Application of Neural Network Algorithm in Optimal Control of Ethylene Distillation Tower

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Authors' contributions

This work was carried out in collaboration between both authors. Author RM designed the study, wrote the protocol and wrote the first draft of the manuscript. Author HW managed the analyses of the study. Both authors read and approved the final manuscript.

Review Article

ABSTRACT

For some nonlinear dynamic systems with uncertainties or disturbances, neural networks can perform intelligent cognition and simulation on them, achieve a good system description, and further realize intelligent control. Aiming at the ethylene rectification process, in order to avoid the time delay of complex rectification process modeling and large-scale process simulation software interface program, and to improve the simulation operation speed, the optimization model combined with the learning function of the neural network is used for the simulation calculation of the rectification process. It can meet the time and accuracy requirements of online optimization. This article outlines several commonly used neural network algorithms and their related applications in ethylene distillation, aiming to provide reference for the development and innovation of industry technology.

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1. INTRODUCTION

Artificial Neural Network (ANN) is an information processing system composed of the structure and function of real human brain neural network in physiology, as well as some theoretical abstraction, simplification and Simulation of some basic characteristics.It achieves the purpose of processing information by adjusting the interconnection between a large number of internal nodes. ANN can accurately identify and learn the potential relationship between input and output, regardless of their dimensionality and nonlinearity, and does not require explicit physical considerations and mathematical model assumptions, and can map the considered input well. The implicit relationship between input and output predicts the performance of the system [1-5]. In recent years, ANN has been widely used in signal processing, voice conversion, artificial intelligence recognition, unmanned driving, stock market index prediction, wind power forecasting, medical diagnosis and automatic control of chemical processes [6-12].

An important part of the ethylene production plant is the distillation system. The rectification system is a complex mass transfer and heat transfer system with strong coupling, so it is difficult to establish an accurate mathematical model for the rectification system. The quality index of the rectification system is the key to all control parameters. Guaranteeing product quality is the most basic requirement. Although the conventional control method can meet the quality control requirements, there is a problem of "excess quality", so it cannot meet the requirements of improving economic benefits. Requirements, and advanced control provides a good way to solve these problems. Neural networks can produce accurate estimates in the case of the complex relationship between input and output, because they map in a non-linear manner and ANN have high self-learning and high fault tolerance, as well as self-organization, self-adaptation and other intelligent characteristics . Therefore, the neural network has greatly improved the technology and production environment in the chemical industry, and provided practical solutions to the problems that are difficult to handle with traditional technologies. In reactive distillation, the neural network can find the best reaction conditions in reactive distillation and obtain the maximum conversion rate of reactants, which can save costs and raw materials, and make the separation purity of the reaction higher and higher efficiency.

2. NEURAL NETWORK ALGORITHM AND ITS RESEARCH PROGRESS

2.1 Artificial Neuron Structure

The human brain is composed of a large number of nerve cells, which can be connected to each other. Each nerve cell (also called neuron) has the following characteristics. Brain neurons are composed of cell bodies, axons and dendrites. The human brain is a very complex network structure with high-level functions composed of many neurons. The structure and function of the biological neural network are simulated as artificial neurons, that is, a typical artificial neuron model [13-16]

In the artificial neural network, the function of an artificial memory neuron is to obtain the inner product of the input vector and the weight vector, and then obtain a scalar result through a nonlinear transfer function. The function of a single neuron: divide an n-dimensional vector space into two parts with a hyperplane (called judgment boundary). Given an input vector, the neuron can determine which side of the hyperplane the vector is on. Neurons and their connections; The strength of connection between neurons determines the strength of signal transmission; The connection strength between neurons can be changed with training; The signal can be stimulating or inhibiting; The cumulative effect of signals received by a neuron determines its state; Each neuron can have a "threshold". Neuron is the basic unit of neural network. The main difference of different mathematical models of artificial memory neurons is that they use different transformation functions, so that neurons have different information processing characteristics. The information processing characteristics of neurons are one of the three factors that determine the overall performance of artificial neural networks, so the research of transform function is of great significance. The transformation function of a neuron reflects the relationship between its output and activation state. The most commonly used transform functions are as follows: threshold transform function, nonlinear transform function, piecewise linear transform function and probability transform function.

