Design and Analysis of Controller for Antilock Braking System in Matlab/Simulation

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Abstract — **Antilock braking mechanism enhances the vehicle steadiness and steering ability to stop a vehicle wheel without locking and minimizing stopping distance. A scientific model of electronically monitored slowing mechanism (ABS) of quarter auto model has been produced. The different sorts of controllers such as P, PI, PD and PID have been executed and results are analyzed in Matlab/Simulink environment. The controller's parameters are streamlined to control wheel slip and stopping distance. A Genetic algorithmic optimization technique has been used to obtain gain parameters of controllers. The simulated results of an ABS system are compared with and without controller and further between the distinctive sorts of controllers. The output response of PID controller is better as compared to different controllers.**

Keywords— Antilock Braking System (ABS), Proportional controller (P), Proportional Integrative (PI), Proportional Derivative (PD), PID, modeling quarter car model, genetic algorithm. Slip ratio, steering ability.

I. INTRODUCTION

The target of ABS (Antilock braking system) is to produce the biggest conceivable braking power progressively while keeping the vehicle stable and avoiding excessive wheel slippage. ABS works when the braking force is more than the force of adhesion [1]. The ABS screens the pace of every wheel to identify locking. When it recognizes sudden breaking, it will discharge breaking pressure for a moment and then continue optimum braking pressure to each wheel [2]. By repeating this procedure in brief time frame, it upgrades steering control amid sudden stops. Thus, it will likewise enhance the soundness of halting the vehicle. Accordingly, ABS advantages in two ways: You will stop prior, and you will have the capacity to direct while you stop. Coefficient of friction between tire and road, the tire slip proportion, and the vertical force on the wheel are the essential procedure parameters influencing the control quality. The estimation of slip ratio between wheel and road surface is highly uncertain. The reason for this instability for the most part comprises of vertical contact force between tire and the road surface, slip ratio and sometimes rapid variation of the road conditions with its related large variations of friction coefficients [3]. The plant to be controlled incorporates elastically suspended wheel, braking servo system and actuator. For the configuration of ABS controllers, various methodologies have been proposed. A prescient methodology to design a non-direct model-based controller for the wheel slips is put forward by [4-9]. A static-state feedback control calculation for Anti-lock braking system is proposed by [10]. The model of a quarter-vehicle and an ABS has been described by [11]. ABS that is updated for one kind of surface can't be trusted upon to work honorably on a different kind of surface. To make ABS work successfully for various road conditions, we need to perceive the perfect wheel slips on a given surface. The goal of the present paper is to outline and examine an efficient controller for antilock braking system.

II. PROBLEM FORMULATION

ABS system helps to achieve shorter stopping distances as compared to those of locked up wheels, furthermore to maintain vehicle's steadiness and steering capability which is explained by the relation between wheel slip ratio (λ) and the coefficient of friction (μ). The friction coefficient relies upon a lot of factors, and thus fluctuates in a wide range. The variables are recorded beneath:

1. The slip proportion between the road and the tire,
2. Tire brand (seasonal tires),
3. Condition of road surface i.e. wet or dry,
4. Slip angle of tire, and
5. Vehicle speed.

The wheel slip ratio likewise changes as per the kind of road [13]. Considering all sorts of road surfaces, the frictional coefficient of almost all the road surfaces is worst when the wheel is locked and the slip proportion of wheel is 1 and is optimum when the wheel slip ratio is 0.2 approximately. So, in order to maximize the coefficient of friction for any road surface, we need to control the wheel slip ratio to an estimation of around 0.2. This is the objective of ABS controller.

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III. MODELLING OF VEHICLE BRAKING SYSTEM

In this section, a mathematical model of quarter vehicle dynamic motion has been obtained by using the physics law. The improved model of quarter vehicle as shown in Fig. 1 was derived [14-15]. The non-linear dynamics can be depicted as follows.

