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(DEPARTMENT OF ELECTRICAL AND ELECTRONICS TECHNOLOGY)

Design of an Improved PID Controller for Antilock Braking System (ABS) using Extremum Seeking Algorithm

MSc Final Thesis for the Partial Fulfillment of
Master of Science in Electrical Automation and Control Technology Management

By,

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In partial fulfillment for the Degree
MASTER OF SCIENCE *in* ELECTRICAL AUTOMATION AND CONTROL TECHNOLOGY

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Dr. Saravanakumar Gurusamy

DECLARATION

I verify that the work provided in this thesis, entitled "Design of an Improved PID controller for Antilock Braking System utilizing Extremum Seeking algorithm," is entirely my original work and that all sources of information utilized in its creation have been properly acknowledged.

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This Final thesis has been submitted for examination with my approval as a TVTI advisor.

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Thesis on

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ABSTRACT

A safety anti-skid braking system known as an anti-lock braking system (ABS) is used on buses, trucks, cars, and motorcycles as well as on airplanes. Modern ABS systems attempt to maximize tire-generated braking forces by keeping the longitudinal slip ratio below a desirable level in addition to trying to prevent wheels from locking. Slip rate is the difference between actual and calculated vehicle speed affects the friction coefficient which varies depending on the road surface mainly used in control of slip. Conventionally, a great number of controllers have been built for ABS, but there is a limitation of maintaining the braking time.

In this thesis, the controller designed is an improved PID controller for ABS using ES Algorithm. To prove the effectiveness, the simulations are carried out in three cases such as Case A - open loop simulation of ABS, Case B - closed loop simulation of ABS with ESC, Case C - closed loop simulation of ABS with ES tune PID. The simulation is carried out using MATLAB-Simulink. The results of the three cases are compared and depicted both in tabular and graphical form. Further, comparisons were also made with existing literature. It is observed that the improvement in braking time and braking distance in the proposed works.

Keywords: *Anti-lock braking systems, Extremum seeking, PID controller, PID Controller Tuning.*

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LIST OF ABBREVIATIONS AND ACRONYMS

ABS	Antilock Braking System
WSC	Wheel Slip Control
SMC	Sliding Mode Control
NMPC	Nonlinear Model Predictive Control
TABLF	Time-Varying Asymmetric Barrier Lyapunov function
PD	Proportional Derivative
PID	Proportional Integral Derivative
EBFD	Electronic Braking Force Distribution
ESC	Extremum Seeking Control
ES	Extremum Seeking
JA	Jaya Algorithm
GA	Genetic Algorithm
SCA	Sine Cosine Optimization Algorithm
PSO	Particle Swarm Optimization Algorithm
SMC-ABS	Sliding Mode Control –Antilock Braking System
ESP	Electronic Stability Program
DOF	Degree of Freedom
AFC	Active Force Control
IL	Iterative Learning
FL	Fuzzy Logic
FL-PID	Fuzzy Logic with Proportional, Integral, Derivative
ILAFC	Iterative Learning Active Force Control
EWB	Electronic Wedge Brake

MRAC	Model Reference Adaptive Control
NPID	Nonlinear PID
MPC	Model Predictive Control
RTO	Real-time Optimization
PV	Process Variable
CAB	Controller Antilock Brake
ECU	Electronic Control Unit
CBC	Cornering brake control
TCS	Traction control system
NMES	Neuromuscular Electrical Simulation
RMSE	Root-mean-square-error
TPMS	Tire pressure monitoring system

CHAPTER ONE

INTRODUCTION

Automobile continuously changes their state by accelerating, braking, or turning. Vehicle dynamics refers to the phenomenon that these forces combine to cause. The vehicle is at rest if the total sum of all forces is zero. Otherwise, that is, if the forces acting on the car are not equal to 0, they will cause it to move.

Each force varies according to acceleration which in turn affects the speed and direction. When a car accelerates, for instance, there is a positive acceleration, and when it brakes, there is a negative acceleration or deceleration. During driving usually, the car follows the driver's instructions as long as the physical condition of the road and the vehicle are not exceeded. Overcoming these limits results in skids wheel locking, and road exits, the anti-skid braking system is braking the system before the problems have occurred.

The significance of antilock braking systems has, when longitudinal slip is increased, the tire's ability to generate lateral forces is reduced. This is known as lateral force generation. As a result, the primary function of the ABS is to prevent longitudinal sliding to maintain steering ability and lateral stability when applying heavy braking pressure. Furthermore, the tire's brake force is at its maximum with a small amount of slip. As a result, the second function of ABS is to retain the maximum braking force to shorten the stopping distance.

An antilock braking system (ABS) controller should aim to maximize the friction coefficient between the tires and the road. The friction coefficient is influenced by the slip rate, or the difference between the calculated and actual vehicle speed. This undefined function varies according to the state of the road. The PID ES Algorithm is used in this thesis to find the best friction gain when braking. In this article, ES tune PID controller is proposed to iteratively update gains of the controller online for every step response by the ES algorithm and comparing performance with Extremum seeking and a brake system without sliding control and also other related previous works to ensure that the braking time and distance are decreased.

Extreme seeking control is a type of control algorithm that looks for the system performance that is highest (or lowest). It's possible that the system that needs regulation is nonlinear, time-varying, and uncertain in both structured and unstructured ways and that its performance function is completely or partially unknowable.

Wheel acceleration has traditionally been used to control the ABS control algorithm in the last years. One such strategy is the logic threshold approach, in which the first and second control thresholds are the slip ratio and acceleration, respectively, and the third control threshold is the slip ratio and acceleration. This technique, on the other hand, is highly dependent on a range of parameters that must be found through trial and error scientific experimentation. Because of this, determining the system's stability is difficult to do accurately.

ABS-based slip ratio control algorithm has received a great deal of attention in recent years, primarily because of its superior performance in terms of control. The primary function of the slide control is to ensure that the maximum amount of tire-road friction is maintained for the vehicles braking system at all times.

All of the control algorithms discussed thus far are largely focused on tracking the best slip ratio while keeping a high level of dynamic performance without considering how to eliminate slip rate operation in unstable areas, which is a critical consideration.

However, the optimum Slip rate varies depending on the type of pavement particularly when the surface is abrupt or uneven. In situations where the slip rate varies instantly, the existing control algorithm is inadequate to ensure that the ABS performs precisely in the stable region, resulting in the vehicle side slipping or tailing.

Therefore, the best ABS must be made so that working in unstable zones is entirely avoided. As a result, there are three different categories of brake operating zones: healthy, light slip, and deep slide. These categories are distinguished by the correlation between the slip ratio and the combination coefficient in the braking operating region. The ABS system is unable to achieve the maximum tire-road friction due to a slip ratio controller operating in the deep slip region, and in the worst case, the system self-locks. In this study main target is developing reduced braking distance during hard braking situations with better results than the previous research works. This thesis focused on the Design and simulations of Extremum seeking tune PID anti-lock braking system.

1.1 Statement of Problems

Antilock Braking System "ABS" One of the most sophisticated Wheel Slip Control (WSC) designs. The ABS control problem is one of the research topics in the field of automotive control because it plays an important role in improving vehicle safety**.** Various methods have been developed in the literature for the purpose of improving braking capacity, but a number of researches have limitation of maintaining the braking time due to control issues. Many conventional numerical optimization algorithms are limiting the capabilities of the controller due to the local optimal solution. To improve such problems this thesis focused on the Design and simulations of Extremum seeking tuned PID controller for anti-lock braking system.

1.2 General Objective

Design and Simulation of ES tune PID Controller for Antilock Braking System

1.2.1 Specific Objective

- ✓ To Design Extremum seeking tune PID controllers for antilock braking system.
- ✓ To improve the capacity of controllers for an antilock braking system using the Extremum Seeking Tuning Method.
- ✓ To compare the performance of the proposed work with previously related works for the antilock braking system.

1.3 Scope and Limitation of the Study

The scope of this study has been limited to simulation of the Improved PID for Antilock braking system using Extremism seeking algorithm.

1.5 Methodology

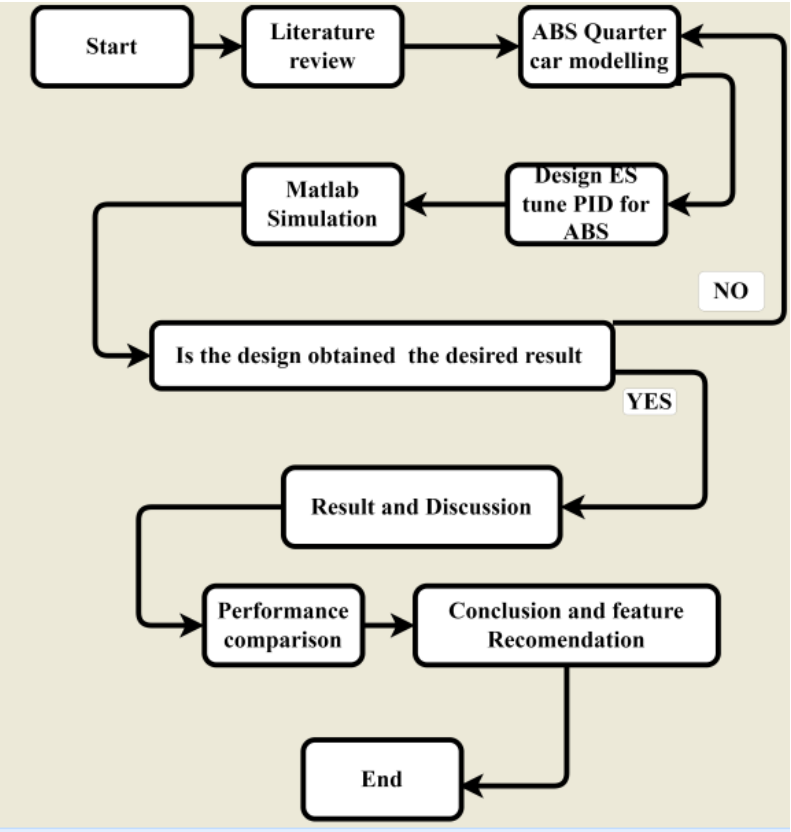


Figure 1.1 Methodology

1.6 Thesis Outline

Chapter one: present an introductions of the entire thesis, statement of problems, General and specific objective, scope, limitations, methodology and Thesis outlines.

Chapter Two: Presents Review of related works in terms of ABS design, parameters, result and finally literature summary.

Chapter Three: Presents This is chapter Introduces the theoretical background of an antilock braking system, PID controller, extremum seeking control, and analysis of antilock braking systems, quarter car modeling.

Chapter Four: Presents Design of Antilock braking system, design of Extremum seeking algorithm for Antilock braking system, design of PID controller for ABS using Extremum seeking Algorithm.

Chapter Five: Simulation results of Antilock braking system, design of Extremum seeking algorithm for Antilock braking system, design of PID controller for ABS using Extremum seeking Algorithm.

Chapter Six: Presents Conclusions and future recommendations of the entire thesis works.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews the different literature related to the ABS system and related controller design found in the different papers.

A set slip value for ABS results in a longer stopping distance. The performance has increased by 7 percent because of the 9 to 15 meter variation in the distances. The results of scenario III, however, are distinct. There are large differences in the braking distances. Almost 73 meters. The traditional ABS seems to operate more effectively. However, the stability results demonstrate the opposite. SMC-ABS has a maximum yaw angle of 0.4° as opposed to traditional ABS's maximum yaw angle of 8°. This example illustrates the trade-off between stability and braking distance. The best option is to maximize friction forces as long as the driver can keep the car under control despite the ongoing discrepancy in friction forces. Direct control of the vehicle's yaw rate, which produces an electrical stability program, can overcome this problem (ESP). The third scenario illustrates the trade-off between stopping distance and stability, in which traditional ABS fails to keep the car stable. even when the driver is steering with all of his or her power. The traditional ABS vehicle spins and exits the road in the 50° limited steer condition. SMC-ABS nevertheless offers excellent handling and nearly the same brake distance as conventional ABS in spite of the restricted steering ability [1].

ABS has relied on heuristic, rule-based control methods since its inception. Much recent technical advancement has improved ABS performance. This study analyzes the state of the art to confirm 6and quantify the benefits of a new generation of wheel slip control systems. A nonlinear model predictive control (NMPC) architecture built on a novel load sensing method was developed as a case study. On Toyota's high-end car simulator, the proposed ABS was compared to the existing industrial controller. The performance and robustness of the suggested NMPC design were assessed using a broad range of tests. The suggested strategy decreased stopping distance and enhanced steering performance. Additionally, the design had the same level of resistance to outside e.ffects as the industry standard [2].

An antilock braking system (ABS), which also shortens the stopping distance and provides lateral stability through the predetermined wheel slip ratio, is one of the main safety features of a vehicle. The basic objective of ABS is to maintain the appropriate amount of wheel slip control while increasing longitudinal tire-runway friction to generate substantial lateral force. Numerous ABS control algorithms have been developed in the past. The main theme of this study is constraint control for an ABS with time-varying asymmetric slip ratio requirements. Considerations include a Burckhardt's tire model and a vehicle brake model with system uncertainty. To solve the time-varying asymmetric slip ratio constraint problems, the controllers are embedded with the time-varying Asymmetric Barrier Lyapunov Function (TABLF). Based on TABLF, two adaptive nonlinear control methods are developed (TABLF1 and TABLF2) that not only track the ideal slip ratio but also ensure that the slip ratio constraints are not violated. According to the simulation results, the suggested controllers may ensure that slip ratio requirements are not violated and that self-locking is not caused. TABLF1 controller, when compared to the TABLF2 controller, can accomplish a faster convergence rate, a shorter stopping time, and a shorter distance [3].

Anti-Lock Braking System (ABS) A vehicle safety device that prevents the wheels from self-locking, shortens braking distances, and adjusts the wheel slip ratio to ensure lateral stability. The main purpose of ABS is to maximize longitudinal friction between the tires and the runway to generate large lateral forces. Many ABS control algorithms have been developed. This paper presents constraint control for ABS with time-varying asymmetric slip ratio constraints. A quarter vehicle braking model with system uncertainty is considered. The controller uses a time-varying asymmetric barrier Lyapunov function (TABLF) to handle the problem of asymmetric slip rate constraints. TABLF-based adaptive nonlinear control methods (TABLF1 and TABLF2) are proposed to track the optimal slip ratio while ensuring that no slip ratio constraint is violated. Simulation results show that the proposed controller avoids slip-ratio violations and self-locking. Using the same control parameters, the TABLF1 controller provides faster convergence, shorter stopping times, and shorter intervals than the TABLF2 controller [4].

SMC for a hybrid power system with a fuel cell, a battery, a unidirectional converter, and a bidirectional converter has been studied in the literature. A unidirectional converter connects the fuel cell and a bidirectional converter connects the battery to the same voltage bus.

