# A Review on Architect of Passenger Vehicle Brake Control System and Different Control Strategies

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***Abstract-*** *The vehicle's braking system is a critical component that ensures safety and stability in a variety of situations. To increase control, the braking unit is connected with the Anti-Lock Braking System (ABS) and Traction Control System (TCS) and provides a variety of control strategies. The current review presents the core architecture of the braking control unit, as well as a performance comparison of several ABS and TCS control strategies, such as PID control and fuzzy logic control.*

***Index terms-*** *Brake Control Unit, ABS, TCS, Vehicle Control System.*

## 1. Introduction

Automobiles, motorcycles, trains, and planes all have brake systems. Friction is a key performance component in brake systems as well as a possible source of unwanted noise and vibration. Different types of automobiles' brake systems have related and similar architectures and principles.

When it comes to vehicle braking systems categorization, there are disc and drum brakes in two and four-wheeler passenger vehicles, as well as pneumatic, hydraulic, and electromagnetic braking systems in big commercial vehicles.

To improve performance, safety, and stability, modern car barking systems are integrated with ABS and TCS. ABS shortens the stopping distance and maintains vehicle control while braking, ensuring safety and performance. TCS offers traction during acceleration, allowing for stability and performance to be maintained.

A suitable braking system for a land vehicle is one that can swiftly halt or reduce the vehicle's speed while maintaining the vehicle's direction and recovering as much kinetic energy as possible. Generally, the braking control system is used for safety, but it can also be used for stability and performance maintenance in certain situations.

## 2. Architect of Braking System

The design of a single wheel brake structure is shown in Figure 1. Each wheel has a different connection because each wheel demands a different amount of braking force. The pressure sensor first measures the pressure. The fluid is subsequently emptied into the accumulator, after which the control unit estimates the required braking force and the motor produces it. In the event that the control unit fails, the electric valve opens, and the system operates as a standard mechanical/conventional braking system. [1][2]