The force balance in the longitudinal direction:

$$ma_x = \mu_r F_N \qquad (1)$$

The slip ratio is defined by:

$$\lambda = \frac{V_x - \omega R}{V_x} \qquad (2)$$

Summing torques about the wheel centre,

$$J_W \alpha_W = -u + \mu_r R F_N \qquad (3)$$

Using equations 1 & 2, and rearranging for λ' yields,

$$\lambda' = -\frac{\mu_r F_N}{V_x}\left(\frac{1-\lambda}{m} + \frac{R^2}{J_W}\right) + \frac{R}{J_W V_x}\mu \qquad (4)$$

The above equations 1, 2, 3 & 4 are used to develop a simulink model of ABS in Matlab as shown in Fig. 2. In this simulink model, the tire torque and the desired slip of value 0.2 is taken as input; whereas the vehicle speed, wheel speed, stopping distance, and slip are the output received. To calculate the value of μ_r, a standard graph between μ_r and λ is used, where the value of λ is calculated from the model. The input parameters that have been used are given in Table 1.

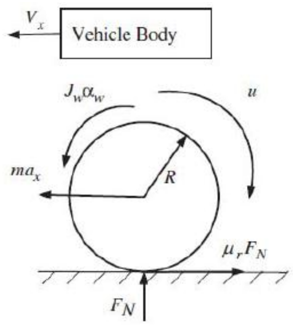

Fig. 1: Quarter vehicle dynamic motion

TABLE 1. Input Parameters

Vehicle Parameters	Values
Radius of the wheel (R)	0.33 m
Mass of the vehicle (m)	342 kg
Moment of Inertia (J_W)	1.13 kgm^2
Gravitational Constant(g)	9.81 m/s^2
Maximum Braking Torque (u)	1200 Nm
Linear velocity of vehicle (V_x)	27.78 m/s
Rotational speed of wheel (ω)	$27.78/0.33$ = 84.18 rad/s
Desired slip (λ_d)	0.2

