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An Effective Control Methodology for Three-phase Induction Motors: Design and Analysis

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Abstract: *This research endeavors to investigate and develop a speed regulation system for three-phase asynchronous motors, a prevalent actuator in industrial applications. The methodology employed herein leverages a Proportional-Integral-Derivative (PID) control algorithm implemented on a Siemens S7-1200 Programmable Logic Controller (PLC) platform to achieve precise, stable, and dynamically responsive speed control under fluctuating load torques.The impetus for this study arises from the escalating demand for enhanced operational efficiency and energy conservation within industrial automation paradigms. Accurate regulation of motor rotational velocity not only optimizes system performance metrics but also contributes to the extended operational lifespan of equipment and a reduction in maintenance expenditures.The novelty of this work lies in the efficacious utilization of the integrated PID Compact function block inherent to the S7-1200 PLC, presenting a streamlined and cost-effective alternative to conventional discrete PID controllers or more complex Supervisory Control and Data Acquisition (SCADA) systems. This integration facilitates a simplified overall system architecture, mitigates initial capital investment, and enhances both the degree of automation and system scalability.Furthermore, this study delineates the design, parameter tuning, and experimental validation of the proposed control system, with the objective of optimizing motor performance characteristics. The empirical findings demonstrate significant potential for practical deployment within contemporary manufacturing systems, thereby contributing to improved reliability and enhanced energy efficiency across a spectrum of industrial applications.*

Keywords: *PID,3-phase induction motor, PLC,speed control, inverter.*

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I. Introduction

This paper details the conceptualization and realization of a speed regulation system tailored for three-phase asynchronous motors. The core of this system lies in the synergistic integration of a Proportional-Integral-Derivative (PID) control algorithm within the architecture of a Siemens S7-1200 Programmable Logic Controller (PLC). The central aim of this endeavor is to engineer an effective and robust control paradigm, distinguished by heightened accuracy and operational stability, a reduction in transient response times and overshoot phenomena, and the ultimate facilitation of energy conservation and simplified implementation across a spectrum of industrial production, manufacturing processes, and broader automation landscapes [3].

While the inherent effectiveness of PID algorithms in regulating motor speed has been well-documented in prior scholarly works, a notable gap persists in the comprehensive utilization of the sophisticated functionalities offered by contemporary PLC platforms, exemplified by the Siemens S7-1200. This advanced platform provides the advantages of high-throughput signal processing, an inherently user-friendly programming environment, and dependable real-time communication capabilities [14]. Although existing bodies of research have explored the application of PLCs in various industrial control scenarios, the deep and nuanced integration of PID functionalities within these platforms, specifically targeted towards applications such as precise motor speed regulation, remains an area warranting further investigation. Moreover, advanced features such as energy optimization strategies and flexible customization options are frequently underutilized [4][13]. Furthermore, older generations of PLC hardware, still prevalent in certain industrial installations, often present limitations in adequately addressing the evolving performance requirements of modern industrial operations and do not fully exploit the efficiencies offered by integrated development environments like the Totally Integrated Automation (TIA) Portal, which significantly simplifies the processes of system configuration and subsequent deployment.

In response to these identified limitations and opportunities, the present study introduces a novel motor speed control system predicated upon the Siemens S7-1200 PLC, featuring an optimized and deeply integrated PID control implementation. This design strategically leverages the PLC's inherent attributes, including its rapid processing capabilities, efficient communication interfaces, and considerable adaptability to diverse operational contexts. The resulting control system is characterized by a compact physical footprint, ease of configuration and parameterization, and broad applicability across a range of industrial equipment, including but not limited to conveyor belt systems, ventilation fans, and pumping mechanisms, thereby contributing to enhanced operational efficiency, a reduction in overall energy consumption, and decreased long-term maintenance costs [5]. The research presented herein offers a solution of significant practical value, directly addressing contemporary industrial automation needs. The proposed system contributes to the enhancement of both the reliability and safety of industrial control systems while simultaneously promoting increased productivity and fostering sustainable development within the broader field of automation technologies.

