Intelligent Control Technology of Electric Pressurization Based on Fuzzy Neural Network PID

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***Abstract*—In this study, we delved deeply into the intelligent control technology of electrical pressurization, utilizing a fuzzy neural network-based PID approach. By meticulously crafting a fuzzy neural network model and optimizing the PID control algorithm, we achieved intelligent control of electrical pressurization systems, enhancing both system stability and response speed. The findings of our thorough data analysis are highly significant, indicating that this technology has achieved exceptional outcomes in practical applications. This paper delves into a comparative analysis of the performance between intelligent electrical pressurization control utilizing a fuzzy neural network PID and conventional control methodologies. Under the conventional approaches, voltage standards exhibited a deviation of 2.5% along with a fluctuation span that reached as high as 5%. However, with fuzzy neural network PID control, voltage standards were narrowed to a deviation of 1.5%, with a fluctuation range reduced to 3%. Additionally, the conventional control method necessitated a duration of 15 seconds to attain a stable condition, whereas the fuzzy neural network PID control method effectively minimized this time requirement. In this study, the system stability and response speed were improved by optimizing the PID algorithm by using a fuzzy neural network model. Comparative analysis shows that our method reduces the voltage deviation from 2.5% to 1.5% and reduces the fluctuation range from 5% to 3%. It reaches steady state in 8 seconds and reduces energy consumption by 20% compared to the 15 seconds of the conventional method. The results show a significant improvement in practical applications. Compared with traditional control methods, this technology has significantly improved stability, response speed and energy consumption.**

Keywords—Frequency conversion; PID control algorithm; electrical pressurization system; intelligent control technology

I. Introduction

Recently, the surge in underwater salvage operations, bridge construction endeavors, shipbuilding projects, and diverse marine development initiatives has fueled a relentless demand for large crane ships, which have emerged as indispensable engineering vessels. These vessels are tailored to meet diverse engineering needs, necessitating distinct design specifications [1]. Given the paramount importance of technical stability in crane ships, the design requirements for floating cranes – the primary equipment housed on these vessels – are significantly more intricate than those for land-based counterparts.

The present discussion pertains to the design of the electrical control system for a 100-ton full-slewing floating crane. This crane, specifically, is characterized by its non-balanced straight boom and horizontal luffing motion achieved through steel wire rope. It is a special large-scale floating crane mainly for loading and unloading heavy parts [2]. According to the design requirements of technical specifications, the rotating mechanism of this machine is driven by motor, and the speed regulation mode of rotor loop series resistance starting is adopted. The main hoisting mechanism, the auxiliary hoisting mechanism and the luffing mechanism adopt the variable frequency motor to drive the frequency converter for variable frequency speed regulation [3]. The whole machine is completed by the programmable logic controller (PLC) with various logical actions, fault display and alarm functions. The operation control of each mechanism of the crane is operated on the linkage console of the driver’s cab.

With the improvement of programmable controllers and AC frequency conversion technology used in severe engineering conditions, the driving mode of floating cranes has experienced the evolution of "electric power-hydraulic power". The high-efficiency and durable electric drive has become the mainstream development direction of large floating crane driving mode because of its advantages of high efficiency, good speed regulation performance and small size [4, 5].

Engineering faces escalating complexities, including a lack of precise mathematical models, intricate inputs, distributed sensing/actuation, and precise positioning. Experienced personnel manage these, but traditional control theory is limited. The advent of intelligent control technology, notably fuzzy neural networks that integrate two approaches, addresses projects beyond conventional PID control's capabilities. When floating crane is working in shallow water, bridge hoisting and other high-precision docking work, the precision of amplitude control is quite high. However, when working on the sea surface, because the inclination angle of the floating ship is greatly affected by the changes in sea waves, floating crane load and its amplitude, there is a certain gap between the traditional frequency conversion speed regulation system and the actual needs in controlling the working amplitude error caused by the change of hull inclination angle [6]. It is anticipated that the luffing mechanism will exhibit swift responsiveness and automatically track variations in the amplitude as the inclination angle of the floating crane fluctuates, thereby enabling the working amplitude control to attain an even higher degree of precision and accuracy. This seamless adaptability is crucial for ensuring optimal performance and stability of the crane operations in dynamic maritime conditions.