The transient response time of a fuel cell is slow So, the battery provides power during system startup and absorbs dynamic power as the load varies. An SMC is proposed to control a unidirectional fuel cell converter and a bidirectional battery converter. The SMC used in this paper is robust enough to control all operating conditions [5].

primary sliding mode steering control using a driver model. For nonlinear 4-wheel models, this method is used to calculate the necessary steering angle for significant lateral accelerations. Sliding mode control has drawbacks because it can harm the actuator and cause chattering. With the continuous function, this issue can be resolved. This work includes the development of linear parameter variant models for the synthesis of nonlinear controls. A separate section describes the experimental validation of data obtained from the Peugeot 307 INRETS-MA vehicle. To assess scenarios with significant dynamic loads on the curve, a test of this control law and the velocity extrapolation of the nonlinear 4-wheel model was also carried out [6].

The most crucial active safety system for passenger automobiles is the Anti-lock Braking System (ABS), but sadly, the literature is not very clear about how it is described, stable, and effective. A five-phase hybrid method based on wheel deceleration is improved in this literature, and is validated using a tire-in-the-loop laboratory facility. Five pertinent impacts are modeled to make the simulations accurate. There are two suggested solutions to the time delays. Without any a priori knowledge of tire parameters, it is possible to verify that the limit cycle of the ABS encircles the ideal braking point [7].

Comparing the ABS to the conventional brake system, there are a several benefits. It can manage the slip rate around the ideal amount in an emergency braking condition, especially on slick roads, to fully use the peak longitudinal adhesion coefficient. While in ABS, the creation of a control strategy is crucial. to boost ABS's control effectiveness and reliable performance while subjected to overload disturbance. Both a brake p6erturbation model and a fourth dynamics perturbation model are created.

The ABS controller is then designed using theory using D-K iterations to verify the robustness of the controller compared with the H controller, simulation and ABS hardware in loop tests are designed using a Cherry vehicle as the research object. The results show that compared with the H□ controller , the controller can effectively reduce the impact of overload perturbation and external noise [8].

When ABS ability detect wheel skid and modulate the brake pressure to prevent wheel locking. The primary function of control the ABS is to achieve the optimal wheel slip rate. This slip rate is function the vehicle's linear and angular speeds. This literature reviews the ABS mechanism and the various applied controllers. ABS is examined in terms of its principles, components, benefits, and drawbacks. They are (ON-OFF) Bang-Bang control, (PD), (PID), (Fuzzy Logic), (EBFD). On a quarter car model with longitudinal and rotational dynamics. A comparison of these used controllers is also shown. The response is simulated based on the braking force [9].

When the plant model is unknown or just partially understood, Extremum seeking is a control method for online optimization of a system's steady-state behavior. The authors recently presented a unified design approach to continuous-time Extremum seeking. This strategy is based on a feedback control paradigm that we have only recently and explicitly summarized. This paradigm encompasses some existing Extremum-seeking schemes and serves as a unifying framework for creating novel Extremum-seeking schemes. We also demonstrate that different formulations of the Seeking issue are similarly interpretable. This integrated viewpoint will facilitate the design and analysis of seeking controllers in various contexts [10].

Convex Optimization to describe a parameterized Extremum Seeking Control (ESC) for antilock braking systems (ABS). This control method uses only output feedback and does not require a plant model. The ESC design challenge is deciding the amplitude, frequency, and cut-off frequency of the high-pass filter, low-pass filter, and integrator gain. For example, the Jaya Algorithm, Genetic Algorithm, Sine-Cosine Optimization, and Particle Swarm Optimization algorithms are used to optimize the filter parameters (PSO). For performance comparisons, the designed ESC controllers control the antilock braking system [11].

The creation of a PID controller for an Antilock Braking System (ABS) utilizing a longitudinal vehicle model is presented in this publication. A mathematical tire dynamics, the Magic Tire model, was developed and linked with five degree of freedom (5-DOF) vehicle longitudinal dynamic model. To validate the vehicle model, several transient handling experiments, including testing for sudden acceleration and sudden braking.

To control longitudinal slide and shorten the stopping distance, an antilock braking system is being developed using the model as a test bed. Hydraulic brake model was created as the brake actuator to generate the brake torque.

To address the significant nonlinearity in the ABS controller design, a traditional PID controller has been introduced. The proposed ABS control structure is shown able to significantly reduce stopping distance and control the longitudinal slip during heavy braking. This literature describes our ongoing research on the dynamical properties of an extreme-seeking (ES) controller class that has attracted significant research interest over the past ten years.

Their properties of local stability have already been studied. We first demonstrate the possibility of semi-global practical convergence with carefully chosen controller parameters and a singular (global) Extremum for the objective function. An intriguing trade-off between the size of the domain of attraction and the convergence rate of the scheme is found: the slower the convergence of the algorithm, the larger the domain of attraction. The Extremum-seeking controller's main design characteristics include the dither signal's amplitude, frequency, and form.

In particular, we demonstrate how adaptively adjusting the dither's amplitude can be used to address global Extremum seeking when local extreme are present. Additionally, we demonstrate that the algorithm's convergence is proportional to the dither signal's power. As a result, the square-wave dither produces the fastest convergence among all dithers with the same frequency and amplitude. In order To illustrate our findings and inspire some open research topics for multivalued objective functions, we explore Extremum seeking of a class of bioprocesses[12] .

The anti-lock braking system (ABS) can detect when a wheel is locking and adjust the brake pressure to prevent wheel locking. Giving the controlled torque needed to achieve the ideal wheel slip rate is the fundamental goal of managing the ABS. This slip rate a function of the vehicle's linear velocity and the rotational speed of its angular wheels. This literature provides an overview of the ABS mechanism and the many used controllers.

The principles, functionality, elements, benefits, and drawbacks of ABS are examined. The following categories apply to the controllers used for ABS: Electronic Braking Force Distribution (EBFD) controller, PD controller, PID controller, fuzzy logic controller, and Bang-Bang control (ON-OFF). These controllers are demonstrated using a quarter-car model with longitudinal and rotational dynamics. Also offered is a comparison of various used controllers.

The response is simulated under the braking force delivered to the brake system. According to the comparison study, the applied fuzzy logic controller is superior to the PID, PD, and Bang-Bang controllers at shortening stopping distances and braking times by managing the vehicle's velocity and the wheel's angular speed. The performance of the EBFD controller is superior to the four earlier controllers. Additionally, a vehicle's EBFD controller provides the most significant level of stability, particularly in challenging driving circumstances [9].

A longitudinal car model to demonstrate how to build a PID controller for an ABS. The five degrees of freedom (5-DOF) vehicle longitudinal dynamic model was coupled with a mathematical tire dynamics known as the Magic Tire model. Several transient handling studies, including testing for abrupt acceleration and sudden braking .The model is being used as a test bed to create an antilock braking system that will reduce stopping distance and control longitudinal slip. To overcome the substantial nonlinearity in the ABS controller design, a conventional PID controller has been added. It has been demonstrated that the suggested ABS control system may greatly shorten stopping distances and control longitudinal slip while braking hard [13].

In-ground vehicles, anti-lock braking systems (ABS) are safety and control features that stop the wheel from locking up during emergency braking. The current ABS controls provide the capacity to adjust the pressure level to best keep the wheel slip within the permissible range for vehicle stability. However, the ABS has strong nonlinear properties, and vehicles fitted with the current controllers may still be prone to over steer and instability.

In this research, a novel active force control (AFC) strategy-based intelligent robust control system is put forth by a thorough simulation analysis. The suggested ABS is conceived and implemented in a hybrid manner, with the self-tuning fuzzy logic (FL)-based proportional-integral-derivative (PID) control and the AFC loop linked to an iterative learning (IL) algorithm cascaded in series.

For the appropriate acquisition and computation of the critical controller parameters, both IL and FL approaches are used. It is clear from the results that, under the specified load and operating conditions, the FL-PID with the ILAFC scheme responds more quickly and effectively than the FL-PID and FL-PID+AFC controllers. The incorporation of an AFC-based scheme into

ABS provides improved and robust performance that can be implemented in practical and real-time systems [14].

It is described how an electronic wedge brake (EWB) actuator and a quarter vehicle brake model were used to produce an antilock braking system (ABS A quarter-vehicle model is created and put through simulation in the longitudinal direction. A control mechanism for the outer loop is then created using the quarter vehicle braking model. For the outer loop controller, three different types of controller are suggested. These include fuzzy logic controllers, adaptive PIDs, and traditional PIDs. Model reference adaptive control (MRAC) is the foundation upon which the adaptive PID controller was created. Meanwhile, the Takagi-Sugeno approach is being used to construct fuzzy logic controllers. The actual actuator is represented by a brake actuator model called a Bell-Shaped curve that uses the Gaussian cumulative distribution approach. Within the ABS control, the inner loop regulates the EWB model. The effectiveness of the ABS is assessed based on the vehicle's longitudinal slide and stopping distance. Compared to traditional PID and adaptive PID control, which only reduce stopping distance by 7.38 percent and 12.08 percent, respectively, the fuzzy logic controller performs well for ABS models [15].

A class of truck ABS (Anti-lock Brake System) problems are addressed using a new NPID control technique. The NPID algorithm combines the benefits of simple tuning and reliable control. TruckSim simulation results in various scenarios demonstrate that the NPID controller outperforms a loop-shaping controller and a typical PID controller in terms of velocity performance and stopping distance [16].

In this work, the application of an additional driving torque connected to a control mechanism working with an ABS is examined to reduce the braking distance. Reaccelerating the locking wheels is only possible in the ABS control cycle by lessening the braking force.

The time for acceleration during the phase of lowering the brake pressure can be shortened by applying an external tractive torque. A source of external tractive force could be the vehicle's engine or an auxiliary electric motor. A mathematical model is used to evaluate whether such a system could shorten the braking distance. A simulation model is used to analyze the effects of the additional accelerating torque, and it is concluded that an increase in braking distance of up to 10% may be achieved [17].

The most popular basic regulatory control algorithm is the PID controller. Chemical engineering processes require PID control because it is the foundation for sophisticated process control and optimization systems like model predictive control (MPC) and real-time optimization (RTO). However, depending on how effectively its three parameters are tuned, its performance can vary greatly. There are several distinct PID tuning heuristics or principles However, selecting the most appropriate rule and applying it correctly in the actual functioning physical system or environment might be challenging for routine operators, instrument technicians, process engineers, or novice process control engineers. The alternative is optimization-based PID tuning, which, because of improvements in computing power, can be a workable strategy if the goal function and set point and load disturbance situations are correctly defined.

There are two distinct categories of numerical optimization approaches One type of optimization is model gradient-based, and the other is non-gradient-based, However, most PID tuning research has been conducted using non-gradient optimization techniques like particle swarm and Extremum searching algorithms due to the non-convexity of the PID tuning model. The other category of research studies has been carried out employing meta-heuristics, such as genetic algorithms, or random search methods. The major goal of this study is to suggest a workable method for re-tuning installed PID controller tuning settings more efficiently using historical set point and load disturbance data.

The specific or brute-force search strategy, which requires traversing a pre-defined PID parameter search space, ensures that the objective function's optimal value will be found without the possibility of halting at a local minimum value.

To further strengthen the trustworthiness of the tuning outcome, the simulation settings are set to be as similar to the real or actual operation as feasible to produce a digital twin or actual operation to create a digital twin or cyber-physical view of the installed characteristics of the PID controller[18] .

The dynamical properties of an Extremum-seeking controller class that has attracted significant research interest over the last 10 years their properties of local stability have already been studied. First, using a single (global) Extremum for the objective function and carefully selected controller parameter, we show the potential for semi-global practical convergence. Designers find an intriguing trade-off between the size of the domain of attraction of the scheme and the convergence rate the larger the region of attraction, the slower the convergence of the algorithm.

The dither signal's amplitude, frequency, and form are significant design considerations for the Extremum-seeking controller.

In particular, we demonstrate how adaptively adjusting the dither's amplitude can be used to address global Extremum seeking when local extrema are present. Additionally, we demonstrate that the algorithm's convergence is proportional to the dither signal's power. As a result, the square-wave dither produces the fastest convergence among all dithers with the same frequency and amplitude. In order to illustrate our findings and inspire some open research topics for multivalued objective functions, we explore Extremum seeking of a class of bioprocesses [12].

Anew control technique to control the wheel slip of ABS by using the ES-PID tuning control. The method is useful in alleviating the problem associated with conventional PID control by optimizing the PID gains in real-time to obtain better-closed loop performance [19].

Taking the single-wheel vehicle model as the research object, the mathematical modeling of the automobile ABS system is carried out in the Simulink environment. Based on the logic control strategy of the main reference value, the overall model of the automobile ABS system is established, and the simulation is carried out with the braking condition without ABS. Comparative analysis. the results show that the car ABS system can significantly improve the braking performance of the car, thereby improving the safety of the vehicle when braking coefficient [20].

A multivariable to develop an adaptive Proportional-Integral-Derivative (PID) control rule for the functional Neuromuscular Electrical Stimulation (NMES) of stroke patients, deterministic Extremum seeking (ES) is being tested. The created scheme is used to regulate the patient's arm's posture so that elbow flexion and extension movements can be made. Since a PID controller is made for linear systems, but the system being managed is nonlinear, it has real limits in these kinds of applications. Additionally, it is important to note that clinicians have a limited understanding of control systems. As a result, they have little experience tweaking controllers. Additionally, each patient in NMES applications is unique and needs a specific set of PID parameters. A more efficient method or an adaptive controller with greater intelligence is required because it can be time-consuming and challenging to discover the right parameters for each patient.

By using ES, the PID settings are updated to achieve the required performance characteristics while minimizing a cost function. Healthy volunteers and stroke patients are used in experiments, which include important advancements based on real data and validation. [21].

In order to improve the step responsiveness of a closed-loop system composed of a PID controller and an unknown plant, this article shows how to apply a discrete variant of Extremum seeking (ES). In particular, ES minimizes a cost function that mimics those employed and gauges the effectiveness of the PID controller. ES, a non-model-based strategy, iteratively modifies the arguments of the cost function (in this case, the PID settings) until the output of a cost function reaches a local minimum or local maximum [22].

MATLAB/SIMULINK is used to simulate the anti-lock braking system (ABS) using a mathematical model of the vehicle's front quarter. This model replicates how an automobile brakes during a sudden stop, and it also employs a PID control to govern the slide under varied road conditions. Comparing the performance of the suggested controller to a hysteresis type controller and an uncontrolled sliding brake system shows that it has the ability to significantly reduce braking distance and time while also controlling slipping during rapid braking [23].

The complex interactions between the elements and parameters, ABS control is a relatively indirect control problem. Numerous problems and difficulties are covered by the study done on ABS control systems. For ABS, numerous alternative control strategies have been created, and research into better strategies is still ongoing. Most of these methods call for system models, and some of them can't deliver factory performance under a variety of driving situations. Soft computing techniques like fuzzy control work without a precise model Here's a quick explanation of how to use soft calculations in ABS control [24] .

The automotive ABS technology is very important for the car it can greatly enhance the braking performance of the car to improve the safety of the vehicle at the same time, The ABS system is not only needed to prevent wheel lock, but the vehicle's movement must also be adjusted to avoid extreme situations due to the malfunction of the car's steering system. With the development of electronic technology, the detection and calculation of car parameters will be greatly improved, which will further promote the development of ABS technology the car has high protection [25].

An overview of Extremum seeking control techniques and their applications to reaction and process systems the perturbation-based and model-based approaches to Extremum seeking control have been taken into consideration both options with full model structure knowledge and with partial model structure knowledge have been taken into consideration for the latter.