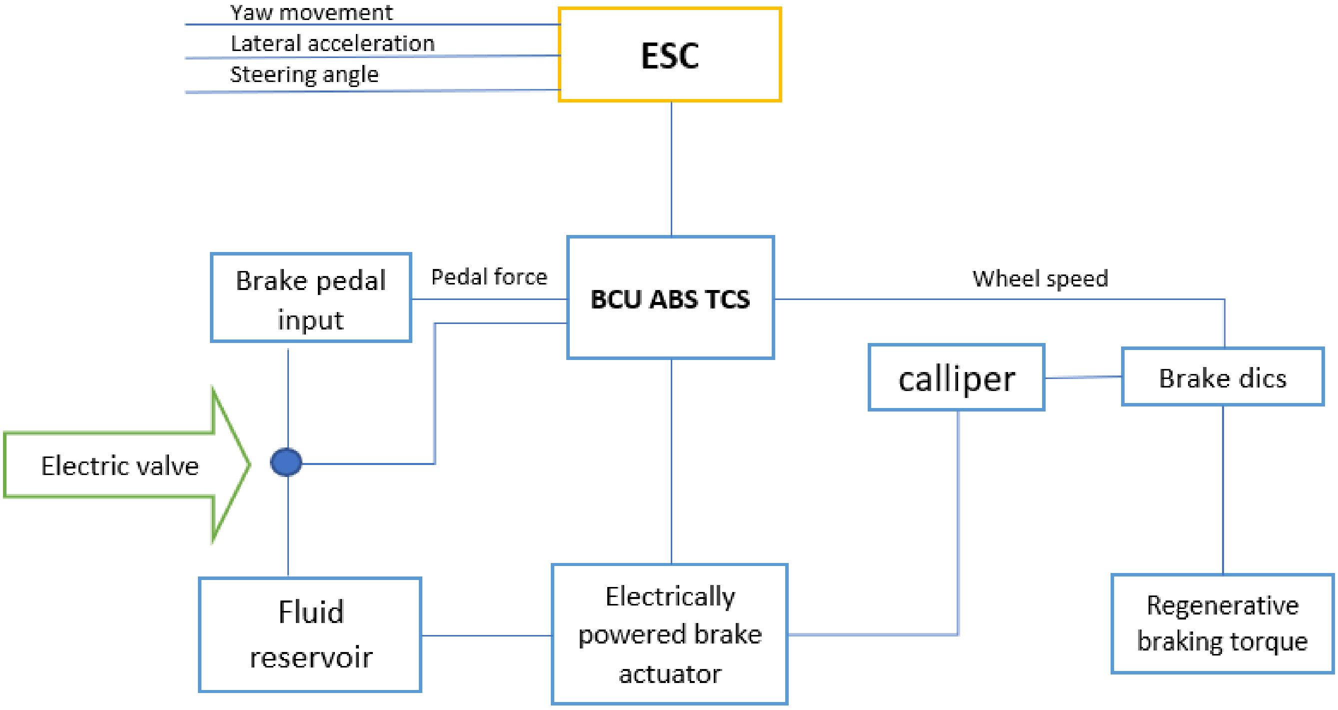


**Figure - 1**: Architect of typical braking system

## 3. Anti-lock Braking System

It is meant to keep a vehicle steerable and stable during hard braking moments by preventing wheel lock, Hence ABS is widely considered as a vital addition to road safety.

ABS keeps the wheels from locking up, ensuring directional stability. While working, ABS considers a variety of elements such as vehicle speed, acceleration/deceleration, friction, and so on. The anti-lock brakes (ABS) play a crucial function in maintaining traction. The traction force (F) is proportional to the normal load (N) on the tyre, with the equation F=μN. μ is known as adhesive coefficient and it depends on tyre condition as well as road conditions. Generally adhesive coefficient is considered as function of slip ratio (s). [2]

**Table 1-** Slip ratio equations in different scenario

| **Case** | **Equation** | Were, |
|---|---|---|
| Acceleration | $s = \frac{R\omega - v}{r\omega}$ | s = Longitudinal slip ratio<br>V= vehicle velocity |
| Braking | $s = \frac{R\omega - v}{v}$ | R = Wheel radius<br>ω=angular velocity of wheel |

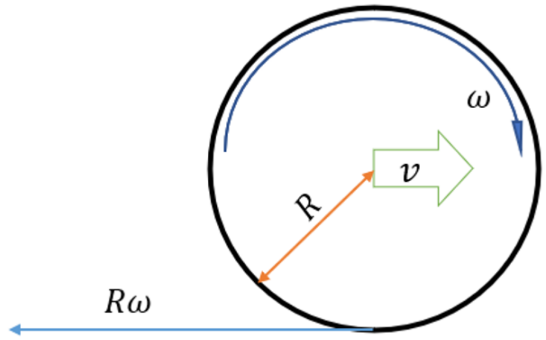


**Figure - 2:** Dynamic Wheel Schematic

Table 1 provides principal equation for the construction of ABS algorithm. While braking, wheel speed changes first and then vehicle speed due to large momentum difference, at a certain stage the wheel velocity reaches zero but vehicle still moves with a certain velocity. At this situation slip value become 1 and we call it wheel lock-up. ABS take input form the speed sensor, which are present in all the four wheel or a pair in front and rear, if sensor deducts slip ratio is in uncontrolled region, ABS immediately changes the brake pattern to maintain the control and thus avoiding the situation of wheel lock-up. Compared with conventional antilock system, the electronically controlled brake system eliminates the mechanical movement in the solenoid valve, which switches between high fluid pressure and low fluid pressure. Thus, its control is much faster and more accurate. [2][3]

If we focus on its categorizations based on number of valves and speed sensor input, we have 4 categories with the sub categorizations too. Here we will take 4-wheeler into the consideration. It is simply dividing the study based on independent brake force control over each wheel and common brake force control i.e., having different valve for all wheels and single valve for rear wheels/front wheels respectively.