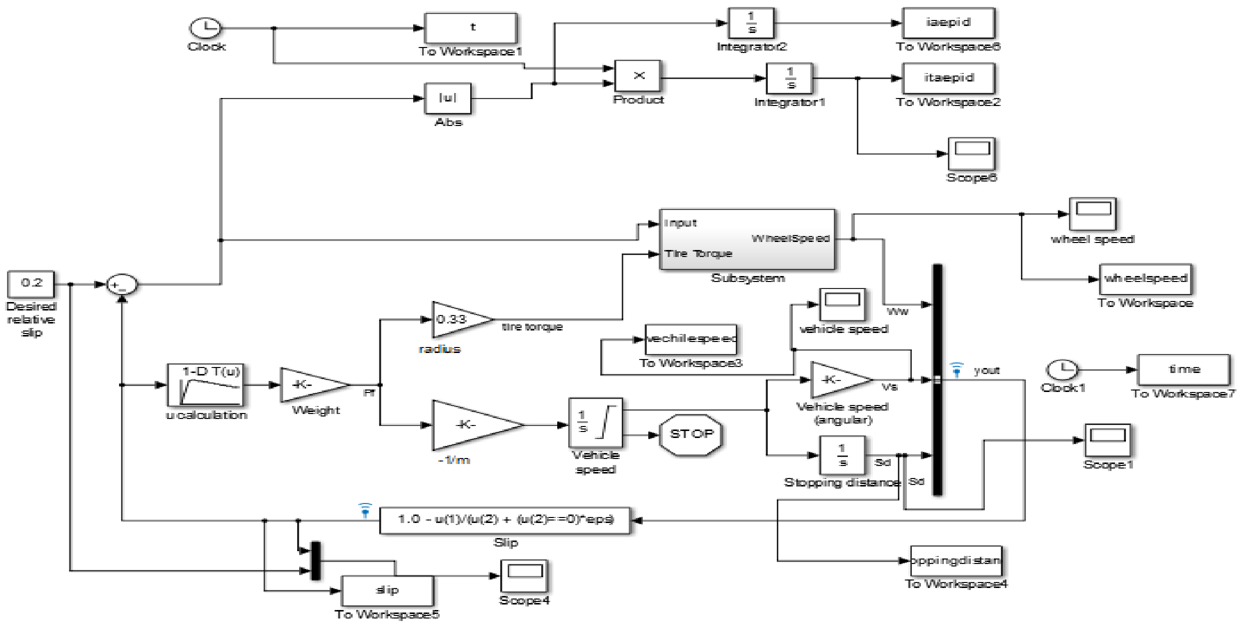

Fig. 2: ABS Model in Matlab/Simulink

IV. CONTROL SYSTEM

The conventional controller such as P, PI, PD, PID has been used in control system, the gain parameters play a vital role in controlling action; so in the present work these parameters are optimized by genetic algorithmic in matlab. A closed loop system is implemented where the output (slip ratio) is compared with the desired value and an error is generated which is controlled by the controllers. The controller output is further fed into the system as shown in Fig. 3, which controls the brake pressure modulator so as to maintain the desired slip ratio. The various plots of ABS system without controller that are slip ratio vs. time, stopping distance vs. time and vehicle & wheel velocity vs. time are shown in Figs. [4-6].

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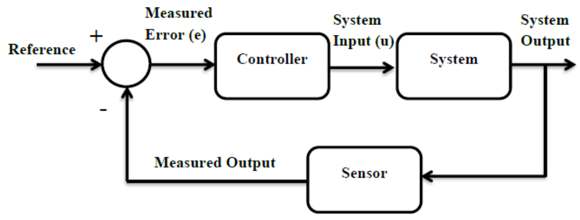

Fig. 3: Feedback Control System

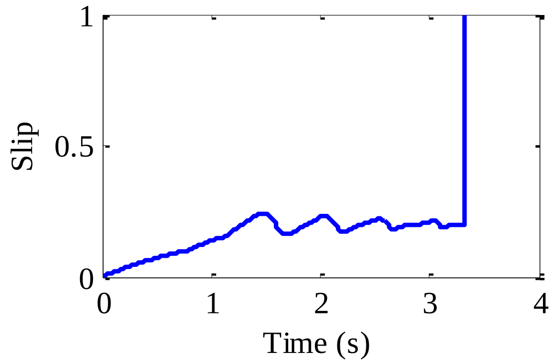

Fig. 4: Slip vs. Time without controller

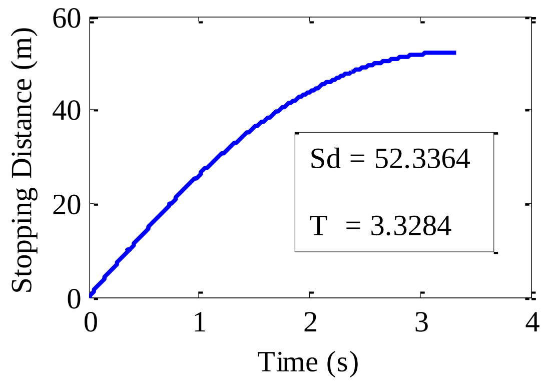

Fig. 5: Stopping distance vs. time without controller

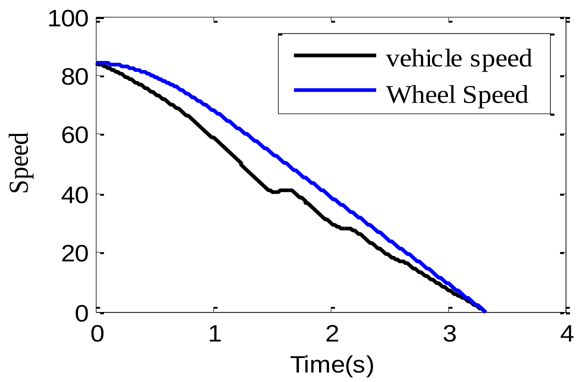

Fig. 6: Vehicle speed and wheel speed vs. time without controller

A. Proportional Control (P Controller)

P controller endeavors to control the output by applying input to the system which is proportional to the measured error (e) between the output and the reference point. Here control torque is defined as,