II. Materials And Methodology

2.1 Block diagram and function

Control block diagrams serve as a visual and abstract representation of a control system, illustrating the functional relationships between its constituent components. Each block typically represents a specific element or process within the system, and the directed lines connecting these blocks denote the flow of signals. These diagrams are instrumental in analyzing system behavior, designing controllers, and understanding the overall architecture and signal processing pathways within a dynamic system. By abstracting the underlying physical details, block diagrams provide a powerful tool for system-level analysis and design.

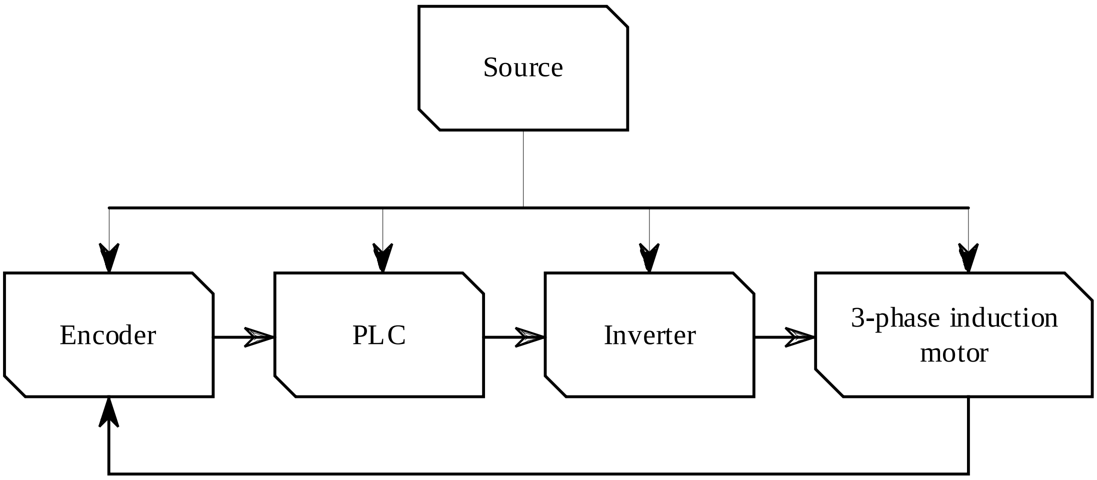

Figure1. Block diagram

As shown in Figure 1, the controlled object in this study is a three-phase asynchronous motor-a widely used type in industrial applications due to its durability, high operational efficiency, and cost-effectiveness. Motor speed adjustment is achieved through the use of a variable frequency drive (VFD), in combination with a PID controller integrated into the Siemens S7-1200 PLC. This configuration ensures fast response, stable operation, and minimal error[9].

The system is composed of the following key components:

- Power Supply Unit: Responsible for supplying electrical power to devices such as the PLC, encoder, and VFD.
- PLC Unit: Executes functions such as system start/stop, speed adjustment based on input requirements, and transmitting control signals to the VFD.
- VFD Unit: Receives control commands from the PLC and adjusts the output frequency accordingly to regulate motor speed.
- Encoder Unit: Gathers real-time motor speed data and sends feedback signals to the PLC for processing.
- Motor Unit: Operates at a speed determined by the output frequency of the VFD.

2.2 Hardware system design

Selection of the electric motor is based on a three-phase squirrel-cage induction motor with the following specifications:

- Rated power: $P_{dm} = 1,1kW$
- Speed: $n = 1400rpm$
- Number of pole pairs: $p = 2$
- Operating voltage: $380/220V$
- Frequency: $f = 50Hz$
- Efficiency: $\eta = 0.79$

To ensure smooth system operation, the selected variable frequency drive (VFD) must have a rated power equal to or greater than that of the motor.
=>The Mitsubishi FR-E700 VFD is selected with the following specifications:

- Power rating**:** 1.5kW ~ 2HP
- Input voltage: 3 pha 380V
- Output voltage: 3 pha 380V
- Output frequency range: 0.2 – 400 Hz
- Multi-step speed control: 8 cấp tốc độ
- Analog input (1): 4 – 20 mA
- Analog input (2): 0 – 5V hoặc 0 – 10V
- Communication interface: RS-485

To measure the motor speed, an encoder is required.
=> The Autonics E50S8-1024-3-T-24 encoder is selected with the following specifications:

- Output phases: A,B và Z
- Maximum allowable speed: 5000rpm
- Resolution: 1024P/R
- Operating voltage: 12-24VDC
- Response frequency: 300 KHz.

Output type: Open collector NPN (requires a pull-up resistor to VCC to establish a high logic level)

To suit the research objectives and experimental model setup, it is essential to select a PLC that is cost-effective, compact, and provides a sufficient number of input and output channels as required. Hence, the Siemens S7-1200 CPU 1212C AC/DC/RLY is selected (see Figure 2).

Figure 2. PLC S7-1200 CPU 1212C AC/DC/RLY

To fulfill the requirements of motor speed control using the PID algorithm on the S7-1200, an expansion module is necessary to transmit control parameters to the variable frequency drive (VFD). The CB 1241 RS485 communication module is selected with the specifications illustrated in Figure 3.

Figure 3. PLC S7-1200 CPU 1212C AC/DC/RLY

2.3 Details of PID controller

The Proportional-Integral-Derivative (PID) controller is a closed-loop control system consisting of three components-proportional, integral, and derivative-used to regulate variables such as speed, temperature, or pressure, in order to reach a desired setpoint with minimal error[1][2]. The structure of a typical PID controller is described in Figure 4.

It is a widely used tool in industrial automation, commonly applied in production lines and various engineering systems due to its simple structure, high stability, flexible tuning, ease of implementation, and reliability[6].Despite its broad adoption, the PID controller faces certain limitations when applied to systems with complex dynamic characteristics-particularly in optimizing performance and enhancing noise resistance[7][8].

In this study, the PID algorithm is integrated into a programmable logic controller (PLC) to directly regulate the frequency of the power supply via a variable frequency drive (VFD), thereby controlling the motor's speed. This enables the system to accurately manage both the speed and torque of the asynchronous motor, ensuring the desired setpoint is reached with minimal error[10].

The PID control method comprises three key components: proportional (P), integral (I), and derivative (D). Each component has a respective gain and performs a specific mathematical operation on the error signal:The proportional term multiplies its gain by the present error, the integral term multiplies its gain by the time integral of the error, the derivative term multiplies its gain by the time derivative of the error[11][12].The resulting values from these three elements are summed to generate the control output. The instantaneous error is defined as the difference between the setpoint (desired value) and the actual output[5]. Denoting the controller output as u(t), the entire process can be represented by the following equation:

$$u(t) = K_p e(t) + K_i \int e(t)\,dt + K_d \frac{de(t)}{dt} \tag{1}$$

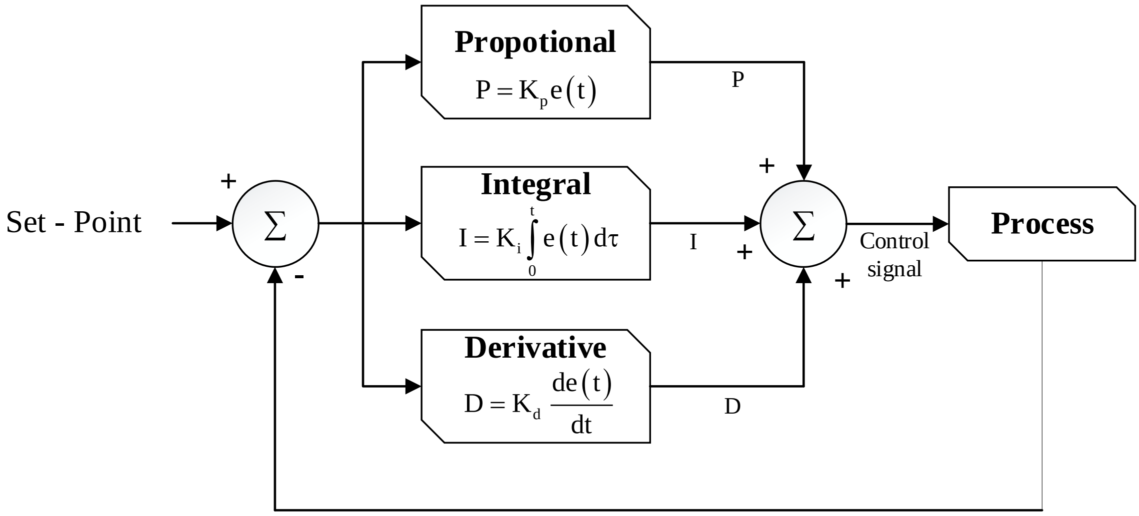

Figure4. Schematic diagram of the PID controller

2.4 PID controller working principle

The proportional (P) component generates an output that is directly proportional to the input error. To meet specific control requirements, the user must tune the proportional gain Kp, which multiplies the instantaneous error to produce the control signal [20].

The integral (I) component functions to eliminate steady-state error by continuously summing the error over time. This component generates a control signal based on the accumulated past error, effectively driving the system toward zero residual error. The output of the integral term changes continuously in response to error magnitude, with its rate of change proportional to the deviation. The integral gain Kidetermines the responsiveness of the controller: a higher Ki value increases the system's corrective action but may compromise stability if not properly tuned[19][20].

The derivative (D) component aims to predict the future trend of the error by calculating its rate of change over time. It adjusts the control output accordingly to minimize overshoot and oscillations. The derivative gain Kd defines the sensitivity of this prediction and plays a key role in smoothing the system's response. When the system's response time is large, the derivative action becomes more effective in providing quick reaction to input variations[18][20] (see Figure 5).

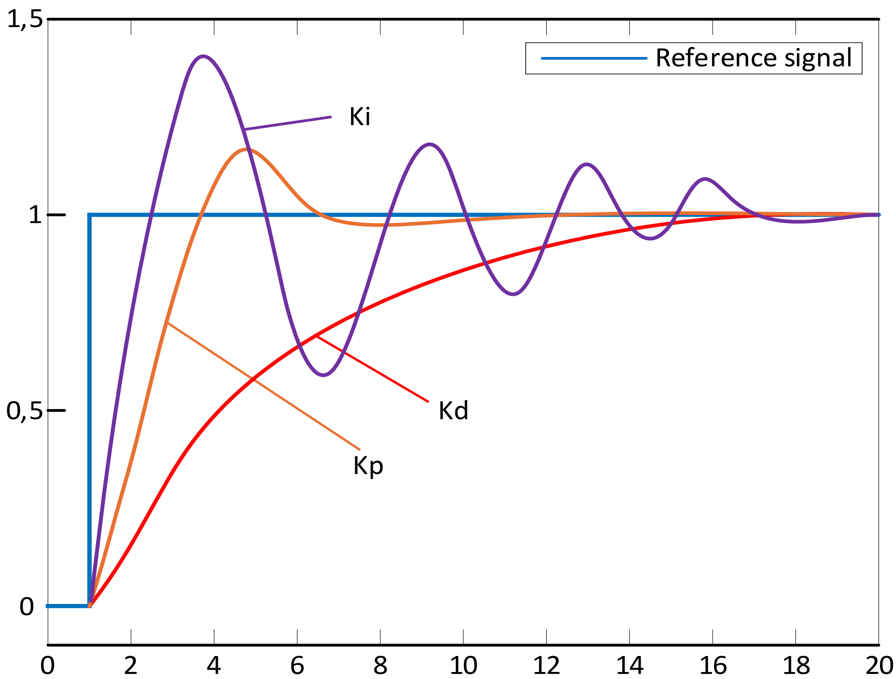

Figure 5. Real value graph over time

III. Results And Discussions

3.1 Experimental results

First, configure the necessary parameters for the Variable Frequency Drive (VFD). Next, initiate the system by pressing the start button, selecting the desired rotation direction of the motor, and entering the target speed value to begin operation.