Since the neural network control system is a system with learning ability, it is adaptive to changes in the environment.

2.2 Feedforward Neural Network

Feedforward neural networks have the structure shown in Fig. 1 and have the following basic advantages, namely parallelism, fault tolerance and self-learning characteristics. Its characteristics are also the basis for distinguishing neural network algorithms from traditional algorithms. Complete functions such as signal processing or recognition, and establish expert systems. The research of neural network can be divided into two aspects: theoretical research and application research. For some nonlinear dynamic systems with uncertainties or disturbances, neural networks can perform intelligent cognition and simulation on them, which can achieve a good system description and further realize intelligent control [17-20].

Both the Hopfield network and the BP algorithm have enabled people to see the development prospects and new hopes of neuron networks, which are one of the main contents of approximate nonlinear science and computer intelligence research [21-23]

2.3 Radial Basis Function Neural Network (RBF）

The RBF structure is three-layer forward. Each layer represents a specific function: the input layer of the first layer has perceptual ability, the nodes of the second hidden layer and the final output layer have computational performance. It contains a non-linear mapping from input to output layer, and the hidden layer is a linear mapping to output. This feature makes its

learning speed become very fast, and it can also solve the local minimum.

The learning of RBF neural network is divided into forward learning algorithm and backward learning algorithm. The former is mainly used to calculate the control output, and the latter is mainly used to modify the network connection weight.

Compared with BP neural network in the application process, it shows many advantages: RBF network can fit arbitrary continuous functions within any required accuracy range; RBF network has relatively fast learning efficiency; RBF network is There are very good solutions to the small local defects.

Bi et al. [24] proposed an optimized control strategy based on the RBF neural network soft instrument and the NLJ method (random search algorithm with variable shrinkage coefficient) to obtain the optimized algorithm. The NLJ optimization algorithm searches for the optimal tower steam flow setting value, which is compared with the sensitive plate temperature direct relation. The optimized control of the card edge of the rectifying tower is realized. In addition, Bauso et al. [25,26] introduced distributional robust game to deal with the robust optimization problem, which makes the multi-objective control problem more stable. Under the premise of ensuring the product quality, the output of the rectifying tower product is obviously increased, and obvious economic benefits are obtained [27,28]
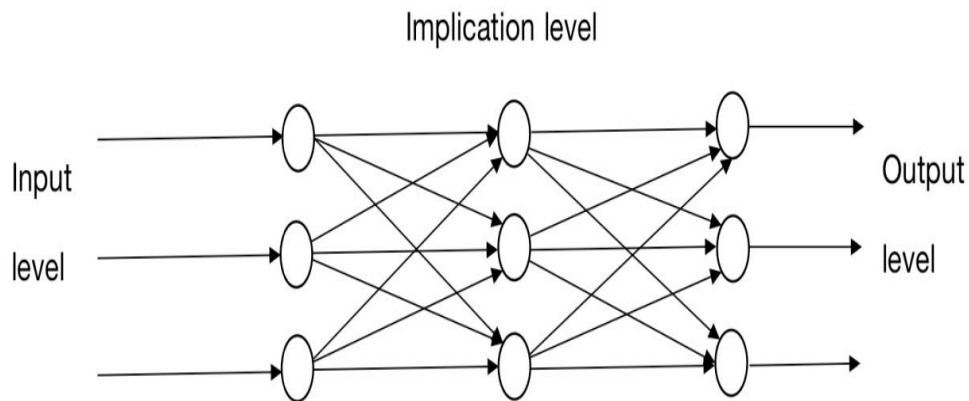

Fig. 1. Structure diagram of multilayer feedforward neural network

2.4 Fuzzy Neural Networks

Fuzzy systems can perform knowledge extraction and simple reasoning through anthropomorphic thinking modes, but lack self-learning and self-adaptive capabilities; neural networks can effectively learn according to corresponding samples, and can achieve parallel computing and distributed information storage, and have strong fault tolerance and adaptive learning function. But it cannot express rule-based knowledge well, so it cannot make good use of existing empirical knowledge (generally it can only take the initial value of zero or random value), which may lead to a long network training time, and network training falls into unrequired Local extremum.

