Optimizing for Large Time Delay Systems by BP Neural Network and Evolutionary Algorithm Improving

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***Abstract*—BP artificial neural network is a non-feedback network. This paper utilizes the initial weights of neural network to choose controller performance. Simultaneously according to the characteristics that process of central air-conditioning energy saving control is the system of multi-parameter and nonlinear time-varying complexity, we analysis and study its algorithm and system architecture. The experimental results demonstrate that new control system gets better results and energy saving.**

***Index Terms*—Steady-state error; Robusfitness; BP Artificial Neural Network; Evolutionary Algorithm; Fuzzy PID Control Strategy**

I. INTRODUCTION

Process type air-conditioning is different from the building type central air conditioning. Process-type central air-conditioning is generally installed in the factory floor, opening for 24/7. Process-type central air conditioning not only have quality of service, stable and reliable, but also end loads generally have a minimum cooling capacity requirements. Central air-conditioning energy uses variable flow operation mode.

Central air-conditioning System consists of chillers, cooling water system, chilled water system, fan-coil system and cooling tower [1]. Its working flow is that refrigerant will be compressed into a liquid state through the compressor and exchange with chilled water through a series of conversion, then through the fans to send in turn to achieve the purpose of cooling.

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A. Industrial real-time and embedded systems to improve reliability.

In the current central air-conditioning control system, the general configuration software as IPC + SCM + PLC control mode[2]. In this system we use S3C6410 industrial chip embedded system which based on the ARM11 core and Linux OS. It has characteristics of real-time, reliability, high stability. It effectively solves the industrial PC, real-time, reliability problems which are based on the current majority of the stability of the program. High-Speed SOC chip can be in a timely manner according to the central air-conditioning system to respond to environmental changes and also reduces system power consumption.

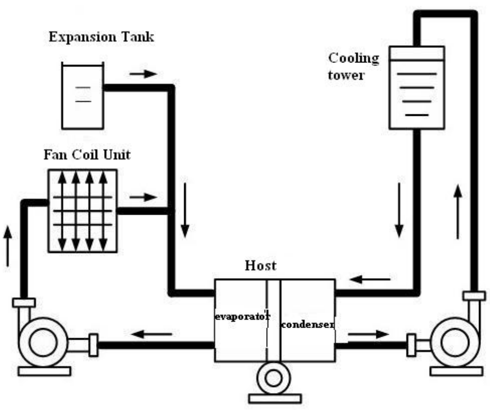

Figure1. Central air conditioning system components

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II. STRUCTURE AND CHARACTERISTICS OF THE OLD SYSTEM

A. Drawbacks of the old methods and traditional PID control.

At present, the controller parameter's optimization methods are the simple type method, e.g. gradient method, experts and so on. Drawbacks of Simplex method, gradient method are more sensitive to the initial value, easy to fall into local optimum to resolve, and lead to optimization failure. Expert tuning rules require too much experience, a different objective function corresponds to a different experience, and knowledge base is a long time finishing project [4].

This system has the characteristics of multi-parameter, non-linear and time-delay. The frequent fluctuations of the load lead to the decreasing of host's heat conversion efficiency, and then increase the system's energy consumption.

Traditional energy-saving control system generally use the PID control, but the traditional PID control algorithm is simple. When it is used to control central air conditioning, so many parameters, nonlinear, time-varying parameters and strong coupling between the complex systems and central air-conditioning system can easily lead to oscillation, it will affect the stability of the system, and reduce the air-conditioned comfort level.