The actual values displayed on the VFD are fully consistent with those observed on the PID Compact block. Figures 6 shows the experimental model results when the system operates at speeds of 1100 RPM.

Figure6. Graph results at 1100prm

3.2 Comments

The PID controller, seamlessly integrated within the Siemens S7-1200 PLC, exhibits efficient operation and provides a flexible framework for the adjustment of the proportional, integral, and derivative gains. This tunability allows for precise adaptation to the dynamic characteristics of the controlled three-phase induction motor. The PLC establishes communication with the Variable Frequency Drive (VFD) utilizing the Modbus protocol, thereby ensuring the real-time transmission of pertinent speed-related data [16][17]. Operators possess the capability to monitor and modulate the motor's rotational speed through the Human-Machine Interface (HMI). The implemented control system demonstrates stable operation and accurately tracks the reference speed setpoint.

Following the appropriate optimization of the PID controller parameters, the system exhibits a rapid dynamic response, minimal overshoot characteristics, and a low steady-state error, quantified at approximately ±0.5%. Furthermore, the system maintains robust operational stability even when subjected to moderate variations in the applied load. The developed control system demonstrates compatibility with a broad spectrum of reference speed setpoints [11].

Empirical validation through experimental results corroborates that the implemented PID control methodology enables a significantly more accurate level of speed regulation when compared to manual control techniques. The PID controller parameters are readily adjustable, the overall system exhibits inherent scalability, and it is well-suited for deployment in large-scale industrial production lines, offering sustained long-term stable operation with minimal operator intervention [9].

Notwithstanding these advantageous characteristics, the system does present certain inherent limitations. The process of PID parameter tuning can be time-intensive and necessitates a degree of operator expertise, particularly when the system operates under varying load conditions. Moreover, the utilization of encoders with suboptimal performance specifications can introduce significant measurement errors into the feedback loop. Finally, the absence of an integrated auto-tuning mechanism for the PID parameters potentially prevents the system from achieving globally optimal performance across all possible operating scenarios.

IV. Conclusion

In this investigation, the control of a three-phase induction motor is realized through a PID controller, implemented utilizing the integrated PID Compact function block within the Siemens TIA Portal V16 software environment. The programmable logic controller (PLC) employed for this implementation is the Siemens S7-1200-1212 AC/DC/RLY.The modulation of the motor's rotational speed is achieved by adjusting the frequency of the power supply via a Variable Frequency Drive (VFD). Communication between the VFD and the PLC is established using the MODBUS RTU protocol over the RS485 serial interface. The PID controller operates by continuously comparing the desired speed setpoint with the actual speed feedback obtained from an encoder, which transmits data to the PLC through the VFD. Based on the resultant error signal, the PID algorithm executes computations to adjust the control output, thereby ensuring the convergence of the actual motor speed towards the target value. The proportional, integral, and derivative coefficients are configured and meticulously tuned within the programming environment to attain optimal closed-loop control performance.

This application-oriented study aligns pertinently with the demands of contemporary industrial automation. Three-phase induction motors are widely adopted due to their inherent robustness, cost-effectiveness, and broad applicability across diverse industrial systems, such as conveyor systems, pumping stations, industrial ventilation, and compression units. However, the maximization of their operational performance necessitates precise control methodologies, which are crucial for enhancing energy efficiency and mitigating mechanical degradation.

The direct implementation of the PID algorithm on the S7-1200 PLC facilitates the full utilization of the existing hardware infrastructure, obviating the requirement for discrete PID controllers or complex, specialized software packages. This integrated approach yields significant reductions in both initial capital investment and ongoing maintenance expenditures. Furthermore, the Siemens TIA Portal platform supports real-time adjustment of PID parameters directly via the Human-Machine Interface (HMI). Consequently, this study not only contributes to the theoretical advancements in control system optimization but also offers tangible practical value for industrial deployment, enabling enhanced efficiency and energy savings within manufacturing environments.