Results for theoretical convergence and stability have been published, and simulations show how well the methods work [26].

An ABS system mathematical model was taken into account, and a slip-ratio based Bang-Bang controller was used. Analysis and comparison of the vehicle's braking performance with and without a Bang-Bang controller. When braking in Bang-Bang Controller mode, the wheel speed and vehicle speed decrease simultaneously, and the vehicle's relative slip, speed, and slip distance are established. Because the wheel speed and vehicle speed are controlled simultaneously to prevent the vehicle from skidding during panic braking, it is concluded that the Bang-Bang Controller has greater braking performance [27].

Automobiles' Anti-lock Braking System (ABS) is a vital active safety technology in this study, continuous and discrete systems are simulated using an ABS model. Simulink is utilized for modeling, and a system simulation method based on finite-state machines is used.

The simulation's findings imply that this system can accurately represent how an automobile's ABS actually operates, cut braking distances noticeably, and increase safety [28].

The ABS can be mathematically described and might be modeled and simulated using software. The system's component equations were collected, A few systemic control measures were explored. Several different simulation programs were used to simulate several system components. There was a presentation of simulations for stopping distance, wheel slip ratio, brake torque, and wheel speed. The simulation software underwent some statistical analysis, which was displayed. The system would be better understood through modeling and simulation, which might be very beneficial for system development. This will contribute to safer driving and perfect braking performance[29].

An ES approach for optimizing drag and reactive power coefficients in power take-off (PTO) mechanisms. Validate optimization results using extreme methods of reference-to-output mapping and analysis solutions. Numerical results show that the other four ES schemes converge reliably for two-parameter optimization problems, while the free-running ES algorithm is better suited for single-parameter optimization.[30].

2.1 Summary of Literature Review

Table 2.1: Literature Summary

Ref	Authors	Year	Condition	Controllers	Slip Ratio	Time (s)	Stopping distance (m)
1	Vimal Rau Aparow [13]	2013	Dry Road	NMPC	0.2	50	500
2	Shady Ashraf Abd El-Fatah1, Abdel-Nasser Sharkawy, Ahmad O. Moaaz, Nouby M. Ghazaly [9]	2021	Dry Road	Fuzzy Logic control	0.2	56	128
3	A. A. Aly, E. Zeidan, A. Hamed, and F. Salem [24]	2011	Dry Road	PID Control	0.2	128	568
4	BARAN BARIS[1]	2008	Wet Road	SMC	0.8	10	341
5	Esref Bogar, selami beyhan [11]	2019	Dry Road	ESC	0.2	20	520
6	Raj Marti Curve [19]	2018		Auto tune PID	0.3	11.01	483.9
7	Wenyan Xia [20]	2019		PID	0.15-0.25	14.01	720.7
8	Blancas, Angel Paleta Galicia, Alejandro Loaiza Eduardo, Mario López, Leal[28]	2019	Dry Road	PID	0.27-0.1	13.1	189
			Ice road	PID	0.202-0.198	124	1745

From the literature, so many controllers are used to control antilock braking systems. Their problems of earlier works till recent works are Considerable braking time which results for many injuries. Mainly, the optimization methods used in the ES tune PID which are more responsible for the controller performance. There is a gap in the literature to control ABS methods in the ES tune PID controller.

CHAPTER THREE

THEORETICAL BACKGROUND AND ANALYSIS

3.1 Introduction

This is chapter Introduces the theoretical background of an antilock braking system, PID controller, Extremum seeking control, and analysis of antilock braking systems.

3.1.2 Antilock braking system

Generally, brake actuation is essential to all vehicle control in any vehicle system. The precise application of brake torque is essential to maintain proper vehicle spacing on the highway to avoid casualties and meliorate ride quality on highways. For emergency maneuver requirements, the precise application of brake torque is imperative for avoiding wheel lock-up. While anti-lock braking technology has been around for about ten years, it is only one of the most recent ways automakers have sought to increase the safety of their customers. Without an antilock braking system (ABS), the vehicle's wheels will not adjust for proper adjustment of braking torque, which is most critical to a vehicle's safety. ABS is in use to protect the front wheels from locking up under conditions where the road is slippery or dry. Boeing Corporation created the first ABS in 1947 for aircraft [14] at that time, automotive was too expensive. French aircraft launched the first automotive that uses ABS in 1954. Few models (Ford, Chrysler, and Cadillac) used analog computers and vacuum actuating modulators in the late '60s. However, at that stage, they are not commercially successful.

However, designing an ABS is problematic because it is very nonlinear and time-variable. In addition, the interaction of road surfaces and tires and the nonlinear performance of components such as the brakes, brake pads, and cylinders are associated with dynamics. Controls are obtained in the ABS by implementing nonlinear procedures. While linear model simplification does allow for the development of control strategies, it is not as precise, which hinders the use of specific, more sophisticated strategies. Due to the non-linearity of the braking systems, even abrupt and drastic situations are predictable and controllable losses of grip are seen in steering although ABS generally improves steering control and shortens stopping durations in dry and certain slick conditions, it may actually lengthen stopping distance significantly on loose gravel or snow-covered ground. Such systems have become more potent since ABS was first used in the production of automobiles.

Modern versions may change the front-to-rear brake bias and prevent to preventing wheel lock during braking. Depending on its capabilities and method of use, this latter function may also be referred to electronic brake force distributions, traction control systems, emergency brake aid, or electronic stability control (ESC). The CAB is another name for the anti-lock brake controller (Controller Anti-lock Brake). ABS systems include a central electronic control unit (ECU), four wheel speed sensors, and at least two hydraulic valves inside the braking hydraulics. The ECU continuously tracks the speed at which each wheel rotates. If it notices that a wheel is rotating significantly more slowly than the vehicle's speed, a sign of impending wheel lock, it activates valves to reduce hydraulic pressure to the brake at the affected wheel, reducing the braking force therein, causing the wheel to rotate more quickly.

On the other hand, if the ECU notices a wheel turning noticeably more quickly than the rest, hydraulic brake pressure is increased so that the braking force is delivered again, slowing the wheel. The driver can notice this process continuously by feeling the brake pedal pulse. Some anti-lock systems can brake 15 times per second. Because of this, even during panic braking under harsh conditions, ABS-equipped vehicles' wheels are almost impossible to lock. Because the two wheels closest to the center of the curve rotate more slowly than the outer two when the automobile is turning, the ECU is configured to ignore variances in wheel rotates speed below a key threshold.

A differential is utilized in almost all road-going vehicles for the same purpose. A warning light will often illuminate on the car's instrument panel if an ABS component develops a malfunction, and the ABS will be turned off until the problem is fixed. Modern ABS controls each wheel's specific brake pressure with a system of hub-mounted sensors and a specialized microcontroller.

The cornerstone for electronic stability control systems, which are quickly gaining popularity due to the significant price decrease of car electronics over time, is ABS, which is an option or comes as standard on most road vehicles built today. The ABS idea has evolved into day’s electronic stability control (ESC) technology.

A steering wheel angle sensor and a gyroscopic sensor are added here as the minimum number of extra sensors needed to make the system function. The ESC software will break the necessary individual wheel(s) up to three with the most advanced systems when the gyroscopic sensor detects that the direction taken by the car does not match what the steering wheel sensor reports.

This will ensure the vehicle travels in the direction that the driver intends. The steering wheel sensor is also helpful in the Cornering Brake Control (CBC) system since it informs the ABS how much more the wheels on the inside of the curve should brake than the outside wheels. When a vehicle accelerates, ABS equipment may also be utilized to implement a traction control system (TCS). The ABS controller can identify the issue and take appropriate action to restore traction if a tire loses traction while accelerating. This can also control the brakes and throttle concurrently in more advanced versions. The indirect tire pressure monitoring system (TPMS), which can detect under-inflation of the tire(s) by the difference in the rotating speed of wheels, occasionally uses the speed sensors of the ABS.

3.1.3 PID Controller

Temperature, flow, pressure, speed, and other industrial control applications can all be controlled by a PID controller. The difference between the desired spatial position (SP) and the measured process variable is used by a PID controller to perform a correction based on proportional, integral, and derivative terms (denoted P, I, and D) (PV) Compared to an on/off controller, this one produces good results there are just two criteria that can be used to manage the system in an on/off type controller it will switch ON when the process value falls below the specified point. Similarly, it will become inactive whenever the value exceeds a fixed value. With this controller, the output is unstable and frequently oscillates about the fixed point. However, compared to an on/off type controller, this one is more accurate and steady. Only two control states totally on or off are conceivable when using a simple, low-cost ON-OFF controller. When these two control states are sufficient to achieve the control aim, it is employed in limited control applications.

However, the oscillating nature of this control restricts its application, and PID controllers are now taking its place by using closed-loop actions, a PID controller keeps the output in such a way that there is no error between the process variable and the set point .the advantages of PID Controllers Feasibility and ease of implementation. Easy to stabilize faster response. No steady state error, the disadvantage of PID Controller Long settling time steady state error, Can Amplify high-frequency noise, narrower range of stability.

3.1.4 Extremum Seeking Algorithm

Extremum seeking Algorithm (ESA) real-time model-free adaptive control technique that can adjust parameters to unknowable system dynamics and unknowable mappings from control parameters to an objective function. Extremum-seeking follows a fluctuating maximum or minimum in a cost-based performance function. It aims to minimize downtime and the requirement for system analysis by figuring out a control system's best performance while it runs. There are two sections to Extremum Seeking and Applications. In the first, the authors discuss existing gradient, perturbation, and sliding mode based controls for Extremum seeking based analog optimization. They then suggest an Extremum seeking control based on perturbation that uses optimization techniques and state regulation. This control strategy is created for straightforward linear time-invariant systems before expanding for a group of nonlinear feedback systems. The robustness of the two primary optimization strategies, line search, and trust region methods, is examined. The state regulators for linear and nonlinear systems are proposed as finite-time and asymptotic, respectively. The robustness outcomes of the optimization algorithms and the asymptotic state regulator allow for introducing of existing nonlinear adaptive control approaches for robust design, increasing design flexibility.

In comparison to strategies that use perturbation-based Extremum seeking control, the employed strategy frequently demonstrates a high level of robustness and is easier to implement.

The Extremum seeking schemes used in the design of antilock braking systems, impedance matching, source seeking, formation control, collision and obstacle avoidance for groups of autonomous agents, and mobile radar networks, to name a few applications this are Academics, graduate control students, as well as professionals in the fields of systems automotive, aerospace, communications, semiconductor, and chemical engineering, will be interested in Extremum Seeking Algorithm and Applications.

3.2 Mathematical Modeling of ABS

Antilock braking systems (ABS) are a crucial component in the auto industry. When the wheels are kept from locking, they make it possible for the vehicle to stop more quickly and turn more safely.

In order to control braking on slippery surfaces, or to prevent the wheels from locking and skidding, the ABS design was initially intended to do this. Because of the dynamics' nonlinearity and the insecurity of the braking systems, the design of ABS is difficult. The friction force acting on the tires decreases as wheel slip increases, peaking for low (nonzero) slip. Standard ABS systems apply brake pressure sporadically and quickly. A handful of them intermittent actions that maximize the friction characteristic. Intending to create a control algorithm for the braking torque to achieve the highest friction force without knowing the optimal slip beforehand, this research uses PID controllers with Extremum-seeking control schemes for the ABS design.

Only the vehicle's longitudinal dynamics are considered when developing the mathematical model, lateral and vertical motions are ignored. The figure is used since it is further believed that there is no interaction between the vehicle's four wheels.

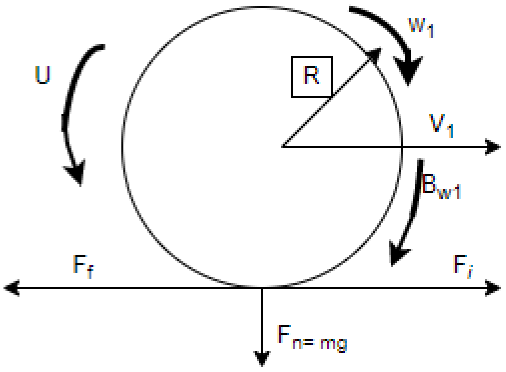


Figure 3.1 Quarter car model

F_i is the force provided by the engine and delivered to the tires to move the vehicle, V is the described speed of vehicle and F_i the inertia force of the car is taken into account. The brake system's braking force during deceleration is represented as F_f. The normal force of the car, represented by N in the diagram, and the vehicle's weight, represented by W, are taken into account when calculating the road's reaction.

$$F_n = mg \qquad (3.1)$$

For horizontal direction vehicle dynamics friction force and force of inertia is opposite and equal.

$$F_f = F_i \qquad (3.2)$$

For vertical direction normal force of vehicle and vehicle weight is equal.

$$F_n = w \qquad (3.3)$$

$$F_f = - F_n \mu \qquad (3.4)$$

$$m\dot{v}_1 = -F_n\mu(\lambda) \qquad (3.5)$$

When Adding torque at the wheel dynamics the Equilibrium written as;

$$I\dot{w}_1 = -Bw_1 + F_n r\mu(\lambda) - U \qquad (3.6)$$

F_f	Friction force
F_i	The inertia force of the vehicle
μ	The friction coefficient
F_n	Normal force
W	Weight of the wheel
v_1	Linear velocity(vehicle speed)
w_1	Wheel Angular velocity
M	Vehicle mass
R	Radius of wheel
I	Wheel Moment of inertia
Bw_1	Braking friction torque
U	Braking torque
$\mu(\lambda)$	The friction force coefficient and wheel slip(λ)

The wheel's rotating speed matches the vehicle's forward speed under normal driving circumstances. The applied braking force lowers the wheel velocity during braking.

As a result, the slip (λ) changes as the wheel velocity decreases relative to the automobile velocity. In this situation, the term slip can be written as

$$\lambda = \frac{v_1 - R\omega w_1}{\mathrm{v}_1} \tag{3.7}$$

Maximum μ^* for μ(λ) at ideal λ but ideal λ^* and μ^* will change as the road condition change therefore In order to maximize braking torque for an anti-lock braking system using the Extremum seeking controls Algorithm (ABS). in equation (3.7) $R\omega w_1$ is the wheel angular velocity and v_1 is the wheel angular velocity under a non-braking condition (vehicle speed divided by wheel radius). Based on this equation, slip is zero when the wheel speed and vehicle speed are equal, and slip equals one when the wheel is locked (ωw_1 is zero). A desirable slip value for braking is 0.2, which means that the number of wheel revolutions equals 0.8 times the number of revolutions under non braking conditions with the same vehicle velocity. This slip value maximizes the adhesion between the tire and road and minimizes the stopping distance for the available friction.

The friction coefficient μ between the tire and the road surface is a function of slip, known as the *μ- λ curve*.

When Antilock braking design proposes is to generate a control input *U* so the friction force coefficient μ (λ) is maximized regardless of the road condition.