Fuzzy neural network is the combination of fuzzy system and neural network, and the fuzzy system is converted into the corresponding neural network, thereby improving the expression ability and learning ability of the system.

The general structure of a fuzzy neural network is five layers: input layer, fuzzification layer, fuzzy rule layer, fuzzy decision layer and output layer. Fuzzy neural networks can be combined with many algorithms to achieve good results: Gu et al. [29] proposed a control scheme based on the RBF fuzzy neural network classifier, which takes the temperature, flow, and liquid level of the distillation tower as input, and the opening of the heat transfer oil valve as output. Through adaptive learning and fuzzification of manual operation Processing to realize the intelligent control of the rectification tower temperature; Wang et al. [30] Used a fuzzy RBF neural network controller on the basis of the cascade control system to improve the control effect of the tower kettle temperature. In 2019, Wang proposed a BP algorithm fuzzy PID controller based on AFSA (Artificial Fish Swarm Algorithm) optimization, which overcomes the shortcomings of the steepest descent method in the back propagation process that easily fall into the local optimal solution, and can obtain the optimal PID parameters. solution. The research results show that the number of iterations of the AFSA-BP algorithm is small and can be close to the given value. When the relevant PID parameters are applied in the DMF recovery system, the temperature of the rectification tower can be kept stable [31]; Guo et al. [32] proposed a fuzzy controller based on immune genetic algorithm optimization, which uses the global search function of immune genetic algorithm and the

self-learning ability of neurons to improve the control accuracy and anti-interference ability of the fuzzy controller. The controller is used in the simulation of a full-stage distillation column model. The simulation results show that the controller can effectively eliminate static errors and has good robustness in the control transition process.

3. RESEARCH ON SIMULATION OPTIMAL CONTROL OF ETHYLENE RECTIFICATION TOWER

The purpose of online optimization of chemical process is to find the new optimal working conditions of the process, that is, the main control variables, in response to changes in external conditions, so as to achieve scientific guidance to the production process and provide conditions for enterprises to obtain maximum economic benefits [33-35]

Regarding the distillation process of ethylene production, Jiang et al. [36] proposed the intelligent operation optimization of the distillation column based on the Reduced Space Sequence Quadratic Programming (RSQP) algorithm. Optimal modeling mostly uses steady state, and Jiang et al . [36] use open model equations. Cui et al. [37] used the process simulation software PRO/II to provide training data for the neural network for the ethylene chemical process, established an optimization model by the neural network, used an improved genetic algorithm (GA), combined with pattern search （PS） technology to realize the separation process Optimized operation to meet the design requirements of the online optimization subsystem in the ethylene digital plant. The research object is the debutanizer in the ethylene production process. The main function of the debutanizer is to separate the mixed carbon four fraction in the C_3 and above fractions from the depolarizer from the mixed heavy hydrocarbons to obtain mixed carbon. Four products. Single column optimization is a partial optimization of the entire distillation section. There are strict regulations on the purity of the mixed carbon four at the top of the tower (hard constraint), and when there is no purity requirement (soft constraint) at the bottom of the tower, the amount of light components at the bottom of the tower should be economically optimal.

Under steady-state conditions, the MESH equation constitutes the steady-state operation

process model of the distillation column, that is, the equation constraint of the optimization problem. The equation has the characteristics of many variables and strong nonlinearity. Regarding the process as a black box model, using mature process simulation software such as PRO/II to simulate and calculate the distillation process, and use the learning function of ANN to provide a calculation basis for optimizing the operation of the distillation process. Based on the steady-state simulation of the debutanizer by LMBP neural network, the HHAGA algorithm is used to optimize the operation. It can be seen from the test results that the simulation calculation results of the black box model basically meet the accuracy requirements, and avoid the time delay of the complicated mechanism modeling and optimization module of the distillation column and the process simulation software interface program. The improved GA introduces a PS operator and an acceleration operator. Through the improvement, the accuracy and efficiency of the solution are significantly improved, which meets the requirements of online optimization. The optimized structure model has certain research significance for the optimization of the debutanizer operation and the improvement of economic benefits, and provides a research basis for expanding to other process systems.

