Speed Control of Electric Vehicles Using Adaptive PID Controller

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Abstract*— Electric vehicles (EVs) are broadly utilized for their High Efficiency, high torque, low volume and gained significant attention due to their potential for reducing carbon emissions and reliance on fossil fuels. To maximize the performance and efficiency of EVs, precise speed control is crucial. This analysis presents a conclusion into the application of Proportional Integral (PI) and Proportional-Integral-Derivative (PID) controllers for speed control in electric vehicles, implemented in the MATLAB environment. This implementation focuses on the development of control algorithms to regulate the speed of an electric vehicle, considering various driving scenarios and disturbances. A comprehensive analysis of the PI and PID controllers' performance, including their stability, transient response, and steady-state accuracy is conducted. Simulations are carried out to assess the controller's effectiveness in maintaining the desired speed while ensuring passenger comfort and safety. To demonstrate that PID controllers offer superior speed control capabilities compared to PI controllers, as they incorporate derivative action to improve response time and minimize overshoot. Furthermore, the study explores the tuning process of these controllers to optimize their performance for electric vehicle speed control. Insights into the choice of control parameters and their impact on the system's behavior are provided. This research contributes to the understanding of control strategies for electric vehicles, which is crucial for achieving energy-efficient and reliable electric transportation. The findings can be used to enhance the design and implementation of speed control systems in electric vehicles, ultimately promoting their adoption and sustainability in the automotive industry.

Keywords*— Electric Vehicles, Speed Control, PI Controller, PID Controller, MATLAB Simulation, Control System Design.

I. INTRODUCTION

Electric vehicles (EVs) are transforming the way we think about transportation. With the rise of climate change and increasing concerns about air pollution, EVs offer a sustainable alternative to traditional gas-powered cars around the World. Rechargeable batteries power these vehicles and produce zero emissions, making them an environmentally-friendly choice for drivers. But EVs aren't just good for the planet – they also offer much cheaper running costs, a smooth and quiet ride, with the benefit of instant torque and acceleration.

Presently, the industrialized world is growing very quickly and the requirement for accuracy and unbending nature has become a significant prerequisite. Various applications require accuracy and are fit for surviving issues . In driving, from a variety of motors, BLDC motors have been broadly utilized in mechanical, restorative hardware, vehicles, aviation, hard circle drive, as the benefits of BLDC are extraordinary execution, advance and lower assurance in power factor.

In the direction of recent years, with their promising presentation in different applications in both the military and regular citizen fields, unmanned aeronautical vehicles (UAVs) have stood out for researchers to control procedures . The UAV is described by its minimal effort, high portability, simple to structure and simple to keep up, and the capacity to work in perilous and dull situations to spare human life . These highlights give a promising option in contrast to different not controlled military and regular citizen applications. As of late, DC electronic motors assume a significant position in UAV rotor control. One of the fundamental preferences of an electric motor is its effortlessness of controlling the speed and its speed of movement. These days, BLDC motors are generally utilized in electronic vehicles, on the fields that the nonattendance of a brush/ transport gathering decreases hearing sharpness and improves productivity and torque. A well-known magnet brushless DC motor (PMBDCM) is mainstream and utilized BLDC motor utilized as a variable speed drive framework for mechanical, car, aviation and computerization applications.

Notwithstanding their general structure and minimal effort, these controllers are likewise portrayed by their quick reaction, short settlement and rise time, and low overshoot. In any case, one of the principal troubles in applying these controllers is found within the sight of dynamic burden conditions where the framework reaction backs off with the difference in arrangement point. Immediately, the FLC was applied to control the speed of the BLDC motor. It is described by its capacity to manage inadequately characterized numerical models. The FLC rules required to make control directions rely to a great extent upon the human experience. Notwithstanding, FLCs require additional time than regular control strategies, for example, PI and PID to determine complex fuzzification and cleansing procedures.

Electric vehicles are not something new to this world, but with the technological advancement and increased concern on controlling pollution has given it a tag of future mobility. The core element of the EV, apart from Electric Vehicle Batteries, which replaces the Internal Combustion engines is an **Electric motor**. The rapid development in the field of Power electronics and control techniques has created a space for various types of electric motors to be used in Electric Vehicles. The electric motors used for automotive applications should have characteristics like high starting torque, high power density, good efficiency, etc.

Previously, several researches have been done on adaptive DC motor control, such as adaptive DC motor using minimum variance to estimate controller parameters in linear control , adaptive DC motor using artificial neural network to estimate the Ki and Kp parameters of the PI controller , adaptive DC motor with RLS to estimate the parameters of the system , Fuzzy Model Reference Adaptive Control (RMFAC) , and the Model Reference Adaptive Control (MRAC).