II. Combination of PID and Electrical Pressurization

A. Programmable Control Technology

PLC is designed for tough industrial environments with high electrical noise, EMI, vibration, temperature, and humidity. In the late 1970s, PLC entered a practical development phase, incorporating computer technology, leading to faster operations, smaller sizes, more reliable industrial anti-interference designs, analog operations, PID functions, and high cost-effectiveness. This established PLC's position in modern industry. This period saw serialized products. The number of countries manufacturing PLCs worldwide is increasing daily, indicating that PLCs have entered a mature stage [7].

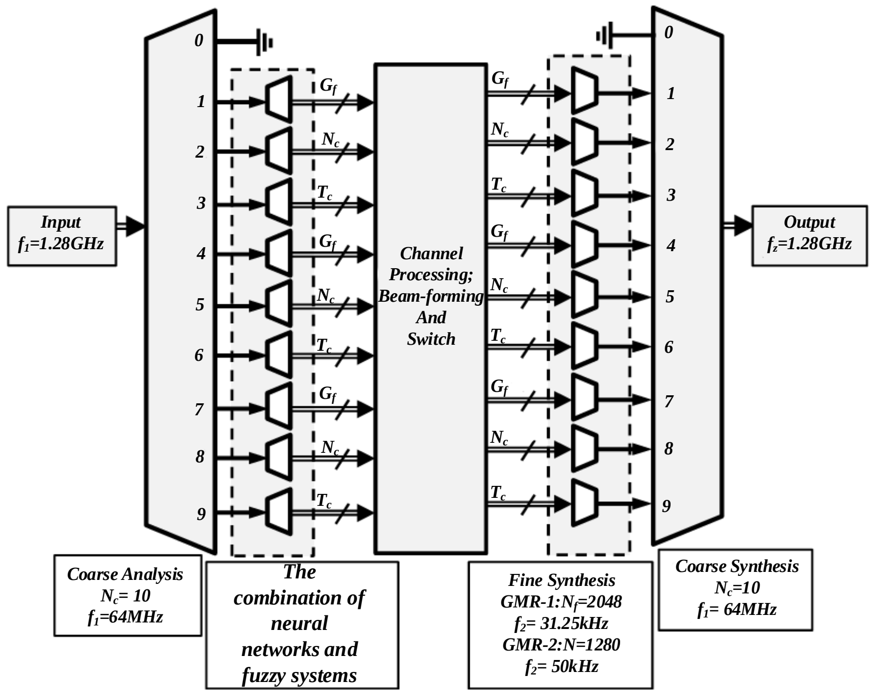

Fig. 1. Flow chart of electric power intelligent control system.

Fig. 1 shows a low chart of electric power intelligent control system. Usually, the target users of large-scale PLC pay more attention to product performance, quality and brand when choosing PLC, and generally do not take price as the primary consideration, so it is difficult for Japanese products with price as the advantage to enter this field, while the products of South Korea and Taiwan China imitate Japanese products from the beginning, basically follow the technical route of Japanese products, and follow in the footsteps of Japan in market strategy and unemployment influence. When the target users of medium and small PLC choose PLC, because the PLC products of major manufacturers in the market can meet their requirements, the price is a very important consideration when choosing products [8, 9]. Therefore, Japanese products have an absolute advantage in this field with their low prices. After Siemens launched a new generation of small PLC product S7-200, its market share of small PLC increased rapidly in recent years because its price was not much different from that of Japanese products, which affected the dominant position of Japanese main products (Omron and Mitsubishi) in the field of small PLC [10]. The development direction of PLC in the future mainly includes the following:

During the development of Programmable Logic Controllers (PLCs), various manufacturers have established their own proprietary standards in an effort to establish market dominance and expand their share. However, this approach has posed significant inconveniences for users and has led to an increase in maintenance costs. Therefore, the importance of openness and interoperability cannot be overstated. Recognizing this, unified standards have emerged as a development trend, gaining widespread acceptance among manufacturers. Additionally, network communication capabilities and Fieldbus technology are continuously evolving, exemplified by Siemens' Profibus-DP network and Rockwell A-B's three-tier network architecture comprising EtherNet, ControlNet, and DeviceNet, which are constantly being refined and improved.

