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Design of Sliding Mode Control Strategy for DC Motor

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Abstract: This research paper presents a comparative study ofsliding mode control (SMC) strategies and proportional- integral-derivative (PID) control for DC motor applications. The project involves the design and implementation of PID and SMC controllers, as well as the evaluation of their respective response characteristics. Furthermore, the SMCcontroller is designed using three different sliding surfaces to analyze their impact on the control system's performance. A model is developed and simulated usingMATLAB/SIMULINK. Overall, the simulation results show that sliding mode controller is superior than PID for speed control of dc motor.
Keywords: Sliding mode control (SMC), DC motor, Proportional-integral-derivative (PID) controller.

I. INTODUCTION

Speed control of DC motors is a fundamental task in various industrial applications, ranging from robotics and automation to electric vehicles and renewable energy systems. Accurate and efficient control of motor speed is essential to achieve desired performance and meet specific application requirements. Two commonly employed control strategies for speed control of DC motors are Proportional-Integral-Derivative (PID) control and Sliding Mode Control (SMC).

PID control is a classical control method widely used due to its simplicity and effectiveness. It utilizes proportional, integral, and derivative terms to adjust the motor's control signal based on the error between the desired and actualspeeds. The proportional term provides immediate response, the integral term addresses steady-state errors, and the derivative term enhances system stability by considering the rate of change of the error. PID controllers are widely adopted due to their intuitive tuning and satisfactory performance in many applications.

On the other hand, Sliding Mode Control (SMC) is a robust control technique that offers excellent disturbance rejection and tracking capabilities. It operates by creating a slidingsurface that guides the system's state trajectory toward a desired manifold. Sliding mode controllers are well-suited forapplications with uncertainties, disturbances, and parameter variations. The control law ensures that the system state stayson the sliding surface, resulting in robust performance evenin the presence of disturbances.

In this study, the focus is on comparing and evaluating the performance of PID control and Sliding Mode Control for speed control of a DC motor. The objective is to investigate and analyze the strengths and weaknesses of each control strategy in terms of tracking accuracy, disturbance rejection, and robustness.

The paper will first provide an overview of the DC motor system and its mathematical model for speed control. It will then introduce the PID control approach, explaining the design methodology and tuning techniques. Next, the principles and concepts of Sliding Mode Control will be discussed, highlighting its advantages in handling uncertainties and disturbances. The design and implementation of both control strategies will be presented.

Simulation experiments will be conducted to evaluate and compare the performance of PID control and Sliding Mode Control in various operating scenarios, including speed tracking, disturbance rejection, and parameter variations. The results will be analyzed to assess the strengths and limitationsof each control strategy.

The findings of this study will provide valuable insights into the selection and design of control strategies for speed controlof DC motors. The comparison between PID control and Sliding Mode Control will help researchers and engineers choose the most appropriate control method based on the specific requirements and constraints of their applications. Ultimately, this research contributes to enhancing the understanding and implementation of effective speed control techniques for DC motors.

II. MODLLING OF DC MOTOR

To model a DC motor for sliding mode control using the given transfer function, you can start by analyzing the transfer function and deriving the dynamic equation of the motor.

Due to their simplicity and controllability, DC motors are frequently utilised in a variety of industrial applications. Understanding a DC motor's electrical and mechanical characteristics is necessary for modelling it. The relationship between the electrical input and the ensuing mechanical output is the fundamental idea behind DC motor modeling to their simplicity and controllability, DC motors are frequently utilised in a variety of industrial applications. Understanding a DC motor's electrical and mechanical characteristics is necessary for modelling it. The relationship between the electrical input and the ensuing mechanical output is the fundamental idea behind DC motor modeling to theirsimplicity and controllability, DC motors are frequently utilised in a variety of industrial applications. Understanding a DC motor's electrical and mechanical characteristics is necessary for modelling it. DC motor modeling's fundamentaltenet is the interplay between transfer function.

III. DESING OF PID CONTROLLER

The mathematical representation of the motor system must include the PID control algorithm when modeling an induction motor with a proportional-integral-derivative (PID) controller. The PID regulator is a generally utilized inputcontrol procedure that plans to work on the exhibition and security of control frameworks by changing the control signalin light of the mistake between the ideal and genuine results.

