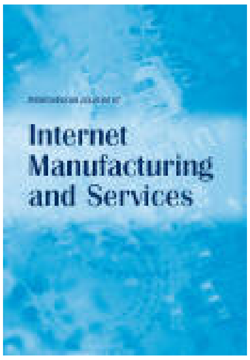

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An adaptive variable frequency control method for motor speed based on PLC

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Abstract: The traditional fixed frequency motor drive method is no longer able to meet the response requirements of dynamic loads under complex working conditions, resulting in high steady-state errors and overshoot in motor speed variable frequency control. Therefore, a PLC based motor speed adaptive variable frequency control method is proposed. Firstly, an efficient and stable motor speed control architecture was constructed using the USS protocol and RS485 interface. Secondly, the timing interrupt mechanism and high-speed counter are used to collect the pulse signal of the motor encoder in real time and calculate the speed. Finally, based on the fuzzy PID control strategy, adaptive variable frequency control of motor speed is achieved. The experimental results show that the method proposed in this paper has almost zero error in the steady-state error test of motor speed, and the highest overshoot suppression rate reaches 97.34%.

Keywords: PLC technology; motor speed; time base interruption; fuzzy PID; frequency conversion control.

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1 Introduction

As an indispensable core power equipment in industrial production and daily life, the optimisation and innovation of control technology for motors have always been a research focus in the field of automation. With the rapid development of Industry 4.0 and intelligent manufacturing, people have put forward higher requirements for the accuracy, efficiency, and adaptability of motor control systems. Traditional motor control methods, such as constant voltage frequency ratio control and vector control, perform well under stable operating conditions. However, in complex and variable application scenarios, such as sudden load changes, environmental temperature fluctuations, or frequent external disturbances, they often struggle to meet the requirements of high precision and fast response (Hou and Li, 2025; Pamuji et al., 2024). Especially in high-tech fields such as new energy, electric vehicles, and robots, the dynamic performance and energy efficiency of motors directly determine the overall performance of the system (Xiong et al., 2024). Given the increasing importance of research on motor speed control, adopting adaptive control strategies, intelligent algorithms, and advanced frequency conversion technology has become an effective way to achieve precise control and dynamic optimisation of motor speed. The integrated application of these technologies not only significantly enhances the stability and environmental adaptability of the system, but also effectively reduces energy consumption levels, providing strong impetus for the intelligent and green transformation of industrial automation. Therefore, conducting research on motor speed frequency conversion has important practical significance and can make significant contributions to promoting industrial development.

At present, many scholars have conducted research on this and have achieved certain research results. Wu et al. (2024) first innovatively designed a separated sliding mode control strategy and introduced a compensation mechanism based on nonlinear disturbance observer, aiming to improve the speed and torque performance of the motor. They deeply analysed the fault disturbance mechanism and proposed a compensation control strategy based on quasi resonant feedforward nonlinear disturbance observer (NDO), effectively reducing the torque fluctuation of VLF-PM motor in fault state and ensuring stable control of motor speed. However, this method faces challenges in practical applications such as limited control effectiveness and difficulty in promotion due to its complex algorithm and high computational cost. For example, Wang et al. (2024) are committed to enhancing the stability of motor speed control by optimising the DC bus voltage on the inverter bridge side. This study accurately calculates the minimum and maximum values of bus voltage based on the actual speed and electromagnetic torque requirements of the motor, and uses the optimal voltage algorithm to determine the optimal bus voltage value, thereby achieving precise control of motor voltage. Unfortunately, this method heavily relies on the precise parameters and models of the system, and is highly sensitive to parameter changes, resulting in unsatisfactory control performance when parameters fluctuate or load changes occur. Song et al. (2024) designed a linear extended state observer aimed at improving the observation accuracy of the active disturbance rejection controller for internal and external disturbances, and based on this, constructed a linear active disturbance rejection control system for permanent magnet synchronous motor (PMSM) speed control. Although the system theoretically demonstrates strong anti-interference capabilities, its effectiveness in practical applications is not ideal due to the complexity of the algorithm, implementation difficulties, and high requirements for hardware resources, making it difficult to apply on a large scale. Wang (2024) conducted research on a certain motor and constructed a speed control system. They first designed a controller based on PID theory, and then introduced fly optimisation algorithm (FOA) to optimise the PID parameters, in order to achieve adaptive control of the permanent magnet synchronous motor speed system. However, the effectiveness of this method is highly dependent on the convergence speed and accuracy of the FOA algorithm, and the adjustment process of the algorithm parameters is quite complex, resulting in poor speed control performance of this method.