B. PID control with BP neural network algorithm to improve energy efficiency.

BP neural network algorithm is a supervised learning algorithm. The learning process is divided into four stages: input signal Forward propaEAtion, error signal back-propaEAtion, connection weight and threshold of change, convergence of judge [8]. Figure 2 is a three-layer BP artificial neural network structure diagram:

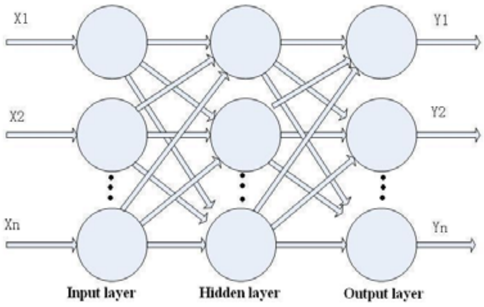

Figure 2. Three-tier network architecture diagrams

The control parameters, which are put into by the input layer, are frozen water temperature, pressure, the frequency of pumps and fans. Take embedded controlling subsystem of chilled water as an example. The formula of hidden layer and output layer are as follows:

Hidden Layer: $Y_j = f(\sum_{i=1}^{m} w_{ji} X_i -$ **Error! Reference source not found.**) . (1)

Output Layer: $Y_k = f(\sum_{j=1}^{n} w_{kj} Y_j - \gamma_k)$. (2)

Xi represents chilled water temperature, chilled water pressure, current frequency of chilled water pumps (with two chilled water pumps) and previous calculating errors; Yj represents calculating output of hidden layer of the frequency of j-chilled water pump; Yk represents controlling output of layer of frequency k-chilled water pump; f (x) represents activation function, s-type function is used in this formula; Wji, Wkj, respectively represent Connection weight vector from input layer to hidden layer and then to output layer[9].

So we try to use the BP neural network method to improve the system , mainly because of neural network PID controller contains the thought of conventional PID control , both non-linear mapping, self-learning and adaptive capacity, simple structure, and can adapt to environmental changes, have stronger robusfitness, adaptive nonlinear control can be achieved [1].

C. Drawbacks of BP network

Using BP artificial neural network optimization algorithm can realize adaptive Nonlinear Control. However, the selection of the initial weights of neural network controller impacts the performance of the ideal controller [2]. Even if it is found, it is hard to be the optimal.

D. Fuzzy Neural Networks .

In D. Arotaritei's paper, he introduced a kind of fuzzy neural network, it seems to be a good method to solve the problem.

There are three basically types of fuzzy neural networks depending on the type of fuzzication of inputs, outputs and weights (including biases): fuzzy weights and crisp inputs, crisp weights and fuzzy inputs and fuzzy weights and fuzzy inputs. In followings we consider the most complete fuzzication of neural networks: fuzzy inputs, fuzzy weights and fuzzy outputs.

We use a three layer FFNN. FFNN propaEAte the signal layer by layer until the signal reach the output layer. For each k layer we have:

$$\tilde{s}_j^k = \sum_{i=1..N_k}^{fuzz} \tilde{w}_{ji}^k \tilde{\cdot} \tilde{x}_i \tilde{+} \tilde{b}_i \quad (3)$$

$$f(x) = f(\tilde{s}_k^j) \quad (4)$$

In the equations above, j is the fuzzy neuron from k layer and i-th is the fuzzy neuron from k-1 layer. The training of FFNN is to adapt the network in order to mapping the known inputs to target outputs. The objective of the learning algorithm is to minimize the error measure between the desired outputs and the real outputs. The learning algorithm must adjust the fuzzy weights based of error measure in order to achieve this objective.

III. EVOLUTIONARY ALGORITHM OPTIMIZATION CONTROLLER

In order to get ideal parameters, we selected evolutionary algorithm to carry out partial parameter optimization, the method does not require any initial information and we can find the global optimal solutions, and efficient optimization from it. We adopt Evolutionary

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algorithm to optimize global parameters of BP neural network PID controller [3]. Local parameters are relatively fewer, so it is easier to get the system locally optimal parameter values. Combination of the two algorithms as a central air-conditioning control system increases the stability of the central air-conditioning, real-time and reliability. So it ensures the comfort of central air-conditioning system, and achieves maximum energy efficiency as well.

This system consists of nine parameters .They are chilled water entry / return water temperature(k0,k1), Chilled water flow k2, Chilled water pressure k3, Chilled water pump frequency k4, Cooling water entry / return water temperature (k5, k6), Cooling Pump Frequency k7, Fan frequency k8 [5]. When we do optimization, first based on expert experience, set the value of these nine parameters and evolutionary optimization of control rules, and then get ki optimization for a fixed value, and then based on evolutionary optimization function, and so forth until you meet the requirements, constitutes a multi-level optimization.