Differentiating wheel slip with respect to time (t),

$$\dot{\lambda} = \frac{\dot{v}_1(1-\lambda) - R\dot{w}_1}{v_1} \tag{3.8}$$

3.2.1 Extremum Seeking Algorithm Design Problem formulation

To formulate the problem into Extremum seeking algorithm lets introduce a constant $\lambda0$(which is unknown) and define

$$\dot{\tilde{\lambda}} = \lambda - \lambda_0 \tag{3.9}$$

The slip ratio value depends on the velocity of torque and input torque during braking.

$$\dot{\lambda} = \left(\frac{Rw_2}{v_1^2} + \frac{mR^2}{Iv_1}\right)\dot{v}_1 + \frac{RB}{Iv_1}w_1 + \frac{R}{Iv_1}U \tag{3.10}$$

$$U = -\frac{ICv_1}{R}(\lambda - \lambda_o) - Bw_1 - \frac{Iw_2}{v_1}\dot{v}_1 + mR\dot{v}_1 \tag{3.11}$$

U is brake torque by modulating brake torque control the wheel dead during hard braking system. The positive constant C is makes the equilibrium λ_o (achieved slip value)

$$\dot{\tilde{\lambda}} = -C\tilde{\lambda} \tag{3.12}$$

$$\frac{1}{C}\dot{\lambda} = -(\lambda - \lambda_o) \tag{3.13}$$

$$y = \mu(\lambda) \tag{3.14}$$

$$\lambda 0 = \tilde{\lambda}_0 + \operatorname{asin}(wt) \tag{3.15}$$

$$\mu(\lambda) = 2\mu * \frac{\lambda^* \lambda}{\lambda *^2 + \lambda^2} \tag{3.16}$$

CHAPTER FOUR

DESIGN OF PID CONTROLLERS USING EXTREMUM SEEKING ALGORITHM FOR ABS

4.1 Introduction

The proportional-engineering-variable (*PID*) controller is widely used in the process industry, but it is sometimes poorly adjusted for different levels of efficiency. This work aims to achieve optimal performance by using extreme search (*ES*) to tune PID parameters. ES is a non-model method that looks for parameters that minimize the cost function online. In this case, the cost function is representative of the performance of controls.

4.2 PID controllers for Antilock Braking System

In a PID controller system input is the addition of error with constant gain (K_p), integral of error with constant gain (K_i), and differential of error with constant gain (K_d).The braking controller is needed to control the vehicle relative slip to the stable slip region and close to the peak friction coefficient. Where the relative slip is 1 is locked the friction characteristics function exists an optimal slip λ^*at where the maximum friction force or desired gradient of μ as λ is obtained

$$e \ = \lambda_{ref} - \lambda_o \tag{4.17}$$

$$e = \frac{1}{t}\int_0^1 (\lambda_{ref} - \lambda_o)^2 \tag{4.18}$$

$$U(t) = \ K_p(e(t) + \frac{1}{TI}\int_0^t e(t)d(t) + Td\ de(t)/dt) \tag{4.19}$$

Where $e(t) = \lambda_{ref}(t) - \lambda(t)$, λ(t) = Wheel Slip, $\lambda_{sp} =$ Reference wheel slip, and K_p, K_i, K_d is proportional, integrated, and initial gain. Although the widely used Ziegler-Nichols *PID* controller tuning method produces good load distortion, it increases overshoot and settling time. It is known that this problem can be avoided by reducing the relative profit.

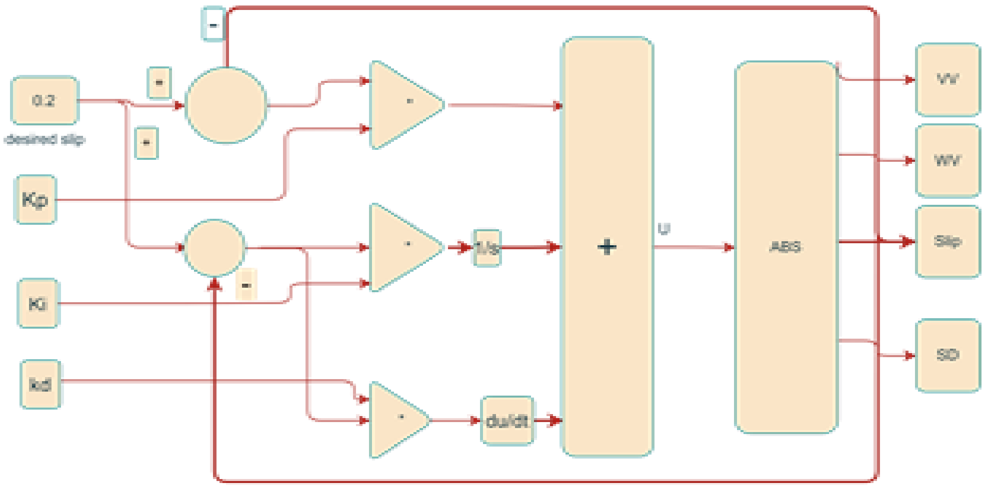


Figure 4.1 Design PID controller ABS

4.2.1 Cost Functions

PID controller parameters are adjusted using ES to reduce a specified cost function. At the conclusion of the step response test, a cost function measuring the efficacy of a specific PID controller is assessed. The integrated squared error (*ISE*) cost function was employed by the thesis's authors.

$$J(\theta) = \frac{1}{T-t_0}\int_{t_0}^{T} e^2(t,\theta)dt \qquad 4.20$$

The error $e\ (t,\ \theta) = \mathrm{r}\ (t) - \mathrm{y}\ (t,\ \theta)$ is calculated the difference in the output and the reference signal in the closed-loop system and include the PID parameters.

$$\theta \triangleq \left[k_{p,}k_i, k_d\right]^T \qquad 4.21$$

Over the time range [t_o, T], the error was defined by the cost function J(θ) effectively gives the initial transient portion of the response zero weight by setting to roughly the time Tpeak at which the step response of the closed-loop system reaches the first peak. As a result, without limitations on the initial transient, the controller is tuned to minimize the error beyond the peak time peak. With the exception that the derivative term affects the measured plant output rather than the reference signal, the authors used a standard *PID* controller.

4.2.2 Extremum Seeking Algorithm Scheme

The cost function's value $J(\theta(k))$ is used by the ES algorithm to calculate new controller parameters $\theta(k)$. The process is then repeated iteratively using the new controller parameters for a second step function experiment. In order to arrive at a local minimizer, ES, a non-model based method, iteratively modifies the input of the cost function $J(\theta)$. In figure 4.2 shows how ES completes this optimization by sinusoidal perturbing the system's input parameters $\theta(k)$ and then calculating the gradient J $(\theta(k))$. Note that t is the continuous-time variable within a single step-response experiment, whereas k is the index of the step-response experiment. The discrete time signal $J(\theta(k))$ is high pass filtered to remove the dc component, and then it is demodulated by multiplying it by a discrete time sinusoid with the same frequency as the perturbation signal. This method calculates the gradient by removing the part of $J(\theta(k))$ that results from a disturbance in the parameter estimate k. The input parameters are then changed in the following iteration using the gradient information; specifically, the gradient estimate is integrated with a step size to produce a new parameter estimate, $\theta(k)$. The integrator serves as a low pass filter in addition to performing the adaptation function. The time-domain the discrete-time ES algorithm shown in figure 4.2

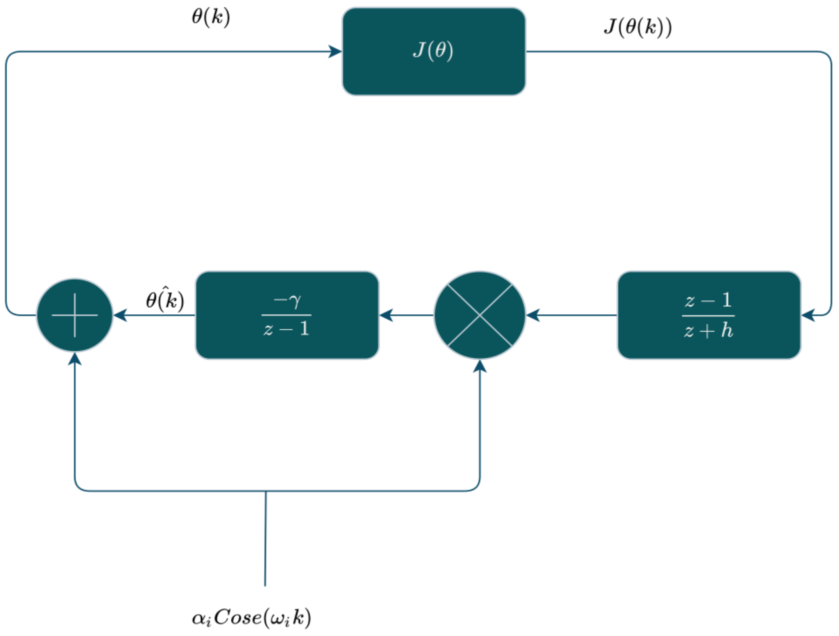


Figure4. 2: ES discrete time scheme.

$$\beth(k) = -h(\beth)k - 1 + j\theta(k-1) \quad 4.22$$

$$\dot{\theta}_1(k+1) \approx \dot{\theta}_1(k) - \gamma_i \propto_i cos\omega_i k[J\big(\theta(k)\big) - 1 + h)\beth(k)) \quad 4.23$$

$$\dot{\theta}_1(k+1) \approx \dot{\theta}_1(k+1) + \propto_i cos\omega_i(k+1) \quad 4.24$$

in which $j(k)$ is a scalar and the subscript i indicates the ith entry of a vector. γ_i is the adaptation gain and α_i is the perturbation amplitude. stability and convergence are influenced by the values of γ , α ,and the shape of the cost function $j(\theta)$ near the minimizer , the modulation frequency ωi is chosen such that $\omega_i = ai\pi$ where a satisfies $0 < a < 1$ additionally, the high pass filter (z-1)/(z-1) is designed with $0 < h < 1$ and a cutoff frequency well below the modulation frequency ω_i. an overview of extreme seek theory and some state-of the-art applications are given in this article's PID tuning, a novel hybrid application is used, in which the es dynamics are discrete time and the plant dynamics are continuous time.

4.2.3 Design of Extremum Seeking tune PID for Antilock Braking Systems

In this study, present a novel control method that makes use of the ES-PID tuning control to regulate the ABS wheel slip by improving the PID gains in real-time to achieve improved closed loop performance, the suggested solution is helpful in resolving the issue with conventional PID control. The wheel slip is controlled by a standard PID controller, however for each step response; the gains of the controller iteratively updated online using the ES algorithm.

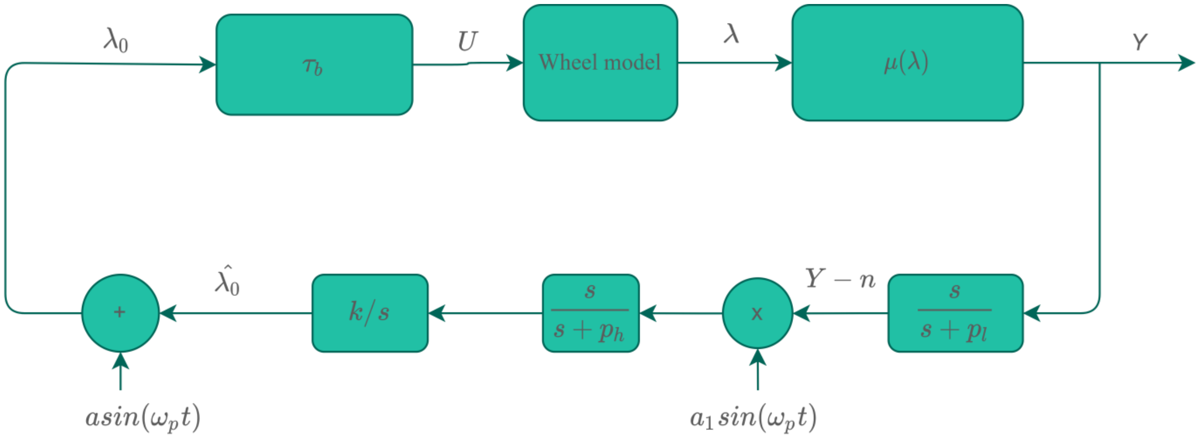


Figure 4.3 Block diagram of ES tune PID for Antilock braking System

CHAPTER FIVE

RESULTS AND DISCUSSION

The Simulations are performed using the model given in equation (3.1up to 4.25) includes control torque, friction force, force of inertia, wheel angular acceleration ,vehicle acceleration ,Esc to improve sliding control of vehicle during sudden braking. The parameter considered in the model and simulations is given in Table 5.1. The simulations are performed using MATLAB tool. Initially, the open loop simulation is performed to check the system dynamics as a Case A. Further, In Case B - the simulation with ESC, Case C – Simulation with ES tuned PID are performed to check the effectiveness and the related results are depicted in Graphical and tabular form.

Table 5.1: Input parameter for Simulink model

Name of Parameter	Symbol	Value
Mass of vehicle	m	400kg
Wheel radius	Rr	0.3m
Moment of inertia	I	1.4kg.m^2
Gravitational constant	G	9.81m/s^2
Braking pressure	Tb_{max}	1600Nm
Wheel damping torque coefficient	B	0.01
Tuning parameter		
Positive coefficient	C	1
Initial conditions		
Initial vehicle velocity	v_o	120/3.6 m/s
Initial wheel angular velocity	w_o	400 / 3.6
Esc tuning parameter		
Frequency	H_z	10
Learning rate	K	1500
Modulation signal	A	0.1
Amplitude signal	Amp	1
HPF	P	1000%

Esc tuning parameter task B		
Frequency	$Freq$	10
Learning rate	K_1	1500
Modulation signal	a_1	0.1
Amplitude signal	amp_1	1
High pass filter	p_1	1000
road condition		
Dry condition		
Tuning coefficient	C	20
Ideal friction coefficient	Mu_max	0.03
Slope		1
Desired slip	λ_{ref}	0.2
Icy Road Condition		
Tuning coefficient	C	550
Ideal friction coefficient	Mu_max	0.03
Slope	$Slope$	1
	t_{offset}	3
Desired slip	λ_{ref}	0.2

5.1 Case A – Simulation of open loop without ABS for Longitudinal vehicle

In this case, the simulation of longitudinal vehicle without ABS is considered in case of hard braking the vehicle ordered driver this cause the wheel is dead before vehicle come to stop this cause the hard braking distance vehicle come to stop is increased ,the loss of steer ability occurred, when wheel locked prevent driver controlling of vehicle. The related Simulink diagram is shown in Figure 5.1

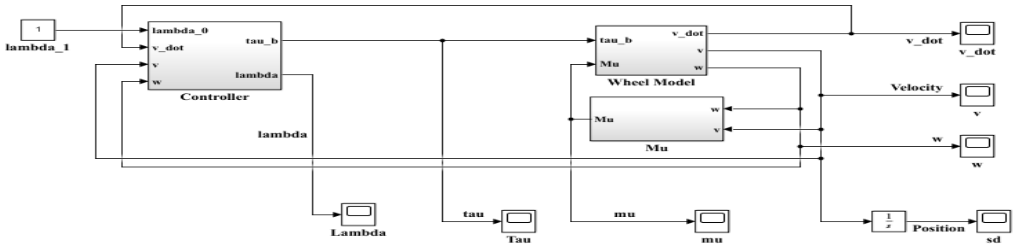


Figure 5. 1 Open loop Simulink model

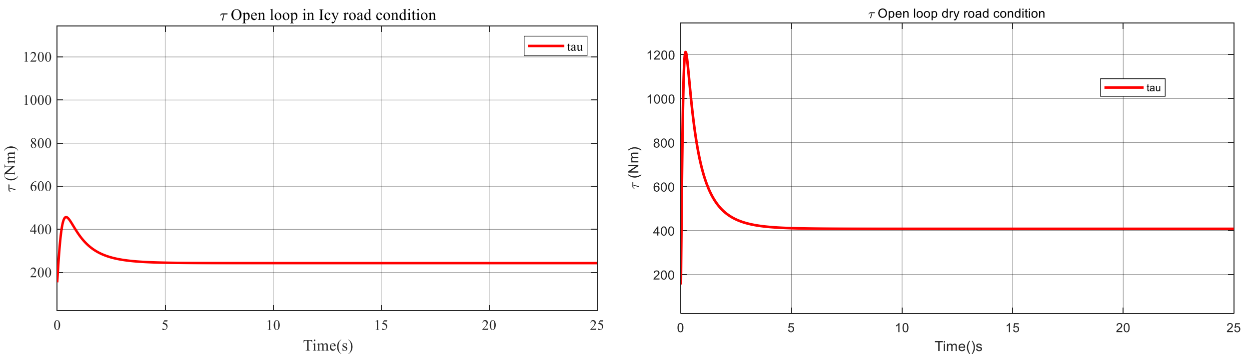


Figure 5.1.1 Braking torque comparison in open loop

Without ABS the angular speed of wheel is less than vehicle speed in emergency braking. In case of deceleration the braking force applied by the brake system is described by friction force is reduced this causes the wheel is to locked and the braking distance increased. In the small amount of slip ratio, the tire braking force is maximum when the longitudinal slip ratio increases the brake force is 410Nm in dry case and in Icy case the braking force is 249Nm therefore the distance vehicle come to stop during hard braking increased in Icy cases when compare from dry cases.

