investigate the application of a fuzzy logic-based control strategy for anti-slip regulation in electric vehicle traction systems, aiming to improve vehicle stability and performance under low-adhesion conditions.

**Methods**: The methodology adopted for this research comprises the development of a fuzzy logic-based control strategy to mitigate wheel slip. A simulation model of an electric powertrain was implemented to evaluate the controller's response to abrupt changes in road conditions. Data collection was carried out through simulation results analysis.

**Results**: The results revealed that the fuzzy logic controller stabilized wheel speeds and mitigated slip across varying road conditions. These outcomes confirm the strategy's effectiveness, with limitations noted under extreme slip conditions, as discussed within the theoretical framework.

**Conclusions**: This work demonstrates the effectiveness of a fuzzy logic-based anti-slip control strategy for electric traction systems. Simulation results confirm that the proposed approach successfully regulates the rotational speeds of the driven wheels and compensates for disturbances caused by adhesion loss. By maintaining vehicle stability even under adverse conditions such as wet or icy roads, this method proves to be both reliable and robust. Therefore, the application of fuzzy logic control presents a valuable perspective for improving the safety and performance of electric vehicles.

**Keywords:** Electric traction system, Adhesion loss, Wheel slip, Anti-slip control, Fuzzy logic, Intelligent control, Dynamic stability, ASR system, Robust control, Electric vehicle.

## INTRODUCTION

The control of an electric vehicle is primarily based on the management of its powertrain, which encompasses the systems responsible for converting electrical energy into mechanical energy to enable the vehicle's movement. This

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powertrain includes, in particular, electric motors, mechanical gearboxes, power interfaces (such as inverters), and transmission components. In modern architectures, and particularly in vehicles equipped with in-wheel motors, this control is carried out in a decentralized manner, with each driven wheel being powered directly by an independent motor. Thus, the control of the powertrain essentially involves precisely managing the in-wheel motors by adjusting parameters such as electromagnetic torque, rotational speed, or angular position. This control is implemented through advanced control algorithms (vector control, DTC, fuzzy logic, etc.), integrated into the electronic control units (ECUs). The dynamic management of the in-wheel motors not only allows for controlling the vehicle's acceleration or braking, but also ensures safety functions such as adhesion loss management, torque distribution, and energy consumption optimization. [1-3].

The control of an electric vehicle essentially relies on the management of its powertrain, which is closely linked to the individual control of in-wheel motors. This approach enables precise and dynamic adjustment of key parameters such as motor torque, rotational speed, and the distribution of tractive effort among the wheels. The control of in-wheel motors is ensured by advanced control algorithms (vector control, direct torque control – DTC, adaptive control, fuzzy logic, etc.), embedded within onboard electronic control units (ECUs). These algorithms process sensor data in real time (including speed, position, current, temperature, and adhesion) to adjust control commands and optimize the vehicle’s dynamic behavior [3-5].

The control of in-wheel motors therefore ensures not only longitudinal control (acceleration/braking), but also more advanced functions such as torque distribution between the wheels, correction of adhesion losses, and energy management based on the vehicle’s operating conditions. This approach enhances the stability, safety, and energy efficiency of the electric propulsion system, while providing high control flexibility for advanced or autonomous driving functions.

Unlike internal combustion engines, the torque produced by electric motors can be accurately estimated and controlled as a function of the motor current. Leveraging these new torque regulation techniques, this work explores the application of an anti-slip control method for electric vehicles, based on managing wheel acceleration to modulate motor torque [6, 7].

One of the major challenges in an electric traction system is the loss of adhesion of a wheel, which represents a significant mechanical disturbance affecting the system's stability and performance. This phenomenon occurs when a driving wheel slips on the road surface, thereby reducing the effectiveness of the traction system. Loss of adhesion primarily occurs under conditions such as slippery surfaces (rain, snow, ice), sudden acceleration or hard braking, uneven load distribution on the wheels, or poor tire condition and inadequate pressure [8].

The loss of adhesion of a wheel disturbs the traction chain by decreasing energy efficiency and inducing torque and speed fluctuations, which can result in vibrations and potential mechanical damage. It also produces inaccurate signals for control systems, undermining system stability, and may lead to component overheating, thereby accelerating their degradation. A solution proposed in this work consists of using a fuzzy logic-based technique, applied to the longitudinal control of the vehicle, to ensure the anti-slip safety function.