$$u = K_p \, e \qquad (5)$$

Where K_p is the proportional gain parameter of the controller, whose value is optimized using GA technique (Fig. 7). The optimized value of K_p is 1.817 and the same is applied in the model. The various plots that are slip ratio vs. time, stopping distance vs. time and vehicle & wheel velocity vs. time are shown in Figs. [8-10]. The stopping distance obtained by implementing Proportional control is 46.9494 meters, and the stopping time is 3.1229 seconds.

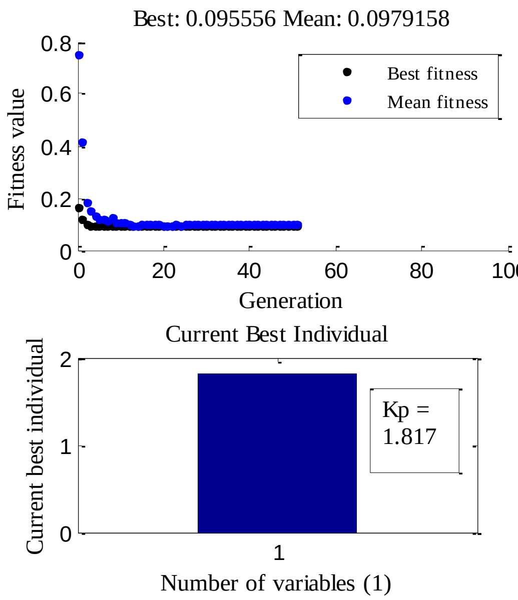

Fig. 7: *GA optimized value of* K_p

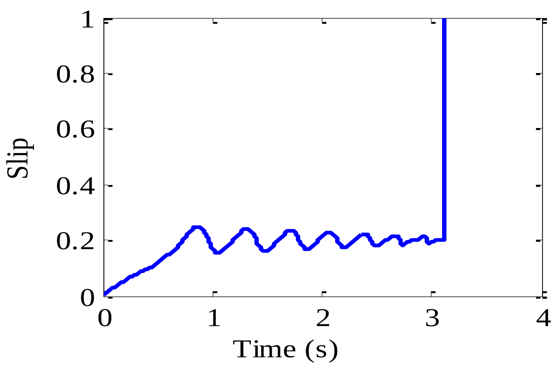

Fig. 8: Slip ratio vs. time for P Controller

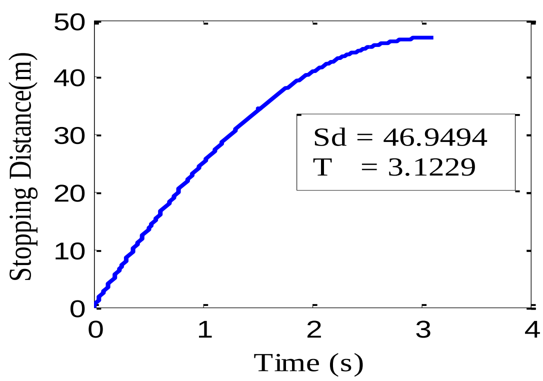

Fig. 9: Stopping distance vs. time for P Controller

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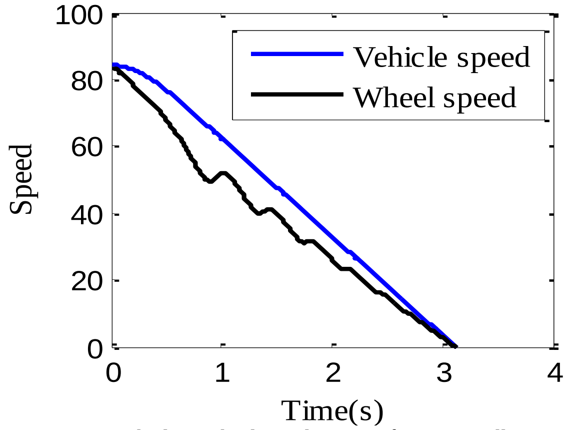