4. APPLICATION OF NEURAL NETWORK ALGORITHM IN ETHYLENE DISTILLA - TION TOWER

4.1 Soft Sensor

In the petrochemical and other process industries, in order to ensure the continuous and stable operation of the production process, improve product quality, and reduce energy consumption, it is usually necessary to conduct online real-time monitoring of the main process parameters that affect product indicators and adjust them in time. Soft measurement technology combines the mechanism of industrial objects with modern control technology and information processing technology. It can calculate process parameters that have a greater impact on product quality and are difficult to measure or cannot be measured by traditional methods. Real-time online measurement of process parameters closely related to product quality, optimization of process control, can replace online analytical instruments, and ultimately improve product quality and output of enterprises [38]. At present, soft measurement

technology is playing an increasingly important role in industrial practical applications and scientific research, and has become one of the key research directions in optimization control.[39]

4.1.1 Soft sensor modeling based on ANN

The soft measurement based on ANN is a kind of soft measurement technology with a wide range of applications [40]. It has the functions of self-learning, associative memory, adaptive and nonlinear approximation. It does not need to have the prior knowledge of the object, but directly models according to the input and output data of the object, takes the auxiliary variable as the input of the artificial neural network and the dominant variable as its output, and solves the estimation problem of unmeasurable variables through network learning. In addition, using the artificial neural network for soft sensing can suppress the measurement noise interference of auxiliary variables. In the actual industrial process, many objects have complex uncertainty, real-time and high degree of nonlinearity, which inevitably makes it impossible or difficult to accurately model. However, the soft sensing method based on artificial neural network has the ability to approximate any nonlinear relationship, which can well solve these problems. At present, artificial neural network has been successfully used in soft sensor modeling. There are two basic forms of soft sensor modeling using artificial neural network: one is to use artificial neural network to directly model, and use artificial neural network to replace the conventional mathematical model to describe the mathematical relationship between auxiliary variables and dominant variables, and complete the mapping from measurable information to dominant variables, Another method is to combine with the conventional model, using artificial neural network to estimate the model parameters of the conventional model, and then realize soft sensing.The technology can directly model the input and output data of the object without the prior knowledge of the object, for example, the generative models [41]. The model has strong online correction capabilities and can be applied to highly nonlinear and severely uncertain systems, such as to model the sequential data with incomplete information [42]. There are two modeling methods: one is to use artificial neural network to directly model, that is, to use the network to replace the conventional mathematical model to describe the relationship between the auxiliary variable and the dominant

variable, and to complete the mapping from the measurable information space to the dominant variable; One is to combine with the conventional model, use ANN to estimate the model parameters of the conventional model, and then realize soft measurement. In order to ensure the quality of ethylene products, increase product output and yield as much as possible, and reduce energy consumption, it is difficult to use conventional control schemes. In process industries such as petroleum and chemical industry, distillation process is a commonly used unit. However, due to its characteristics such as difficult online measurement of quality parameters, prominent multi-variable correlation problems, and strong nonlinearity, the automatic control and modeling of distillation columns has always been a research hotspot in the process control field [43-47].

4.2 Product quality of Ethylene Distillation Tower

The purpose of the ethylene rectification tower is to obtain high-purity ethylene, while reducing ethylene loss and energy consumption. Therefore, the factors affecting product quality must be reasonably controlled. Such as tower feed flow rate, sensitive plate temperature, tower kettle heating flow rate, tower reflux ratio, tower top pressure, tower top and tower bottom temperature.

In the soft measurement of the product quality of the ethylene distillation tower, due to the complex system, large uncertainty, and fewer samples collected on site, regression analysis, neural network and support vector machine are used to establish the soft measurement model of the product quality of the ethylene distillation tower. And a comparative analysis is a feasible plan.