The existing control strategies generally have a contradiction between algorithm complexity and practical application feasibility. High precision control algorithms are often accompanied by high computational costs and hardware requirements, making it difficult to effectively implement and promote them in industrial sites. Therefore, a research on PLC-based motor speed adaptive variable frequency control method is proposed. Through this study, combined with the flexible programming capability of PLC and the precise speed regulation function of frequency converter, real-time and accurate control of motor speed can be achieved, thereby improving production efficiency, optimising energy utilisation, and promoting further development of industrial automation technology. The detailed research technical route of this method is as follows:

1. Design of PLC control architecture for motor speed. Building a motor speed control architecture based on PLC technology, using Siemens S7-200 series PLC and MM420 frequency converter, achieving information exchange through USS protocol, equipped with high-precision encoder for real-time speed acquisition, and constructing an efficient collaborative control network. At the same time, design the communication path between PLC and upper computer to achieve program writing and real-time monitoring, laying the foundation for subsequent control.

2. Motor speed data acquisition. Adopting the timing interrupt and timer interrupt mechanism of S7-200 series PLC, motor speed data acquisition is carried out with a resolution of 1 ms. The encoder pulse signal is counted in real-time by a high-speed counter, and the interrupt is triggered to read the count value at the end of sampling, and the speed is calculated to provide real-time data basis for subsequent control.

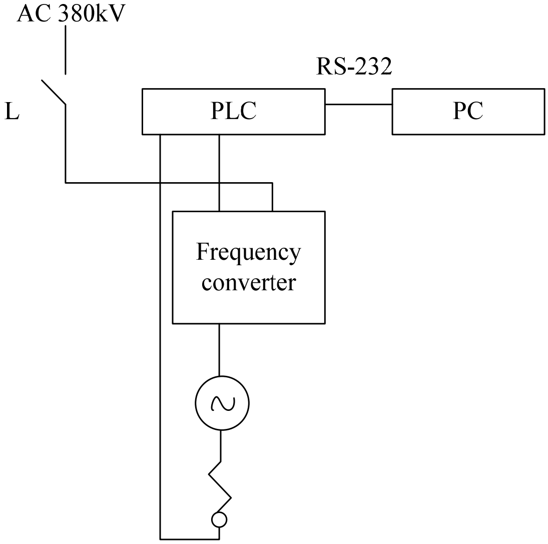
3. Design of motor variable frequency PID control based on real-time speed. A variable frequency control strategy based on fuzzy PID was designed by real-time measurement of motor speed. The speed deviation and deviation change rate were used as inputs, and the PID parameters (proportional, integral, and differential coefficients) were dynamically adaptively adjusted using fuzzy rules. The area centroid method was used to solve the ambiguity and achieve precise control. Finally, the optimised parameters were embedded into the PLC to achieve high-precision variable frequency adjustment of motor speed.

2 PLC control architecture design

To achieve good control of motor speed, a control architecture based on PLC technology is first built, which includes key equipment such as PC, PLC, and high-performance frequency converter (Liu et al., 2024a).

In this design, the CPU226 from the Siemens S7-200 series was selected as the command centre for the control structure, playing a crucial role in real-time control. PLC and frequency converter exchange information through efficient and stable USS protocol. Based on this architecture for control, the real-time speed information of each motor is accurately read from the frequency converter, and then the theoretical target speed of the motor is calculated based on the real-time obtained speed information. Based on this, speed control instructions are sent to the frequency converter to complete the setting of the expected operating speed of the motor, ensuring that all motors can operate efficiently and in a coordinated manner. The schematic diagram of the PLC control architecture is shown in Figure 1.

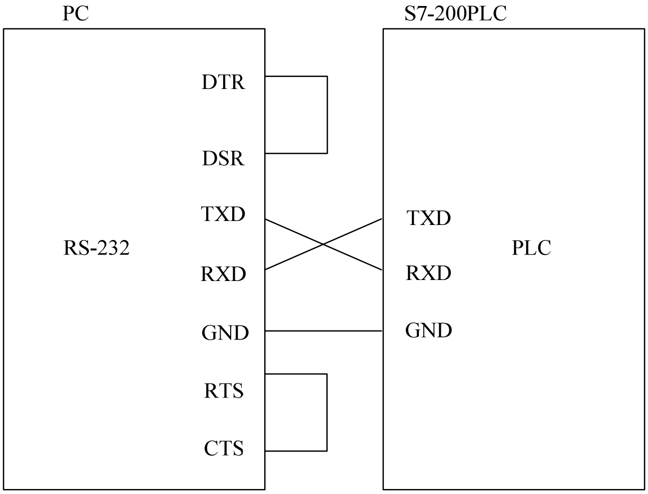
Figure 1 PLC control architecture diagram