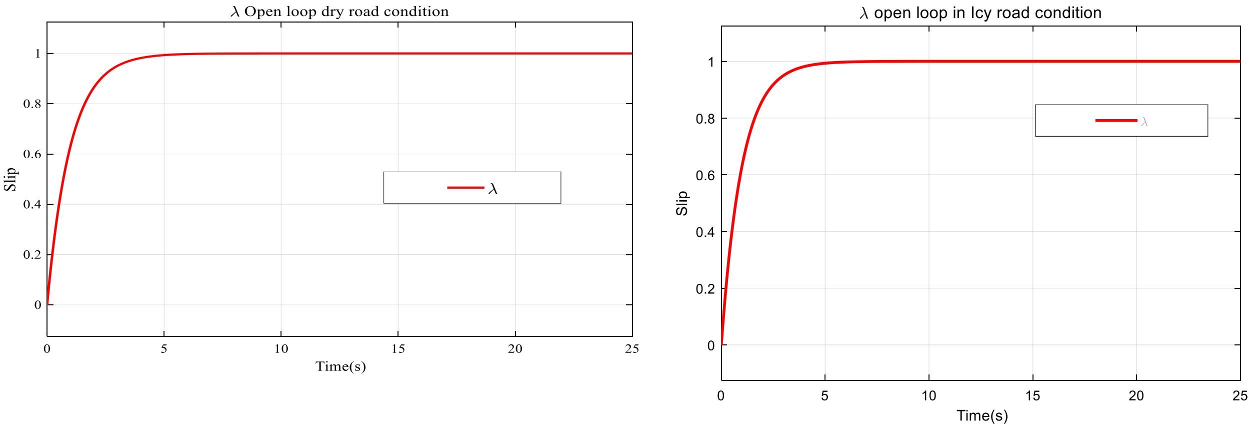


Figure 5.1.2 Wheel slip comparison in open loop

The friction coefficient is the reaction between the tire and the road surface it is the function of slip is known as the mu slip curve, when the angular velocity of the tire reaches zero the mu slip curve is reduced, and the longitudinal slip is increased.

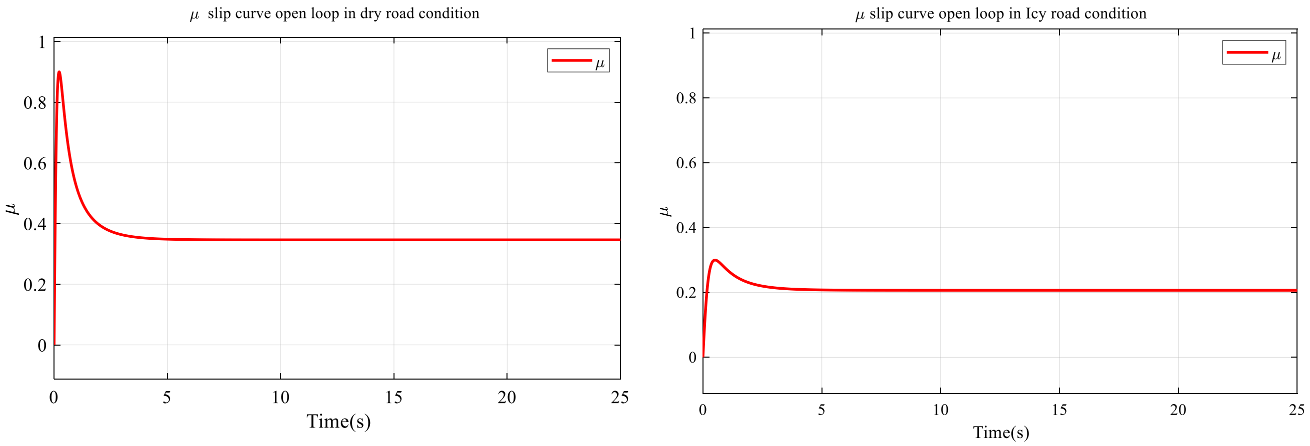


Figure 5.1.3 Mu slip curve comparison in open loop

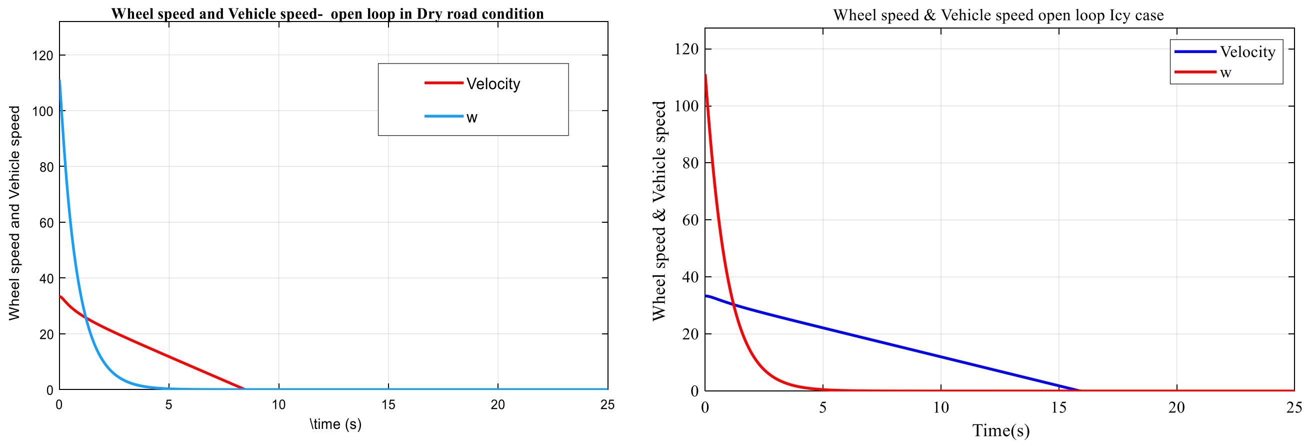


Figure 5.1.4 wheel speed and vehicle speed in open loop

When the wheel angular speed is Zero (0) at 4.2s but the braking distance of vehicle come to stop is at 8.5s in dry cases and in Icy Cases the wheel angular speed is Zero at 4.2s but the vehicle come to stop at 16s this indicate that the wheel has been locked before vehicle come to stop. This causes during braking steer ability is lost at 4.2s due to locking of the wheel this causes accident.

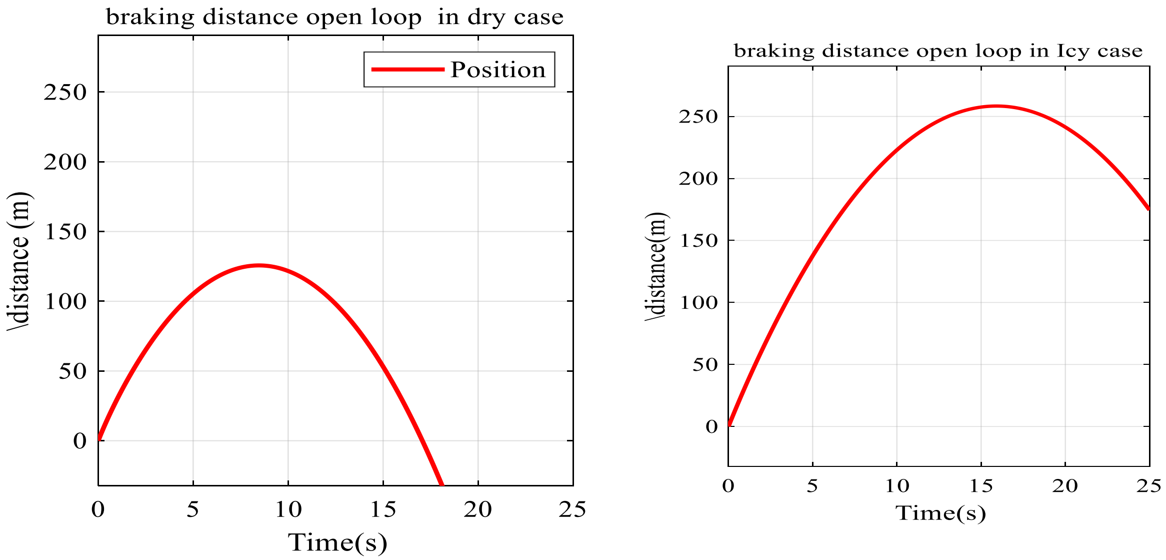


Figure 5.1.5 braking distance in open loop

During braking when the wheel angular velocity less then vehicle speed the wheel is locked before the vehicle come to stop the car braking distance is increased 126*m* at 8.5s in dry case and 258*m* at 16s in Icy hard braking cases this causes an accident.

5.1.1 Conclusion of open loop simulation

Table 5.2: Conclusion Open loop Simulation

	In dry cases		In Icy cases		Reason
Breaking torque	1200Nm	400Nm	455Nm	248Nm	Reduced
Lambda/slip	at 3.8s	0.98		App.1	Reduced Wheel locked
Mu slip curve	0.89	0.35	0.3	0.2	Decreased
Wheel speed	Stop at 4.2s		Stop at 4.2s		Dead
Vehicle speed	Stop at 8.5s		16s		Increased
Braking distance	126m at 8.5s		258*m* at 16s		Increased

Without sliding control Braking torque is reduced, the slip is increased the friction coefficient is unstable region.

5.2 Case B – Simulation of ESC for ABS

In this case, the simulation of ESC for longitudinal vehicle is considered and the related Simulink diagram is shown in Figure 5.2.1 the output response of the system is shown in the bellow simulation results.

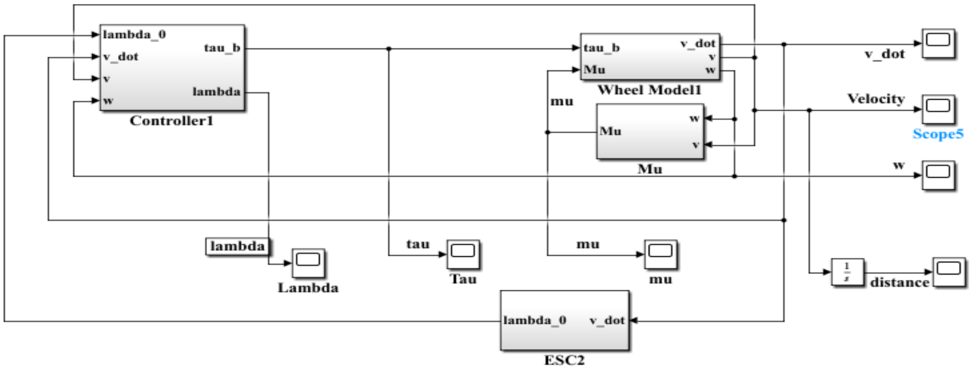


Figure 5.2.1 ESC Simulink model for ABS

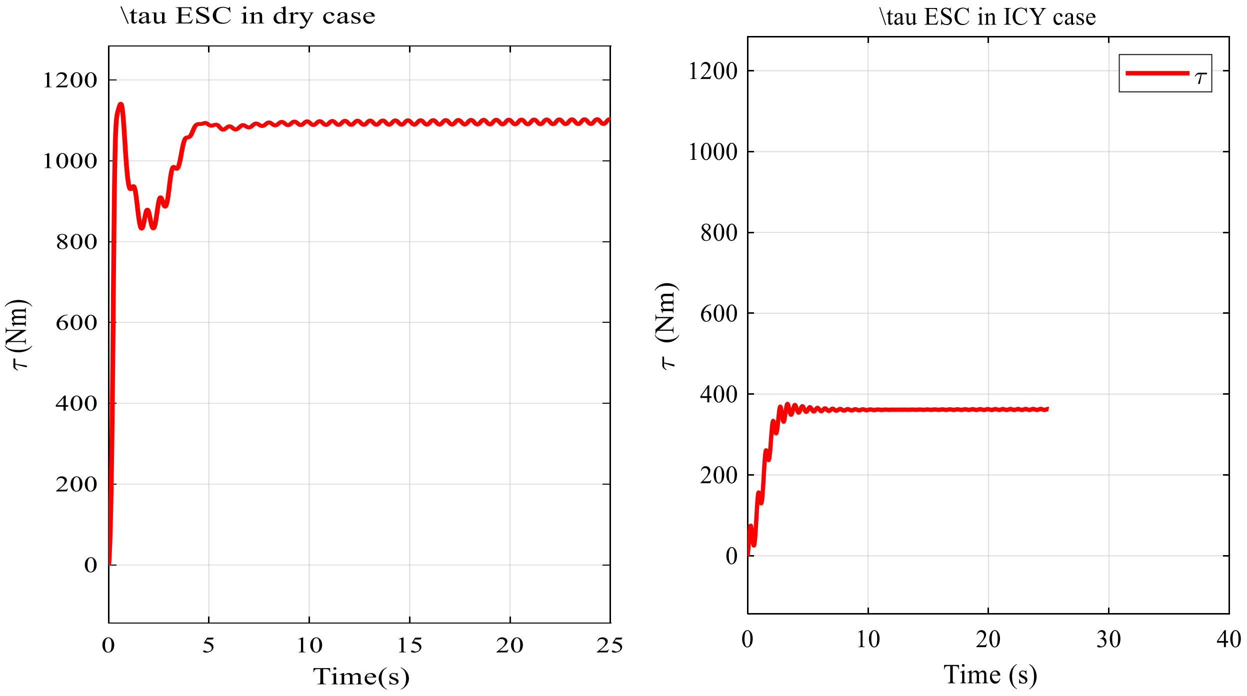
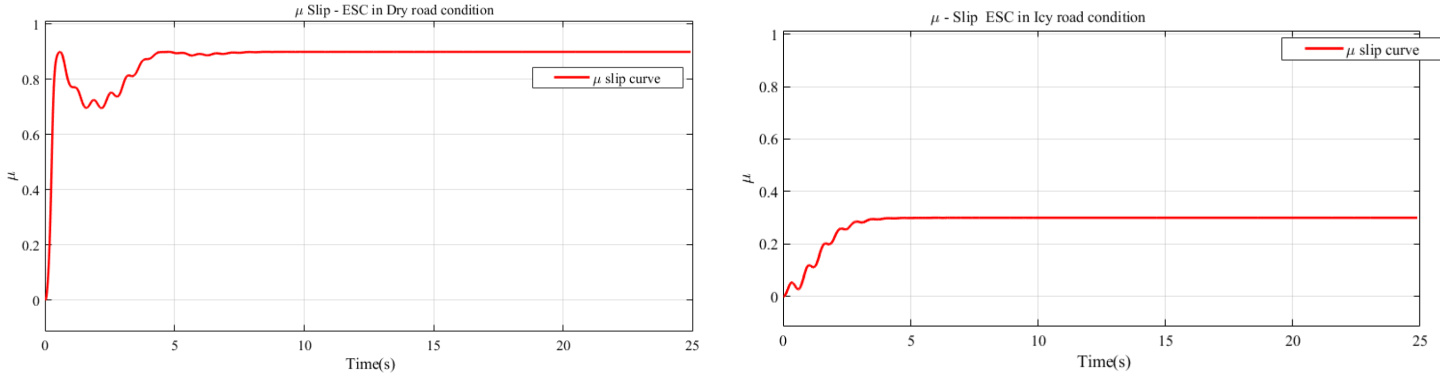


