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Chaos Cooperative Particle Swarm Optimization Based Water Level Control for Nuclear Steam Generator

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Abstract. The Stability of SG (Steam Generator) water level plays an important role in the safety of nuclear power plants, but it is difficult to tune the parameters of water level PID controller. A proposed novel algorithm, CCPSO (chaos cooperative particle swarm optimization), is used for tuning PID controller parameters. The (chaos particle swarm optimization)CPSO algorithm has the ability to avoid falling into local minimum and the (cooperative particle swarm optimization)CPSO-S_k has fast convergence in certain functions, so CCPSO algorithm is proposed to utilize the advantages of CPSO and CPSO-S_k. Therefore, half of the particles are updated in the CPSO-S_k, and the other half are updated in the CPSO. The information exchange of the optimal solutions obtained after the end of each iteration is the performance of CPSO-S_k and CPSO collaboration.The simulation results: compared with the PID controller whose parameters are tuned by ZN method, CCPSO show smaller overshoot, better stability, and shorter adjustment time. The simulation results show that the proposed method is effective for tuning PID parameters.

1 Introduction

The SG water level system is highly nonlinear, with time-varying characteristics [1]. The parameters of system change greatly with the power of the reactor. The system exhibits serious "contraction" and "expansion" phenomenon resulting in false level signals. So it is difficult to tune the parameters of PID controller. As a result, the system hard to meet the requirements of all conditions, namely, it is difficult to take into account the best dynamic characteristics and static characteristics.

Particle swarm optimization algorithm is a stochastic global optimization evolutionary algorithm based on swarm intelligence. According to the advantages of CPSO and CPSO-S_k, where CPSO algorithm has the ability to avoid falling into local minimum and CPSO-S_k has fast convergence in certain functions[2,3]. a new algorithm CCPSO is proposed for PID controller tuning[4]. Simulation test is conducted by matlab.

2 Particle Swarm Optimization Algorithm

A swarm is composed by S particle in D dimension space. The position of the ith particle is $x_i = (x_{i1}, x_{i2}, \ldots, x_{iD})$, $i = 1,2,\ldots s$, and its speed is $v_i = (v_{i1}, v_{i2}, \ldots, v_{iD})$. The optimal position of the

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particle to be searched is $P_i = (P_{i1}, P_{i2}, \ldots, P_{iD})$. Therefore the optimal positions to be searched by particle swarm optimization are $P_g = (P_{g1}, P_{g2}, \ldots, P_{gD})$. Then we compute the adaptive value of x_i is computed by (2). The updating strategy of particle status is as follows:

$$v_{id} = wv_{id} + c_1 r_1 (P_{id} - x_{id}) + c_2 r_2 (P_{gd} - x_{id}) \quad (1)$$

$$x_{id} = x_{id} + v_{id} \quad (2)$$

3 Improved Cooperative Particle Swarm Optimization Algorithm

Chaos cooperative particle swarm optimization (CCPSO) algorithm is proposed by introducing chaos particle swarm optimization (CPSO) into cooperative particle swarm optimization (CPSO-S_k).

The CPSO algorithm has the ability to avoid falling into local minimum and CPSO-S_k has fast convergence in certain functions, so CCPSO algorithm is proposed to utilize the advantages of CPSO and CPSO-S_k. When the CPSO-S_k algorithm stagnation, changes over to uses the CPSO algorithm. Therefore, half of the particles are updated in the CPSO-S_k, and the other half are updated in the CPSO. The information exchange of the optimal solutions obtained after the end of each iteration is the performance of CPSO-S_k and CPSO collaboration.

3.1 The cooperate Particle Swarm Optimization

The components of D dimension vectors are divided into K groups according to the correlation by CPSO-S_k algorithm. The correlation components constitute a group. The sub vectors which are compose by each group, correspond to a particle vector, and the K sub population co-evolute. If the relationship of the k components can not be identified, then they are splited into $k_1 = D \bmod k$ groups, where each group contain $\lceil D/k \rceil$ components. Or they are splited into $k_2 = k - k_1$ groups, where each group contain $\lceil D/k \rceil$ components. Global optimal value is computed by

$b(j,z) = (P_1.\hat{y}, P_2.\hat{y}, \ldots, P_{j-1}.\hat{y}, z, P_{j+1}.\hat{y}, \ldots, P_k.\hat{y})$, where $P_j.\hat{y}$ is the global optimal value of the ***j***th particle swarm. Global optimal value is computed by the vectors which are searched as global optimal.