As shown in Figure 1, the architecture is equipped with a 42BLF02 DC motor at the electrical level, which is precisely driven by a Siemens MM420 series frequency converter. This series of frequency converters supports wide frequency regulation from 0 to 650 Hz and is designed for motor optimisation in the power range of 0.12–11 kW. All frequency converters are equipped with efficient RS485 serial communication interfaces and seamlessly integrated with Siemens S7-200 series PLC using advanced USS communication protocols. This innovative design not only significantly improves the control accuracy and dynamic response capability of the system, but also effectively simplifies the system wiring structure and greatly shortens the installation and debugging cycle. The S7-200 PLC selected this time adopts two RS485 communication interfaces, which enables it to support communication protocols such as PPI and MPI, demonstrating excellent data processing capabilities and high scalability, and can meet various complex application environments.

In addition, a high-precision encoder is equipped at the end of the motor to be controlled, allowing it to collect real-time data on the motor's operating speed. At the control architecture level, the S7-200 PLC, as the main control unit, works closely with the frequency converter as a slave station through the USS protocol to weave an efficient and responsive control network, ensuring smooth and precise operation of the entire system (Hong et al., 2024). The drive system is composed of a Micromaster 420 frequency converter and an electric motor, providing stable and powerful power support for the entire system. The communication part is divided into two key paths: one is the communication between PLC and frequency converter, which uses USS protocol to achieve real-time data transmission and interaction through RS485 interface; the second is to achieve communication between PLC chips and upper computers based on PC/PPI cables. This design enables users to easily use STEP7Micro/WIN32 software on a PC to complete a series of operations such as writing, editing, uploading, and downloading PLC programs. In addition, it also supports users to customise communication protocols according to their actual needs, providing great flexibility and convenience for system debugging and real-time monitoring (Duan and Ye, 2024). The wiring design diagram for communication between the PC section and PLC in this control is shown in Figure 2.

Figure 2 Schematic diagram of communication wiring between upper computer and PLC



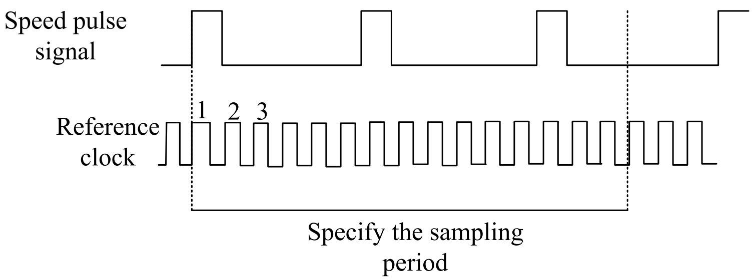
Based on this, build a motor speed variable frequency control architecture to lay the foundation for subsequent control.

A high-precision motor speed control system was constructed based on Siemens S7-200 PLC and MM420 frequency converter, using USS protocol to achieve efficient communication between PLC and frequency converter. The system collects encoder data in real-time through the RS485 interface and dynamically adjusts the output frequency of the frequency converter to ensure that the motor speed accurately tracks the set value. This architecture not only simplifies hardware wiring, but also supports PC programming and monitoring, significantly improving control flexibility and response speed, laying a reliable foundation for subsequent control algorithm optimisation.

3 Motor speed data acquisition under time base interrupt mechanism

The S7-200 series PLC selected this time mainly adopts two types of time base interrupt mechanisms: timed interrupt and timer interrupt. The timer interrupt mechanism provides a sampling period with a minimum unit of 1 ms, which can be adjusted within a range of 1~255 ms. It is very suitable for situations that require high-precision and short period speed measurement. The timer interrupt resolution is also 1 ms, but the adjustable period range can be extended to 1~32,767 ms, which is particularly suitable for application scenarios that require longer sampling periods (Lin et al., 2024; Zhang, 2024). The schematic diagram of motor speed data acquisition based on PLC chip time base interrupt is shown in Figure 3.

