2006년도 대한전기학회 전력기술부문회 추계학술대회 논문집(2006.11.3~4)

교육용 PSO 시뮬레이터의 개발: 경제급전에의 적용

이우남, 정윤원, 이주원, 박종배, 신중린
건국대학교 전기공학과

Development of an Educational Simulator of Particle Swarm Optimization: Application to Economic Dispatch Problems

Woo-Nam Lee, Yun-Won Jeong, Joo-Won Lee, Jong-Bae Park, Joong-Rin Shin
Dept. of Electrical Engineering, Konkuk University

Abstract - This paper presents a development of an educational simulator of particle swarm optimization (PSO) and application for solving the test functions and economic dispatch (ED) problems with nonsmooth cost functions. A particle swarm optimization is one of the most powerful methods for solving global optimization problems. It is a population-based search algorithm and searches in parallel using a group of particles similar to other AI-based heuristic optimization techniques. In developed simulator, lecturers and students can select the functions for simulation and set the parameters that have an influence on PSO performance. To improve searching capability for ED problems, a crossover operation is proposed to the position update of each individual (CR-PSO). To verify the feasibility of CR-PSO method, numerical studies have been performed for two different sample systems. The proposed CR-PSO method outperforms other algorithms in solving ED problems.

1. Introduction

Most of power system optimization problems including economic dispatch (ED) have complex and nonlinear characteristics with heavy equality and inequality constraints.

In 1995, Eberhart and Kennedy suggested a particle swarm optimization (PSO) based on the analogy of swarm of bird and school of fish [1]. The individual particles are drawn stochastically toward the position of present velocity of each individual, their own previous best performance, and the best previous performance of their neighbors [2].

The practical ED problems with valve-point and multi-fuel effects are represented as a non-smooth optimization problem with equality and inequality constraints, and this makes the problem of finding the global optimum difficult, To solve this problem, many salient methods have been proposed.

This paper discusses the development of the educational simulator for the PSO algorithm. In the developed simulator, lecturers and students can set information related with PSO algorithm. In addition, a crossover operation is proposed to the position update of each individual in order to improve the searching capability. The better solution was obtained by using this operation for the various kind of optimization problems including ED problems that have multiple minima.

2. Overview of PSO

In a physical n-dimensional search space, the position and velocity of individual i are represented as the vectors $X_i = (x_{i1}, \cdots, x_{in})$, and $V_i = (v_{i1}, \cdots, v_{in})$, respectively, in the PSO algorithm. Let $Pbest_i = (x_{i1}^{Pbest}, \cdots, x_{in}^{Pbest})$ and $Gbest_i = (x_{i1}^{Gbest}, \cdots, x_{in}^{Gbest})$, respectively, be the best position of individual i is modified under the following equation in the PSO algorithm:

$$V_i^{k+1} = w V_i^k + c_1 \mathrm{rand}_1 \times (Pbest_i^k - X_i^k) + c_2 \mathrm{rand}_2 \times (Gbest^k - X_i^k) \quad (1)$$

where,

V_i^k	velocity of individual i at iteration k;
w	inertia weight factor;
c_1, c_2	acceleration constant;
rand_1, rand_2	random numbers between 0 and 1;
X_i^k	position of individual i at iteration k;
$Pbest_i^k$	best position of individual i until iteration k;
$Gbest^k$	best position of the group until iteration k;

Each individual moves from the current position to the next one by the modified velocity in (1) using the following equation:

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (2)$$

Suitable selection of inertia weight w in (3) provides a balance between global and local explorations.

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \quad (3)$$

where $iter_{\max}$ is the maximum number of iterations (generations), and $iter$ is the current number of iterations [3].

3. Development of an Educational Simulator

In this section, development processes of an educational simulator for normal PSO and improved PSO will be described in solving the mathematical example functions [4] and the ED problems. This educational simulator was developed by Matlab 6.5. For the convenience of users, the developed simulator is implemented with the form of GUI(Graphic User Interface). Therefore, most of the parameters can be directly inputted by users.

The Fig. 1, 2 is show a screen of developed PSO simulator.

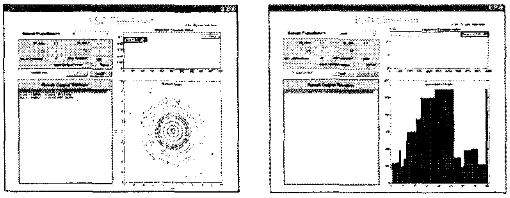

Fig. 1,2. A Screen of Developed PSO Simulator

4. Formulation of Economic Dispatch(ED) Problem

4.1 ED Problem With Smooth Cost Functions

The ED problem is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. The total generation cost function and the most simplified cost function of each generator can be represented as a quadratic function as the following equation(8):

$$C = \sum_{j \in J} F_j(P_j) \tag{4}$$

$$F_j(P_j) = a_j + b_jP_j + c_jP_j^2 \tag{5}$$

where

C	total generation cost;
F_j	cost function of generator j;
a_j, b_j, c_j	cost coefficients of generator j;
P_j	electrical output of generator j;
J	set for all generators;

While minimizing the total generation cost, the total generation should be equal to the sum of the total system demand and the transmission network loss. However, the transmission network loss is not considered in this paper for simplicity. Therefore, the equality constraint is defined as the following equation:

$$\sum_{j \in J} P_j = D \tag{6}$$

where D is the total system demand.