Cui et al. [39] proposed an online optimization structure model for the ethylene rectification process when studying the intelligent operation optimization process of the debutanizer in the ethylene rectification system. The research object is the debutanization tower in the ethylene production process, which separates the mixed C_4 fraction from the mixed heavy hydrocarbons to obtain a mixed C_4 product. Single column optimization is a partial optimization of the entire distillation section. There are strict regulations on the purity of the mixed C_4 in the top product (hard constraint), and when the purity of the bottom product is not required (soft constraint), the loss of light components at the bottom of the column

should be economically optimal. Under the condition of setting the feed, the operating variables of the tower include liquid phase recovery and reflux ratio. At the same time, attention should be paid to the influence of feed volume fluctuations on the operation. In order to avoid the time delay of complex distillation process modeling and interface program with large-scale process simulation software, and to increase the speed of simulation calculation, the model combines the learning function of neural network for the simulation calculation of distillation process.Based on LMBP neural network steady-state simulation of debutanizer, HHAGA algorithm is used to optimize the operation. It can be seen from the test results that the simulation results of the black box model basically meet the accuracy requirements, and the time delay between the complex mechanism modeling and optimization module of the distillation column and the process simulation software interface program is avoided. The improved GA is used to realize the online optimization system of the debutante tower in the ethylene digital factory, and the PS technology and acceleration strategy are introduced into the algorithm to meet the time and accuracy requirements of online optimization. The calculation results show that this method has the advantages of short operation time and fast convergence, and can meet the requirements of online optimization.

Huang et al. [48] proposed a cultural algorithm process of training neural network to construct cultural neural network based on the characteristics of neural network modeling, and used this network for soft-sensing modeling of ethylene distillation tower product quality. According to the characteristics of neural network weight and threshold training, the cultural algorithm flow and specific function design suitable for neural network training are proposed based on the basic cultural algorithm framework. The design process includes:

(1) Definition and Update of Belief Space
(2) Design of acceptance function
(3) Update of belief space
(4) Design of influence function

The cultural neural network is used in the quality soft measurement modeling of the finished ethylene, and the feed flow rate, the temperature of the sensitive plate, the ratio of the internal return flow to the side line discharge (reflux ratio), the heating capacity of the tower kettle, the

heating capacity of the middle boiler, etc. are selected. Two auxiliary variables are used as input variables. In order to improve the accuracy of the network, the output signal uses 10^6 times the sum of the content of the impurities methane and ethane in the finished ethylene. Comparing the fitting and generalization capabilities of BPNN and CANN（Cultural algorithm neural network） models, it is found that when the number of hidden nodes increases, the fitting error of the model gradually decreases, while the generalization ability begins to improve, but when the number of hidden nodes increases to 8, it begins to decrease, so the model has better fitting and generalization ability when there are 8 hidden layer nodes. The results show that the CANN model value fits the actual test value better, the training process meets the requirements, and the model has higher prediction accuracy. Moreover, the cultural algorithm searches for each individual in parallel and oriented, without demand-driven calculation, so there are no strict restrictions on the model parameters, flexible and convenient to use, and wide in application. Through the comparative analysis of training and generalization ability, the results show that the soft sensor model based on cultural neural network has good performance and good application prospects.

Qiao et al. [13] took the rectification tower of a pharmaceutical company as the research object, and studied the neural network adaptive control of the nonlinear time-delay system and its application in the rectification tower control process through the neural network adaptive method. Aiming at the control process of nonlinear system with time delay, design indirect adaptive control method based on cellular neural network, including neural network adaptive identification method and control method, realize neural network online identification for nonlinear system, and use Lyapunuv-Krasovskii pan The function compensates for the time lag, and performs online learning of neural network weights based on adaptive algorithms. Based on the in-depth study of the current situation and development trend of neural network control, aiming at the current situation and characteristics of neural network adaptive control, combined with the method of nonlinear system identification and control, the neural network adaptive identification and control method is given. The effectiveness of the algorithm is given by Lyapunov stability theory, and the results are given by MATLAB simulation, The neural network control process is realized.Designs

neural network identification algorithms through neural network indirect adaptive methods, designs controllers on the basis of neural network identification models, and uses Lyapunov The stability theory proves the convergence of the identification algorithm and the controller, and the convergence proves that the dynamic system is uniformly asymptotically bounded and stable. Matlab simulation experiments are used to verify the feasibility of the algorithm. Finally, for the distillation tower system, a PLC control system is designed to build a DCS control platform to realize the control process of the system, and realize the system design of the distillation tower control process through the neural network adaptive control method, and complete the process of the distillation tower system control.