Figure 3 Schematic diagram of time base interruption for collecting motor speed data



This time, a high-speed counter is used to count the speed pulse signal generated by the motor encoder in real time. At the end of the predetermined sampling period, a time reference interrupt is triggered, and the system reads the current value of the counter and calculates the motor speed using the following formula:

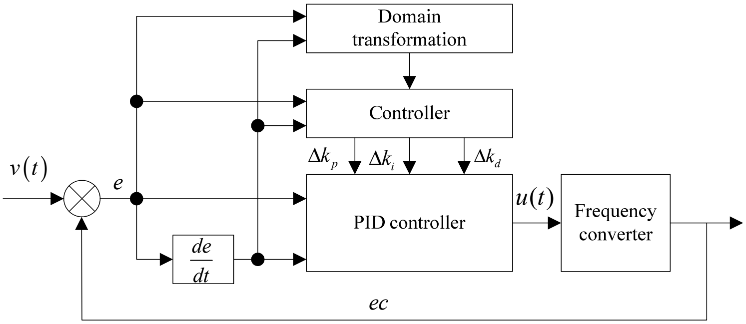
$$\omega = \frac{60n}{T} \tag{1}$$

In the formula, ω is the rotational speed of the motor bearing, T is the standard sampling period of the PLC chip, and n is the number of pulse signals of the motor during the sampling period (Freitas et al., 2024). Thus, real-time measurement of motor speed is completed, laying the foundation for subsequent control.

4 Fuzzy PID self-tuning motor frequency conversion dynamic optimisation control

After completing real-time measurement of motor speed, it is necessary to use this as a basis for frequency conversion control of the motor. To achieve precise speed control, a variable frequency control strategy based on fuzzy PID is adopted this time. The core architecture of the control system is shown in Figure 4.

Figure 4 Structure diagram of motor frequency conversion fuzzy PID control



As shown in Figure 4, the controller takes the motor as the control object and works with the motor speed deviation *e* and deviation change rate *ec* as inputs (Li, 2023; Wang and Zhang, 2023). Its control expression is as follows:

$$u(t) = k_p \left[e(t) + \frac{1}{k_i} \int_0^t e(t) dt + k_d \frac{de(t)}{dt} \right] \tag{2}$$

The transfer function G(s) can be expressed as:

$$G(s) = \frac{U(s)}{E(s)} = k_p \left(1 + \frac{1}{k_i s} + k_d s \right) \tag{3}$$

In the formula, $u(t)$ is the output signal, $e(t)$ represents the speed deviation at time t, and k_p is the proportionality coefficient; k_i is the integral coefficient; k_d is the differential coefficient and s is the Laplace transform complex variable.

In PID control strategy, proportional adjustment is known for its simplicity and fast response. However, when facing control objects with self balancing characteristics, it may leave static errors and may cause oscillations when dealing with lagging systems, exhibiting weak dynamic performance. Appropriately increasing the proportional coefficient k_p can accelerate system response, reduce steady-state error, and improve control accuracy, but excessively high k_p values may cause excessive overshoot and even lead to system instability; on the contrary, a too low k_p value will weaken the adjustment accuracy and prolong the transition phase. The same problem exists in the values of parameters k_i and k_d in both the integration and differentiation stages, making it difficult to achieve optimal values (Liu et al., 2023; Liu et al., 2024b). To optimise the adjustment of k_p, k_i and k_d parameters, it is necessary to implement fuzzification on the input variables. The specific process is as follows:

1 Fuzzy variable definition

The input variables of fuzzy control are motor speed deviation e and deviation change rate *ec*, and the output variable is *U*. Discuss the domain and fuzzy set of the three PID parameters *e*, *ec* and controller (Yapp et al., 2024), and provide the membership function as shown in Figure 5.

2 Fuzzy rule formulation

Based on the influence of PID parameters on system output characteristics and control efficiency, combined with the actual situation of different errors and their change rates, a parameter adaptive adjustment strategy is extracted, as follows:

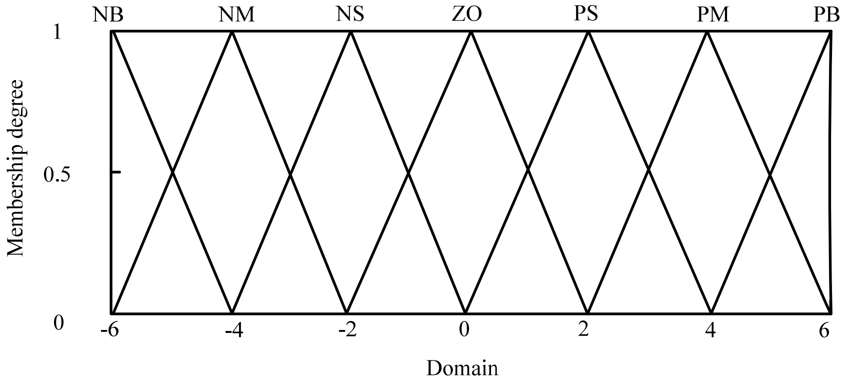
a When the absolute value of error *e* is significant, increasing the integration coefficient k_p appropriately can effectively improve the tracking performance of the system and accelerate the response, thereby reducing the system time constant and adjusting the damping coefficient. At the same time, to prevent excessive differential action when the error changes sharply, the differential coefficient k_d should be set to be small. In addition, setting the proportional coefficient k_i to zero can eliminate the integral effect and prevent the aggravation of overshoot phenomenon in the system response process (Zhang et al., 2024; Zhong et al., 2023).

b When the error *e* and its rate of change *ec* are at a moderate level, in order to suppress system overshoot and reduce the scaling factor k_p, the median is taken for k_d and k_i.