Fig. 10: Vehicle & wheel speed vs. time for P Controller

B. *Proportional Derivative Control (PD Controller)*

This controller feeds the error with constant gain (K_p) as well as the differentiation of error with constant gain (K_d) to the system so as to maintain the output of system at the reference point.

$$u = K_p e + K_d \frac{dE}{dT} \qquad (6)$$

The GA optimized values of k_p and k_d are 4.052 and 0.187 (Fig.11). After implementing the same value, various plots that are slip ratio vs. time, stopping distance vs. time and vehicle & wheel velocity vs. time are drawn as shown in Figs. [12-14]. The stopping distance obtained by implementing PD control is 43.3268 meters, and the stopping time is 2.9779 seconds.

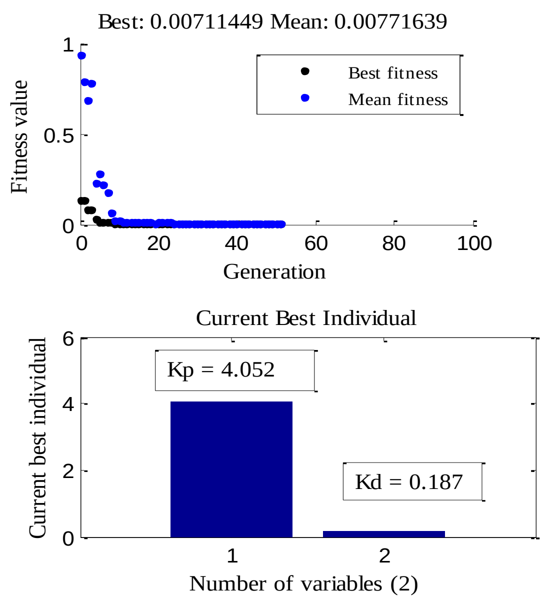

Fig. 11: GA optimized value of K_p and K_d

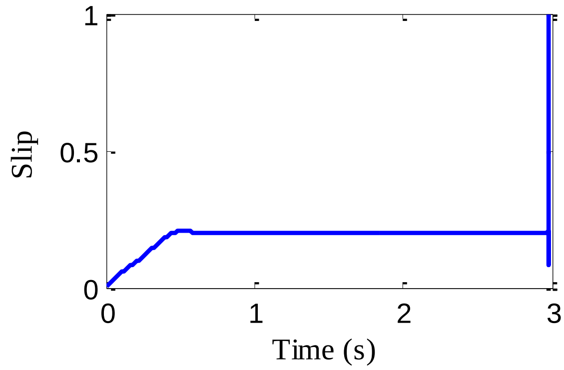

Fig. 12: Slip ratio vs. time for PD Controller