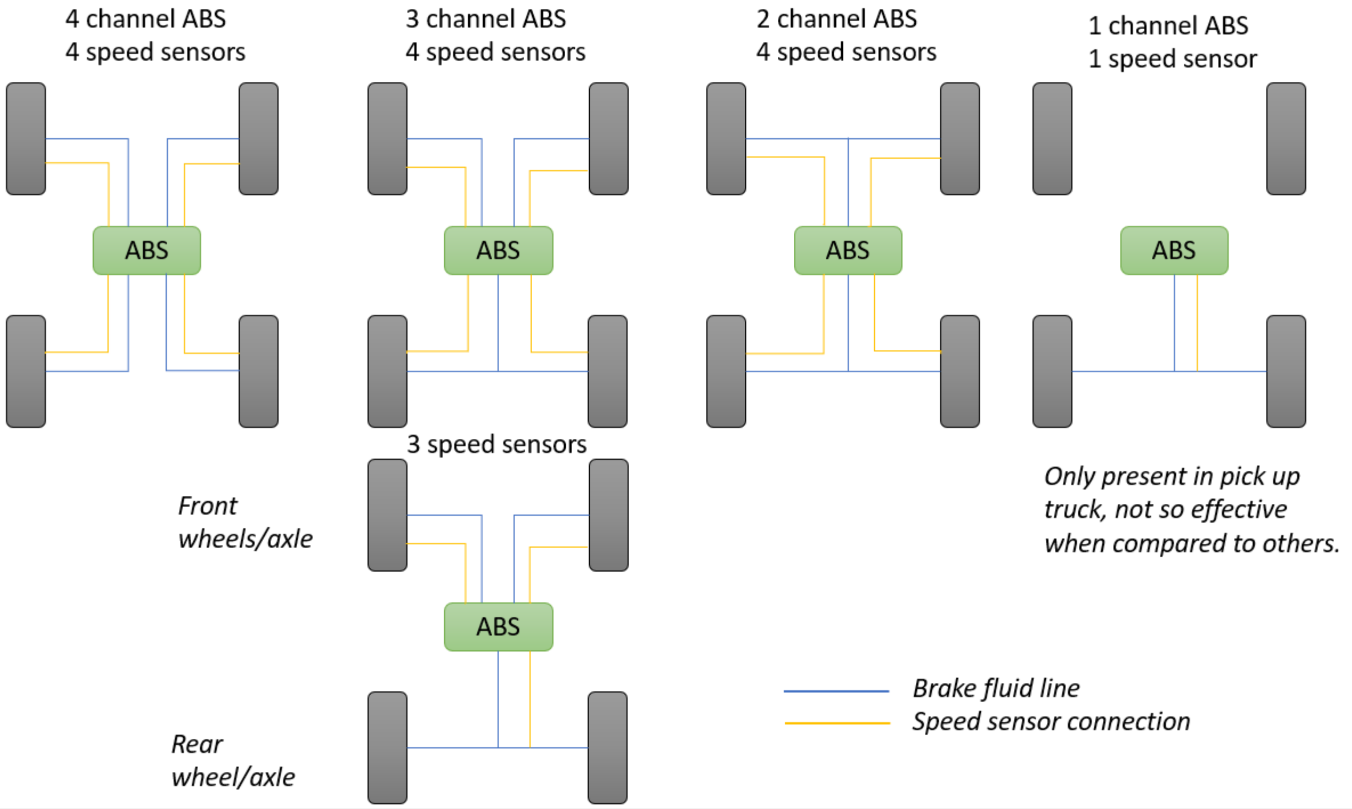


**Figure - 3**: Types of ABS

There are different control approaches for the design of ABS each has its own advantages and number of challenges to clear, such as:

(a) Optimum performance with maintaining passenger comfort.
(b) Maintaining stability with different braking force/Torque in different wheel.
(c) Working with varying brake pad and road coefficient of friction.
(d) Depending on the road condition, high variation in braking force can be required, system must be quick to minimize the time delay.