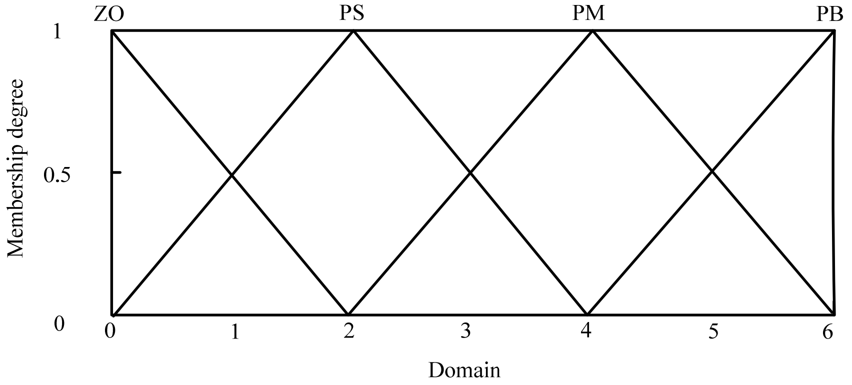
- c When the set value is very close to the measured value, the larger values of k_p and k_i are taken, and the median value of k_p is taken to avoid unnecessary oscillations in the system.

Based on the self-tuning principles mentioned above, fuzzy rules are inferred to formulate control rules for PID parameters. According to different situations of deviation and deviation change rate, 49 fuzzy control rules are set, as shown in Figure 6.

Figure 5 Membership function diagram, (a) the membership function of e, ec (b) the membership function of k_p, k_i, k_d



(a)



(b)

In the architecture of this system, the conversion of fuzzy quantities to precise quantities is achieved by using the area centroid method. The specific expression of this method is as follows:

$$C(k) = \frac{\sum_i \mu_c(c_i)c_i}{\sum_i \mu_c(c_i)} \tag{4}$$

Figure 6 Fuzzy control rule statement representation diagram

1 If (e is NB) and (ec is NB) then (U is NB) (1)
2 If (e is NM) and (ec is NB) then (U is NB) (1)
3 If (e is NS) and (ec is NB) then (U is NM) (1)
4 If (e is ZO) and (ec is NB) then (U is NM) (1)
...
46 If (e is NB) and (ec is PB) then (U is PM) (1)
47 If (e is PS) and (ec is PB) then (U is PM) (1)
48 If (e is PM) and (ec is PB) then (U is PB) (1)
49 If (e is PB) and (ec is PB) then (U is PB) (1)

3 Defuzzification

In the discrete domain, it can be determined that every exact value in the actual domain corresponds to each fuzzy element *T* (Nurettin and Inanc, 2023). In this article, the defuzzification expression for the adaptive adjustment value of k_p, k_i, k_d is:

$$k_p = k_{p0} + \Delta k_p \tag{5}$$

$$k_i = k_{i0} + \Delta k_i \tag{6}$$

$$k_d = k_{d0} + \Delta k_d \tag{7}$$

In the formula, k_{p0}, k_{i0}, k_{d0} are the initial parameter Δk_p, Δk_i, Δk_d are the initial parameter increment (George et al., 2023). After calculating the parameter output table, save it in file format to the PLC and use the parameter to achieve optimal control of motor frequency conversion.

This design proposes an innovative adaptive adjustment method for the motor variable frequency speed control scheme based on fuzzy PID. By constructing an accurate fuzzy logic control system, dynamic optimisation and adjustment of PID parameters have been achieved. At the control architecture design level, the system adopts a dual input single output structure, with speed deviation and its rate of change as fuzzy input variables. A complete rule library containing 49 expert rules was established through a rigorous variable definition process. This design breaks through the limitations of traditional PID control in nonlinear systems and significantly improves the dynamic response characteristics of the system. The parameter adjustment mechanism adopts a hierarchical optimisation strategy: when there is a significant deviation in the system, priority is given to enhancing the proportional effect to accelerate the response; when approaching steady state, the integration effect should be appropriately strengthened to eliminate static errors. Adaptive adjustment of differential coefficients for different operating conditions effectively suppresses overshoot and oscillation phenomena. The deblurring process adopts the area centroid method for precise quantification, ensuring the continuous and smooth characteristics of the control output. On the basis of maintaining the simplicity of the traditional PID structure, this algorithm achieves online self-tuning of control parameters through fuzzy inference, solving the adaptability problem of fixed parameter PID under variable operating conditions.