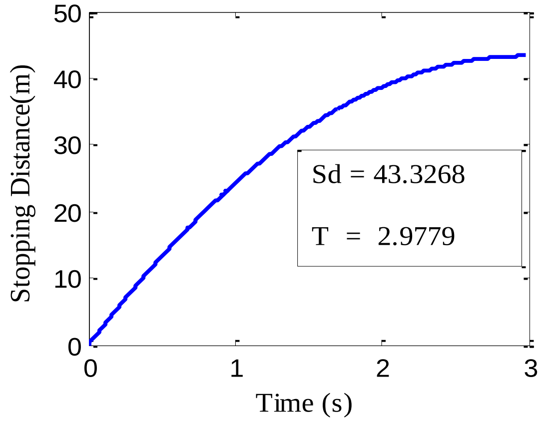

Fig. 13: Stopping distance vs. time for PD Controller

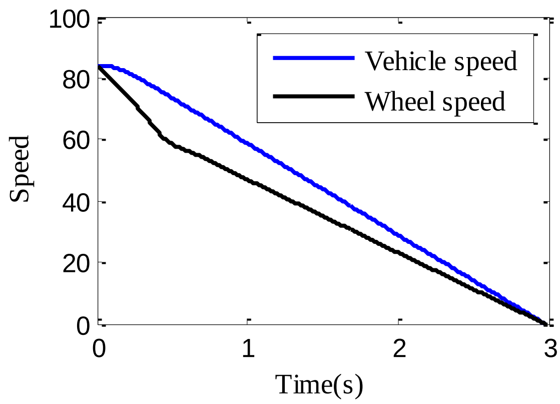

Fig.14: Vehicle & wheel speed vs. time for PD Controller

C. *Proportional Integral Control (PI Controller)*

In this controller, input to the system is the error with constant gain (K_p) in addition to the integral of error with constant gain (K_i) to control the system output.

$$u = K_p e + K_i \int e \, dt \qquad (7)$$

The GA optimized value of k_p and k_i are 2.503 and 0.01 (fig. 15). Obtained graph of slip ratio vs. time, stopping distance vs. time and vehicle & wheel velocity vs. time are shown in Figs. [16-18]. The stopping distance obtained by implementing PI control is 45.1382 meters, and the stopping time is 3.0582 seconds.

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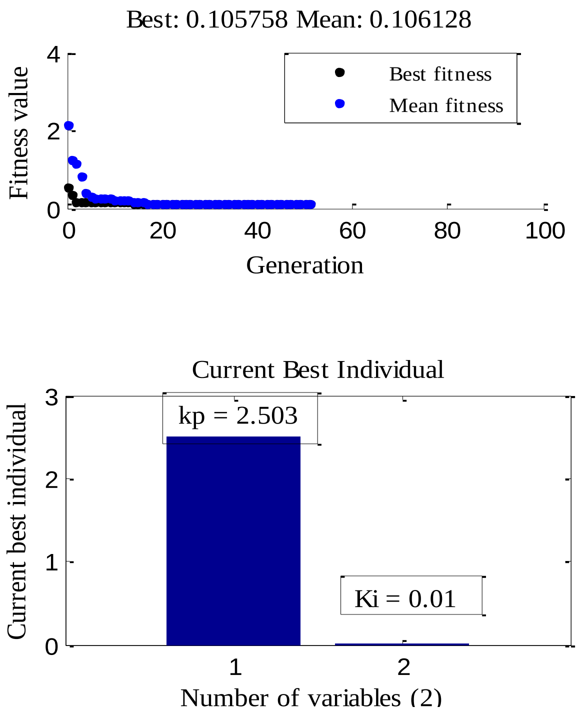

