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Optimized Discrete PID Controller Design for Precision DC Motor Speed Regulation Using MATLAB

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Abstract: *This paper presents an optimized approach to the design and implementation of a discrete Proportional-Integral-Derivative (PID) controller for precise speed regulation of DC motors using MATLAB. DC motors are critical components in various industrial and robotic applications, where maintaining accurate speed control is essential for efficient operation. The study explores the dynamic modeling of a DC motor and the application of discrete PID control techniques to achieve superior performance in terms of transient response, stability, and disturbance rejection. MATLAB/Simulink is utilized for system simulation, parameter tuning, and performance evaluation. Advanced tuning methods, including Ziegler-Nichols and heuristic techniques, are employed to optimize controller gains, ensuring minimal overshoot, reduced settling time, and robust steady-state accuracy. Simulation results validate the proposed approach, highlighting its effectiveness in achieving high-precision speed regulation under varying operational conditions. This study provides a valuable resource for engineers and researchers focused on enhancing DC motor control systems*

Keywords: Discrete PID controller, DC motor speed control, MATLAB/Simulink, control systems, Ziegler-Nichols tuning, speed regulation, transient response, steady-state performance, optimization, industrial automation

I. INTRODUCTION

Precise control of DC motor speed is crucial for a wide range of industrial applications, including robotics, automation systems, electric vehicles, and renewable energy solutions. Achieving accurate and responsive speed regulation necessitates the use of efficient control strategies. Among these, the Proportional-Integral-Derivative (PID) controller is widely regarded for its simplicity, robustness, and versatility. This study focuses on the design and implementation of a discrete PID controller for managing DC motor speed, leveraging the capabilities of MATLAB. A discrete controller facilitates the analysis of the motor system in the discrete-time domain, making it ideal for digital control systems and microcontroller-based applications.

The PID controller integrates three fundamental control actions:

1. Proportional (P): Produces a control signal proportional to the error between the target and actual motor speed.
2. Integral (I): Addresses cumulative past errors to eliminate steady-state errors and improve system stability.
3. Derivative (D): Responds to the rate of change in error, allowing the system to react promptly to dynamic speed variations.

The transition from continuous to discrete control is achieved by discretizing the motor system's continuous-time transfer function using numerical techniques such as Tustin's method or the Euler method. MATLAB serves as the platform for modeling, analysis, and simulation, offering an integrated environment to test and refine the controller design. This paper outlines a structured approach to designing and fine-tuning the discrete PID controller to achieve optimal motor speed control. Key tuning methods, including Ziegler-Nichols and Cohen-Coon techniques, are discussed, along with their respective strengths and limitations. The performance of the controller is assessed using metrics such as rise time, settling time, overshoot, and steady-state error, ensuring a comprehensive evaluation.

Simulation results validate the effectiveness of the proposed discrete PID controller by comparing its performance with alternative control strategies like proportional-only and PI controllers. The comparative analysis highlights the superiority of the PID controller in delivering precise and reliable speed control. The insights and methodologies presented in this paper are valuable for engineers, researchers, and practitioners exploring DC motor speed control and discrete PID controller implementation. By offering a step-by-step guide and performance analysis, this study contributes to advancing the practical application of control theory in real-world systems.

II. LITERATURE SURVEY

The paper "Speed Control of DC Motor Using Discrete PID Controller" by V. Prabhakar and P. Santhi, published in the International Journal of Control Theory and Applications (Vol. 8, No. 1, 2015), focuses on the design of a discrete PID controller for DC motor speed regulation. The controller parameters were tuned using the Ziegler-Nichols method, and simulation results demonstrated its efficiency in achieving accurate and consistent speed control.[1]

The study "Adaptive Discrete PID Control for DC Motor Speed Regulation" by J. Huang et al., featured in IEEE Transactions on Control Systems Technology (Vol. 23, No. 6, 2015), proposes an adaptive discrete PID controller for speed regulation. This controller is based on Lyapunov stability analysis and incorporates an adaptive algorithm to dynamically adjust the control parameters in real time. Both simulation and experimental results confirmed that the adaptive controller outperforms traditional PID controllers in terms of robustness and disturbance rejection.[2]

In the paper "Speed Control of DC Motor Using Fuzzy Self-Tuning PID Controller" by J. Jiang et al., presented at the IEEE International Conference on Mechatronics and Automation (2015), a novel fuzzy self-tuning PID controller is introduced. This approach leverages a fuzzy logic system to adjust the controller parameters based on the error and its derivative. Simulation results revealed that this method significantly enhances performance by reducing steady-state error and overshoot compared to traditional PID controllers.[3]