This paper will discuss a system that is able to find the PID constants based on the characteristics of DC motor and also able to change the PID constants in case of parameter changes. This paper is organized as follows; section II presents the DC motor description which contains the modelling of dynamic system and state space model for DC motor speed. Section III presents estimation using RLS method. Section IV presents the controller method. Section V presents the result of the simulation. Section VI presents the result of experiment using STM32F663NR microcontroller, and the last section presents the conclusion based on the purpose of this paper.

II. VARIOUS TYPES OF ELECTRIV MOTORS USED IN EV'S

Electric vehicles are not something new to this world, but with the technological advancement and increased concern on controlling pollution has given it a tag of future mobility. The core element of the EV, apart from Electric Vehicle Batteries, which replaces the Internal Combustion engines is an **Electric motor**. The rapid development in the field of Power electronics and control techniques has created a space for various types of electric motors to be used in Electric Vehicles. The electric motors used for automotive applications should have characteristics like high starting torque, high power density, good efficiency, etc.

1. DC Series Motor
2. Brushless DC Motor
3. Permanent Magnet Synchronous Motor (PMSM)
4. Three Phase AC Induction Motors
5. Switched Reluctance Motors (SRM)

1. DC Series Motor

High starting torque capability of the DC Series motor makes it a suitable option for traction application. It was the most widely used motor for traction application in the early 1900s. The advantages of this motor are easy speed control and it can also withstand a sudden increase in load. All these characteristics make it an ideal traction motor. The main drawback of DC series motor is high maintenance due to brushes and commutators. These motors are used in Indian railways. This motor comes under the category of DC brushed motors.

2. Brushless DC Motors

It is similar to DC motors with Permanent Magnets. It is called brushless because it does not have the commutator and brush arrangement. The commutation is done electronically in this motor because of this BLDC motors are maintenance free. BLDC motors have traction characteristics like high starting torque, high efficiency around 95-98%, etc. BLDC motors are suitable for high power density design approach. The BLDC motors are the most preferred motors for the electric vehicle application due to its traction characteristics. You can learn more about BLDC motors by comparing it with normal brushed motor.

BLDC motors further have two types:

i. Out-runner type BLDC Motor:

In this type, the rotor of the motor is present outside and the stator is present inside. It is also called **as Hub motors** because the wheel is directly connected to the exterior rotor. This type of motors does not require external gear system. In a few cases, the motor itself has inbuilt planetary gears. This motor makes the overall vehicle less bulky as it does not require any gear system. It also eliminates the space required for mounting the motor. There is a restriction on the motor dimensions which limits the power output in the in-runner configuration. This motor is widely preferred by electric cycle manufacturers like Hullikal, Tronx, Spero, light speed bicycles, etc. It is also used by two-wheeler manufacturers like 22 Motors, NDS Eco Motors, etc.

ii. In-runner type BLDC Motor:

In this type, the rotor of the motor is present inside and the stator is outside like conventional motors. These motor require an external transmission system to transfer the power to the wheels, because of this the out-runner configuration is little bulky when compared to the in-runner configuration. Many three- wheeler manufacturers like Goenka Electric Motors, Speego Vehicles, Kinetic Green, Volta Automotive use BLDC motors. Low and medium performance scooter manufacturers also use BLDC motors for propulsion.

It is due to these reasons it is widely preferred motor for electric vehicle application. **The main drawback is the high cost due to permanent magnets.** Overloading the motor beyond a certain limit reduces the life of permanent magnets due to thermal conditions.

3. Permanent Magnet Synchronous Motor (PMSM)

This motor is also **similar to BLDC motor which has permanent magnets on the rotor**. Similar to BLDC motors these motors also have traction characteristics like high power density and high efficiency. The difference is that PMSM has sinusoidal back EMF whereas BLDC has trapezoidal back EMF. Permanent Magnet Synchronous motors are available for higher power ratings. PMSM is the best choice for high performance applications like cars, buses. Despite the high cost, PMSM is providing stiff competition to induction motors due to increased efficiency than the latter. PMSM is also costlier than BLDC motors. **Most of the automotive manufacturers use PMSM motors for their hybrid and electric vehicles**. For example, Toyota Prius, Chevrolet Bolt EV, Ford Focus Electric, zero motorcycles S/SR, Nissan Leaf, Hinda Accord, BMW i3, etc use PMSM motor for propulsion.

4. Three Phase AC Induction Motors

The **induction motors do not have a high starting toque like DC series motors** under fixed voltage and fixed frequency operation. But this characteristic can be altered by using various control techniques like FOC or v/f methods. By using these control methods, the maximum torque is made available at the starting of the motor which is suitable for traction application. Squirrel cage induction motors have a long life due to less maintenance. Induction motors can be designed up to an efficiency of 92-95%. **The** drawback of an induction motor is that it requires complex inverter circuit and control of the motor is difficult**.**

In permanent magnet motors, the magnets contribute to the flux density B. Therefore, adjusting the value of B in induction motors is easy when compared to permanent magnet motors. It is because in Induction motors the value of B can be adjusted by varying the voltage and frequency (V/f) based on torque requirements. This helps in reducing the losses which in turn improves the efficiency.