Fig.15: GA optimized value of K_p and K_i

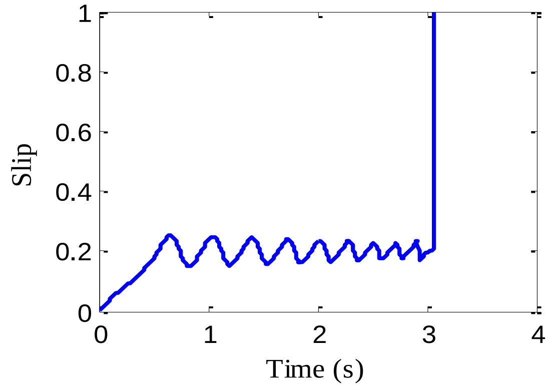

Fig.16: Slip ratio vs. time for PI Controller

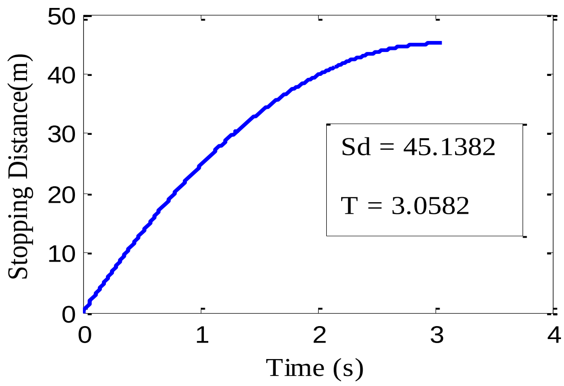

Fig. 17: Stopping distance vs. time for PI Controller

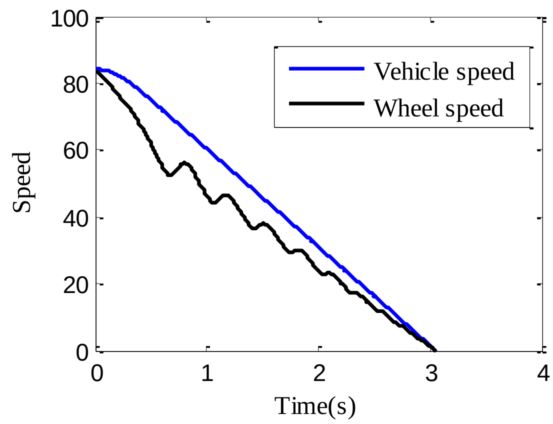

Fig. 18: Vehicle & wheel speed vs. time for PI Controller

D. Proportional Integral Derivative Control (PID Controller)

In PID controller, system input is the summation of error with constant gain (K_p), integral of error with constant gain (Ki), and differential of error with constant gain (K_d).

$$u = K_p\, e + K_i \int e\, dt + K_d \frac{de}{dt} \qquad (8)$$

The G

The GA optimized value of k_p, k_i and k_d is 5.009, 0.001 and 0.189 (Fig. 19). Obtained graphs of slip ratio vs. time, stopping distance vs. time and vehicle & wheel velocity vs. time are shown in Figs. [20-22]. The stopping distance obtained by implementing PID control is 42.6188 meters, and the stopping time is 2.9514 seconds.

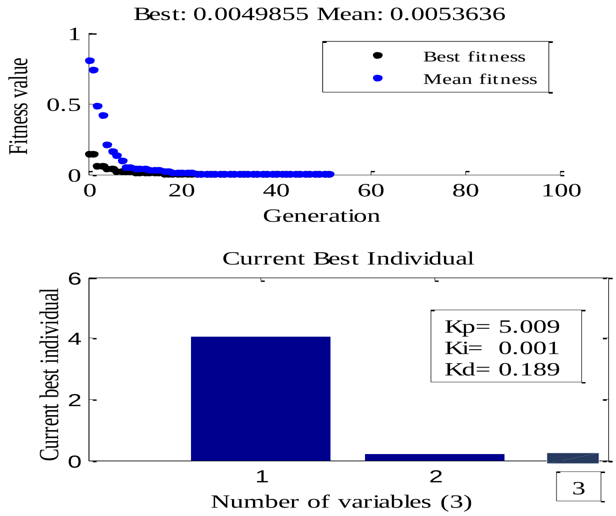

Fig.19: GA optimized value ofK_p, K_i and K_d

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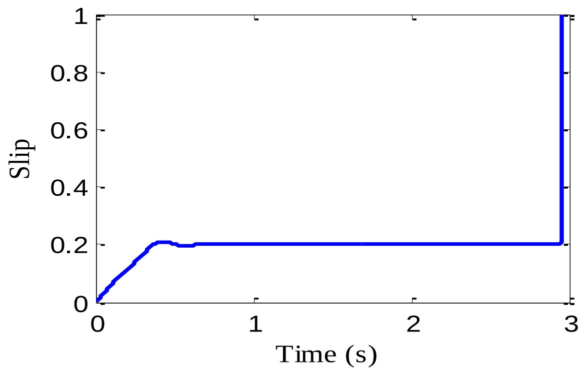