**Table - 2:** Analysis of different control strategi for ABS

| Reference Title | Description & Parameters considered | Observation & Conclusion |
|---|---|---|
| Modelling and PID control of antilock braking system with wheel slip reduction to improve braking performance [4] | 5-DOF vehicle longitudinal dynamic model is utilized for the designing the ABS control.<br><br>Closed loop is generated and PID controller are used in inner and outer loop system to regulate the wheel longitudinal slip and maintaining brake torque for reducing stopping distance.<br><br>For simulation several parameters have been adopted from the modern vehicle, Mercedes Benz, which is using a V8 engine.<br><br>Front wheel base: 1.5 m<br>Rear wheel base: 1.5 m<br>Height of Vehicle: 0.6 m<br>Vehicle mass: 1626 Kg<br>Tyre radius: 0.3 m<br>Aerodynamic drag Co.: 0.29<br>Rolling resistance: 0.01<br>Viscous Friction co.: 0.1 Nm/radS-1<br>Single equivalent lag for throttle: 0.2 s<br>Single equivalent lag for brake: 0.3 s<br>Front brake constant: 13.33 Nm/Bar<br>Rear brake constant: 6.666 Nm/Bar<br>Inertia of wheel: 4.5 Kgm2<br>Final drive ratio: 2.82:1<br>First gear ratio: 3.56:1<br>Second gear ratio: 2.19:1<br>Third gear ratio: 1.41:1<br>Forth gear ratio: 1:1<br>Fifth gear ratio: 0.83:1 | Brakes are applied after vehicle reaches the speed of 60 m/s.<br><br>PDI control maintained the slip between 0.1 to 0.3 until the vehicle stops.<br><br>Compared to P, PI and PD, better performance is obtained in PID with less overshoot and settling time. |
| A combining sliding mode control approach for electric motor anti-lock braking system of battery electric vehicle [5] | The model proposed is verified under TruckSim environment. It consists of vehicle dynamic, suspension, power train model and tire magic formula.<br>Parameters of Vehicle:<br>Gross vehicle weight: 2200 Kg<br>Radius of tire: 364 mm<br>Wheel base: 3360 mm<br>Inertia of wheel: 1 Kg/m2<br>Unsprung Front mass: 450 Kg<br>Unsprung Rear mass: 550 Kg | Case 1. Low adhesion road<br>Initial speed is 50 km/hr, desired deacceleration is 1.4 m/s2, optimum slip is 0.06.<br>RL and RR wheel are in stable state variation of slip is observed in 0.06<br>Case 2. High adhesion road<br>Initial speed is 100 km/hr, desired deacceleration is 4 m/s2, optimum slip is 0.16.<br>Minimum oscillation in slip is observed, stability of RL and RR wheel also coincides. |

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| A fuzzy logic controlled Anti-lock Braking System (ABS) for improved braking performance and directional stability [6] | The fuzzy control developed consist of 2 parts, longitudinal and side-slip control.<br>Vehicle data:<br>Mass of vehicle: 1300 Kg<br>Inertia of vehicle: 1620 Kgm2<br>Radius of wheel: 0.33m<br>Inertia of wheel: 2.03 Kgm2<br>Track width front: 1.45 m<br>Track width rear: 1.45 m | Simulation was done for 3 kinds of road surface i.e., dry, wet and ice with 0.85, 0.5, 0.15 respectively as coefficient of friction.<br>For dry and wet road surface initial velocity is 100 km/hr, and for icy road initial velocity is 50 km/hr.<br>Braking torque is 3000 Nm, taken with step input.<br>Pre-specified slip is 0.075 in longitudinal member.<br>Less stopping distance is observed (45.3 m in dry road), vehicle deaccelerated with stability and possible to steer with small side slip. |

Each control approach is providing the control effectively, PID provides less settlement time and reduced steady state error. Focusing on longitudinal slip, PID and combine sliding model shows less amplitude in variation of slip (max variation is 0.12 to 0.22 of slip value in sliding model and 0.08 to 0.15 in PID control) and its reduction appears in a constant manner. In the presence of steering input PID is obtaining the controlled slip region with proper variation in individual wheel speed and slip.