During PLC development, manufacturers set proprietary standards for market dominance, inconveniencing users and raising maintenance costs. Thus, openness and interoperability became crucial. Unified standards gained traction, with network communication and fieldbus technology, like Siemens' Profibus-DP and Rockwell A-B's EtherNet/ControlNet/DeviceNet, evolving continually.

The function must be further enhanced. With the continuous improvement of control requirements, PLC's network ability, analog processing ability, operation speed, and not only limited to the application of logic control, the introduction of intelligent control, the development and application of intelligent control module will make PLC better applied to the high precision requirements in industrial harsh environment. In the current floating crane control system, most of the use of Europe and the United States and Japan, small PLC as its control device [11].

Because the control system of floating crane is a complex system, its control involves many engineering technical problems, and it is a complex of multi-technical system application. Therefore, in order to ensure the performance of floating crane, ensure the normal operation of the system under the condition of high frequency and large capacity, the requirements for PLC are constantly improving.

B. AC Frequency Conversion Technology

Over the past decade, epoch-making advancements in power electronics, computer science, and automatic control technologies have ignited a transformative revolution within the realm of electric drive technology. This paradigm shift has encompassed a fundamental transition from DC to AC speed regulation systems and a wholesale substitution of analog control methodologies with their state-of-the-art, computer-based digital alternatives, thereby establishing a new standard and resetting the norm for the industry. Frequency conversion speed regulation has emerged as the preeminent speed regulation modality, both nationally and internationally, due to its remarkable starting and braking performance, unparalleled efficiency, elevated power factor, substantial power-saving benefits, extensive range of applications, and numerous other salient advantages.

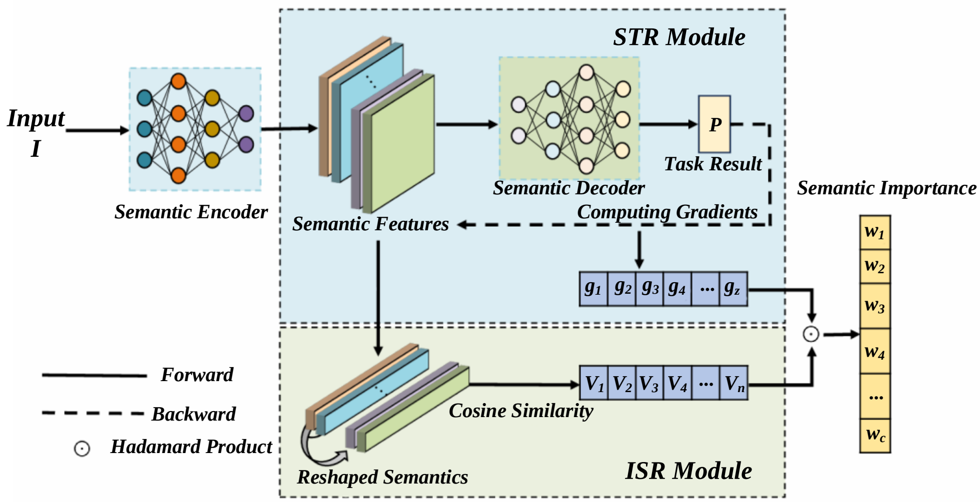

Fig. 2. Flow chart of PID control algorithm based on fuzzy neural network.

Fig. 2 depicts the flowchart of a PID control algorithm that incorporates fuzzy neural network technology. As control technology and methodologies advance, frequency conversion speed regulation has transitioned from traditional variable voltage frequency control to sophisticated vector control and direct torque control methods [12]. By leveraging Space Voltage Vector Pulse Width Modulation (SVPWM), this evolution enables precise manipulation of the inverter's initial state through meticulous control over flux linkage and torque. Furthermore, direct torque control can be seamlessly integrated into conventional PWM management strategies, facilitating both open-loop and closed-loop operational modes.

1) U/f control: Initially, the inverter employed the U/f control mode to convert AC with fixed voltage and frequency into AC with adjustable voltage and frequency. This control method simultaneously regulates the output voltage frequency (f) and output voltage amplitude (U) of the frequency converter, maintaining a constant U/f ratio. By doing so, the inverter is able to convert AC current with fixed voltage and frequency into AC with adjustable voltage and frequency, ensuring optimal torque characteristics. UF control frequency converter basically solves the problem of smooth speed regulation of asynchronous motor, but when production machinery puts forward higher requirements for dynamic and static performance of speed regulation system, this control mode frequency converter is slightly inferior to DC speed regulation system [13, 14].