Tesla Model S is the best example to prove the high performance capability of **induction motors** compared to its counterparts. By opting for induction motors, Tesla might have wanted to eliminate the dependency on permanent magnets. Even **Mahindra Reva e2o uses a three phase induction motor for its propulsion.** Major automotive manufacturers like TATA motors have planned to use Induction motors in their cars and buses. The two-wheeler manufacturer TVS motors will be launching an electric scooter which uses induction motor for its propulsion. Induction motors are the preferred choice for performance oriented electric vehicles due to its cheap cost. The other advantage is that it can withstand rugged environmental conditions. Due to these advantages, the Indian railways has started replacing its DC motors with AC induction motors.

5. Switched Reluctance Motors (SRM)

Switched Reluctance Motors is a category of variable reluctance motor with double saliency. Switched Reluctance motors are simple in construction and robust**.** The rotor of the SRM is a piece of laminated steel with no windings or permanent magnets on it. This makes the inertia of the rotor less which helps in high acceleration. The robust nature of SRM makes it suitable for the high speed application. SRM also offers high power density which are some required characteristics of Electric Vehicles. Since the heat generated is mostly confined to the stator, it is easier to cool the motor. The **biggest drawback of the SRM is the complexity in control and increase in the switching circuit**. It also has some noise issues. Once SRM enters the commercial market, it can replace the PMSM and Induction motors in the future.

III. PROBLEM IDENTIFICATION

Notwithstanding their general structure and minimal effort, these controllers are likewise portrayed by their quick reaction, short settlement and rise time, and low overshoot. In any case, one of the principal troubles in applying these controllers is found within the sight of dynamic burden conditions where the framework reaction backs off with the difference in arrangement point. Immediately, the FLC was applied to control the speed of the BLDC motor [8]. It is described by its capacity to manage inadequately characterized numerical models. The FLC rules required to make control directions rely to a great extent upon the human experience. Notwithstanding, FLCs require additional time than regular control strategies.

IV. PROBLEM RECTIFICATION

Various researchers have studied problem of tuning PID controller for speed control of BLDC motor. Fuzzy-logic based approach is elaborately discussed in which derive the values of PID parameters using fuzzy interface. They rely on rules formed to improve dynamic performance of the drive. However, detailed literature and universal laws governing the formulation of membership functions, rule sets and its interface is not addressed and the process for it is very complex. Moreover, tools for executing fuzzy interface is exhaustive and requires high end controllers to implement them. Other adaptive controllers include artificial intelligence based artificial neural network for control of speed of BLDCM, genetic algorithm, model reference adaptive system (MRAS) and the Heuristic Approach (HA). Characteristics of BLDC motor exhibit non-linear characteristics as they are susceptible to changes in motor parameters due to environmental effects including temperature, and other disturbances. Genetic algorithm for the for the most part works disconnected on lots of potential arrangements as indicated by their wellness esteem. The MRAS controllers utilize one or numerous framework models to decide the contrast between the yield of the customizable framework and the yield of a reference model, and alter the parameters of the movable framework or create a reasonable information signal. The techniques dependent on HA don’t require deciding the ideal arrangement of an issue, overlooking whether the arrangement can be demonstrated to be right, given that it creates a decent outcome. Such techniques depend on master human experience. However, these approaches require state of the art micro-controller to be implemented and are extensive to code. Moreover, the relative outcome in terms of improved performance in most of the drive applications in marginal. Hence a simple yet effective method is needed to self-tune PID controller to get optimal performance in most of the scenarios.

V. SPEED CONTROL STRATGIES OF THE EV MOTORS

The proposed controller was simulated by the MATLAB simulation process, but the controller needs to develop mathematical equations and monitor the performance of simulation.

A. Fuzzy Logic Controller

This figure 2 shows that Input and output are non-fuzzy values. The basic configuration of FLC is featured in Figure 2. In the system presented in this study, Mamdani type of fuzzy logic is used for speed controller. Inputs for Fuzzy Logic controller are the speed error e(k) and change in speed error ce(k). Speed error is calculated with comparison between reference speed, ωref and the actual speed, ωact e(k) = ωref – ωact

(1) ce(k) =e(k) – e(k-1) $A = \pi r^2$

(2) The output of the fuzzy controller u(k) is given by: u(k) = e(k) – ce(k).