## 4. Traction Control System

The working of TCS is similar to ABS, its job is to maintain traction during acceleration. People generally get confused between ABS and TCS operation, ABS acts during braking while TCS acts when vehicle accelerates [7]. The maximum torque needs to be transmitted to wheel is determined by the coefficient of friction generated between tyre and road surface. If toque exceeds the level, then wheel will lose grip results in losing the control of driver on vehicle [8].

Generally, ABS, TCS and ECM works together in order to maintain traction. Whenever slip is determined in uncontrolled region while acceleration, TCS sends command to ECU, which actuates the hydraulic pressure brakes to apply brakes, even the required brake pressure is also calculated by the processer, alternately TCS sends signal to ECM which reduces the engine torque by reducing throttle, this also save the fuel, here the actuator is fuel injector. In a genera EVs and hybrid vehicle, separate TCS switch is provided. When it is OFF, all the actuator valves off and vice-versa [9].

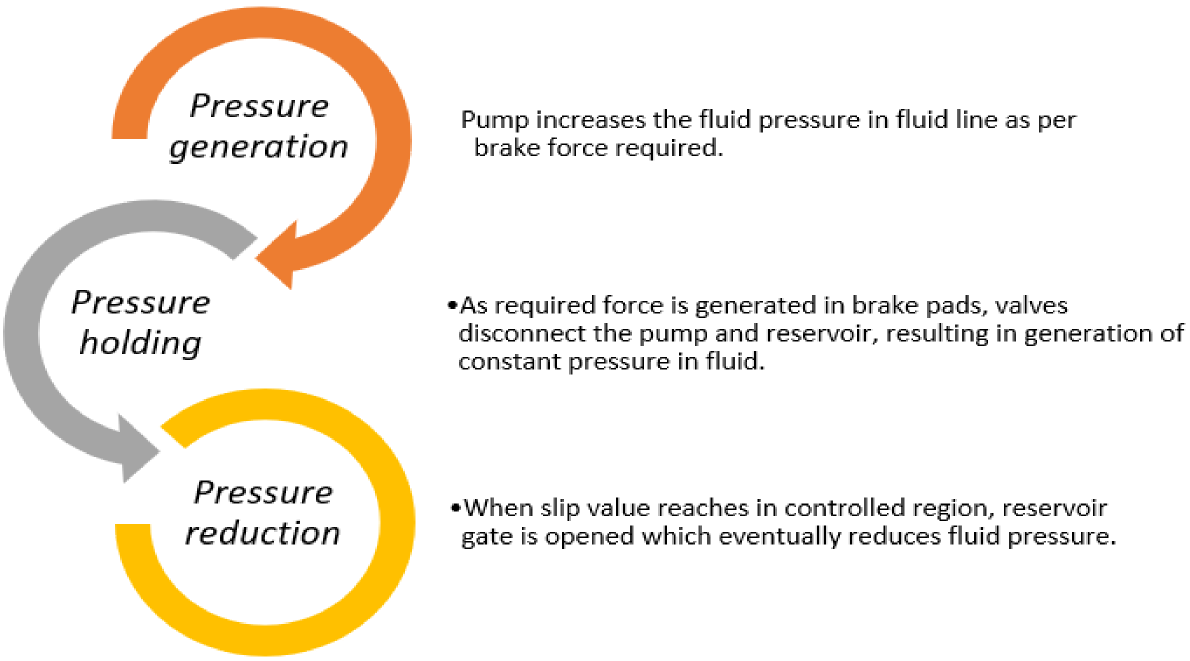


**Figure - 4:** Process of Brakes under TCS.

TCS has several control methods, major one are analysed and compaed in Table 3.