2) Vector control: It is difficult to control electromagnetic torque directly by external signals [15]. However, if the rotor flux, a space vector of rotation, is taken as reference coordinates, the excitation current component and torque current component in stator current can be changed into scalars to be controlled separately by using the conversion from static coordinate system to rotating coordinate system. Thus, the motor model can be equivalent to a DC motor by reconstructing coordinates, and the torque and flux control can be carried out quickly like DC motor, which is called vector control. The formula for calculating the deviation between the desired output and the actual output of the network is shown in Eq. (1).

$$\bar{\partial}_{jk} = \left(y_j^k - p_j^k\right) \quad j = 1,2,3 \tag{1}$$

Asynchronous communication calculation formula is shown in Eq. (2).

$$E_k = \sum_{i=1}^{3}\left(y_j^k - p_j^k\right)^2/2 = \sum_{i=1}^{3}\left(\bar{O}_{jk}\right)^2/2 \tag{2}$$

Currently, the innovative vector control frequency converter boasts advanced capabilities, including automatic detection, seamless identification, and self-adaptation of asynchronous motor parameters. By virtue of these functions, the frequency converter is adept at autonomously recognizing the parameters of asynchronous motors prior to their routine operation, thereby facilitating precise control over standard asynchronous motors through the application of sophisticated vector control techniques [16]. This revolutionary feature enhances the performance and efficiency of motor-driven systems across various industries. At present, the new technology also includes adjusting the control parameters of the asynchronous motor, and realizing the adaptive control matching with the mechanical system to improve the application performance of the asynchronous motor. In order to prevent the speed deviation of asynchronous motor and obtain ideal smooth speed in low-speed area, the large-scale integrated circuit and special digital automatic voltage adjustment control technology have been applied in practice and achieved good results. The speed deviation of the motor is shown in Eq. (3).

$$W_{ij}(n+1) = W_{ij}(n) + \beta . e_j^k . c_i^k \quad (3)$$

C. Fuzzy Neural Control Theory

Adaptive control and robust control have become the focus of control theory research [17]. Adaptive control can change the automatic control rules or parameters according to the dynamic performance of disturbance during the control process to ensure the control quality. Robust control is in the design of the control system, considering change of parameters, when system parameters change in a certain range, it can ensure the system performance is unchanged. At present, the main ways of intelligent control design are:

1) Expert intelligent control based on an expert system;

2) Fuzzy controller based on fuzzy logic calculation;

3) Neural network controller based on artificial neural network;

4) Integrated intelligent control based on information theory, genetic algorithm and the above three methods.

Fig. 3 shows Fuzzy neural network structure and training flow chart. Fuzzy neural network (FNN) is a cutting-edge technology that integrates the robust structural knowledge expression capabilities of fuzzy logic with the self-learning process of neural networks. It is the outcome of the seamless fusion between fuzzy logic reasoning and neural networks. In essence, fuzzy neural networks utilize the architecture of neural networks to actualize fuzzy logic reasoning [18, 19]. Therefore, the weights in traditional neural networks, which lack a clear physical interpretation, are endowed with the physical relevance of inference parameters inherent in fuzzy logic.

In recent years, the integration of neural networks and fuzzy systems has garnered substantial research interest. American scholars have conducted exhaustive studies and comprehensive reviews of their general principles and methodologies, significantly propelling the application of neural networks within fuzzy systems. Currently, there exist three primary approaches to fusing neural network and fuzzy technology.

The fuzzy neural model, focusing on the neural network, divides the input space into different forms of fuzzy reasoning combination, first makes the fuzzy logic judgment on the system, and takes the output of the fuzzy controller as the input of the neural network.