The research "Discrete PID Controller Design for Speed Control of DC Motor with Time-Delay Using Particle Swarm Optimization" by M. J. Yaghoubi and M. R. Azimi, published in the International Journal of Power Electronics and Drive System (Vol. 8, No. 3, 2017), addresses the challenge of time-delay in DC motor speed control. Time-delays, caused by mechanical and electrical factors, are mitigated using particle swarm optimization (PSO) to fine-tune the controller parameters. Simulation results demonstrate that the proposed method offers improved stability and superior compensation for time-delays compared to conventional PID controllers.[4]

Lastly, the paper "Speed Control of DC Motor Using Discrete PID Controller: A Review" by M. R. Islam et al., published in the International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering (Vol. 7, No. 2, 2018), provides a comprehensive review of discrete PID controllers for DC motor speed control. It covers the fundamental principles of PID controllers, their applications, and various tuning methods. The paper concludes with a comparison of different discrete PID controller designs, analyzing their performance and implementation complexity.[5]

III. METHODOLOGY AND ALGORITHM

DC Motor transforms electricity energy to mechanical energy and it act as a power actuator. It has a rotation armature winding, nonrotating armature magnetic field, permanent magnet which generates different magnetic field and armature connections. Winding develops a different intrinsic speed and helps in regulating the torque. DC motor speed is controlled either by changing armature current or changing variable resistance in armature circuit or field circuit. The above mentioned DC motor come under traditional speed control method. To increase the speed of traditional DC motor, it can be upgraded by integrating the DC motor with power electronics circuits. Thereafter the performance of the DC motor speed control system gets improved and tracks the desired speed. Therefore the proposed DC motor plays a vital role in the industrial applications where adjustable speed control action is required such as electric cranes robotic and manipulative vehicles. Metin Demirtas analyzed a Proportional Integral (PI) speed controller for a PLDC motor on off-line and the response of the controller has been reviewed. K. Premkumar et. al designed a soft computing technology with PID controller for DC Motor system and the results were analyzed in time domain with varying speed and load conditions. Saqib et. al examined antiwindup controller with DC Motor for speed control and the performance of the motor has been checked for closed loop stability. Dayarnab Baidya et. Al has adopted Fuzzy based Model

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Reference Adaptive Control (MRAC) for DC motor speed control and the implementation were done with first-order system with second-order system by MIT Rule. Adel A.El-samahy et. al implemented Fuzzy based PID with MRAC for DC Motor Speed control and compared Conventional PID against proposed control technique [1-5]. The conventional PID controller is of analog system which need additional module to interface with digital computers. The proposed idea of Discrete PID Controller of DC Motor Speed Control is to easily interface the digital computers with the motors. Root - Locus method has been adopted in implementation of Discrete PID controller.
Figure 1 shows DC Motor equivalent circuit with armature resistance (Ra), self inductance (La), induced emf (e)

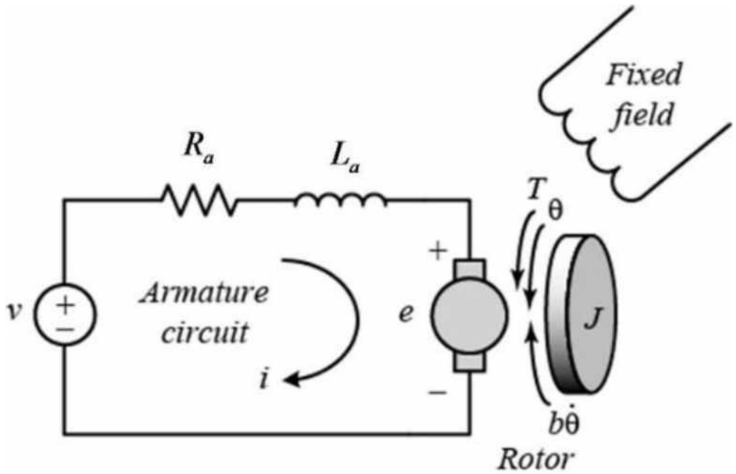
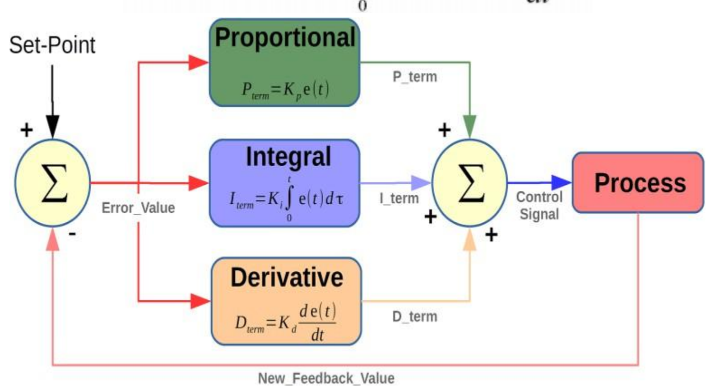