3.2 Chaos optimization method

Chaos is a common phenomenon in nonlinear systems. We do an optimization search in the solution space by using the randomness, ergodic and regularity of chaos, so that the local optimal solution can be avoided. In this study the chaotic variables is generated by the following Logistic mapping:

$$z_{n+1} = \mu z_n (1 - z_n) \quad n = 0,1,2,\ldots \quad (3)$$

where μ is control variables, take $\mu = 4$, set $0 \le z_0 \le 1$, system (3) is in a state of chaos completely. Iterates definite time series $z_1, z_2, z_3, \ldots$, and with arbitrary initial value $z_0 \in [0,1]$.

3.3 Chaotic cooperative particle swarm optimization algorithm(CCPSO)

A chaotic sequence is generated based on the optimal position which the whole particle swarm searched. The position of a particle in the current particle swarm is replaced by the position of the optimal position particle in chaotic sequence. In the iterative procedure, the search algorithm of introducing the chaotic sequence can generate many neighberhood of the local optimal solution, which can help the inert particles to escape from the local extreme points, and quickly find the optimal solution.

CCPSO operation steps are as follows:

Step 1: k_1 population are initialized, which are $\lceil D/k \rceil$ dimensional chaotic PSO population, Each dimension has s particles: $P_j, j \in [1..k_1]$; k_2 population are initialized, which are $\lceil D/k \rceil$ dimensional chaotic PSO population Each dimension has s particles: $P_j, j \in [(k_1+1)..k]$

Step 2: A D dimensional chaotic PSO population is initialized: Q

Step 3: The group P of Chaotic PSO is updated by using the basic particle swarm algorithm formula.

The circulations are carried out as follow regarding each group $j \in [1..k]$:

The circulations are carried out as follow regarding each group $i \in [1..s]$:

If $f(b(j, P_j.x_i)) < f(b(j, P_j.y_i))$

Then $P_j.y_i = P_j.x_i$

If $f(b(j, P_j.y_i)) < f(b(j, P_j.\hat{y}))$

Then $P_j.\hat{y} = P_j.y_i$

Step4: Select random $k \sim U(1, s/2) | Q \cdot y_k \neq Q \cdot \hat{y}$,then $Q.x_k = b(1, P_1.\hat{y})$, The group Q of Chaotic PSO is updated by using the basic particle swarm algorithm formula.

The circulations are carried out as follows regarding each group $i \in [1..s]$:

If $f(Q.x_j) < f(Q.y_j)$

Then $Q.y_j = Q.x_j$

If $f(Q.y_j) < f(Q.\hat{y}_j)$

Then $Q.\hat{y}_j = Q.y_j$

End the cycle of particles.

Step5: The circulations are carried out as follows regarding each group $j \in [1..k]$

Select random $k \sim U(1, s/2) | Q \cdot y_k \neq Q \cdot \hat{y}$

$P_j \cdot x_k \neq Q \cdot \hat{y}_j$

Step6: We judge whether the end condition is satisfied. If it is not satisfied, repeat step four, if it is satisfied, then the procedure is completed.

4 Experimental Analyses

Analysis and simulation are based on the simplified mathematical model of the steam generator water level which was proposed by E.Irving[5]. Tuned PID controllers of feed water, and the steam generator water level are controlled on this basis. The structure of control system is shown in Figure 1.

In this system, the inner loop uses PI controller to control the flow of feed water, and there is a PID controller for water level in the outer loop. At varying load, the role of the water level signal is ignored. The steam flow rate and reach of the basic balance are to feed water flow by PI controller. The system is basically stable, so the false water level is avoided[6]. Then the PID controller for water level participates control again. The control process is shortened and the range of water level is reduced by the PID controller.

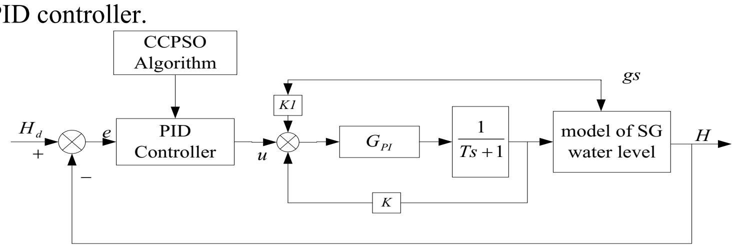

Figure 1. Structure of control system

Usually the parameters of SG level model change when adding perturbation. This is the difficulty of tuning parameters of the PID SG controller of water level. This situation is analysed and simulated as follow: Water level is at 0mm. Add perturbation of steam flow rate at 300s, namely, add steam flow, rate then the response of water level is simulated when steam flow rate step signal change.

1. Simulation of steam flow rate positive step signal change: At first the water level is stabilized at the level set value 0mm on the condition of 50% loading. The steam flow rate is increased from 660kg/s to 815kg/s at 300s, namely loading increase to 60%. As shown in Fig 2, the dashed line is the water level response curve when the parameters of PID controller are tuned by ZN method. Solid line is the water level response curve when the parameters of PID controller are tuned by CCPSO method. The results are shown in the graph; the PID controller whose parameters are tuned by CCPSO reduces overshoot, and raises its convergence speed, and enhances its stability, when adding perturbation of steam flow rate.