## 2. PRINCIPLE OF MECHANICAL DISTURBANCE DUE TO LOSS OF ADHESION IN AN ELECTRIC TRACTION SYSTEM

As part of this study, the chosen configuration for the electric vehicle's traction chain is a four-wheel-drive (4WD) architecture, in which each wheel actively contributes to the vehicle's propulsion. Motors M1 and M2 are placed on the front axle, while M3 and M4 are located on the rear axle, forming an all-wheel drive system. This configuration offers several advantages: improved torque distribution, optimized traction on all types of terrain, and enhanced dynamic response, particularly under low-adhesion conditions. The traction system under study is illustrated in Figure 1 and primarily consists of the following components: a battery pack, power converters (inverters), and four independent in-wheel motors. Each motor is individually controlled using a dedicated control system, allowing precise management of the torque delivered to each wheel based on road conditions and driving parameters. This architecture provides an ideal framework for developing and validating advanced anti-slip control strategies, such as the fuzzy logic-based approach proposed in this work [6] [7] [10].

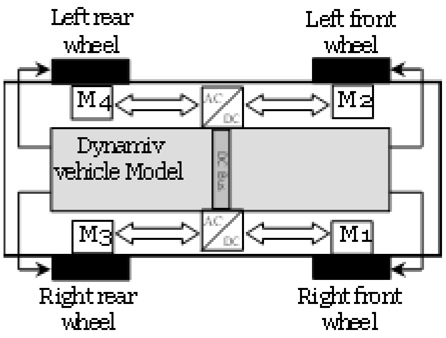


Figure 1: Schematic of the traction system architecture.

In an electric traction system, the primary objective is to efficiently convert electrical energy into mechanical energy to propel the vehicle. This process relies on a traction chain that includes components such as electric motors, mechanical gearboxes, drive shafts, and, most importantly, the wheels that ensure direct contact with the road surface. One of the major challenges in this system is the loss of adhesion of a wheel, which represents the primary mechanical disturbance that can affect the stability and performance of the entire system.

### a. Nature of Adhesion Loss

Adhesion loss occurs when there is slip between the driven wheel and the road surface. This phenomenon primarily occurs under the following conditions:

- Slippery surfaces (rain, snow, ice)
- Sudden acceleration or intense braking
- Uneven load distribution across the wheels
- Poor tire condition or incorrect tire pressure

### b. Consequences on the Traction Chain

When the wheel loses its adhesion, several disturbances occur in the traction chain:

- **Disturbance of the transmitted torque**: The torque provided by the electric motor is no longer effectively converted into propulsion force. The system may continue to transmit torque, but it is wasted in the form of slip, which reduces energy efficiency.

- **Mechanical imbalance**: The slip of a wheel can cause sudden variations in torque and rotational speeds within the transmission components. This generates vibrations, mechanical shocks, and may eventually damage the mechanical parts.

- **Chain reactions in the control system**: Control systems (such as vector control or DTC) receive erroneous information (incorrect speed, under-estimated torque), which may lead to inappropriate corrective actions (overcompensation, oscillations, loss of system stability).

- **Abnormal heating of components**: Prolonged slip can cause overheating of the motor or transmission devices (clutch, differential, etc.), accelerating their wear.

### Description of the slip phenomenon

In an electric traction system, the loss of adhesion of a driven wheel, also known as slipping, is one of the most critical mechanical disturbances. This phenomenon occurs when a driven wheel slips relative to the road surface, usually due to a sudden reduction in the road's adhesion capacity (e.g., transition from a dry surface to a wet or slippery surface). This loss of adhesion causes an imbalance in the transmission of the traction effort between the wheels, thereby disrupting the proper functioning of the traction system. Indeed, the force transmitted to the ground by the affected wheel becomes insufficient, leading to a sudden variation in its adhesion function. This results in a sudden increase in its rotational speed, as the applied motor torque remains constant while the resisting torque (related to adhesion) drops sharply.

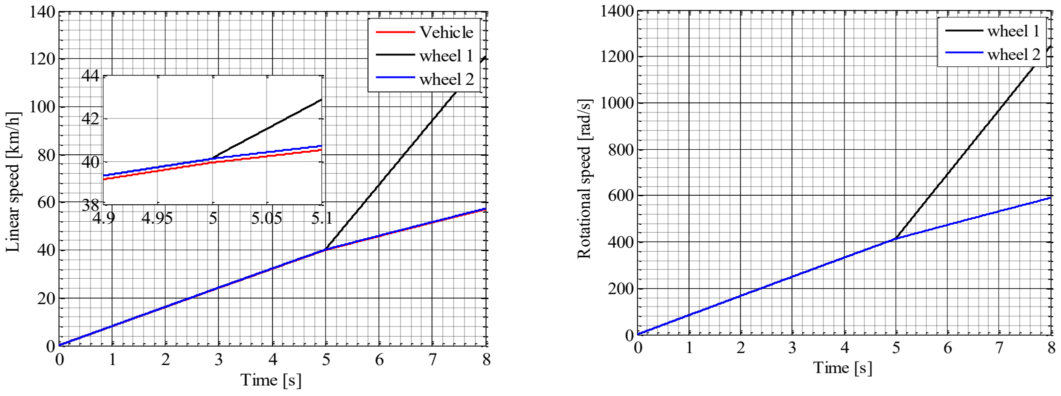
In this study, the slip phenomenon is highlighted through a numerical simulation. The vehicle under investigation is equipped with four independent wheel motors, controlled by a direct torque control (DTC) system.