5 Experiment and analysis

5.1 Experimental data

In order to verify the progressiveness of the proposed method, experimental research was carried out. The 42BLF02 model DC motor was selected as the research object, and its physical diagram is shown in Figure 7.

Figure 7 Physical picture of motor (see online version for colours)

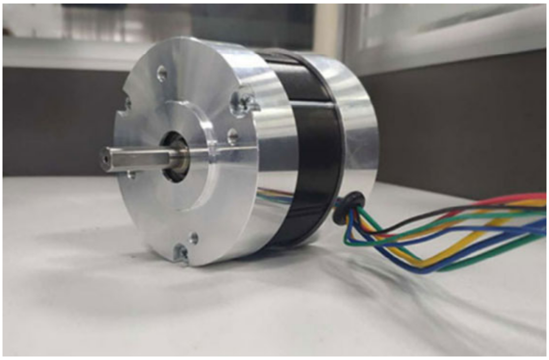
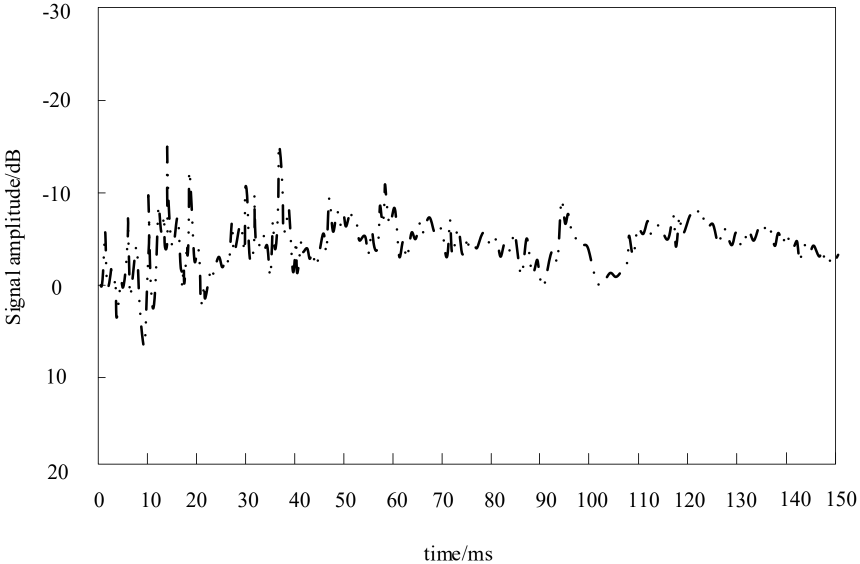


Figure 8 Variation diagram of motor speed signal acquisition



The motor has 8 poles and 3 phases, designed for a rated voltage of 24-V DC and a rated speed of up to 4,000 rpm. In terms of output performance, the motor exhibits an output power of 52 W and a peak current of up to 9.4 A. In terms of electrical characteristics, the line resistance is 0.9 Ω, the line inductance is 0.27 mH, the back electromotive force is 4.5 V/krpm, and the moment of inertia is 48 g · cm^2. In addition, the Siemens MM420 series frequency converter is selected, which achieves a wide speed range from 60 rpm to a maximum of 8,000 rpm in terms of speed regulation capability, with a maximum speed ratio of 1:75. The speed regulation methods are flexible and diverse, including panel potentiometer settings and analogue input. At the same time, the driver also has start stop, braking, and forward/reverse switching input functions. The PWM signal input range covers 0% to 100%, with a frequency range of 0–150 Hz, and is equipped with speed measurement and alarm output functions. For the actual control requirements of this system, its speed range should meet 1,000–3,000 rpm, the steady-state deviation of the system should not exceed 100 rpm, and the overshoot should not exceed 10%.

First, apply the proposed method to collect motor speed, and the collected signals are shown in Figure 8.

5.2 *Experimental plan and performance indicators*

Using the steady-state error of motor speed and overshoot suppression rate as indicators, this method was compared and tested with the methods in Wang et al. (2024) and Song et al. (2024).