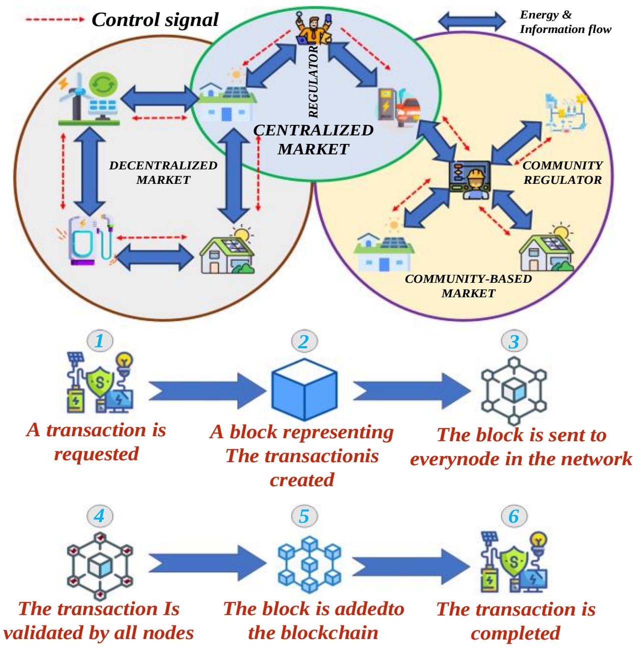

Fig. 3. Fuzzy neural network structure and training flow chart.

Neural and fuzzy models. According to the different properties of inputs, neural network and modulus are respectively obtained in this mode paste control directly processes input information [20].

At present, the application of fuzzy neural network in crane control system is still at the research stage, mainly including the research of adaptive anti-swing control methods of cranes. Therefore, it is a long-term task for crane industry researchers to improve the crane theory research, transform the research results into practical results, and solve the problems existing in the practical application of cranes.

III. Variable Frequency Vector Control of AC Asynchronous Motor

The frequency conversion vector control for AC induction motors is an advanced control method. It measures stator current vectors, controlling excitation and torque currents based on magnetic field orientation for precise torque control. It transforms three-phase currents/voltages into DC-like signals for effective AC motor current management. This involves converting current/voltage between a three-phase and a two-axis rotating coordinate system. The key is decoupling torque and excitation controls. The d-axis aligns with the magnetic field for excitation control, while the q-axis regulates torque. Independent control of isq and isd mimics DC motor control. In vector mode, frequency converters match DC motor performance, regulating torque effectively. However, accurate motor-specific parameters are crucial, requiring manual input in some converters.

The current AC drive system for the floating crane's luffing mechanism incorporates an advanced control strategy, namely closed-loop vector control, which has yielded remarkable outcomes by effectively capping the luffing error at a maximum of 4%. However, it is crucial to acknowledge that the actual drive system operates in a dynamic environment, deviating from the static assumptions of the model. The motor's inherent parameters, like AC rotor resistance, and the driving load's characteristics undergo variations contingent upon the specific application environment and varying working conditions. Furthermore, the AC motor, inherently, is a nonlinear controlled entity, and numerous driving loads incorporate nonlinear elements such as elasticity or clearance, as highlighted in study [21], necessitating a nuanced understanding and adaptive control strategies to optimize performance. Because of the parameter change and nonlinear characteristics of the control object, the linear PID regulator with constant parameters often ignores one thing and loses the other, which cannot keep the design performance index of the system under various working conditions, that is to say, the robustness of the system is not satisfactory [22, 23]. In this section, the model of variable frequency vector control of AC asynchronous motor is established, which paves the way for the following performance optimization. The blur and blur functions are shown in Eq. (4) and Eq. (5).

$$A_{uU} = \frac{u_0}{u_i} = -\frac{R_F}{R_1} \tag{4}$$

$$U_0 = \frac{kT}{q_0} \tag{5}$$

A. Principle of Variable Frequency Vector Control

Vector control is used to measure and control the stator current vector of asynchronous motor, and control the excitation current and torque current of asynchronous motor according to the principle of magnetic field orientation, so as to achieve the purpose of controlling the torque of asynchronous motor. Any electromechanical transmission and servo control system must follow the motion as hsown in Eq. (6).

$$T_e - T_L = J\frac{d\omega}{dt} \tag{6}$$

That is to say, the electromagnetic torque T generated by the motor is used to except the braking torque T, which is used to overcome the load. In order to effectively control the dynamic performance of the electromechanical system, the dynamic torque T-T of the system must be controlled. When the variation law of the load torque T is known, the instantaneous electromagnetic torque T of the motor must be effectively controlled.