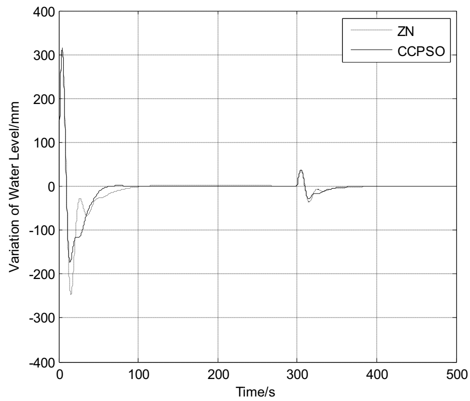

Figure 2. Water level response curve of positive step from 50% to 60%

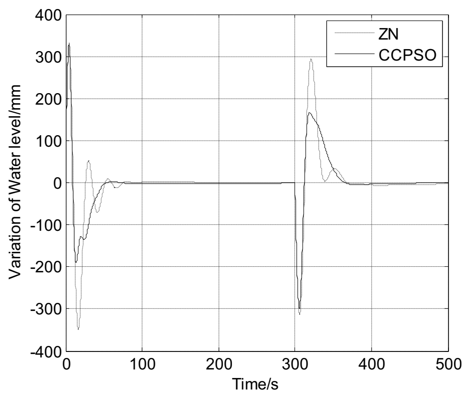

Figure 3. Water level response curve of negative step from 70% to 15%

2. Simulation of steam flow subjected to negative step signal change: At first the water level is stabilized at the level set value 0mm on the condition of 70% loading. The steam flow rate is decreased from 970kg/s to 180.8kg/s at 300s, namely loading decrease to 15%. As shown in Fig 3, the dashed line is the water level response curve when the parameters of PID controller are tuned by ZN method. Solid line is the water level response curve when the parameters of PID controller are tuned by CCPSO method. The results are shown in the graph; the PID controller whose parameters are tuned by CCPSO reduces overshoot, and raises its convergence speed and enhances stability, when adding perturbation of steam flow rate.

3. Now the PI controller is also tuned by CCPSO algorithm, the structure of the block diagram as shown in Figure 4. at first the water level is stabilized at the level set value 0mm on the condition of

50% loading, and then it decrease to 30%. As shown in figure5, The performance of tuning the PI controller by CCPSO algorithm is better than the conventional PI controller of given value.

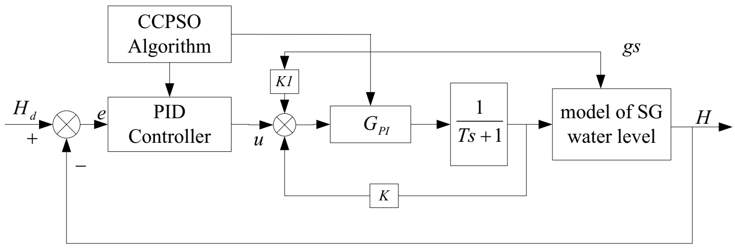

Figure 4. Structure of control system

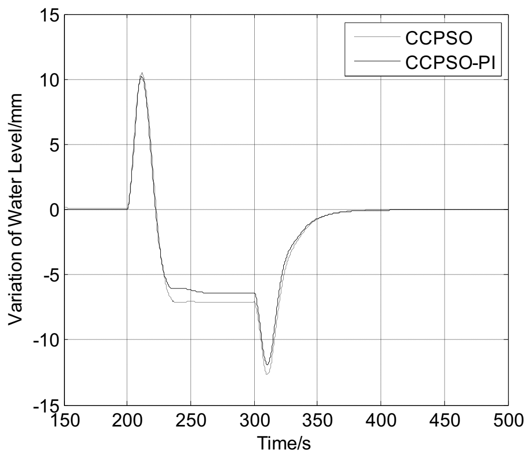

Figure 5. Water level response curve of negative step from 50% to 30%

5 Summary

According to the simplified mathematical model of the steam generator water level, we use a novel algorithm: CCPSO, which overcomes PSO algorithm in not guaranteeing the global convergence,with easiness to produce pseudo optimal value problems. CPSO-S_k algorithm improves the case by using the random and ergodic properties of chaos. We can update the information of each subgroup by chaotic motion, when the CPSO-S_k algorithm fall into local extreme value. And continue to search according to the new optimal values.

The simulation results shows: a comparison against the PID controller whose parameters are tuned by ZN method, where PID controller with tuned parameters by CCPSO has smaller overshoot, better stability, and shorter adjustment time. The results of simulation prove the effectiveness of CCPSO algorithm in tuning PID parameters.

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