The simulation experiment consists of maintaining a constant torque of 30 N·m on each wheel, then at t = 5 s, transitioning the left front wheel (wheel 1, motor 1) from a dry surface to a wet surface, while the vehicle is in the acceleration phase. Upon the loss of adhesion, a divergence in the rotational speed of the disturbed wheel is observed compared to that of the other wheels or the vehicle (Figure 2(a)). The affected wheel begins to accelerate excessively (Figure 2(b)), as the motor continues to supply the imposed torque despite the reduction in mechanical resistance.

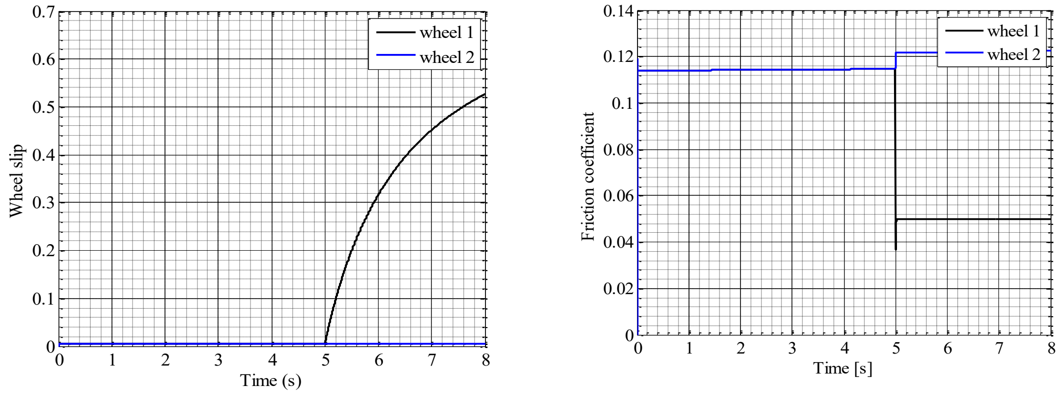
This phenomenon leads to two major consequences that can compromise the vehicle's stability [8]:

- **A traction force imbalance**: The loss of adhesion of one wheel causes a disruption in the symmetrical distribution of propulsion forces between the wheels (Figure 2(c)). This imbalance can lead to trajectory drift or improper load transfer, thus disturbing the vehicle's longitudinal behavior.
- **A reduction in lateral forces**: Increased slip reduces the ability of the tires to generate the necessary lateral forces to keep the vehicle on its trajectory, particularly in turns or during dynamic maneuvers. This weakens the vehicle's directional stability, especially on low-adhesion surfaces.

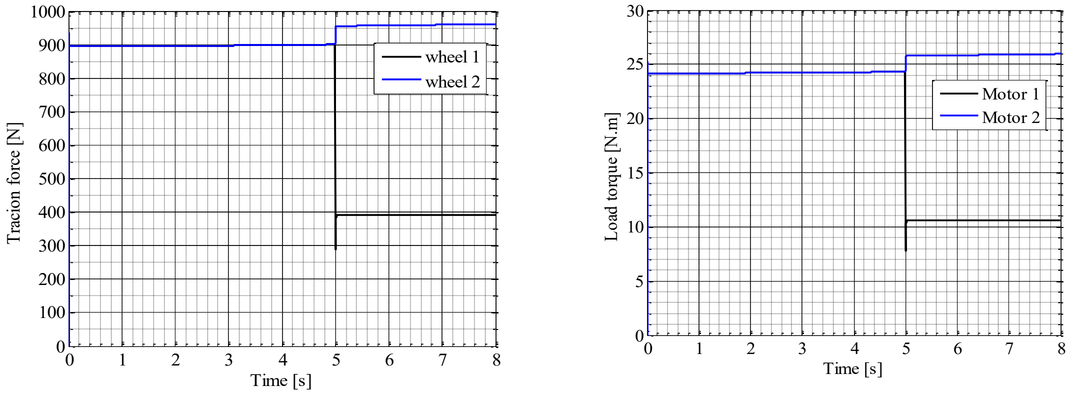
Thus, slipping, although a localized phenomenon at the level of a single wheel, affects the overall dynamic behavior of the vehicle. This fully justifies the use of intelligent control strategies capable of detecting and quickly compensating for the loss of traction, in order to preserve the safety, stability, and energy efficiency of the traction system.