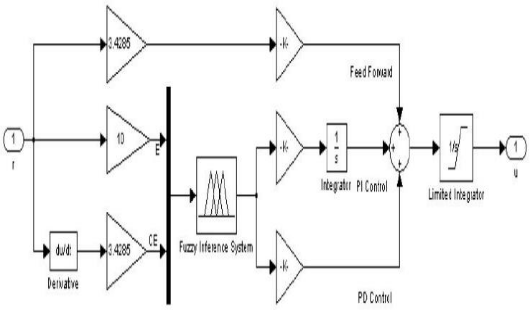


Fig.1. Fuzzy Logic Controller

B. PID Controller

PID controllers are a family of controllers. PID controllers are sold in large quantities and are often the solution of choice when a controller is needed to close the loop. The reason PID controllers are so popular is that using PID gives the designer a larger number of options and those options mean that there are more possibilities for changing the dynamics of the system in a way that helps the designer. If the designer

works it right s/he can get the advantages of several effects. In particular, starting with a proportional controller, and adding integral and derivative terms to the control the designer can take advantage of the following effects.

- The proportional, integral and derivative outputs are added together.
- The PID controller can be thought of as having a transfer function.
- The PID controller transfer function can be obtained by adding the three terms.

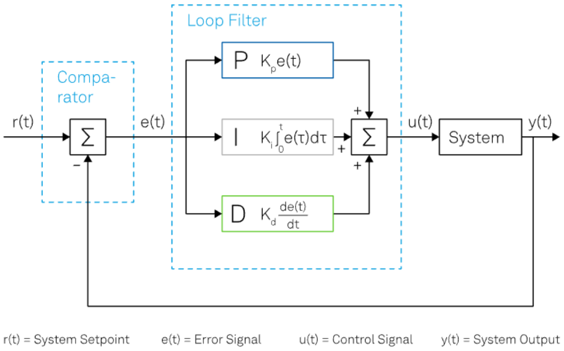
PID(s) = Kp + Ki/s+ s Kd

- The transfer function can be combined into a pole-zero form.

PID(s) [s Kp + Ki+ s^2Kd]/s

Since there is a quadratic in the numerator, there are two zeroes in this transfer function as well as the obvious pole at the origin, s = 0. Now, here's a good way to think about the effect of using a PID controller. The PID controller transfer function really adds a pole at the origin, and two zeroes that can be anywhere in the s-plane that the designer wants, depending upon the designer's choice of the three gains.

$$PID(s)\ [s\ Kp + Ki + s^2Kd]/s$$



PID CONTROLLER STRUCTURE:

In this tutorial we assume the controller is used in a closed loop unity feedback system. The variable denotes the tracking error which is sent to the PID controller. The controller single u forms the controller to plant equal to the Proportional gain (KP) times the magnitude error gain Integral gain (KI) times the integral of the time pulse the Derivative gain (KD) times the derivative of the error

PID PARAMETERS:

We are most insured in four major characteristics of the closed loop step response

• Rise time: the time it takes for the plant output y to rise beyond 90% of the desired Level for the first time.

• Overshoot: how much the peak level is higher than the steady state, normalized against the steady state.

Settling time: the time it takes for the system to converge to its steady state.

Steady state error: the difference between the steady state output and the desired output.

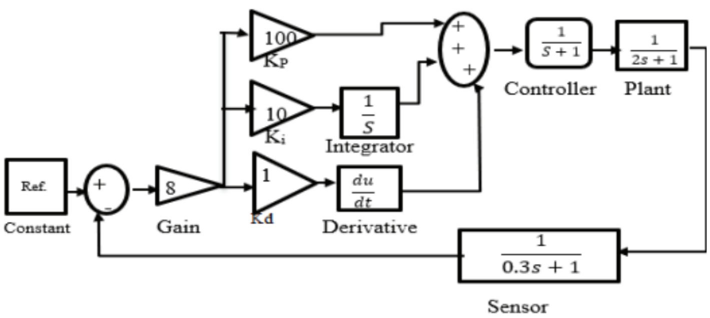


Fig. 3. PID controller in the block diagram.

In Figure 3. is proportional-integral-derivative controller (PID controller), a co-worker of the three-test and two consecutive matrimonial treatments covering proportional integral-derivative (PID), is sometimes the easiest to solve and true-world control everywhere. At the end of the PID control period in 1910. The PID controller should be reviewed as the ultimate change in a phase lead-logging experience with one raising and the other starving. Similarly, its cousins, the PI and PD controllers have been identified.

C. Adaptive Controller

Adaptive control is an active area of the control system design to address uncertainties in figure 4. The main difference between the adaptive controller and the linear controller is the adaptive controller's ability to adjust itself to handle the uncertainties of the unknown model. Adaptive control is roughly divided into two categories: direct and indirect. Indirect methods allow estimation of plant parameters and more inferred model information is used to adjust the controller. The direct method is one in which the assumed parameters are used directly as the adaptive controller.

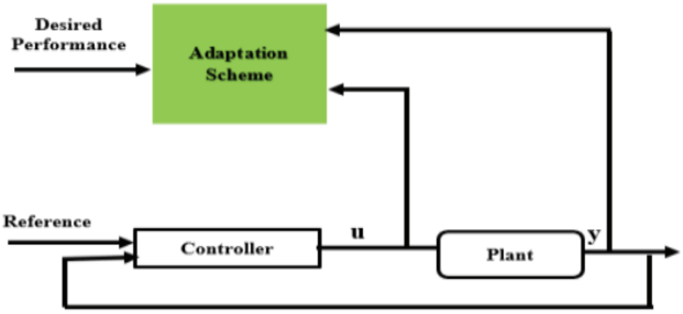


Fig. 4. Structure of adaptive control.