To demonstrate an enlistment engine utilizing a PID regulator, the accompanying advances are commonly followed:

A. Representation of the Transfer Function

To find out the transfer function, the initial step is to acquire the exchange capability portrayal of the acceptance engine, which depicts the connection between the information(voltage) and result (e.g., rotor speed) of the engine framework. State-space models, circuit-based models, and experimental identification techniques are just a few of the methods that can be used to derive this transfer function.

B. Equations for the PID Controller

There are three parts to the PID controller: integral (I), proportional (P), and derivative (D). Depending on distinct aspects of the system's behavior, each component makes a contribution to the control signal.

1) *Component of the Proportion (P):* The P component makes adjustments to the control signal in proportion to the difference in output quality between the intended and actual values. It immediately responds to changes in the error signaland aids in the reduction of steady-state errors.
2) *Component of Integral (I):* The I part coordinates the blunder after some time and adds to the control signal in light of the amassed mistake. It helps eliminate steady-state errorsbrought on by system biases and disturbances, for example.
3) *Component of a derivative (D):* The D component takes into account the error's rate of change and makes a contribution tothe control signal in accordance with this. To lessen overshoot and boost system stability, it provides damping and anticipatory response.

The PID controller equations can be represented as follows: $u(t) = Kp * e(t) + Ki * \int e(t)dt + Kd * de(t)/dt$

where $u(t)$ is the control signal, $e(t)$ is the error between the desired and actual outputs, Kp is the proportional gain, Ki is the integral gain, and Kd is the derivative gain.

C. Closed-Loop System Modelling

The induction motor model with the PID controller can be represented as a closed-loop system, where the control signal is fed back and compared with the desired output. The error between the desired and actual outputs is then computed, and the PID controller adjusts the control signal accordingly.

D. Parameter Tuning

To achieve optimal performance, the PID controller gains (Kp, Ki, and Kd) need to be appropriately tuned. Various methods such as Ziegler-Nichols, trial-and-error, or advancedoptimization techniques can be employed for tuning the PID gains. The tuning process aims to balance stability, responsiveness, and robustness of the control system.

By incorporating the PID controller into the induction motor model, it becomes possible to simulate and analyze the performance of the motor system under different operating conditions. The PID controller helps in regulating the motor speed, improving tracking accuracy, and providing robustness against disturbances and parameter variations.

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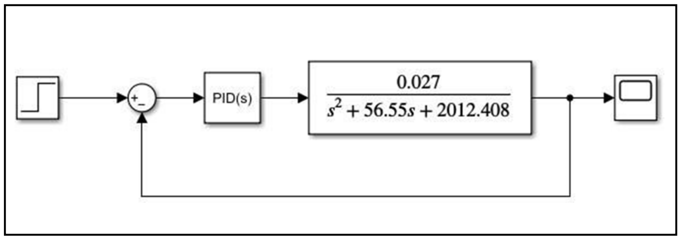

Fig 1): Modelling diagram system by using PID

IV. DESIGN OF SLIDING MODE CONTROLLERTO CONTROL SPEED OF DC MOTOR

A. Design of Sliding Surface

1) Sliding Surface 1

For the first equation, S(t) = λ e(t) + ė(t), the sliding surfacecan be designed as:

S(t) = λ $e(t)$ + ė(t)[14] (1)

The first sliding surface incorporates a reaching law, represented by λ, and the tracking error, e(t), along with a perturbation term, ė(t). The reaching law ensures that the system state reaches a desired equilibrium point. This sliding surface aims to minimize the tracking error and maintainstability during the control process.

2) Sliding Surface 2:

For the second equation, S(t) = $C1$ e(t) + $C2$ ė(t), the sliding surface can be designed as:

S(t) = $C1$ $e(t)$ + $C2$ ė(t) (2)

The second sliding surface introduces additional coefficients,

$C1$ and $C2$, to balance the contributions of the tracking error, e(t), and the perturbation term, ė(t). By appropriatelyadjusting these coefficients, the control system can achieve improved tracking accuracy and disturbance rejection capabilities.