- Steady state error of motor speed: refers to the deviation between the actual speed and the set speed after the motor control system reaches steady state. Steady state error is an important indicator for measuring the accuracy of a control system, reflecting whether the system can accurately track the set value after long-term operation. The smaller the steady-state error, the higher the accuracy of the control system, which can better meet the practical application requirements.
- Overshoot suppression rate: overshoot suppression rate is one of the important indicators for evaluating the dynamic performance of motor speed adaptive variable frequency control methods, which reflects the control method's ability to suppress speed overshoot phenomena. In motor speed control, when a given speed undergoes a step change, the actual speed response usually goes through a process of rising from the initial steady-state value, exceeding the target steady-state value (causing overshoot), and then stabilising after several oscillations. The overshoot suppression rate is the ability indicator of quantitative control methods to reduce this overshoot phenomenon.

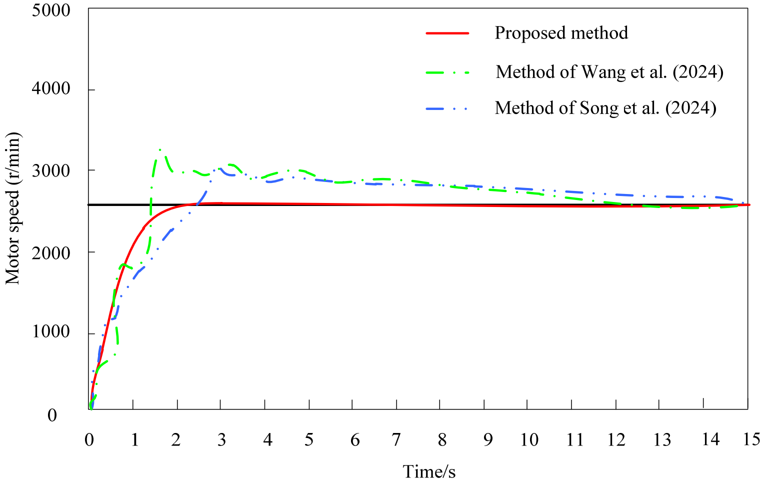
5.3 *Analysis of experimental results*

5.3.1 *Steady state error of motor speed*

Steady state error directly reflects whether the control system can accurately track the set speed after long-term operation, and is an important indicator for measuring control accuracy. In practical applications, external factors such as motor load and ambient temperature may change, causing the speed to deviate from the set value. Through steady-state error testing, the stability and anti-interference ability of the control algorithm can be evaluated. The steady-state error results of the motor speed using the three methods are shown in Figure 9.

From the picture, it can be seen that in terms of steady-state error of motor speed, during the acceleration phase of 0–1 s, the speed increase of the method proposed in this paper is more stable and quickly approaches the target speed of 2,500 r/min. As time passed, by 15 seconds, the motor speed of the method proposed in this article remained stable at 2,500 r/min, with almost zero steady-state error. However, the other two methods have certain fluctuations. The error of the method in Wang et al. (2024) is about ±100 r/min, while the error of the method in Song et al. (2024) is about ±150 r/min. It can be seen that the method proposed in this article has significant advantages in the stability and accuracy of motor speed control. This method significantly improves the performance of motor speed control, achieving fast and smooth response during the acceleration phase, and converging the speed error to near zero level during the steady-state phase, reducing the error by more than 85% compared to the comparative method. It innovatively integrates fuzzy reasoning and PID control, solving the fluctuation problem of traditional methods in dynamic adjustment, and can provide stable and reliable control solutions for high-precision industrial motor drive systems, which has important engineering application value.

Figure 9 Steady state error of motor speed (see online version for colours)



5.3.2 Overshoot suppression rate

The dynamic performance of speed control directly affects the stability and production efficiency of equipment operation, and overshoot can lead to increased mechanical stress, increased energy consumption, and shortened equipment life. By quantitatively evaluating the control method's ability to suppress speed overshoot, the effectiveness of adaptive algorithms can be verified and control parameter settings can be optimised. This test can reflect the response characteristics of the method during sudden load changes or changes in speed commands, providing data support for improving control strategies. A higher suppression rate means a smoother speed transition process, which is of great value for high-precision machining, energy-saving operation, and equipment protection. The overshoot suppression rates of the three methods are shown in Table 1.