*(a) Linear speed of the vehicle and the wheels* *(b) Rotational speeds of the wheels*



*(c)* Wheel slip *(d) Friction coefficient*



*(e) Traction forces* *(f) Load torque*

Figure 2 : Simulation Results – Slip Phenomenon

## 3. INTELLIGENT SLIP CONTROL IN ELECTRIC TRACTION SYSTEMS

Static friction-slip models are commonly used to simulate the longitudinal dynamics of vehicles, as illustrated in Figure 3 [11, 12]. These models describe the relationship between the longitudinal friction coefficient ( $\mu$ ) and the slip rate ( $\lambda$ ). This relationship exhibits a typical three-phase behavior. In the first phase, known as the linear phase, the friction coefficient increases proportionally with the slip. Then, in a nonlinear region, the coefficient reaches a maximum value, corresponding to the optimal adhesion. Beyond this point, the system enters a decreasing region (often referred to as the thermal region), where the friction coefficient decreases with increasing slip, indicating a loss of efficiency in the transmission of driving force. In general, the maximum of the friction coefficient is reached for a slip of about 10% ( $\lambda \approx 0.1$), which serves as a reference for optimal adhesion control.

When an excessive motor torque is applied to a drive wheel on a slippery surface, the slip rate increases rapidly. This increase leads to exceeding the optimal point on the adhesion characteristic, shifting the wheel's operation into the decreasing region of the force-slip curve. In this region, the friction coefficient decreases despite the increase in applied torque, leading to a loss of effective contact between the wheel and the road. This imbalance results in a slip phenomenon, significantly reducing traction capability and compromising the stability of the vehicle [6, 7].

The modeling of the vehicle's longitudinal dynamics allows for the description of the vehicle's motion evolution in the direction of advancement (longitudinal axis) [13]. This dynamics is typically modeled using a set of equations that estimate the acceleration or deceleration of the vehicle based on the torque applied to the driven wheels. It is expressed as:

$$J_{\omega}\dot{\omega}_{\omega} = C - fR_{\omega} \tag{1}$$

$$M_{v}\dot{v} = F_{d} \tag{2}$$

$$F_{d} = f \tag{3}$$

The linear acceleration of the wheel and the vehicle's acceleration are related by the following equation:

$$\dot{v}_{\omega} = \frac{CR_{\omega} - M_{v}\dot{v}R_{\omega}^{2}}{J_{\omega}} \tag{4}$$

We denote $\alpha$ as the ratio between the vehicle's acceleration and the wheel's acceleration, expressed by:

$$\alpha = \frac{\dot{v}}{\dot{v}_{\omega}} \tag{5}$$

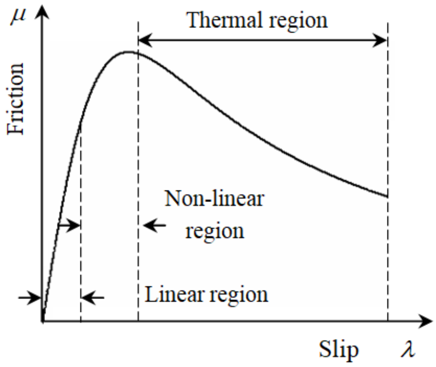


Figure 3: Friction profile as a function of slip.

Since the vehicle's acceleration is difficult to measure directly, a new parameter is introduced for the proposed anti-slip control. This parameter is defined as the ratio between the wheel's acceleration and the applied motor torque, whether it is a traction or braking torque. This ratio allows for the indirect monitoring of the vehicle's dynamic variations and enables the adaptation of motor torque control to maintain the optimal wheel adhesion [6, 7, 10]:

$$R_{at} \cong \frac{\dot{v}_{\omega}}{C} = \frac{R_{\omega}}{J_{\omega} + \alpha M_{v} R_{\omega}^{2}} \tag{6}$$

On the other hand, the ratio between the vehicle's acceleration and the wheel's acceleration can be expressed in terms of this parameter as follows:

$$\alpha = \frac{\frac{R_{\omega}}{R_{at}} - J_{\omega}}{M_{v} R_{\omega}^{2}} \tag{7}$$

In the case of acceleration, the relationship between the slip coefficient and speed can be expressed as follows:

$$\lambda = 1 - \frac{v}{v_{\omega}} = 1 - \frac{\int_{0}^{t} \dot{v}(t)dt}{\int_{0}^{t} \dot{v}_{\omega}(t)dt} = 1 - \frac{\int_{0}^{t} \alpha \dot{v}_{\omega}(t)dt}{\int_{0}^{t} \dot{v}_{\omega}(t)dt} \tag{8}$$

The anti-slip regulation strategy adopted in this work relies on the indirect control of the ratio between the longitudinal acceleration of the vehicle and that of the wheel, denoted by the parameter $\alpha$. This ratio is maintained within a range defined by safety limits, making $\alpha$ a bounded function over time. Assuming that α is constrained between a lower bound $\alpha_L$ and an upper bound $\alpha_H$, and relying on equation (8) related to the slip coefficient, it is then possible to express the admissible range of the slip coefficient using the following relationship [10]:

$$1 - \frac{\int_{0}^{t} \alpha_{H} \dot{v}_{\omega}(t)dt}{\int_{0}^{t} \dot{v}_{\omega}(t)dt} \leq \lambda \leq 1 - \frac{\int_{0}^{t} \alpha_{L} \dot{v}_{\omega}(t)dt}{\int_{0}^{t} \dot{v}_{\omega}(t)dt} \tag{9}$$