Choice of evolutionary parameters to take into account the complexity of computing . In this article, you want to take into account is the central air-conditioning and security of real-time [6]. Take population size M = 40, the termination of algebra Td = 250, the crossover probability Pc = 0.9; Mutation probability to a certain extent, to prevent premature. Check Pm = 0.1, while the introduction of reference [7] proposed catastrophic ways to further prevent premature. As it runs in the embedded ic,it needs to take into account the computational complexity.

IV. EA WITH LOCALLY CROSSOVER

EA are optimization techniques based on principles of mechanism of natural evolutionary. EA are working on possible space of solutions (usually codied by chromosomes) in order to find the best candidate suitable for a particularly problem. The fitness is a measure of performance of the individual in order to achieve the desired objectives. The objective function can be the maximization of fitness or minimization of fitness. Two problems arise from EA usage for solving the optimization problems: the choice of the fitness function and the encoding method the values of parameters that must optimized into an individual chromosome. The range of values that are part of this encoding method play an important role related to both convergence speed of EA and the accuracy of the results.

In our approach we will use the minimization of objective function that is a measure of output errors related to fuzzy numbers. This function is usually named the fitness function.

The general function can be denied based on distance among desired fuzzy numbers and actual fuzzy numbers at outputs [15]. However, in our application we will use a more practical measures based on Hamming distance. By this objective function we estimate more intuitive the differences between desired and real outputs.

EA uses binary encoding method in order to represent genes or chromosomes. Each binary value (0 or 1) is named allele [12]. The value of solutions is mapped as binary string in the process of encoding using linear of nonlinear functions. We used the representation of TFN as LR-type fuzzy numbers with n parameters [16]. Each parameter is coded as binary string of a specified Length.

The selection process has two stages. The first stage is selection of two parents for cross overusing a known schema: tournament, roulette or stochastic sampling. After this global selection, we perform a local choice within the chromosome. This selection is inspired by the fact observed in crisp feed forward neural networks that not all the weights have the same contribution to forward propaEAtion of the signal. Usually, the weights from k layer has a different contribution than the weights from k+1 layer. Conversely, it is natural to suppose that some parameters give a more contribution to best solution than others, so a ne locally adjustment can improve the global solution.

The local selection selects the weights, the locations in the chromosome where the corresponded weight is coded in binary string for local crossover.

The crossover operation picks the selected genes and mates them in order to produce two offspring genes. The split point (SP) is chosen randomly, the same for both parents. The example from Fig. 6 illustrate the local crossover. The same SP is applied to corresponding gene that code the left and right spread of the selected weights.

Mutation generated within the entire chromosome. The mutation picks the bit (allele) with a probability pm and overturns this value to 1 if the value is 0 and to 0 if the value is 1. Mutation implements a random search at global level. By pm , the level of search can be modified, the pm is changed greater, the level of search in the solution space is greater.

The EALC algorithm is based on the practical following observation. Due to nonlinear aspect of the transfer function of the neuron, the changes in some weights can have a greater contribution to result than the changes in the other weights. Also, the impact of this changes for FFNN can decrease or increase in the forward process. EALC propose to use this observation in order to "encourage" the more contributing weights to be selected in order to do crossover and evolve faster meanwhile the rest of weights will evolve slowly, based only on mutations. For the same dx (dx1 = dx2), we can have dy2 > dy1 in same cases with one or two magnitude order.

Let denote by NN the total number of neurons in the FFNN. The proposed algorithm based on basic EA procedures is summarized below.

Step 1: Linear mapping of the solution space (fuzzy weights) into chromosomes (binary string) that represent individuals of the population P.

Step 2: Initialize the population P with random solutions (uniform distribution). The popula- tion has N individuals that represents 3*N set of chromosomes for TFN with no fuzzy bias and 3*N + 3*NN set of chromosomes for TFN with fuzzy

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bias.