Figure 5.2.2 braking torque in ESC ABS

The use of brake torque to prevent the vehicle from slippage/skid/ and maintain the driver during braking as observe from simulation In dry cases from start up to 0.63s the brake torque is 1140Nm then down in to 841Nm at 1.6s then regulated in to 1093Nm at 4.7s .



In Icy Cases from start up to 3.51s the brakeforce is369Nm then regulated to 364Nm at 5s. When ABS is active the slip is regulated at around 0.2 or (20%) which keeps optimum operating value by adjusting braking torque this couse reduce braking distance.

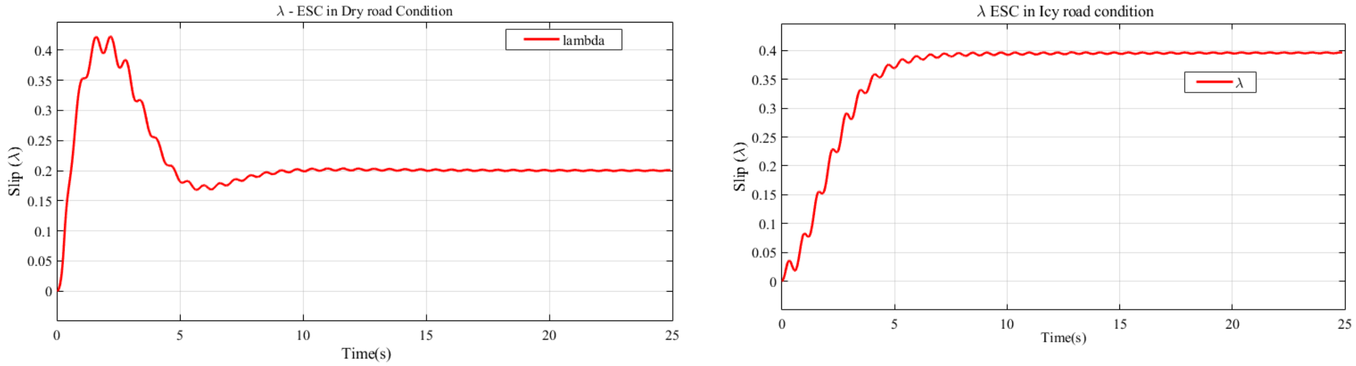


Figure 5. 2.2 wheel slip in ESC ABS

The output of ESC block is slip coefficient this coefficient maximize the friction coefficient also the achieved wheel slip is unknown when achieved wheel slip close to ideal slip coefficient the slip will be regulated the braking distance reduced in case of dry the ideal slip coefficient is 0.2 & 0.4 in case of Icy road condition.

Figure5. 2.3 Friction coefficient in ESC ABS

The slip is controlled maintain the friction coefficient at the optimum value through greater frictional force between the tire and the road condition to decrease the braking distance during hard braking in dry cases .when the slip is controlled by adjusting the braking torque the friction coefficient is maximum the ESC maximize the friction by using ESC block. In case of dry condition high traction force between tire and road mu slip curve is 0.89 at 4.6s.

In case of Icy the friction coefficient is 0.3 due to observation the braking distance is reduced compare to open loop.

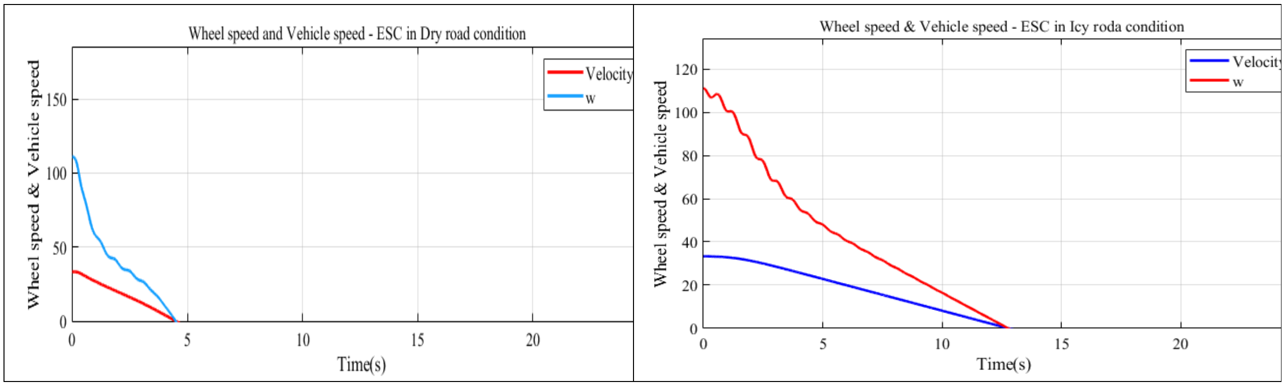


Figure5. 2.2 wheel speed and vehicle speed in ESC ABS

ABS active the slip is controlled the ESC is by searching optimum value the tire is not locked before the vehicle come to stop therefore vehicle speed and wheel speed during hard braking come to stop at the same time this causes shorten braking distance 80m at 4.5 s In dry Cases and 235m at 13s .

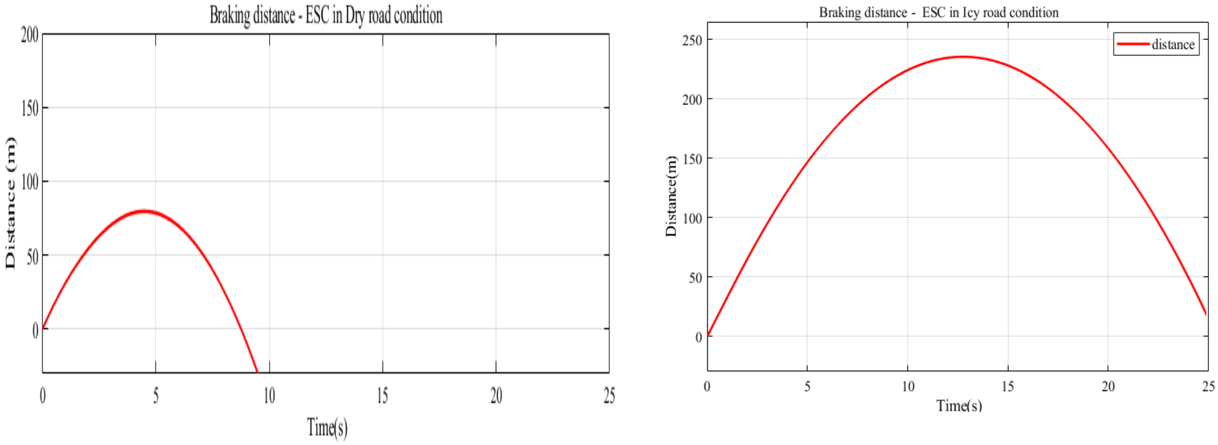


Figure 5. 2.3 braking distance ESC ABS

The vehicle &wheel speed come to stop in dry case 4.5s, & 13s this point is indicate braking distance. The braking distance Extremum seeking control for Antilock braking as observed from simulation result reduced in to dry cases 80*m* at 4.5s and Icy cases the braking distance during Emergency is 235*m* at13s for further clarification refer Table 5.3.

5.2.1 Conclusion Result simulation of ESC for ABS

Table 5.3: Conclusion simulation result ESC for ABS

		In dry	In Icy
1	Breaking torque	1200Nm	500Nm
2	Friction coefficient	0.9	0.3
3	Wheel slip	0.2	0.4
4	Vehicle speed	4.5s	13s
5	Wheel speed	4.5s	13s
6	Braking distance	80m	235m

5.3 Case C- Simulation of ES tune PID controller ABS

In this case, the simulation of ES tuned PID for longitudinal vehicle is considered and the related Simulink diagram is shown in Figure 5.3.1 the output response of the system is shown in the bellow from simulation results.

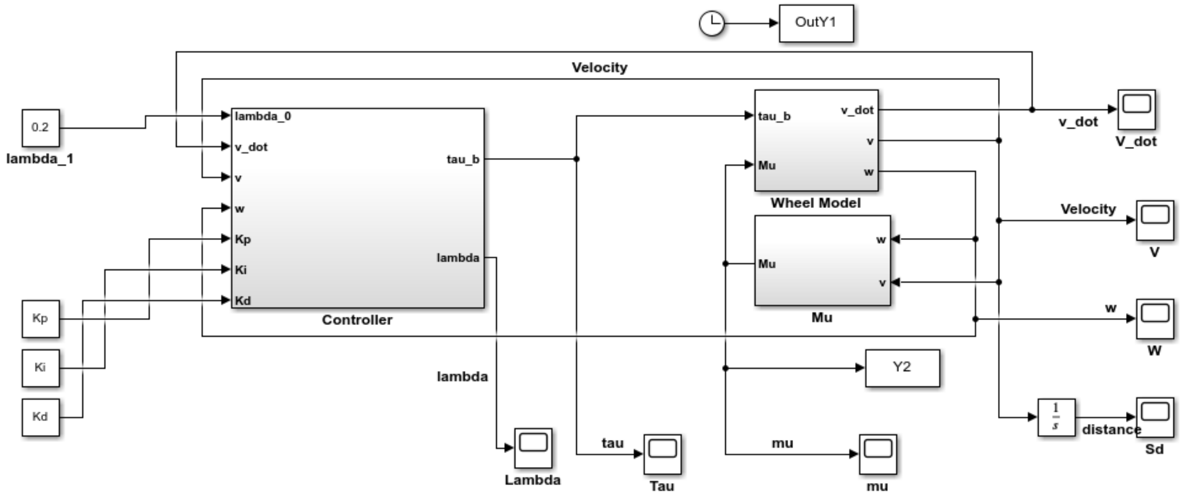


Figure 5. 3 ES tune PID for ABS

Control wheel slip of ABS using ES-PID tuning control used for to overcome the problem associated with conventional PID control by optimizing the PID gains.

The standard PID employed for controlling the wheel slip but the gains updated on line for every step response by Extremum seeking Algorithms. ESA Iteratively updated the PID gains with respect to the cost function. The input of ESC block is the maximize the value of friction coefficient and the output is the slip coefficient. The slip coefficient is regulated by braking torque.

PID tuning Extremum seeking to maximize the friction force coefficient which has a maximum at some non-zero value of slip the friction coefficient is unknown &cannot be measured it changes different road and wheel conditions. ESC track is a well suited for performing automated PID tuning the cost function is composed based on the difference between the actual response &the desired response this cost function output is then feedback to the Extremum seeking loop in order to tune the three parameter of PID controller.

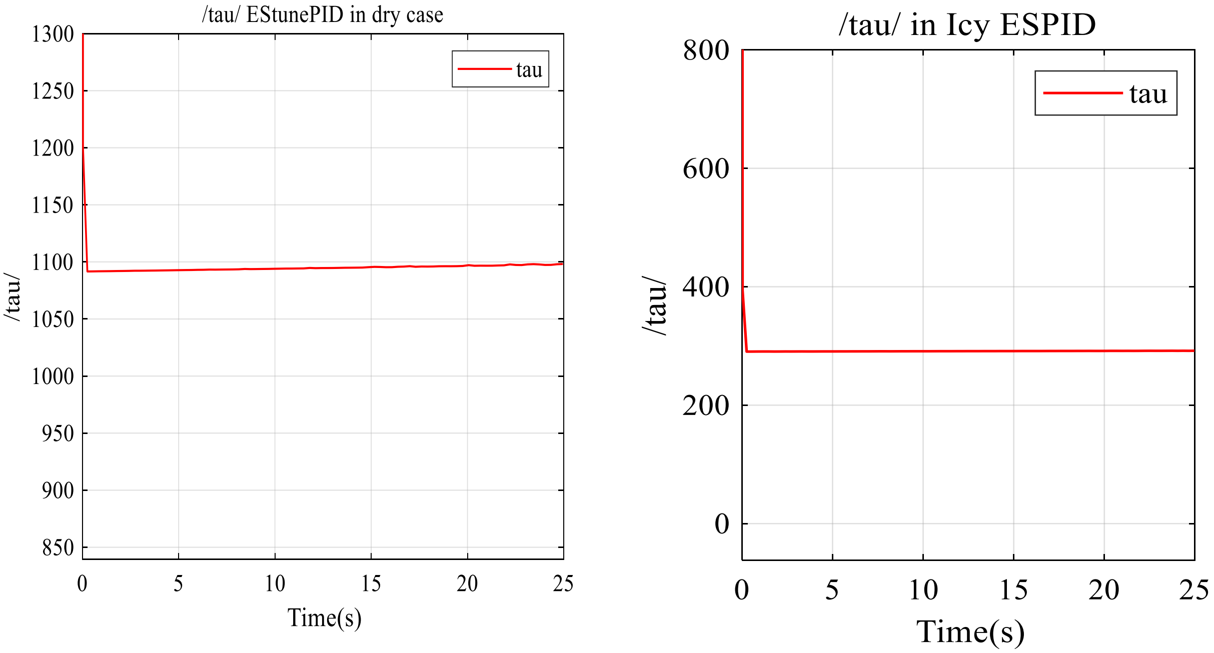


Figure 5. 3.1 braking torque ES tune PID for ABS

In order to shorten braking distance the slip is regulated by friction force this call braking torque can modulate based on the road condition, braking torque is modulated to keep the wheel slip target value(20%) in dry case maximum traction force between tire and road surface so the braking torque is adjusted in to 1100N*m* and Icy cases the traction force is reduced by 85% from normal road surface because in Icy case packed frozen snow &black ice maximum traction reduced by 85% &very dengerious conditon therefore the braketorque in Icy case is to regulate the wheel slip is 290Nm to prevent the wheels during hard braking.