3) Sliding Surface 3:

For the third equation, S(t) = kp e(t) + $ki \int$ e(t)dt + kdė(t), the sliding surface can be designed as:

S(t) = kp e(t) + $ki \int$ e(t)dt + kdė(t) (3)

The third sliding surface incorporates proportional (kp), integral (ki), and derivative (kd) terms. The proportional term, kp (t), provides an immediate response to the trackingerror. The integral term, $ki \int (t)t$, accumulates and corrects any steady-state error. The derivative term, kdė(t), takes into account the rate of change of the perturbation term to enhance disturbance rejection.

B. Design of Sliding Mode

let's consider three sliding surfaces: Equivalent control, Switching control, and a custom sliding surface.

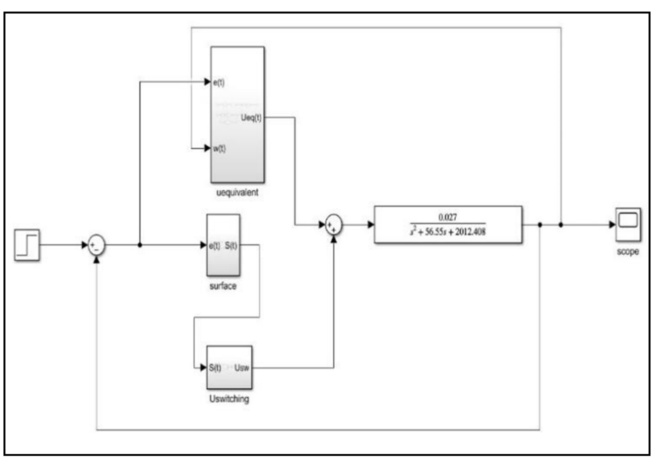

Fig2: Modelling of sliding mode control on Simulink

C. Equivalent Control

Equivalent control is a block which gets 2 inputs from error amplifier and feedback system which gives the output to the plant. The above diagram contains 2 input which are e(t) & y(t). e(t) gives its output to the lambda by taking it's derivative & in y(t) two gains are connected and derivative is taken of one of the gains which is given to the additional amplifier and the output is given to the lambda from which we get the final output.

$$U_{eq}(t) = \frac{1}{c}[\lambda \dot{e}(t) + \ddot{\omega r} + A\dot{\omega}(t) + B\omega(t)]$$

D. Switching Control

switching control is a block which gets the input from surfaceblock and it gives its output to the plant through additional amplifier. In above diagram, the surface block gives out.

$$U_{sw}(t) = k \tan h \frac{s(t)}{\beta}$$

The Control system is design with the following parameter:Parameter:

Quantity	Symbol	value
Armature Resistance	Ra	1.5
Armature Inductance	La	0.02H
Torque constant	Kt	0.015Nm/A
Back emf constant	Kb	0.0022Vs/rad
Viscose friction	b	0.0004
Moment of inertia of rotor	J	$0.0004kgm^2/s^2$

V. SIMULATION RESULTS

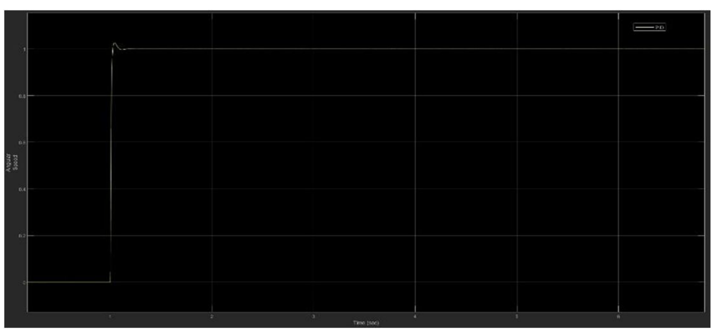

Fig 3): Output response of PID

Fig4: output response of SMC

Sr.no	Parameters	PID	SMC
1	Settling time	2 sec	1.1 sec
2	Percentage Overshoot	88.17%	0%
3	Peak	1.034e+00	0

VI. CONCLUSION

This study looked into the design of sliding mode control strategies for controlling speed in DC motor system. The objective was to evaluate the effectiveness of various sliding mode control strategies in controlling precise speed, resisting parameter changes, rejecting disturbances, and reducing chattering phenomena. The sliding mode control strategy outperformed the conventional PID control method, as evidenced by the obtained results. The sliding mode control strategies demonstrated enhanced capability for disturbance rejection, robustness to parameter variations, and improved speed tracking accuracy.