Li et al. [49] first conducted an in-depth study and analysis on the mechanism of the ethylene distillation process, applied ASPEN PLUS software to simulate the industrial device, obtained the deep mechanism knowledge base of the ethylene distillation process, and optimized the process operating parameters. Furthermore, the fuzzy system is combined with the GMDH network, and a new neuro-fuzzy GMDH network is proposed, and the learning steps and algorithms of the network are given. The example simulation verifies that the neuro-fuzzy GMDH network proposed in the article has a good fit Performance and generalization ability. Based on the above research, the deep knowledge base of the ethylene rectification process is closely combined with the neuro-fuzzy GMDH network modeling technology to establish a soft-sensing model for the product concentration of the ethylene rectification process, and the model is applied to implement the ethylene rectification tower top Inferred control of alkane concentration and ethylene concentration at the bottom of the tower. The real-time operation effect of the industrial device shows that the operation effect of the advanced control system is satisfactory, and it has achieved the effect of "scratch" control of the product concentration at the top of the ethylene distillation tower and energy saving.

According to the requirements of rectification tower operation, there are mainly the following control schemes in rectification tower control:

1) Basic control scheme of rectification tower

The basic control of the rectification column is based on a single loop. The more common ones include open-loop control of product quality, indirect balance control and pressure control. This type of control aims at ensuring the basic operation requirements of the tower.

2) Complex control scheme of rectification tower

In actual rectification control schemes, complex control systems such as cascade, uniformity, ratio, feed forward, split range, and selectivity are often used due to the improvement of operating requirements or the need for safety. Commonly used are cascade control systems, feed forward control systems and selective control systems. This type of control aims to improve the operation level and ensure safety.

3) Advanced control scheme of distillation tower

With the development of ANN, fuzzy logic, artificial intelligence and expert systems and other theories, many scholars have also applied these theories to control, so many new control methods have been produced, called advanced control, advanced control of rectification tower includes several options.

Soft measurement and inference control: In the product quality control of the rectification tower, the commonly used method is to use the indirect quality index-temperature, or use the automatic analysis instrument as the controlled variable. If the former is adopted, it is difficult to guarantee product quality when the operating conditions change; if the latter is adopted, the automatic analysis instrument is expensive and has a large lag, which brings difficulties to control. Since Brosillow proposed the inferred control strategy in the 1970s, inferred control based on soft sensing has gradually been widely used in industrial distillation tower control. In this research, the idea of inferred control is adopted, and an advanced control scheme based on soft measurement is established.

Predictive control: In recent years, predictive control has gradually been widely used in the process industry. Such as predictive control applied to air separation plant control, reactor control and so on. In the control of the rectification tower, there are also examples of the application of predictive control. Many domestic manufacturers have adopted predictive control on the atmospheric distillation tower.

Expert system: The operation in the rectification tower is not only satisfied with the stable and safe production, but is moving towards high efficiency and low cost, so it needs to be optimized, and the expert system can solve these problems. The expert system can optimize the distillation operation based on the mechanism model knowledge, practical experience knowledge and mechanism model simulation knowledge, and use IF-THEN rules to express the knowledge of the optimization operation. Therefore, the expert system can optimize production operations and reduce operating costs.[50]

5. CONCLUSION

Because the distillation system has the characteristics of nonlinearity and strong coupling, it is difficult to establish an accurate mathematical model by means of mechanism. With the development of fuzzy logic and neural networks, the research on using fuzzy neural networks to describe uncertain and nonlinear complex systems has also continued to develop. Neural networks can produce accurate estimates in the case of the complex relationship between input and output, because they map in a non-linear manner and ANN have high self-learning and high fault tolerance, as well as self-organization, self-adaptation and other intelligent characteristics . Therefore, the neural network has greatly improved the technology and production environment in the chemical industry, and provided practical solutions to the problems that are difficult to handle with traditional technologies. In the reactive distillation, the neural network can find the best reaction conditions in the reactive distillation and obtain the maximum conversion rate of the reactants, which can save costs and raw materials, and make the reaction separation purity and efficiency high. It can be predicted that in the near future, the neural network algorithm will be more widely used in the optimization of ethylene distillation control.From the neural network system identification method, not only need input and output data, but also need to estimate the time delay, which is difficult to achieve, so further analysis of the model, understanding the influence of time delay and other factors on the system needs more in-depth research.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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