It is important to note that, given the relationship between the slip coefficient $\lambda$ and the parameter $\alpha$, this coefficient belongs to the interval $\left[1-\alpha_{H}, 1-\alpha_{L}\right]$. Therefore, the admissible range for the ratio between the wheel's acceleration and the applied motor torque can also be determined based on the lower bound $\alpha_L$ and upper bound $\alpha_H$, and is expressed as follows:

$$R_{atH} = \frac{R_\omega}{J_\omega + \alpha_L M_v R_\omega^2} \tag{10}$$

$$R_{atL} = \frac{R_\omega}{J_\omega + \alpha_H M_v R_\omega^2} \tag{11}$$

Where $R_{atL}$ and $R_{atH}$ represent the lower and upper limits of this ratio, respectively.

As mentioned earlier, directly obtaining the parameter $\alpha$ is difficult to achieve in practice, so an indirect regulation approach is adopted. This approach relies on controlling the ratio $R_{at}$, which is more accessible in practice, to keep it within the interval $[R_{atL}, R_{atH}]$. This control ensures that $\alpha$ remains within its admissible range, in line with the objectives of the anti-slip strategy.

In braking situations :

$$\lambda = \frac{v_\omega}{v} - 1 = \frac{\int_0^t \dot{v}_\omega(t)dt}{\int_0^t \dot{v}(t)dt} - 1 = \frac{\int_0^t \dot{v}_\omega(t)dt}{\int_0^t \alpha\dot{v}_\omega(t)dt} - 1 \tag{12}$$

and

$$\frac{1}{\alpha_H} - 1 \leq \lambda \leq \frac{1}{\alpha_L} - 1 \tag{13}$$

The anti-slip control proposed in our study, based on the regulation of the parameter $R_{at}$, is consistently applicable to both operating modes of the vehicle: acceleration and braking. This approach allows for optimal slip control in both situations by adjusting the $R_{at}$ ratio, which represents the linear acceleration $\dot{v}_\omega$ of the wheel required to drive the motor torque $T_m$. Thus, this strategy ensures optimal traction while respecting the dynamic constraints of the system.

$$R_{at} \cong \frac{\dot{v}_\omega}{C_m} \tag{14}$$

The problem being studied is related to the nonlinear nature of the tire-road contact, as well as the constraint imposed on the vehicle's acceleration, which must be maintained within a specified range. If the wheel's acceleration deviates significantly from the vehicle's acceleration, the vehicle enters a slipping situation. Generally, a slip coefficient $\lambda$ between 0.1 and 0.3 is considered optimal [6, 7]. According to equation (8), the corresponding parameter $\alpha$ should be between 0.7 and 0.9 to avoid any vehicle slipping. If $\alpha$ is lower than 0.7, the wheel loses traction, leading to slipping. On the other hand, if $\alpha$ exceeds 0.9, the vehicle's acceleration performance is compromised [10].

As indicated in equation (7) and Figure (3), the parameter $R_{at}$ is related to $\alpha$. Thus, the wheel slip can be estimated and controlled using the parameter $R_{at}$. It is important to note that in equation (6), the denominator is directly linked to the total inertia effective on the motor shaft, and $\alpha$, the ratio between the vehicle's acceleration and the wheel's acceleration, must be kept constant. Maintaining wheel-road contact in the pseudo-slip regions, characterized by low slip, is desired to bring the vehicle's equivalent inertia to its nominal value. Therefore, the wheel's acceleration can be controlled by adjusting the allowable variation range of the equivalent inertia using the parameter $R_{at}$. To achieve an optimal balance between the vehicle's acceleration performance and the prevention of wheel slip, it is preferable to maintain a fixed value of $R_{at}$ within an acceptable range.

The vehicle dynamics exhibit marked non-linearity, along with inherent uncertainties in the system. Fuzzy regulators have proven their effectiveness in controlling complex nonlinear systems. Consequently, an anti-slip controller based on fuzzy logic is proposed to regulate the $R_{at}$ parameter, ensuring that it remains within the range defined by $\alpha$, which is between 0.7 and 0.9.

The block diagram of the anti-slip control, illustrated in Figure 4, is based on fuzzy adjustment of the $R_{at}$ parameter, which is calculated from the motor torque and the acceleration of the driven wheel. A fuzzy controller is designed based on $R_{at}$ and its derivative to determine the variation of the compensation torque $\Delta T_c$. This variation is then integrated to provide the necessary compensation torque $T_c$ to prevent vehicle slip.