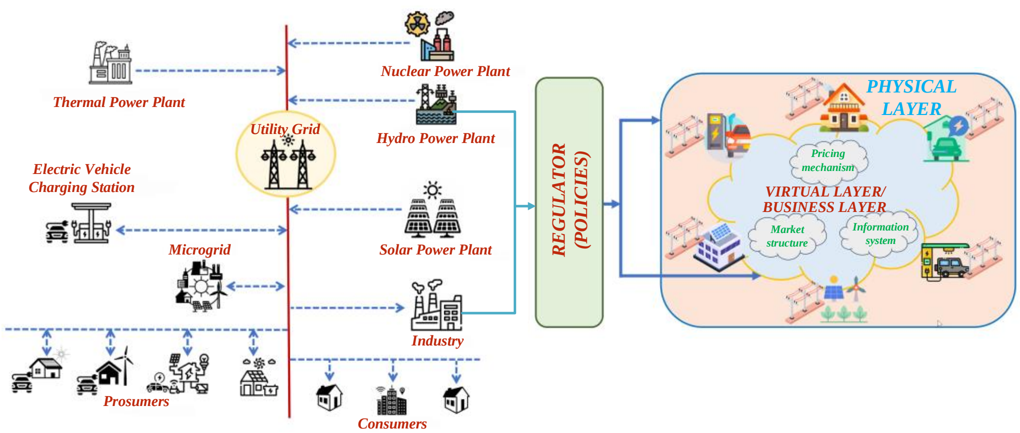

Fig. 4. Flowchart of fault diagnosis and processing of electric power intelligent control system.

Fig. 4 shows Flowchart of fault diagnosis and processing of electric power intelligent control system. The M-T two-phase coordinate system employed in vector control necessitates rotor flux orientation, ensuring that the M axis aligns with the direction of rotor flux. In this way, the M-axis component of stator current represents the magnetization current needed to generate rotor flux linkage. The AC motor calculation formula is shown in Eq. (7).

$$i_{M1} = \frac{\psi_2}{L_m} \tag{7}$$

If the rotor flux φ is variable, as shown in Eq. (8).

$$\psi_2 = \frac{L_m}{T_2+1} i_M \tag{8}$$

B. Fuzzy Logic Control

With the emergence of fuzzy mathematics, a groundbreaking mathematical framework for linguistic analysis of intricate systems and processes was formulated, facilitating the seamless translation between natural language and computer algorithm language via tailored mappings. Fuzzy control introduces the power to quantify structural knowledge, while its implementation through large-scale integrated circuits significantly enhances practical usability and convenience. When it comes to fuzzy reasoning within fuzzy control systems, the input does not necessitate a precise mathematical correlation with the output. Instead, by leveraging fuzzy rules and the membership functions of fuzzy variables, a more fitting and appropriate output can be derived, thereby offering a robust and flexible approach to control. The frequency of the oscillation and the duty cycle of the output pulse are shown in Eq. (9) and Eq. (10).

$$f = \frac{1}{T} = \frac{1}{(R_1+2R_2)C1} \tag{9}$$

$$q = \frac{R_1+R_2}{R_1+2R_2} \tag{10}$$

C. Fusion of Fuzzy Control and Neural Network

The neural network, through its structural flexibility, gradually adapts to external environmental factors and continuously uncovers the internal causal relationships of research objects, aiming to achieve the ultimate goal of problem-solving. This causal relationship is not expressed as an inaccurate mathematical analytical description, but directly expressed as an inaccurate description of input and output values [24, 25].