Figure 1 Equivalent circuit of DC motor

PID Controller

PID controllers are used in wide range of industrial applications. Around 95 percent of the industry's closed loop operations use PID controllers. PID stands for Proportional- Integral- Derivative. Such three controllers are combined in such a way that a control signal is produced. The general form of an PID controller is given by,

$$u(t) = K_p.e(t) + K_i \int_0^t e(t).dt + K_d.\frac{de}{dt}$$



PID controller functions with closed-loop system. Variable (e) specifies tracking error, difference among desired output (r) and actual output (y). Error signal (e) is provided to PID controller, and controller evaluates derivative and integral of error signal with time. Control signal (u) is equal to proportional gain (Kp) times magnitude of error plus integral gain (Ki) times integral of error and derivative gain (Kd) times error derivative. There are several PID controller structures and it depends upon the manufacturers. However only two topologies are used frequently: Parallel (non-interactive) and Series (interactive). PID controller is employed for SISO and MIMO systems. Numerous systems comprise interconnected loops. Controller design is successfully solved by traditional MIMO techniques. MIMO drawback results in state space high order controllers. In addition, the systems contain non negligible time delays which

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cannot be handled easily. Considering all these drawbacks SISO procedures for decentralized PID controllers tuning for MIMO systems was employed.

IV. RESULT ANALYSIS

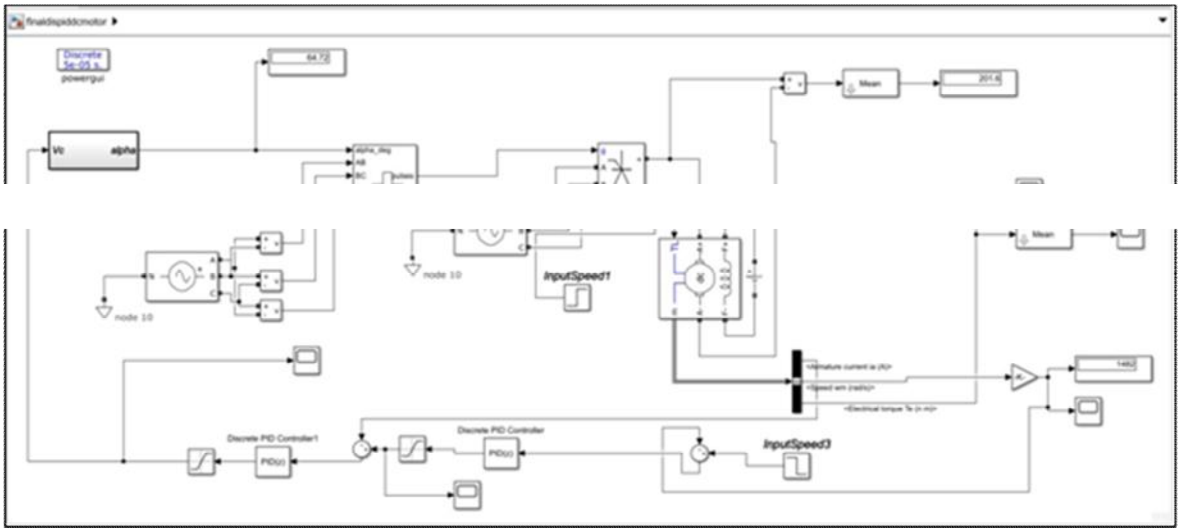

Fig. 4.1 Basic Model For Speed control for DC motor using Discrete PID Controller