Therefore, the control motor torque $T_m^*$ is adjusted according to the following equation:

$$T_m^* = T_{cmd} - \sum \Delta T_c \tag{15}$$

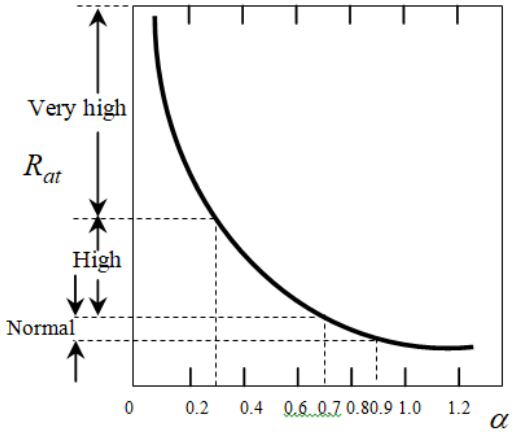


Figure 4 : Correlation between $\alpha$ and $R_{at}$

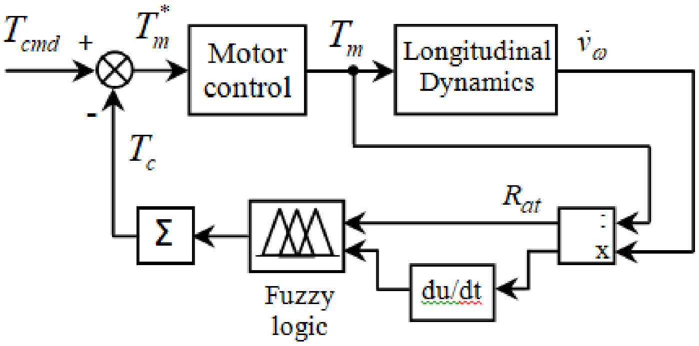


Figure 5: Fuzzy anti-slip control diagram based on the parameter $R_{at}$.

In order to define the basic rules for our fuzzy controller, it is essential to establish the relationship between the parameter $R_{at}$ and the variation of the compensation torque $\Delta T_c$. Based on the relationship between $\alpha$ and $R_{at}$ represented in Figure 4, the following analysis can be made: If $R_{at}$ is "very high" (which corresponds to $\alpha$ being less than 0.2), this indicates a potentially dangerous situation that could lead to severe vehicle slipping.

In this case, a significant increase in the compensation torque is required to reduce the motor torque. Conversely, if $R_{at}$ is "very low" (with $\alpha$ greater than 0.9), the vehicle's acceleration performance will be limited. Compared to the case where $R_{at}$ is "very high," this situation is not as critical, and a slight decrease in the compensation torque can be applied.

The relationship between the input and the output of the fuzzy controller is shown in Figure 6.

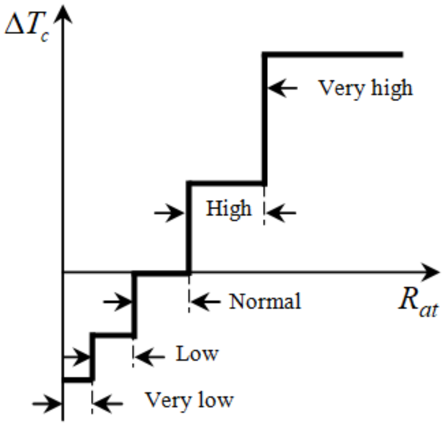
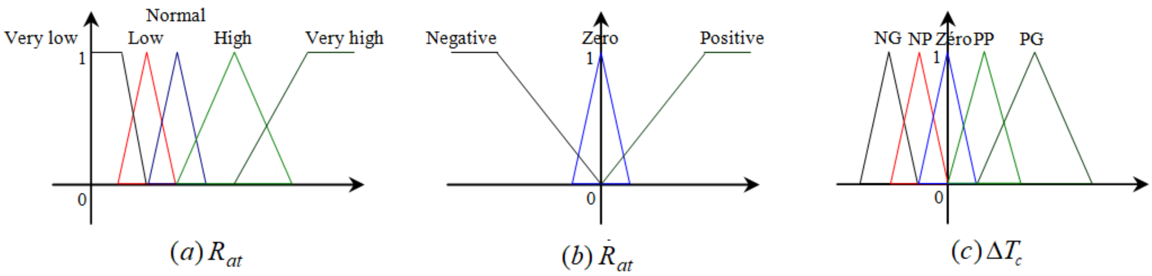


Figure 6: Correlation between $\Delta C_c - R_{at}$ defining the basic rules.

Figure 7 presents the membership functions of the input and output variables of the fuzzy controller used for anti-slip control. Table 1, on the other hand, details the fuzzy rules applied to regulate the anti-slip system. These rules and membership functions are essential for precisely adjusting the motor torque and preventing slipping, while optimizing vehicle performance under various driving conditions.