Step 3: Evaluate the fitness of the population P.

Step 4: Evaluate the stop criteria. If the end condition is met, go to Step 10.

Step 5: Store the best individual of the current generation and the best individual of all the generations.

Step 6: Generate a new population using selection operator according to selection schema based on fitness values of the chromosomes.

Step 7: Random selection of genes for local crossover. The selected genes are a percent pr from total number of the genes that represent a chromosome.

Step 8: Local crossover for selected genes and creation of new generation of the population. The corresponding genes are mated with probability pc and the results offspring replace the parents in the new population.

Step 9: Global mutation over chromosomes with random probability pm .

Step 10: Map the best individual of all the generations into solution, the fuzzy weights of the FFNN.

The stop criterion can have different forms. One of the most common is a predefined number of generations. Another one can be the stop of the process, before a maximum number of generations if no significant improvement has been made in the best individual. In our application we used the first criterion.

The EALC algorithm can be easily extended to α-cuts. For each h-level we must allocate 2 chromosomes that correspond to dL and dR values al level h (Fig. 9). The central value is unchanged from one level to next level. We start with the base level (h=0) where we adapt the L, C and R values using L-R type representation (12). Next we consider the C value and we must adapt the left and right spread at the level h=1,2,3,... n.

Because of max/min operators and multiplication operation, the shape of membership for fuzzy weights (and biases) is a curved triangle. Restrictions must be made in order to avoid non desired occurrence in the weights adaptation process.

These restrictions are included in the algorithm in the following way. If after the crossover, the children accomplish the rules (15), the local crossover operation is validated and the children are selected in the next generation depending on the fitness. If the children doesn't accomplish the rules (15), the local crossover operation is canceled and the selected weights remain unchanged.

V. SYSTEM THEORY FRAMEWORK

We know that BP artificial neural network decision-making controller makes the parameters of central air-conditioning global optimization; they are able to more accurately reflect the dynamic characteristics of the controlled process output variables [4]. When the load changes of the central air-conditioning system cause the deviation from the best power of water system and the host, according to data collection, the intelligent Evolutionary optimization of Fuzzy PID controller gets a variety of operating parameters, and then use the Evolutionary optimization of fuzzy PID control algorithm to adjust the system operating parameters, and then ensure that the host is in an optimized operating environment at any load conditions. Thereby conversion efficiency (COP) is the highest, energy consumption is the lowest, and then achieves energy-saving 17% of the host.

Host thermal conversion efficiency formula for calculating COP:

$$COP = \frac{Q_O}{N_d} \tag{5}$$

Each controlling parameter of the subsystem is different. In the chilled water control subsystem, controlling parameters include the volume of chilled water into the parameters / return water temperature, chilled water flow, chilled water pressure, frequency of chilled water pumps, chilled water, temperature of water, cooling water pump power[5]. In the cooling fan control subsystem, the controlling parameters contain the cooling water entry / return water temperature, fan frequency, fan power..

A. Fifitness function.

Simple evolutionary algorithms in accordance with the individual fifitness are proportional to the probability to determine the current group of evolutionary each individual the opportunity to the next generation the number of groups. The objective function associated with the fifitness function, evolutionary optimization is to find the extreme fifitness value that is the objective function search problem [8]. The provisions of the fifitness function: In the Fifitness function σ , t_s , e_s respectively, for the control system overshoot, adjust the time and steady-state error; σ_m , t_{sm} , e_{sm} respectively, for overshoot, adjusting the time and the maximum steady-state error; $\frac{\sigma_m-\sigma}{\sigma_m}$, $\frac{t_{sm}-t_s}{t_{sm}}$, $\frac{e_{sm}-e_s}{e_{sm}}$ said control system overshoot, adjust the time and steady-state error of three aspects of quality control; η,λ,ω for these three areas in the overall performance of the proportion, request $\eta+\lambda+\omega=1$. Fifitness function of evolutionary optimization is a key factor in good and bad effects.