V. SIMULATION RESULTS AND DISCUSSION

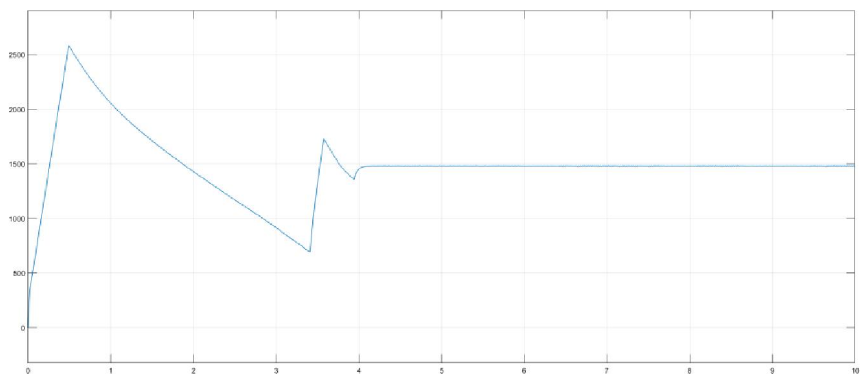

Fig. 4.2 Speed VS Time of DC motor at Running Condition

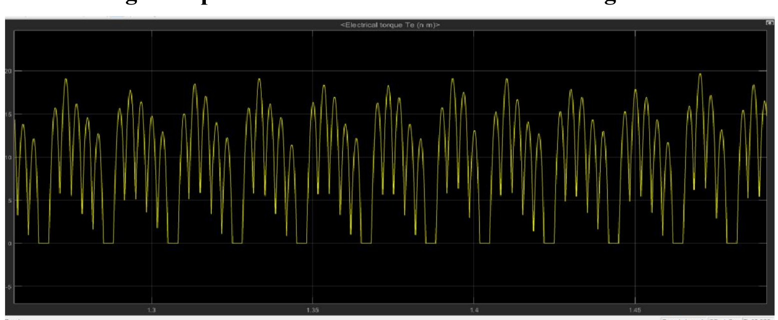

Fig.4.2 Electrical Torque Vs Time Output Waveform

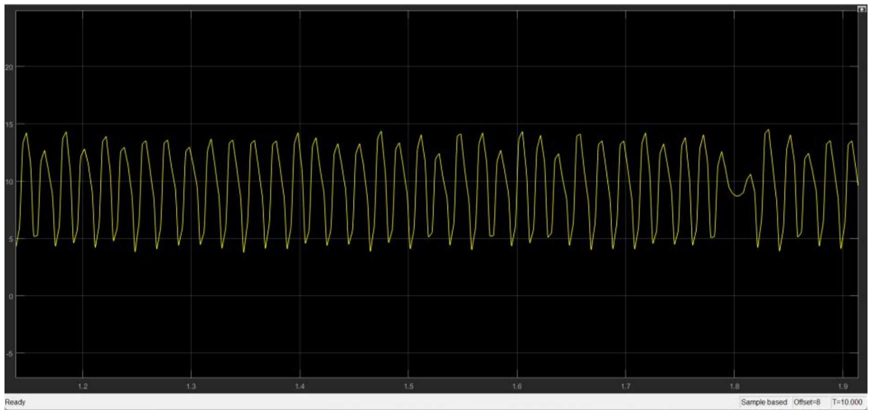

Fig.4.3 Armature Current Vs Time Output Waveform

The armature current vs. time graph exhibits a periodic fluctuation between 5 and 10 units. The armature current initially starts at 5 units and gradually increases, reaching a peak value of 10 units. Following the peak, the current decreases, returning to the lower bound of 5 units. This cyclic pattern repeats over time, indicating a periodic variation in the armature current. The duration of each cycle and the frequency of the fluctuations can vary depending on the specific system or application. The graph visually represents the dynamic behavior of the armature current, showcasing its oscillatory nature within the specified range.

VI. CONCLUSION

The precise control of DC motor speed is a critical requirement in various industrial applications, such as robotics, automation, and renewable energy systems. The discrete PID controller has emerged as a highly effective and versatile solution due to its ability to provide robust and responsive control. Through its proportional, integral, and derivative actions, the PID controller ensures accurate speed regulation, minimizes steady-state errors, and effectively handles dynamic changes in system parameters. Simulation and experimental studies consistently show that discrete PID controllers outperform traditional control strategies in terms of stability, response time, and robustness. The application of MATLAB as a development and testing platform facilitates efficient design and analysis, enabling engineers and researchers to refine control strategies effectively. In conclusion, the discrete PID controller remains a cornerstone of DC motor speed control, with continued research and development promising even greater advancements in control accuracy and adaptability. By leveraging modern tuning techniques and computational tools, this technology will continue to play a pivotal role in addressing the evolving demands of industrial automation and motor control systems.

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