Table 1: Fuzzy Decision Rules.

| | $\dot{R}_{at}$ | | |
|---|---|---|---|
| $R_{at}$ | Negative | Zero | Positive |
| Very high | PP | PG | PG |
| high | zero | PP | PP |
| Normal | NP | zero | PP |
| Low | NP | NP | zero |
| Very low | NG | NG | NP |



$(a)\, R_{at}$ $(b)\, \dot{R}_{at}$ $(c)\, \Delta T_c$

Figure 7: Membership functions of the fuzzy controller for anti-slip control.

## 5. RESULTS AND DISCUSSION

### Traction System Behavior in the Presence of slip

In this simulation test, the objective is to highlight the effectiveness of the vehicle's longitudinal control, based on fuzzy logic, by ensuring the anti-slip safety function. To achieve this, a slip scenario is simulated at t = 5 s, where a wheel (driven by motor 1) experiences a sudden loss of adhesion. This slip is caused by the instantaneous transition of wheel 1 from a dry surface (characterized by normal adhesion) to a wet surface, as shown in Figure 8. This change in road condition leads to a significant loss of adhesion.

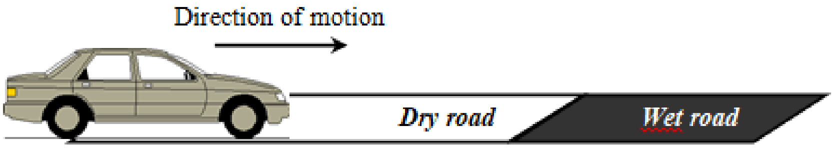
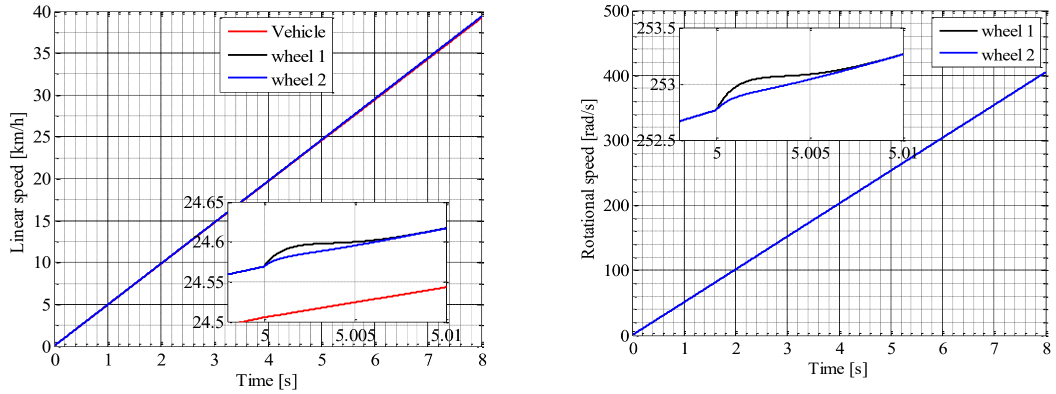


Figure 8: Transition from a dry to a wet road surface – Slip phenomenon.

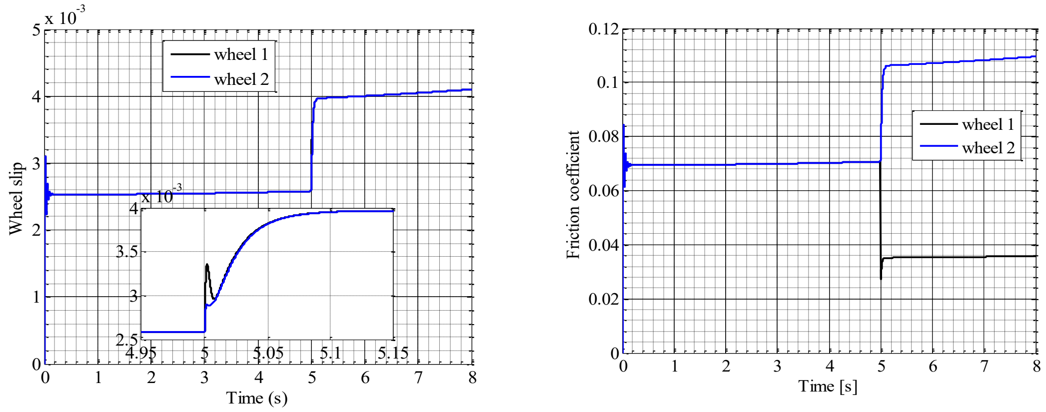
Behavior of the traction system in the presence of slip. In this simulation test, the goal is to highlight the effectiveness of the vehicle’s longitudinal control, based on fuzzy logic, in ensuring the anti-slip safety function. To do this, a slip scenario is simulated at t = 5 s, where a wheel (driven by motor 1) experiences a sudden loss of traction. This slip is caused by the instantaneous transition of wheel 1 from a dry surface (characterized by normal traction) to a wet surface, as illustrated in Figure 8. This change in road condition leads to a significant loss of traction. During this acceleration phase, the motor torque command applied to each wheel is kept constant at 30 N.m. A notable first consequence of the proposed anti-slip strategy is the synchronization of the dynamic behavior of the two motors, even in the presence of traction loss (see Figure 9(a)). Regarding the rotational speed, wheel 1 maintains a nearly constant speed, which indicates the effective suppression of the slip phenomenon (Figure 9(b)). An enlargement shown in Figure 5(b) highlights the proper decoupling between the two control processes. Moreover, due to the robustness of the control strategy, motor 1 manages to maintain a stable speed without any loss of control. As a result, wheel 1 shows no signs of slip. The speed is therefore perfectly regulated, demonstrating the effectiveness of the implemented anti-slip system.