D. Adaptive PID Controller

This figure 1 shows the basic model of the Adaptive PID controller. To develop motor controlling controller many scholars, follow the different method and technic. In this research also apply another technic to increase the motor speed. For better output efficiency of the BLDC, motor speed control is very impotent in this situation. So, solved this problem and get better efficiency proposed this basic model.

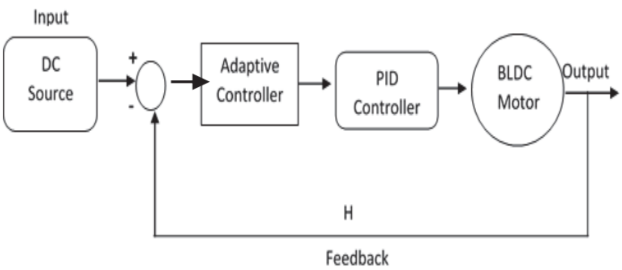


Fig.1. Basic Diagram of Adaptive PID Controller

The PID controller is placed in the forward path, so that its output becomes the voltage applied to the motor's armature the feedback signal is a velocity, measured by a tachometer. the output velocity signal C (t) is summed with a reference or command signal R (t) to form the error signal e (t). Finally, the error signal is the input to the PID controller.

E. $$u = K^p e + K^i \int \quad edt + Kd\frac{de}{dt}$$

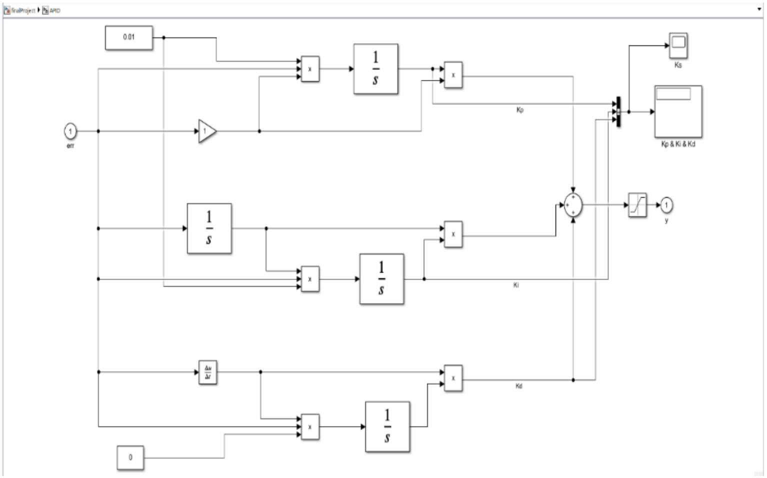
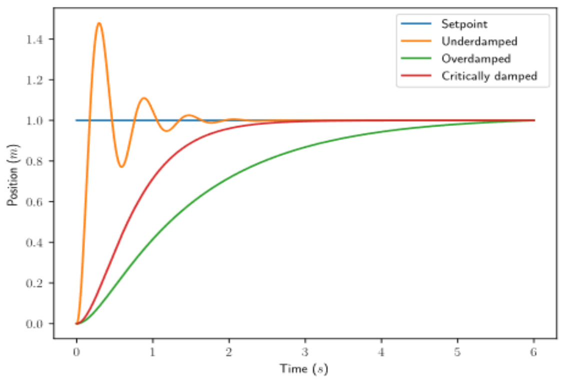


Fig 2. Adaptive PID Controller Block Diagram

A conventional PID controller has fixed gains (Proportional (Kp), Integral (Ki), and Derivative (Kd)) designed for a specific system.



An adaptive PID controller continuously modifies these gains online based on the system's behaviour.

Adaptation Mechanism:

There are several approaches to achieve adaptation, each with its own advantages and limitations. Here are two common techniques:

Parameter Estimation Methods:

These methods rely on algorithms to estimate the system's dynamic characteristics.

Based on the estimated model and a desired control performance, the controller calculates new PID gains.

Common algorithms include:

Recursive Least Squares (RLS): This is a popular choice for its fast convergence and ability to handle time-varying systems.

Least Mean Squares (LMS): A simpler approach, but may be slower to converge.

Intelligent Control Techniques:

These methods utilize artificial intelligence concepts to adjust the gains.

Examples include:

Fuzzy Logic: Uses fuzzy rules to determine appropriate gain adjustments based on control error and system state.

Neural Networks: Learn the relationship between control error and optimal gains through training data.

Stability and Convergence:

A critical aspect of adaptive PID control is ensuring the controller itself remains stable and the parameter adjustments converge to optimal values. Different adaptation algorithms have varying convergence rates and robustness to noise.