**Table - 3:** Comparisons of TCS Control Systems

| Reference Title | Description & Parameters considered | Observation & Conclusion |
|---|---|---|
| Development of Integrated Brakes and Engine Traction Control System. [10] | Fuzzy and PID control is utilized for controlling brakes and engine actuators respectively.<br><br>Vehicel paramets:<br>Vehicle mass: 1200 kg<br>Number of driving wheels: 2<br>Wheel radius: 0.3307 m<br>Wheel inertia: 2.656 kg.m2<br>Aerodynamic drag coefficient: 0.29<br>Rolling coefficient: 0.01 | Three cases were studied, excessive acceleration on dry road, wet road and transition from dry to wet road.<br><br>Initial velocity is taken as 5 m/s and required slip is kept as 0.18.<br><br>At initial stage for short duration of time slip exceeds target value, brake control takes the slip regulation role initially and after 3 sec engine control comes into play for smooth action, later after 7.6 sec brakes get deactivated in dry road and 6.7 sec on wet road.<br><br>In road transition condtion, it occurs after 15 sec hence longer action of TCS is present, at transition brake play for 0.35 sec role and throttle reduction is more. |
| Coordinated vehicle traction control based on engine torque and brake pressure under complicated road conditions [11] | Sliding mode control approach is present to achieve max driving acceleration and assistance of brake for slip regulation.<br><br>Vehicle parameter:<br>Vehicle mass: 1660 kg<br>Distance from front axles to CG: 1130 mm Distance from rear axles to CG: 1660 mm Height of the CG: 500 mm<br>Wheel base: 2790 mm<br>Wheel radius: 307 mm<br>Brake disc friction coefficient: 0.38<br>Brake disc radius: 122 mm | Simulation was done in 3 cases with TCS<br><br>*Case 1:* Split Road condition:<br><br>Road friction for left and right wheel are 0.2 and 0.8 respectively.<br><br>High variation and slip occilation can be observed in left wheel because of less traction.<br><br>On overall view vehicle speed remain stable.<br><br>*Case 2*: Slippery Road condition:<br><br>Road friction is 0.2 and target slip is 0.11.<br><br>Slip occilation is observed with a gap holding constant slip for short duration of time and then occilation again.<br><br>No brake action is observed.<br><br>*Case 3*: Transition Road conditions:<br><br>Here torque is the target value.<br><br>Firstly road friction changes from 0.2 to 0.8, here engine torque increases to desire value, no brake action is present, increament in vehicle speed is in stable manner.<br><br>Secondly road friction changes from 0.8 to 0.2. Here high slip is dedcuted so brakes come into play for short duration to bring wheel in stable state. Decrement in acceleration can be observed at the point of action. |

| | | |
|---|---|---|
| Development and Validation of the Controller of Vehicular ASR System via Braking Intervention [12] | Control system is developed with modern methodology V-cycle, and slip control is obtained by braking action only. | Several kinds of test have done on it, focusing mainly on the road test with ASR ECU, its finished in short duration of time hence appears with high efficiency for maintaing slip.<br><br>Tough no control is present on engine, could effect fuel economy. |

Integration of throttle mechanism shows the good result without much variation in longitudinal slip, maintaining constant slip value with integrated throttle and brake actuations, also reducing excessive fuel consumption comparing to only brake actuated ASR mechanism. With the integration of brake torque with coordinate control I method for traction maintenance, high amount of slip variation is observed and it's in uneven manner, hence in this cases integration of throttle mechanism with brake via PID and fuzzy controller show good result with approximately 50 % reduction in throttle input in all cases and slip variation from optimum value of 0.18 is +-0.02 which is very minimum variation with observation of constant reduction manner in brakes, providing stable acceleration in end.

## 5. Conclusion

Number of experiments were performed in braking system improvement and is hot research topic for engineers. Lot of new control strategies were developed. Provided paper delt with few of the popular ones in ABS and TCS as they are the major control units in Braking system including PID, Sliding mode and various integration with Fuzzy logic control.

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