The fuzzy controller operates to reduce the speed gap between the two driving wheels, thereby contributing to a balanced distribution of the traction effort. This results in an effective mitigation of the slip phenomenon, made possible by regulating the relative slip rate, Figure 9(c). Although a moderate increase in the slip rates of both wheels is observed, they remain within the so-called pseudo-slip zone, ensuring optimal traction and robust dynamic behavior of the vehicle, Figure 9(c). The behavior of the motor torques is illustrated in Figure 9(e). It is observed that, during a loss of traction, the load torque associated with the affected wheel — in this case, the driven wheel 1 — decreases significantly. This drop in torque reflects a rapid adaptation of the control system to the degradation of traction conditions.

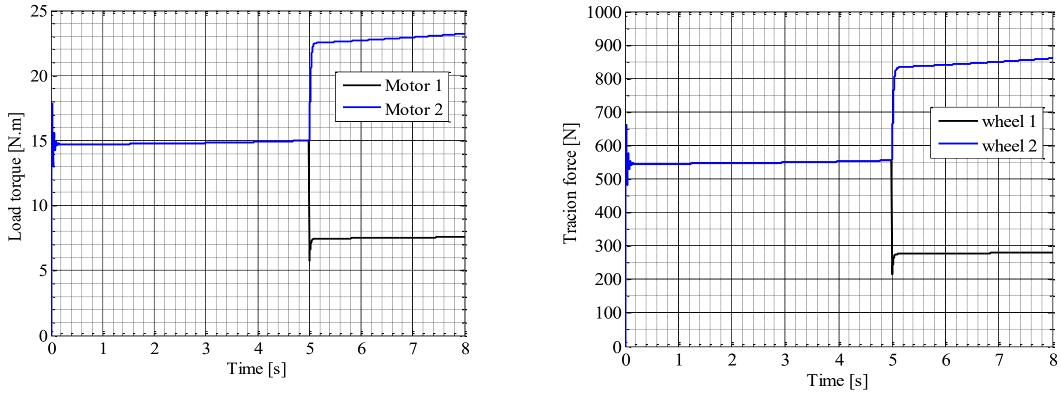
The reduction in the motor torque applied to the disturbed wheel helps limit slipping, thereby promoting a progressive re-adhesion. This result highlights the effectiveness of the automatic torque reduction strategy, which is a key element in the proper functioning of the anti-slip control system. The temporal trajectories of the traction forces in the presence of slipping are shown in Figure 9(f). The loss of adhesion of the driven wheel 1 is manifested by a significant drop in its traction force. This decrease directly reflects the impact of the degradation of adhesion conditions on the transmission of effort to the ground.



*(a) Linear speed of the vehicle and the wheels* *(b) Rotational speeds of the wheels*



*(c) glissement des roues* *(d) Friction coefficient*



*(e) Load torque* *(f) Forces de traction*

Figure 9 : *Simulation* results – *Système d'antipatinage*

## 6. CONCLUSION

One of the major challenges in the design of electric traction systems lies in the management of loss of adhesion, a phenomenon that can significantly affect the vehicle's dynamic stability and the performance of the traction chain. To address this issue, the implementation of robust control strategies, such as the integration of intelligent anti-slip systems, emerges as a relevant solution to limit or compensate for the effects of slipping. In this work, a control approach based on fuzzy logic has been developed and applied to an electric vehicle, aiming to ensure effective regulation of the slip phenomenon. This strategy leverages the adaptive capabilities of fuzzy logic to dynamically modulate the motor torque based on the wheel/ground adhesion state, while considering the inherent nonlinearities in the tire contact. The results from numerical simulations highlight the fuzzy controller's ability to maintain optimal traction, stabilize motor speeds, and effectively mitigate disturbances caused by loss of adhesion. These performances confirm the relevance of the proposed approach to enhance the safety and robustness of electric vehicle traction systems, particularly in low-adhesion contexts.

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