Benefits of Specific Algorithms:

RLS: Offers fast convergence and good tracking performance for time-varying systems.

Fuzzy Logic: Provides good interpretability of the control strategy due to the use of fuzzy rules.

Neural Networks: Can handle highly nonlinear systems but require careful training data selection.

Implementation Considerations:

The choice of adaptation algorithm depends on the system dynamics, desired control performance, and computational resources available.

The adaptation mechanism should be designed to avoid excessive parameter adjustments that could destabilize the control loop.

Overall, the theory of adaptive PID control focuses on using various algorithms to estimate the system behavior and automatically adjust the PID gains for optimal performance in real-time. This approach offers significant advantages for controlling dynamic systems but requires careful design and consideration of implementation complexities.

F. Equations

The model of the armature twisting for the BLDC motor is communicated as pursues:

$$v_a = Ri_a + L\frac{di_a}{dt} + e_a \quad (1)$$

$$v_b = Ri_b + L\frac{di_b}{dt} + e_b \quad (2)$$

$$v_c = Ri_c + L\frac{di_c}{dt} + e_c \quad (3)$$

where L is armature self-inductance [H], R - armature resistance [Ω], va, vb, vc - terminal phase voltage [V], ia, ib, ic - motor input current [A], and ea, eb, ec - motor back-emf [V]. The equivalent circuit for one phase is represented in Figure 5.

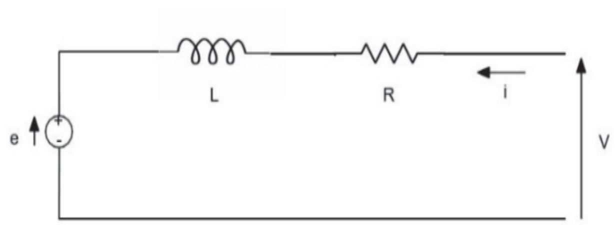


Fig. 5. Equivalent circuit of the BLDC motor for one stage.

VI. SIMULATION MODEL

Figure 6 shows the overall simulation model of an adaptive PID controller with connected 3- phase BLDC motor with Load. To design this controller used MATLAB/Simulink software. There are many parameters used to design this controller such as Reference source, PID block, adaptive block, IGBT drive, MOSFET driver, voltage sensor, Buck converter, 3- phase power inverter, current sensor, Torque Load, BLDC motor, PWM generator, gate, DC voltage source and others parameters also used mathematical equation in this controller.

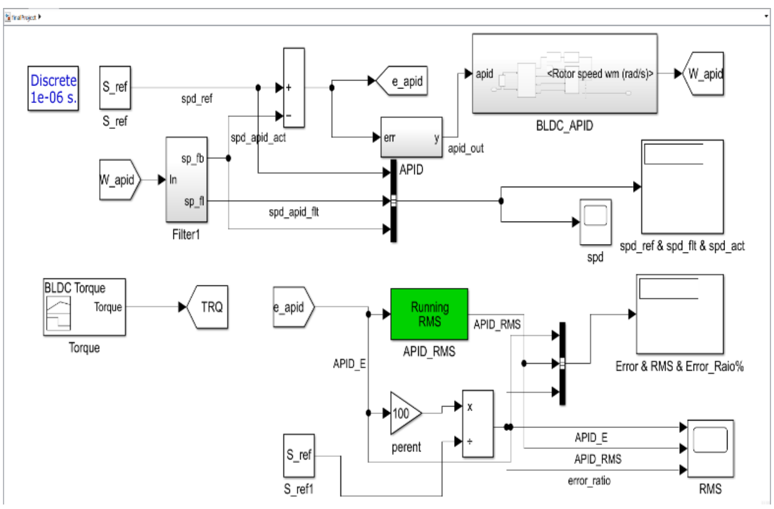


Fig – 6 Proposed Simulation Model of APID Controller.

Figure 7 is the most important parts of this research. At first, fixed reference R.P.M than reference rpm and load connected with the controller. There are two types of controllers used one is PID and another one is the adaptive controller. After completing all mechanism than signal comes to MOSFET drive. Its also connected with DC voltage source, motor and output connected with 3-phase inverter and voltage sensor.