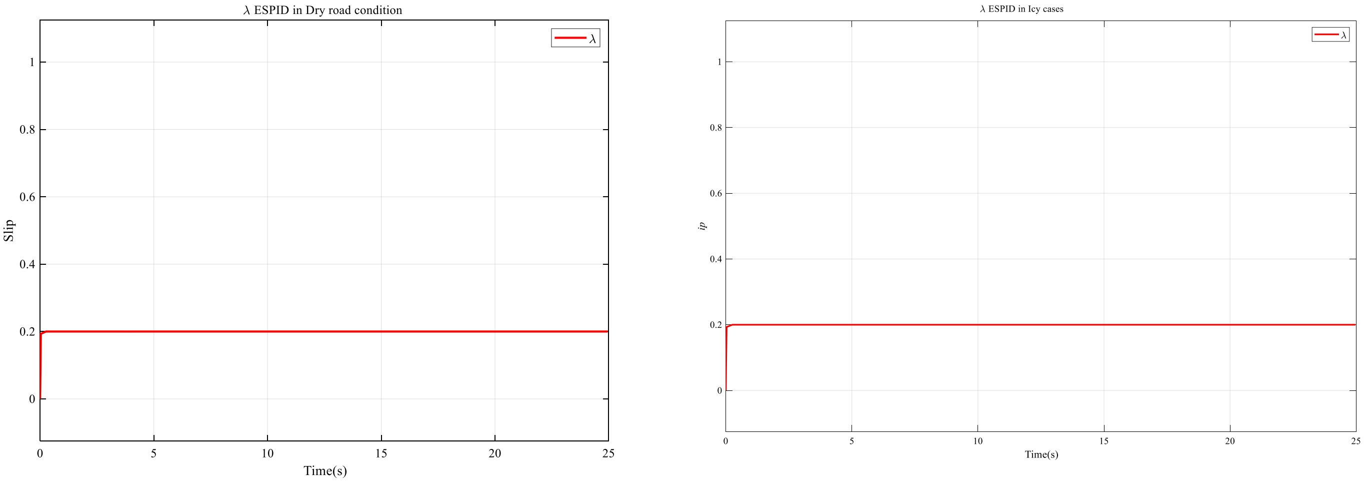


Figure 5. 3.2 wheel slip ES tune PID for ABS

The braking torque modulated to keep the wheel slip optimum value at around 20% and kept in efficient value the friction coefficient is maintained in optimum value which provides high friction force between the tire and the road to decrease the brake distance during hard braking. Slip value maximizes the adhesion between the tire and the road and minimizes braking distance. When the actual slip coefficient is achieving ideal slip coefficient the braking distance is reduced. Wheel slip control is not active below 33.33m/s the wheel locks and the slip go to 1.

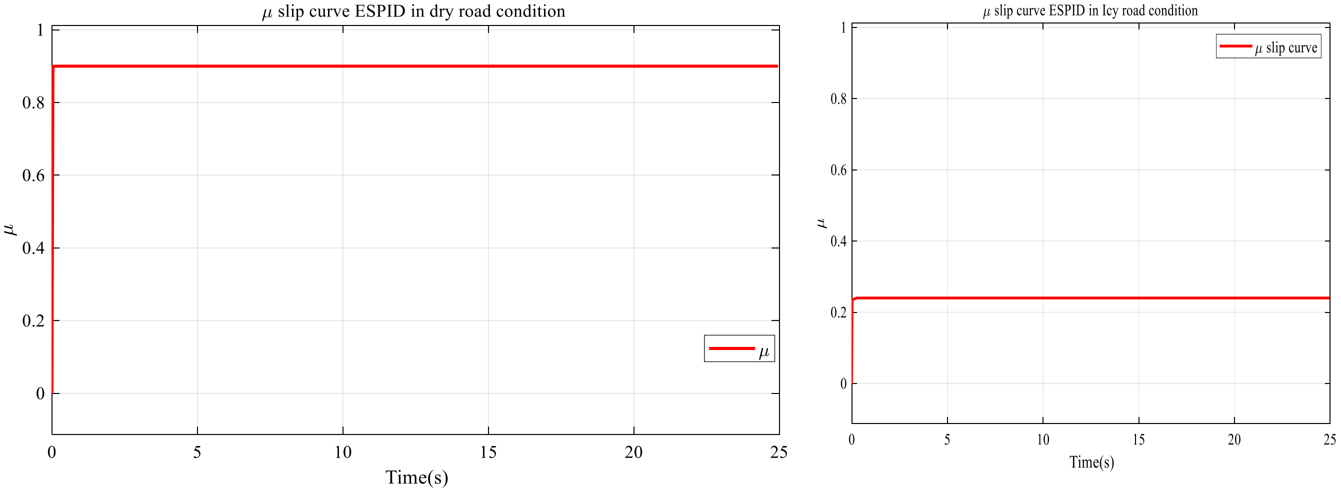


Figure 5. 3.3 Friction coefficient ES tune PID for ABS

When slip is regulated by adjusting the brake torque the tire have optimum slip value which provides higher friction between the wheel and road surface improves the maneuverability of the operator, and maintains vehicle speed. In dry cases the mu slip curve is 0.89 &0.23 in Icy cases to reduce braking distance during hard braking.

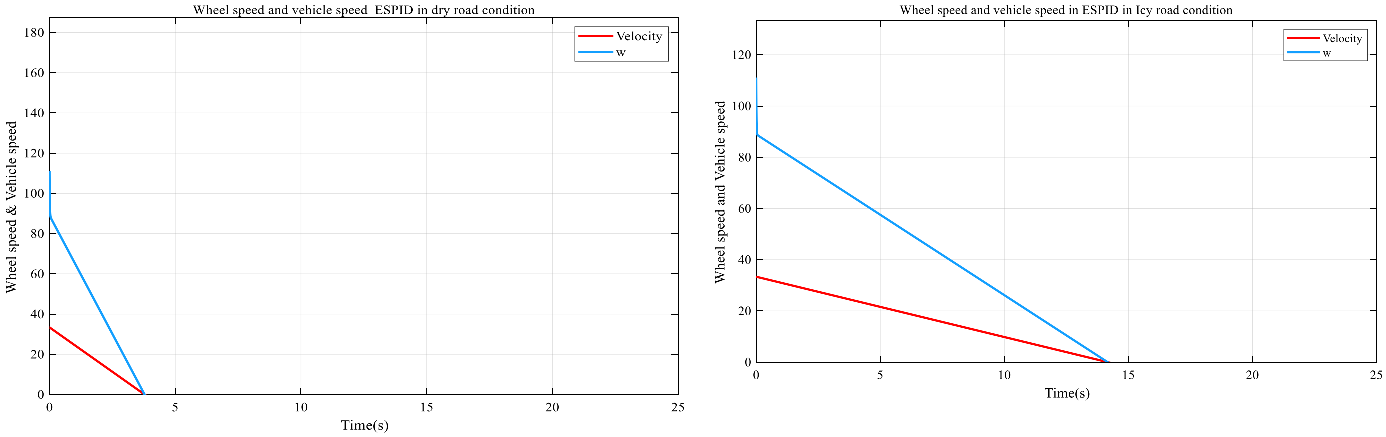


Figure 5. 3.4 wheel speed and Vehicle speed ES tune PID for ABS

When Slip control by adjusting the braking torque the wheel speed and vehicle speed come to stop at the same time in dry cases 3.8s and in Icy cases 13s.

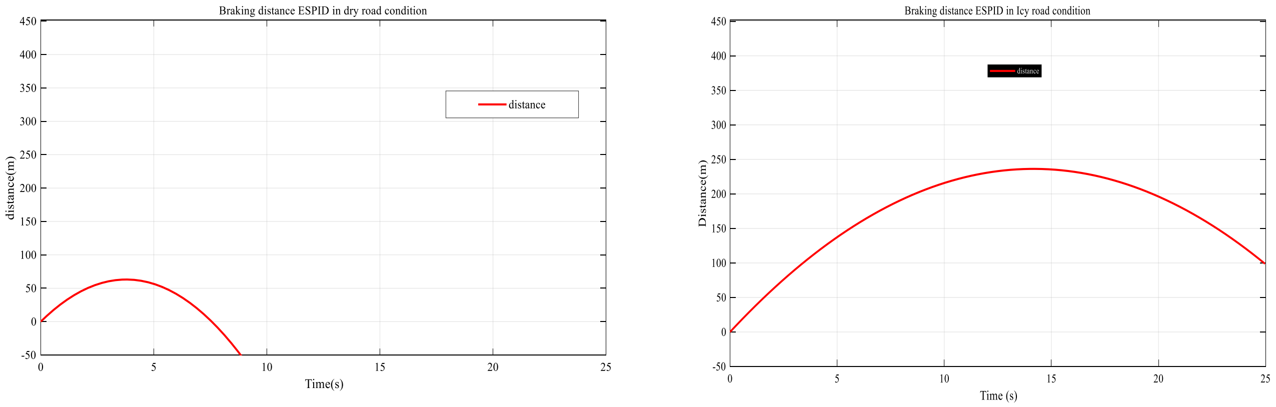


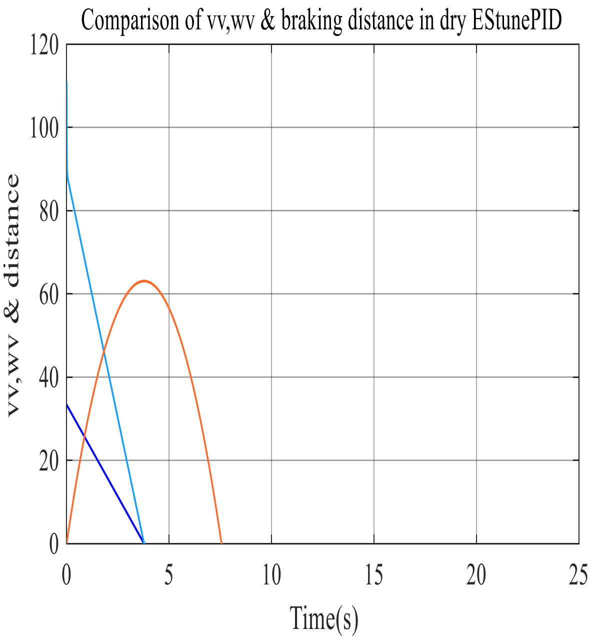
Figure 5. 3.5 braking distance ES tune PID ABS

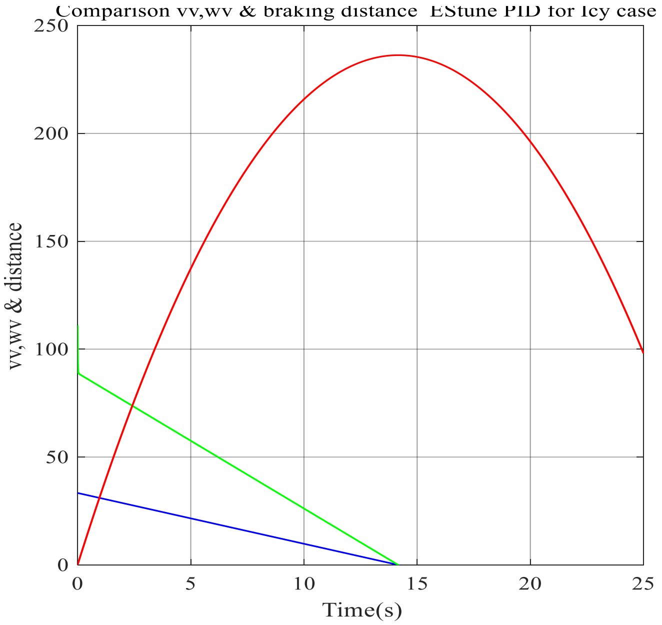
The vehicle &wheel speed come to stop in dry case 3.8s, & 13s in Icy cases this point is indicate braking distance. In dry case maximum traction force by using ES tune PID the braking distance reduced in to 63*m* at 3.8s and in Icy cases the maximum traction force is reduced by 85% due this the braking distance is 235*m* at 13s.

5.3.1 Conclusion Simulation result ES tune PID for Antilock braking system

When design ES tune PID first determine the value of the tuned parameter(KP,ki,kd) Brake torque with ES tune PID limits the maximum value and lower limit during hard braking used to Control the slip rate over the range of 0.2 operations. Wheel slip (Sliding) remains stable in the reference range at 0.2 so less chance of the tire tends to Skid. The friction coefficient as shown from the result in the simulation does not vary over time. It is quite stable since the measured slip is very close to the reference slip and the friction coefficient very close to the optimum value which the design improved braking distance to 63*m* and braking time3.8s in hard braking during dry case **.**In case of Icy road surface Packed frozen snow and black ice lie on the road surface. The maximum traction reduced by 85% and very dangerous condition based on this consideration the simulation result in Icy road surface braking distance is 235*m* at 13s braking time.

5.3.2 Comparison of vehicle speed (vv), wheel speed (wv)& braking distance (bd) of ESPID for ABS in graphical way





5.4.1 Comparision of Simulation resultAntilockbraking system in openloop,ESC and ESCtune PID controller.

In this case, the simulation Comparison of Open loop, ESC, and ES tuned PID for longitudinal vehicle is considered and the related Simulink diagram is shown in Figure 5.2.1 the output response of the system is shown in the bellow simulation result.