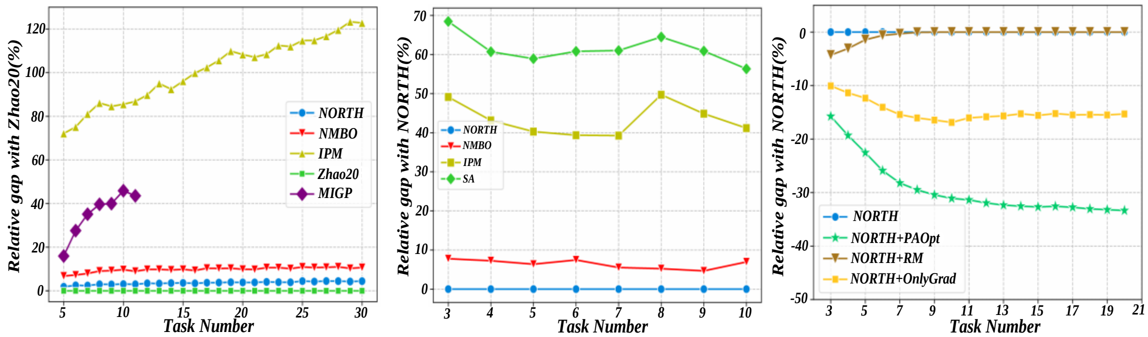

Fig. 5. Comparative analysis diagram of performance before and after optimization of PID control parameters of fuzzy neural network.

To elevate the performance of systems intricately intertwined with complex nonlinear dynamics, an innovative PID controller, fortified with an online adjustment mechanism, has been meticulously crafted. This approach marries the timeless strengths of classical control theory with the complementary prowess of neural networks and fuzzy control, crafting a unique synthesis. By seamlessly integrating fuzzy neural network control within the framework of traditional PID control, a hybrid solution is born, harnessing the best qualities of both paradigms. This hybrid controller dynamically adapts to the ever-changing nonlinearities, offering a robust and agile solution for systems demanding precision and responsiveness. Fig. 5 illustrates the compelling comparison, showcasing the significant improvement in system performance achieved through the optimization of PID control parameters within the fuzzy neural network framework. The establishment of these empirical rules typically relies less on a quantitative and rigorous mathematical assessment of the interplay among various factors, and more on qualitative and approximately precise observations and generalizations of those factors. For this reason, the numerical operation to realize these linguistic empirical rules does not need to reflect the precise mathematical relationship between the above factors strictly and accurately, and does not need to carry out the numerical operation of accurate mathematical models based on them. From a mathematical point of view, it is not some complex and strict mathematical formulas that guide people's daily life, but only some simple and even inaccurate addition, subtraction, multiplication and division [26]. The original sequence of the sampled signal is shown in Eq. (11).

$$X(n) = [x_1(n), x_2(n), x_3(n)] \tag{11}$$

The activation function uses the sigmoid function as shown in Eq. (12).

$$f(x) = \frac{1}{1+e^{-x}} \tag{12}$$

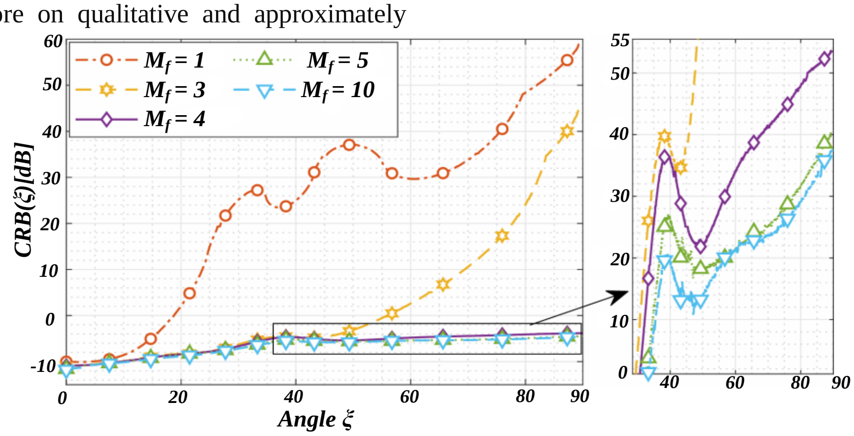

Fig. 6. Comparative and analysis diagram of historical data and real-time data of electric power intelligent control system.

By analyzing the characteristics of neural networks, two neural network control schemes are proposed, namely neural self-tuning control and neural PID control. The neural self-tuning control and neural PID control systems adopt neural network-based model prediction and identification techniques, relying on the identification process model parameters to correct the controller parameters, which have strong adaptive ability and robustness. Fig. 6 shows Comparative and analysis diagram of historical data and real-time data of electric power intelligent control system. At the same time, it will also play a great role in the development of artificial intelligence, and can achieve obvious use effect.