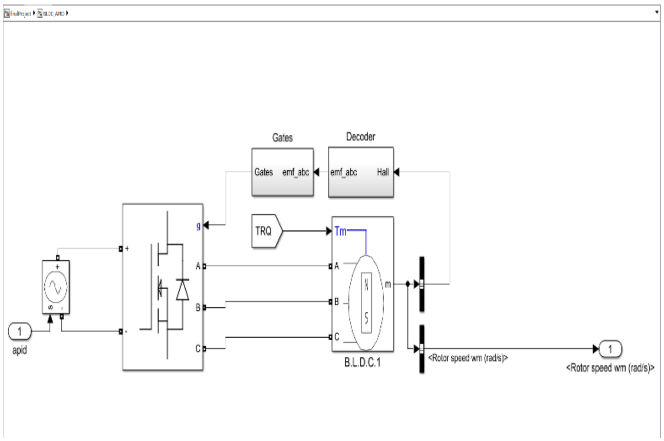


Fig – 7 Controller of the BLDC Motor

Filter:

Fig. 8 shows the conversion of radians per second to rotation per minute. A nifty formula works to convert angular velocity from radians per second (rad/s) to revolutions per minute (RPM):

$$RPM = (rad/s) * (60/2\pi).$$

A conversion factor in this equation (60/2π) is the transition between seconds and minutes, as well as deftly handling the conversion between radians and revolutions. Basically, the frequency in RPM can be obtained by multiplying the angular frequency in radians per second by 2π and then dividing by 60.

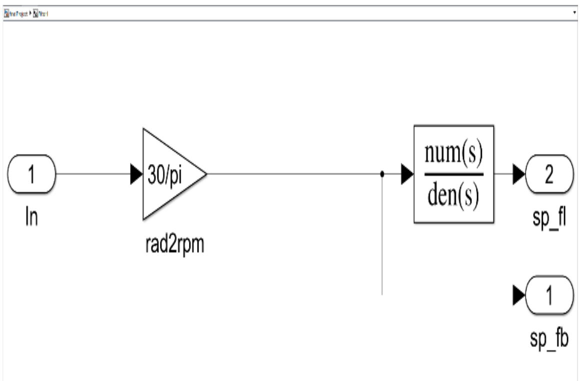


FIG – 8 Filter

VII. RESULT AND DISCUSSION

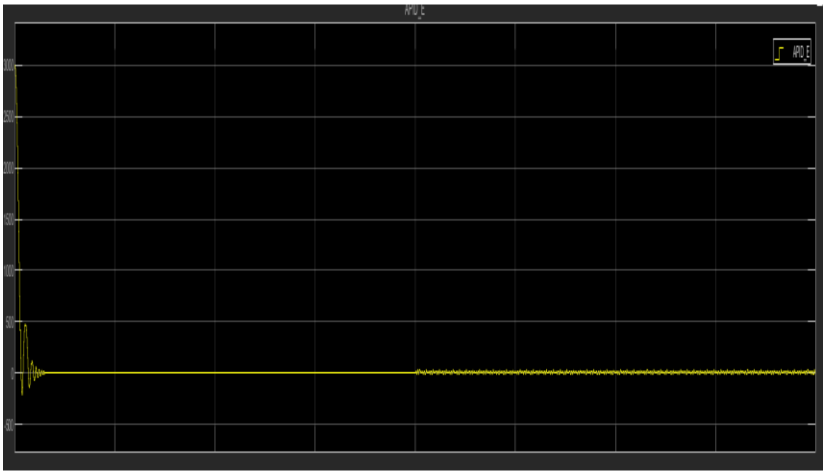


Fig – 1 APID_E

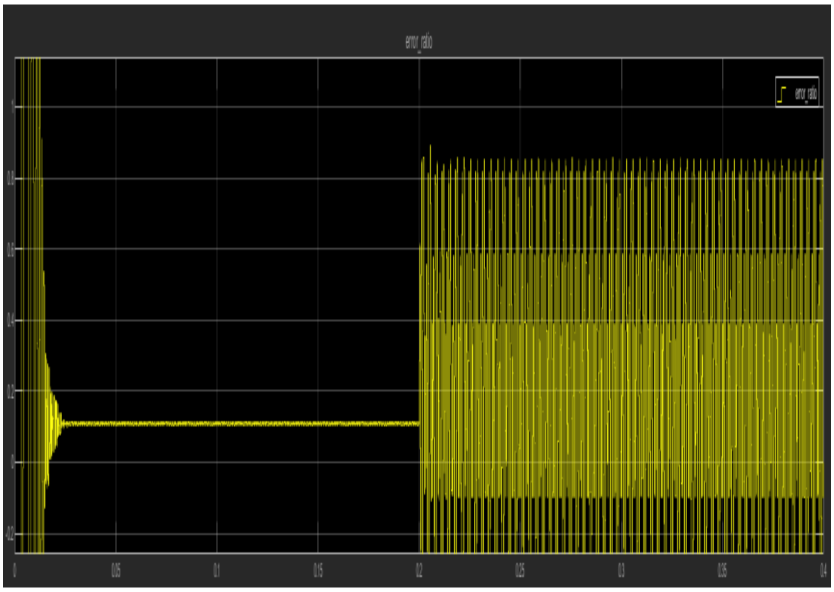


Fig – 2 Error Ratio

Figure 2 shows PID Controller Performance on the benchmark platform and same requirements. Figure 1 shows the simulated waveform of the controller. Where, in no load condition, the controller gave overshoot and never touch the required signal, that might be possible, the researcher always checked the performance with load. From the performance, it can say that, the controller can be use for higher load and fast response where precision performance is not mandatory.