This research contributes to the understanding and application of sliding mode control in the context of speed control for DC motors, demonstrating its effectiveness and potential forachieving high-performance control.

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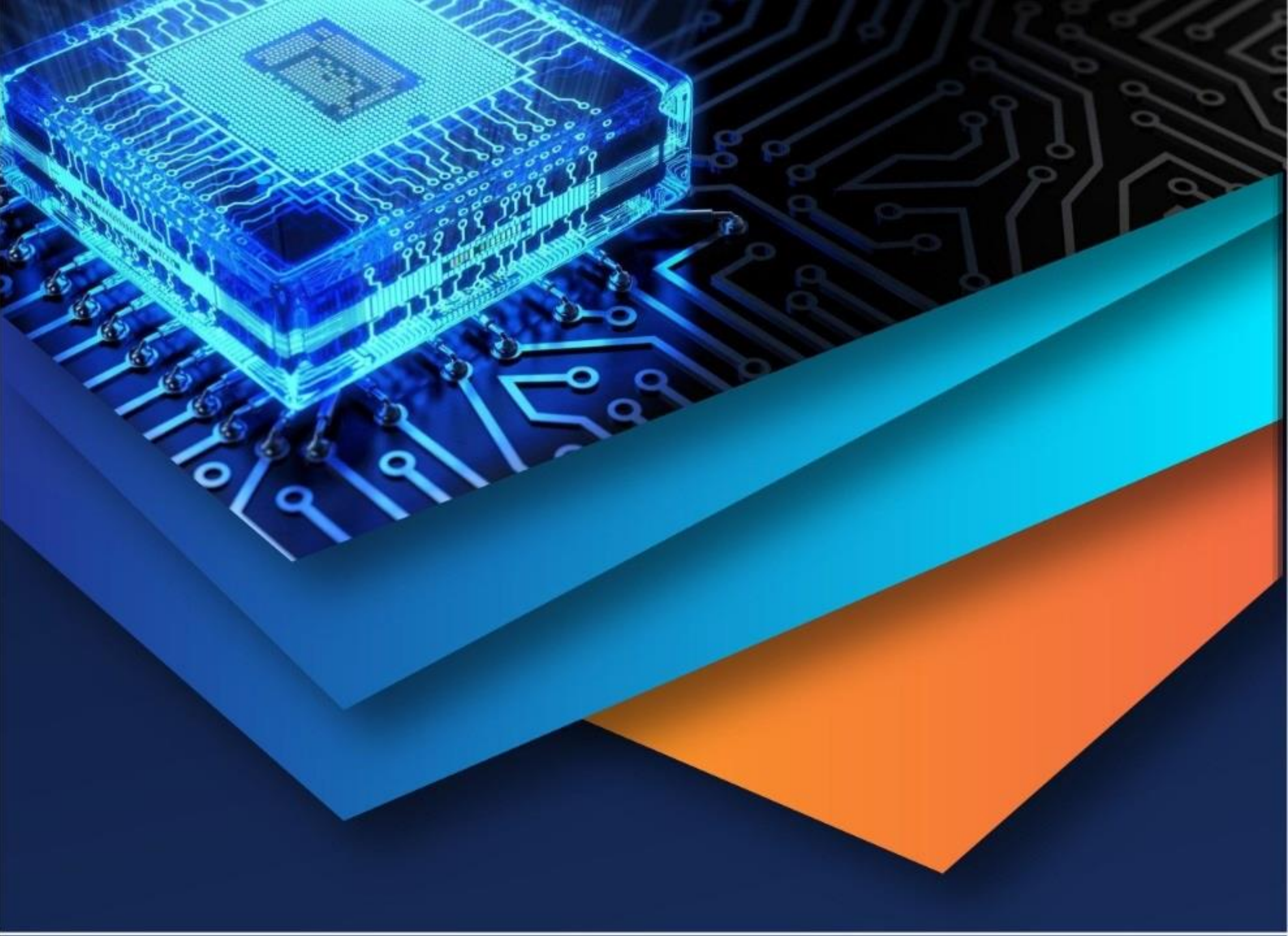

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