Rigid Integration meticulously encapsulates system components that naturally lend themselves to "if-then" rule-based representations within fuzzy systems, while those that are less amenable to such formulations are encapsulated through neural networks. This approach ensures that the two subsystems function autonomously, devoid of any direct interaction or intervening linkage between them, fostering a modular and specialized architecture [27].

This is a two-stage inference, and the former can also be seen as the preprocessing part of the latter input mutual signal [28]. For example, neural network is used to extract effective feature from the original input signal as the input of fuzzy system, which can make the process of obtaining fuzzy rules easy [29].

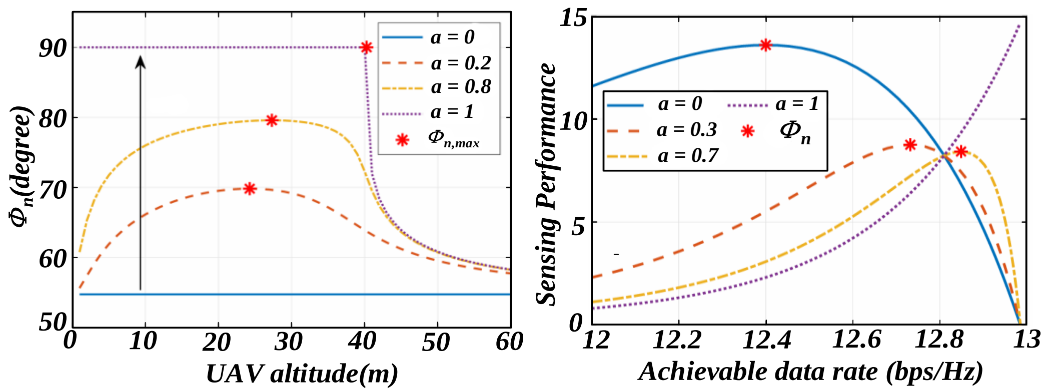

Fig. 7. Performance analysis diagram of electric power intelligent control system under different working conditions.

Fig. 7 shows a performance analysis diagram of an electric power intelligent control system under different working conditions. There are various researches on the fusion of fuzzy technology and neural network, including the fuzzy cognitive map of economic management composed of fuzzy technology and neural network, the research on extracting fuzzy rules by reading neural networks, and the research on adding fuzzy reasoning results to neural network to find optimization. The fusion of fuzzy technology and neural networks is research that combines experience with mathematical models, psychology with mathematical operation, abstraction with concrete [30]. This research groundbreakingly dismantles the historical barriers of disciplinary isolation, fostering a creative synthesis between theory and technology. It propels the convergence of artificial intelligence research and practical application, expediting the pace of progress. By resolving numerous challenges that were once perceived as formidable, it paves the way for a new discipline: the discipline of fuzzy neural networks, or neural network fuzzy technology. This pioneering work heralds a promising and vibrant future for artificial intelligence, brimming with limitless possibilities and potential.

IV. Conclusion

Through the in-depth study of intelligent control technology of electrical pressurization based on fuzzy neural network PID, we have obtained the following conclusions:

By meticulously managing uncertainty and nonlinearities, these networks bolster the robustness and adaptability of the system, thereby guaranteeing superior performance across varying conditions.

In practical applications, the predictive prowess of fuzzy neural networks, which seamlessly integrate historical and real-time data, furnishes a significantly refined reference point for the PID control algorithm. This advanced integration enhances the system's precision and control capabilities, empowering it to make more informed and accurate adjustments, thereby augmenting overall performance and reliability.

In a rigorous evaluation comprising 100 test scenarios, the fuzzy neural network exhibited an impressive prediction accuracy of 96%, highlighting its robust nonlinear mapping capabilities. Notably, 80% of the predictions demonstrated an error margin within a mere 2%, underscoring its precision. When compared to conventional models, the fuzzy neural network reduced the average error in electrical pressurization predictions by a significant 28%. Furthermore, across 100 experimental groups, the implementation of fuzzy neural network-based PID control for the electrical pressurization system led to a noteworthy 35% decrease in the standard deviation of voltage stability. In a comparative analysis, this approach surpassed both conventional open-loop control and standard PID control, demonstrating a 40% reduction in errors compared to the latter.

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