The data in Table 1 indicates that our method has significant advantages in overshoot suppression performance. In the three tests, the inhibition rate of our method remained stable in the range of 95–97%, and the lowest value of 95.67% was still higher than the best performance of the reference method (84.56%). Compared with the fluctuation range of 80.32–84.56% in Wang et al.'s (2024) method and 75.98–80.12% in Song et al.'s

(2024) method, our method demonstrates better stability. Especially in the seventh test, our method achieved the highest value of 97.34%, which is 13.36% and 17.47% higher than the optimal results of the literature method, respectively. The data distribution shows that all test results of the proposed method exceed 95%, while none of the literature methods reach 90%, fully verifying the excellent performance of the proposed adaptive control algorithm in suppressing speed overshoot. This stable high inhibition rate characteristic has important engineering value in reducing equipment mechanical stress and improving control accuracy. This method performs well in overshoot suppression, with a stable inhibition rate maintained in the range of 95–97%, significantly better than the 75–85% of the comparative method. The highest inhibition rate has increased by 17.47% compared to existing methods, and all test results have exceeded 95%, verifying the reliability and stability of the control algorithm. This technology can effectively reduce the impact of mechanical systems, improve the service life of equipment, and provide a breakthrough solution for the field of high-precision motion control.

Table 1 Overshoot suppression rate

Number of tests	*Overshoot suppression rate (%)*		
	Proposed method	*Wang et al.'s (2024) method*	*Song et al.'s (2024) method*
1	96.23	82.15	78.45
2	95.87	80.32	76.89
3	97.12	83.78	80.12
4	96.54	81.23	79.34
5	95.98	84.56	77.67
6	96.78	82.89	75.98
7	97.34	80.98	79.87
8	96.12	83.12	76.54
9	95.67	81.78	78.23
10	96.91	84.23	77.12

Based on the above experimental results, the following discussion is made:

1 From the experimental results, it can be seen that the control method proposed in this paper exhibits significant advantages in both steady-state error of motor speed and overshoot suppression rate. The steady-state error is close to zero, indicating that the algorithm has excellent anti-interference ability and stability, and can effectively cope with the influence of load changes and environmental factors. In contrast, the error fluctuation of the reference method is relatively large, indicating that its robustness is insufficient. In addition, the overshoot suppression rate of the method proposed in this article remains stable at over 95%, which is much higher than the comparative method. This indicates that the adaptive control strategy can effectively suppress speed fluctuations during dynamic response, thereby reducing mechanical losses and extending equipment life. This high-performance performance makes it suitable for high-precision industrial applications, such as CNC machine tools and automated production lines.

2 The experimental data further validated the reliability and repeatability of the method proposed in this paper. In the three tests, the steady-state error and overshoot suppression rate remained at a high level, with minimal fluctuations, indicating that the algorithm has strong adaptability and is not affected by short-term interference. The suppression rate of the reference method fluctuates greatly, indicating its limited parameter adjustment ability. However, this paper achieves a more stable output by dynamically optimising the control parameters. In addition, the ability of the speed to quickly approach the set value reduces energy loss during the acceleration phase, which is beneficial for energy-saving operation. Overall, the method proposed in this article not only improves control accuracy, but also has high engineering practical value, suitable for scenarios with strict requirements for stability and efficiency.

This study proposes a novel adaptive control algorithm that significantly improves the steady-state accuracy and dynamic performance of motor speed control. Experimental results have shown that this method can reduce steady-state errors to near zero while maintaining a stable overshoot suppression rate of over 95%, which is superior to existing literature methods. Its innovation lays in the integration of dynamic parameter adjustment and anti-interference optimisation strategies, enabling the system to maintain stable output even under sudden load changes and external disturbances. This research achievement provides a better solution for high-precision motor control, which is of great value for the efficient operation and energy-saving optimisation of industrial automation equipment.

6 Conclusions

This study focuses on the difficult problem of variable frequency control of motor speed under complex working conditions, and successfully constructs an adaptive variable frequency control system based on PLC. Through the deep integration of USS protocol and RS485 interface, a highly reliable motor speed control architecture has been established, ensuring the stability and real-time transmission of instructions. In the speed monitoring process, we innovatively adopt a time-based interrupt mechanism combined with high-speed counter technology to achieve millisecond level accurate acquisition of motor encoder pulse signals, providing reliable data support for speed calculation. Through experimental verification, this control method exhibits excellent performance under dynamic load conditions: the steady-state error of motor speed approaches zero, completely breaking through the accuracy bottleneck of traditional fixed frequency drive methods; the overshoot suppression effect is significant, reaching up to 97.34%, effectively solving the oscillation problem in the dynamic response process. The research results provide high-precision and highly adaptable control solutions for the field of industrial motor drives, which have important practical value in improving the stability of equipment operation under complex working conditions.

Declarations

The author declares that she has no conflicts of interest.

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