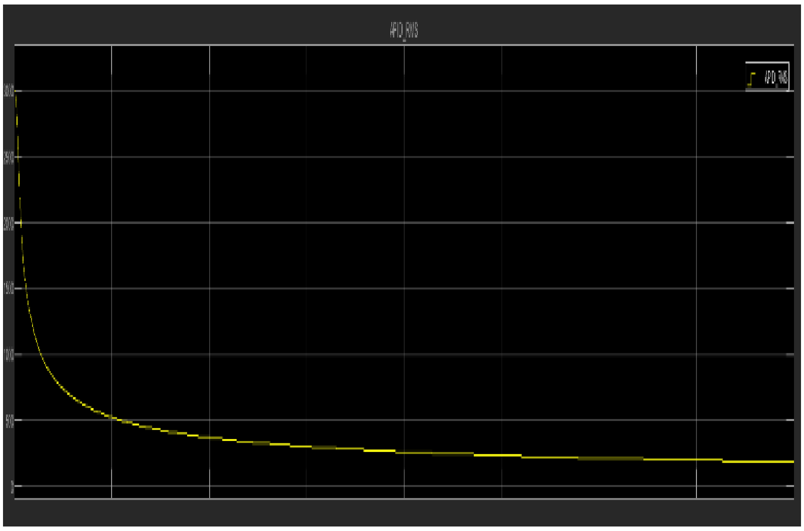


Fig – 3 APID_RMS

Figure 3 filter is used, when used in a BLDC motor control system, can help reduce these oscillations. It does this by smoothing out the current waveform, thereby reducing the electrical noise. This results in a more stable and accurate motor operation.

This means the motor can react more quickly to changes in load or speed requirements, which is particularly beneficial in applications where rapid motor response is critical. can enhance the motor's performance by reducing oscillations and errors, and improving response time. This leads to a more efficient and reliable motor operation.

By using the filter for the BLDC motor it reduces the oscillations and error in the output and it results the faster response. by reducing the error in the output, the motor's response time can be improved.

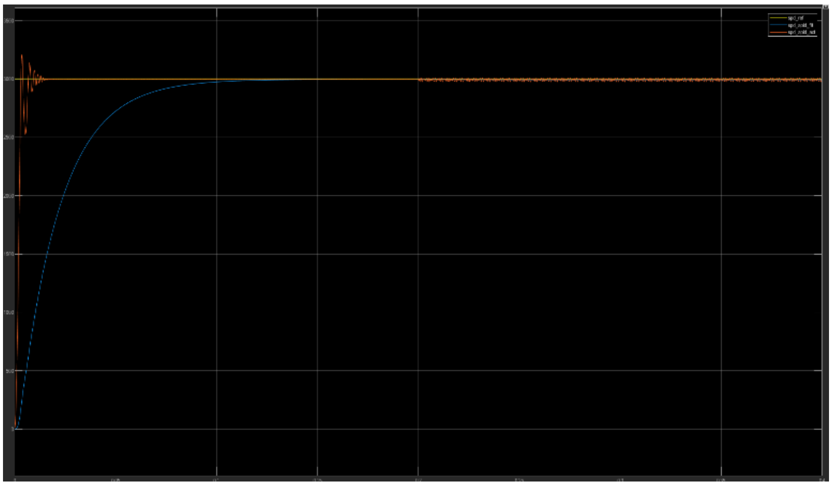


Fig - 4 The output of the Adaptive PID controller

TABLE 1. SIMULATED MEASUREMENTS FOR 1000RPM

Measurements	Value
Rising time (No load/ with load)	36.386 ms / 51.542 ms
Max / Min high	1003 rpm / 998.939 rpm (-2.061)
With load maximum high	999.3 rpm
Overshoot	0.452%
With load overshoot	0.499%
With load undershoot	1.963%

Figure 4 shows the adaptive PID controller output. This output with torque load Te 10 N-m and its supply voltage is 48 DC volt. The output of the controller had an overshoot of 0.497% and undershoot is 1.963% (48V/unit), settling time 0.35 seconds (0.1seconds/unit) and had no steady-state error. The performance indicates that the adaptive PID controller has very good controllability than the existing other controller but needs little improvement. So, the results of the proposed adaptive PID controller simulation model for the BLDC motor speed control. Here the simulation results are shown in figure and the particulars are shown in table 1.

VIII. CONCLUSION

This controller used for three-phase BLDC motor for its speed control. As a result, an adaptive PID controller gives excellent Simulation results. An adaptive PID controller technology has more advanced to control BLDC motor. However, it is worth noticing that when the motor functions at up and down speeds, for it to be well responsive, the motor speed must be continuous when the load will change. This study aims will be developed a Prototyping an adaptive PID controller to control BLDC motor. It helps to developed BLDC motor speed and efficiency.

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