VI. EVOLUTIONARY ALGORITHM AND THE COMBINATION OF PID CONTROL ALGORITHM.

According to temperature, pressure and current frequency, it is analyzed W = (0.4, 0.15, 0.2, 0.2, 0.05), **Error! Reference source not found.**, γ_k represent hidden layer and output layer threshold, the threshold is depended on the hardware inverter and the minimum load needs, (θ_j value is 0.1, γ_k value is 0.3) .

Error function:

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$$E_p = \frac{1}{2}\sum_k (O_{pk} - Y_{pk})^2 \quad (6)$$

Opk: the first p k-input mode, the desired output frequency; Ypk: the actual frequency calculation for the network output.

To sum up (2) (3) (4), we summarize that in two chilled water pump control subsystems, the output layer formula:

f(x): Sigmoid function; T: chilled water temperature; H: chilled water pressure; HZ1, HZ2: chilled water pumps 1, 2 frequency; E: sampling error; M: actual maximum inverter (if it is 48, indicating to set a maximum frequency of inverter 48HZ).

Evolutionary algorithms and the combination of PID control algorithm is the core of the Control subsystem, Through Evolutionary optimization of the evolution of local parameters optimization, And then using the combination of PID control algorithm to these sub-optimal PID values calculated to be the final parameters, input to the hardware circuit t and realize the control of the hardware [9]. This constitutes a set of intelligent self-optimizing control strategy.

By analyzing the Evolutionary optimization of intelligent PID controller, the input and output can be drawn, this is a self-optimizing the process.

If the energy-saving air-conditioning running in front of a certain period of time, the whole operation of the system power reaches the optimal running of the various parameters will be recorded in the database; If the system is not in the best condition, then the Evolutionary optimization of PID controller will be based on Evolutionary optimization algorithm continually iterative optimization, With the recent time away from the current system in its best state of the various parameters, then the whole system in its best state run power.

For example, in recent years from the current system in its best state:

K0*T0+ k1*T1+ k2*L+ k3*P+ k4*F1+ k5*T2 + k6*T3 + k7*F2 + k8*F3 = Best.

In the current time, the host COP obtained by calculating the current system is not the best power. So they can been modified k0, k1, ..., k8:

K0'*T0'+ k1'*T1'+ k2'*L'+ k3'*P'+ k4'*F1'+ k5'*T2' + k6'*T3' + k7'*F2' + k8'*F3' = Best.

VII . EXPERIMENTAL AND COMPARATIVE ANALYSIS

Evolutionary Algorithm and BP artificial neural network algorithms are the most important parts of applications of artificial intelligence. We put the environment temperature, humidity, seasonal changes, day and night alternation and the operating environment and other parameters in the multi-layer BP neural network hidden layer nodes, give them the right values, repeat adjustment training in line with weights and biases, then insure the output vector and the desired vector as close as possible[10].Figure3: comparison of consumption with the combination between central air-conditioning using Evolutionary algorithm and BP artificial neural network algorithms or not:

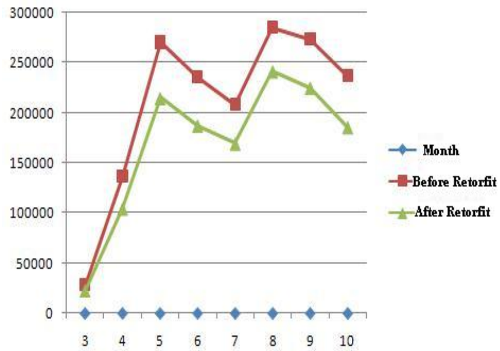

Figure 3. Consumption comparison charts

It is clearly shown in Figure 3 that through the new system central air-conditioning gets significant improvements in energy efficiency. The average energy saving rate in summer reaches to more than 25%, and in winter the average energy saving rate reaches to no less than 33%, obtaining good economic and social effects.

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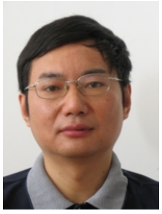

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