In conclusion, the implementation of a PID-based speed control system for a three-phase induction motor, utilizing the Siemens S7-1200 PLC platform, has been successfully executed, demonstrating its technical feasibility and operational effectiveness for a range of industrial applications.

Conflict of interest

There is no conflict to disclose.

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References

[1]. M. G. Ioannides, C. Bejan, PID Neural Network Based Speed Control of Asynchronous Motor Using Programmable Logic Controller. Advances in Electrical and Computer Engineering, 2021.
[2]. H. Hartono, R. A. Putra, A. S. Ramadhan, Speed Control of Three Phase Induction Motor Using Universal Bridge and PID Controller. Journal of Physics: Conference Series, 2019.
[3]. M. G. Ioannides, C. Bejan, Monitoring and Control of a Variable Frequency Drive Using PLC and SCADA. Jurnal Nasional Komputasi dan Teknologi Informasi, 2022.
[4]. S. Vadi, R. Bayindir, Y. Toplar, I. Colak, Induction Motor Control System with a Programmable Logic Controller (PLC) and Profibus Communication. Journal of Process Control, 2020.
[5]. J. Zhang, L. Wang, X. Liu, Optimal Tuning of PID Controller Parameters for Industrial Processes. IEEE Transactions on Industrial Informatics, 2021.
[6]. A. Kumar, S. Sharma, R. K. Gupta, PID Controller Optimization for Motor Speed Control Using PLC and VFD. IEEE PEDES, 2022.
[7]. M. A. Ahmad, S. R. M. Shukor, Anti-Windup Techniques for PID Controllers in Industrial Applications. Journal of Control Science and Engineering, 2020.
[8]. K. H. Lee, J. H. Kim, S. W. Park, Fractional-Order PID Controllers for Induction Motor Speed Control. IEEE Access, 2020.
[9]. J. Pramudijanto, A. R. Pratama, D. Santoso, PLC-Based PID-Predictive Controller Design for 3-Phase Induction Motor. IEEE Conference, 2019.
[10]. R. K. Sharma, P. S. Rao, Monitoring and Control of a VFD Fed Three Phase Induction Motor. IEEE Conference, 2021.
[11]. A. S. Ali, M. H. Qureshi, Fuzzy Logic and PID Control for Induction Motor Drives. Advances in Electrical and Computer Engineering, 2019.
[12]. P. Garcia, J. M. Lopez, Real-Time PID Control of Induction Motors Using PLC. IFAC-PapersOnLine, 2020.
[13]. K. H. Khudier, M. M. Ibrahim, Design of a PLC-Based Variable Load, Speed Control System. Journal of Automation and Control Engineering, 2020.
[14]. A. R. Saher, J. Mahmood, PLC-Based Control of Induction Motors with VFD. Journal of Automation and Control Engineering, 2021.

[15]. R. Bayindir, S. Vadi, PID Control with Profibus Communication for Motor Drives. IEEE Transactions on Automation Science, 2021.
[16]. P. K. Sharma, A. K. Jain, Energy-Efficient PID Control for Induction Motors. Energy Reports, 2020.
[17]. J. M. Silva, P. A. Costa, Auto-Tuning PID Controllers for Motor Speed Control. IFAC-PapersOnLine, 2021.
[18]. S. P. Singh, R. K. Tripathi, PID Control for Induction Motors with VFD and PLC. IEEE Transactions on Industry Applications, 2020.
[19]. A. P. Kaldate, S. A. Kulkarni, PLC-Based Speed Control of Induction Motors Using PID. International Journal of Electrical Engineering, 2020.
[20]. M. Zajmovic, H. Salkic, S. Stanic, PID and SCADA for Induction Motor Control. Journal of Control and Automation, 2020.