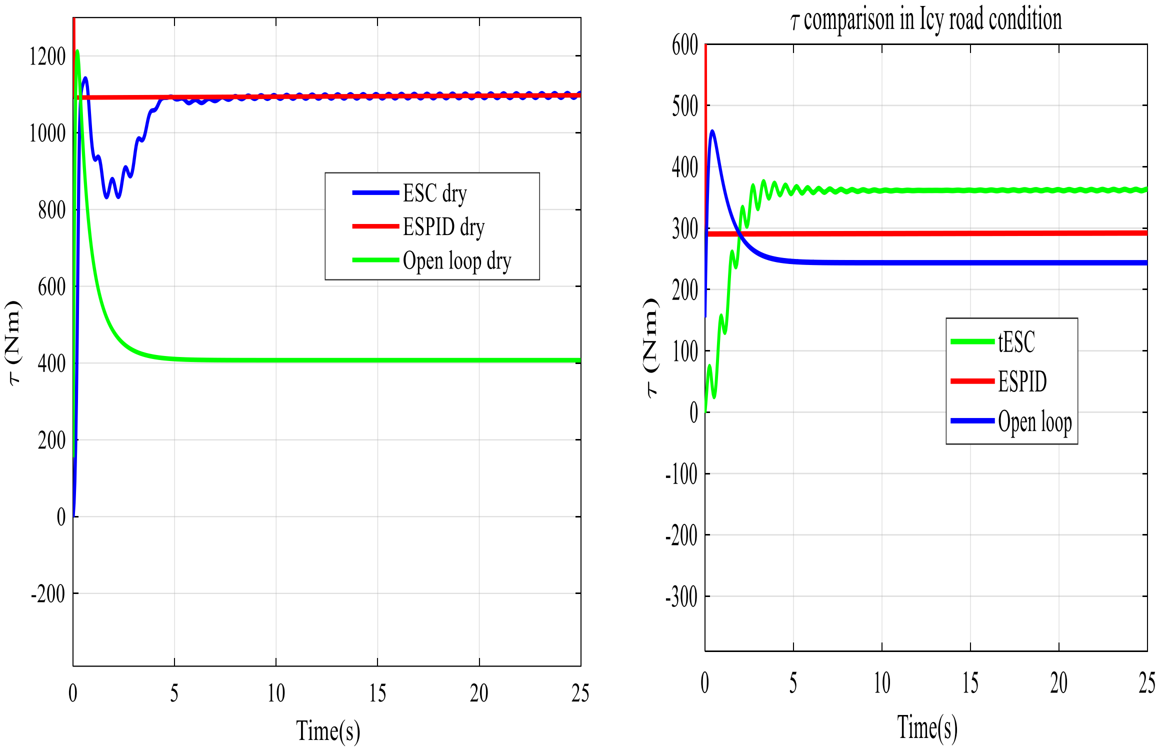


Figure 5. 4.1 braking torque comparison in open loop, ESC & ES - PID for ABS

Table 5.4 Brake torque Comparison

	Slip rate	Braking Torque (Nm) τ_b	
		Dry Road Case	Icy Road Case
Open loop	0.2	400N*m*	248.8 N*m*
ESC	0.2	1091N*m*	364 N*m*
ES-PID	0.2	1092N*m*	290 N*m*

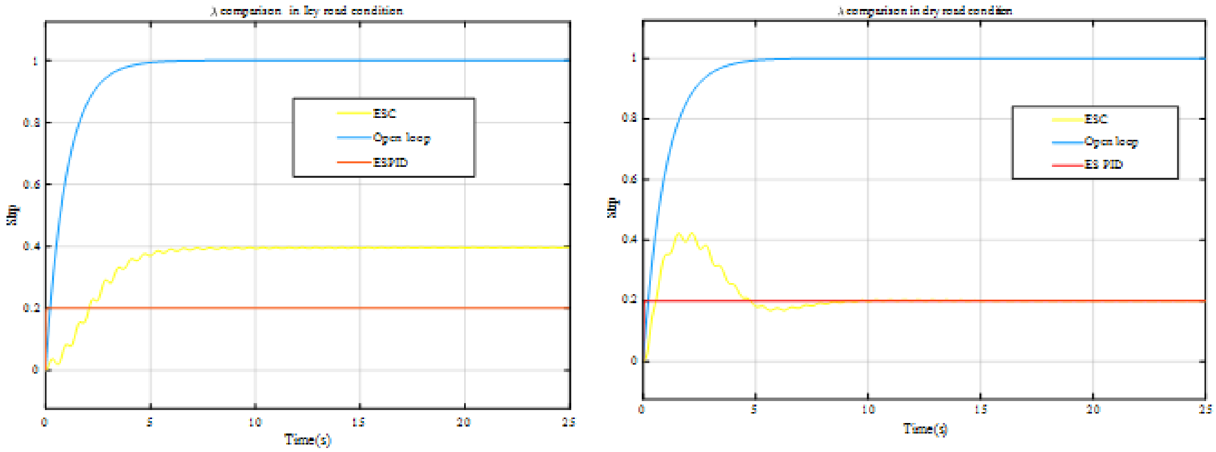


Figure 5. 4.2 wheel slip comparison in open loop, ESC for ABS & ES tune PID for ABS

Table 5.5 Wheel slip comparison

	Slip rate	Slip		
		In dry cases		In Icy cases
		Max	Min	
Open loop	0.2	1		1
ESC	0.2	0.4	0.2	0.38
ESPID	0.2	0.2		0.2

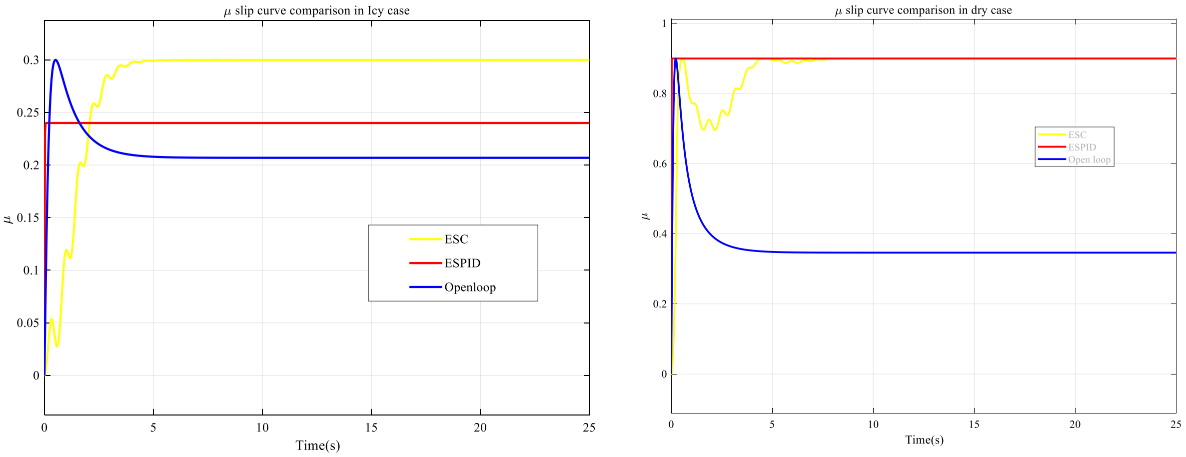


Figure 5.4.3 Friction Coefficient Comparison in open loop, ESC & ES -PID for ABS.

Table 5.6 mu slip curve Comparison

	µ- slip curve			
	In dry case		In Icy case	
	Max	Min	Max	min
Openloop	0.89	0.35	0.3	0.22
ESC	0.89	0.89	0.3	0.3
ESPID	0.9	0.9	0.23	0.23

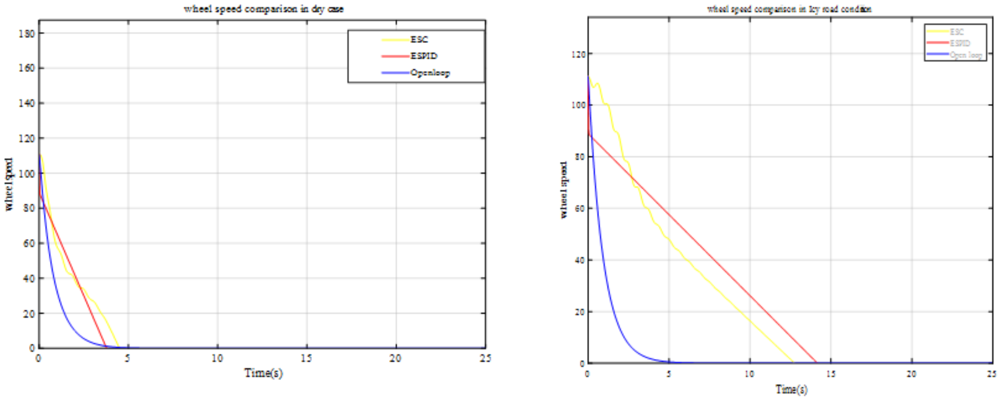


Figure 5. 4.4 wheel speed comparison in dry& Icy case

Table 5.7 Wheel speed comparison

	Wheel speed locked	
	In dry cases	In Icy cases
Openloop	3.2s	4.2s
ESC	4.5s	13s
ESPID	3.8s	13s

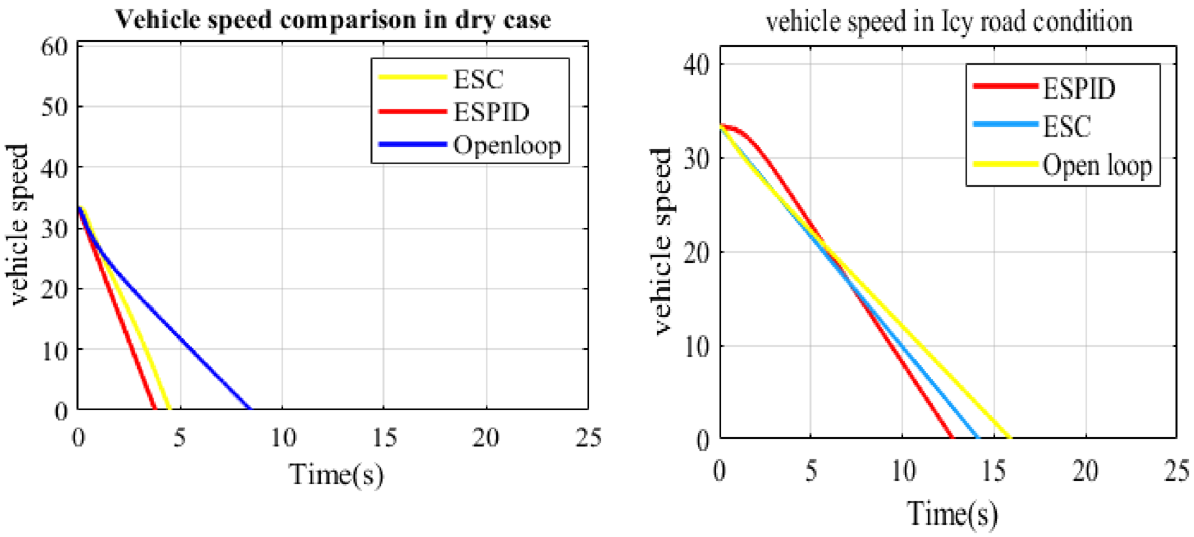


Figure 5. 4.5 Vehicle speed Comparison in dry Road case

Table 5.8 Vehicle speed Comparison

	Vehicle speed come to stop	
	In dry cases	In Icy cases
Open loop	8.5s	16s
ESC	4.5s	13s
ESPID	3.8s	13s

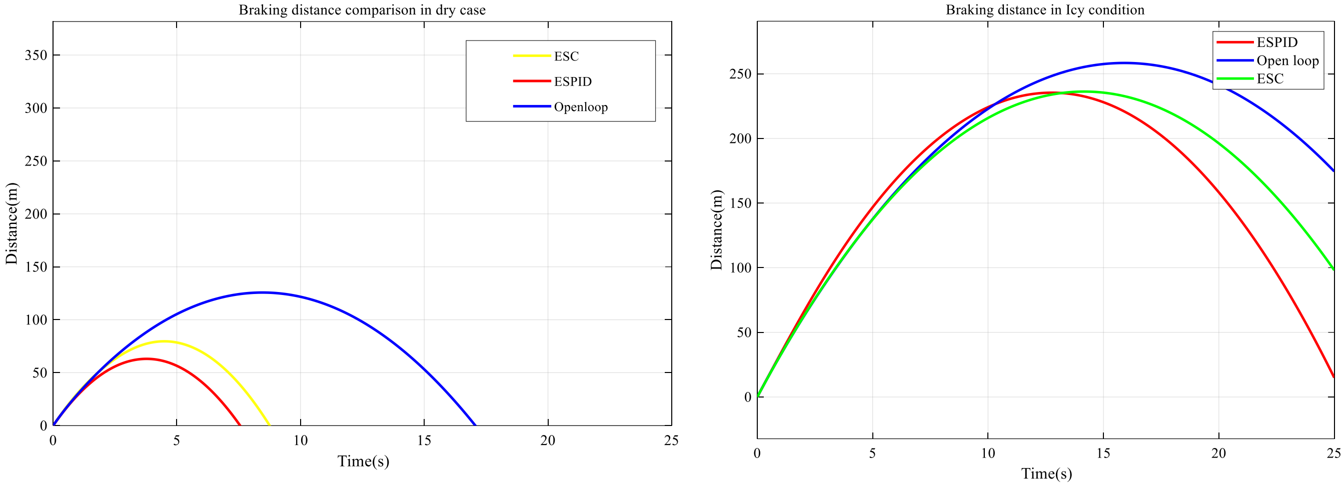


Figure 5.4.6 braking distance comparison in open loop, ESC & ES-PID for ABS

Table 5.9 braking distance comparison

	Sliprate	Braking distance			
		In dry case		In Icy case	
		Braking distance	Braking time	Braking distance	Braking time
Openloop	0.2	126m	8.5s	258m	16s
ESC	0.2	80m	4.5s	235m	13s
ESPID	0.2	63m	3.8s	235m	13s

Observe from simulation result the new proposed work improve braking distance during hard braking situation and improve braking time from the related work.

5.5 Comparative study of Proposed and Conventional Works

Table 5.10 Comparative Studies of Proposed and Conventional Works

Ref	Authors	Year	Condition	Controllers	Slip Ratio	Time(s)	Stopping Distance(m)
1	Vimal Rau Aparow[13]	2013	Dry Road	N/M		50	500
2	Shady Ashraf Abd El-Fatah1, Abdel-Nasser Sharkawy1, Ahmad O. Moaaz2, Nouby M. Ghazaly[9]	2021	Dry Road	Fuzzy Logic control	0.2	56	128
3	A. A. Aly, E. Zeidan, A. Hamed, and F. Salem[24]	2011	Dry Road	PID Control	0.2	568	128
4	BARAN BARIS[1]	2008	Wet Road	SMC	0.12	10	341
5	Esref Bogar, selami beyhan[11]	2018	Dry Road	ESC	0.2	20	520
6	Raj Marti Curve[19]	2018		ES PID	0.3	11.01	483.9
7	Wenyan Xia[20]	2019		PID	0.15-0.25	14.01	720.7
8	Blancas, Angel Paleta Galicia, Alejandro Loaiza Eduardo, Mario López, Leal[28]	2019	Dry road	PID	0.27-0.1	13.1	189
			Ice road	PID	0.202-0.198	124	1745

5.9 Discussions

This section presents the effectiveness of the newly proposed works for the antilock braking system. From the comparison results, the new controllers for ABS improve braking distance & braking time after the braking has been applied to the vehicle in dry road conditions.

CHAPTER SIX

CONCLUSION AND FUTURE RECOMMENDATIONS

6.1 Conclusions

In this thesis, antilock braking system problems were identified, a mathematical model where analyzed, Extremum seeking control tune PID control for antilock braking system has been designed, simulated In two cases in dry road case ,and Icy road condition their performance has compared with previous related works.

From the simulation results, the new proposed controlling systems in dry road cases have been controlled at 63m at 3.8s. This result is compared with the conventional controlling system, from the comparison results, ES tune PID controller for antilock braking systems improves braking distance & braking time to stop the car after braking. Therefore, the new controllers of antilock braking systems have better performance than conventional works.

6.2 Recommendation

- ✓ Implementations of ES tune PID controller for antilock braking systems.
- ✓ Design ES tune sliding mode controllers for Antilock braking systems.
- ✓ Fabrications of ES tune PID controller for antilock braking systems.

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