Fig. 20: Slip ratio vs. time for PID Controller

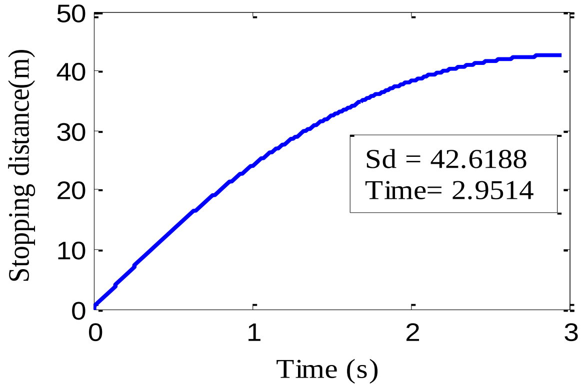

Fig. 21: Stopping distance vs. time for PID Controller

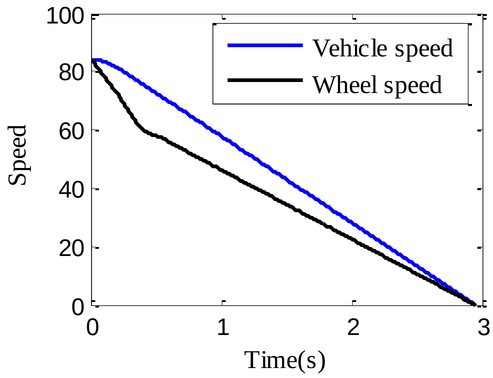

Fig. 22: Vehicle & wheel speed vs. time for PID Controller

V. RESULTS

The P, PD, PI and PID controllers have been effectively executed and consequences of ABS framework with and without controller are analyzed. The output response of P controller in which stopping distance results out to be 46.9494 meters and stopping time comes out as 3.1229 seconds which is superior to braking without controller where the stopping distance is 52.3364 meters and the stopping time is 3.3284 seconds. Also, we have executed PI controller in which stopping distance results out to be 45.1382 meters and stopping time results out to be 3.0582 seconds which is better than P controller where the stopping distance is 46.9494 meters and the stopping time is 3.1229 seconds. Thirdly, we have executed PD controller in which stopping distance results out to be 43.3268 meters and stopping time comes out as 2.9779 seconds which is superior to PI controller where the stopping distance is 45.1382 meters and the stopping time is 3.0582 seconds. After that, we have actualized PID controller in which stopping distance results out to be 42.6188 meters and stopping time turns out as 2.9514 seconds which is superior to PD controller where the stopping distance is 43.3268 meters and the stopping time is 2.9779 seconds. So, after observing all these results, it is found out that PID controller yields the best result in terms of least stopping distance and least stopping time. By applying PID controller, the stopping distance is reduced by 9.7176 meters and stopping time is decreased by 0.377 seconds as compared to braking without controller. These results are shown in Table 2.

TABLE 2. Comparison of different types of controllers

Controller type	Stopping Distance (m)	Stopping time (s)
Without Controller	52.3364	3.3284
P Controller	46.9494	3.1229
PI Controller	45.1382	3.0582
PD Controller	43.3268	2.9779
PID Controller	42.6188	2.9514

VI. CONCLUSION

A mathematical model of antilock braking system is made in matlab/simulink. We actualized different controllers, for example; P, PI, PD and PID. By comparing the outcomes that are shown in table 2, PID is the best amongst every one of them. The stopping distance obtained in PID controller is 42.6188 meters and stopping time is 2.9984 seconds.

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