The generation output of each generator should be satisfied the maximum and minimum limitation as the following condition:

$$P_{j\min} \le P_j \le P_{j\max} \tag{7}$$

where $P_{j\min}, P_{j\max}$ is the minimum and maximum output of generator j.

4.2 ED Problem With Non-Smooth Cost Functions with Valve-Point Effects

The generator with multi-valve steam turbines has very different input-output curve compared with the smooth cost function. Typically, the valve point results in, as each steam valve starts to open, the ripples are appeared [5], [6], [7].

To take account for the valve-point effects, sinusoidal functions are added to the quadratic cost functions as the following equation:

$$F_j(P_j) = a_j + b_jP_j + c_jP_j^2 + |e_j \times \sin(f_j \times (P_{j\min} - P_j))| \tag{8}$$

where e_j and f_j are the coefficients of generator j reflecting valve-point effects.

5. Implementation of CR-PSO Algorithm for ED Problems

5.1 Treatment of Equality and Inequality Constraints

To create a group of particles satisfying the equality and inequality constraints is very important. Therefore, it is necessary to develop a strategy for satisfying the equality and inequality constraints. In [8], the heuristic-based technique was applied to handle the equality and inequality constraints.

5.2 Solution Procedure of Proposed CR-PSO

The process of PSO algorithm including the proposed CR-PSO algorithm can be described as follows:

Step 1) Creating Initial Position and Velocity

Step 2) Modification of Velocity and Position

Step 3) Crossover(CR) Operation

In order to effectively explore the promising regions in the search space, this paper introduces the crossover operation. The position of particle i modified by (2) isi mixed with $Pbest_i$ to generate the trial vector $\widehat{X}_i^{k+1}$ as follows:

$$\widehat{X}_{ij}^{k+1} = \begin{cases} X_{ij}^{k+1} & \text{if } r_{ij} \le CR \\ Pbest_{ij}^k & \text{otherwise} \end{cases} \tag{9}$$

for $j = 1, 2, \cdots, n$. r_{ij} is the uniformly distributed random number between [0,1], and CR is the crossover rate in the range [0,1].

Step 4) Update *Pbest* and *Gbest*

The *Pbest* of each individual at iteration $k+1$ is updated as follows:

$$Pbest_i^{k+1} = \begin{cases} \widehat{X}_i^{k+1} & \text{if } f(\widehat{X}_i^{k+1}) < f(Pbest_i^k) \\ Pbest_i^k & \text{otherwise} \end{cases} \tag{10}$$

where f is the value of the objective function.

Also, *Gbest* at iteration $k+1$ is set as the best evaluated position among $Pbest_i^{k+1}$.

Step 5) Go to Step 2 until satisfying stopping criteria.

The proposed CR-PSO is terminated if the iteration reaches the predefined maximum iteration.

6. Case Studies

To verify the feasibility of the proposed method, four different mathematical examples and one power systems were tested: (i) The Sphere function, (ii) The Rosenbrock (or banana-valley) function, (iii) Ackley's function, (iv) The generalized Rastrigin function, and (v) 40-unit system with valve-point effects.

To successfully implement the CR-PSO, some parameters must be assigned in advance. The population size NP and maximum number of iterations $iter_{\max}$ are set to 30 and 500, respectively. Since the performance of PSO depends on its parameters such as inertia weight w and two acceleration coefficients (i.e., c_1 and c_2), it is very important to determine the suitable values of parameters. The inertia weight is varied from 0.9 (i.e., w_{max}) to 0.4 (i.e., w_{min}), as these values are accepted as typical for solving wide varieties of problems. Two acceleration coefficients are determined through the experiments for each problem so as to find the optimal combination.

6.1 Mathematical Examples

For development of user's understanding of the PSO algorithm, six non-linear mathematical examples are used here. In each case, the maximum number of iterations (i.e., $iter_{max}$) was set to 500. The acceleration coefficients (i.e., c_1 and c_2) was equally set to 2 by the experiments for each case using the typical PSO algorithm. And all of the global minimum value of each function is 0.

In conclusion, the global minimum value was successfully verified by this simulator.

6.2 Economic Dispatch (ED) Problems with Valve-point Effects

Because the global minimum total generation cost is unknown, in case of the 40-unit system, the maximum number of iterations(i.e. $iter_{max}$) is set to 10000 in order to sufficiently search the minimum value. And the acceleration coefficients (i.e., c_1 and c_2) was respectively set to 2 and 1 by the experiments for each case using the CR-PSO algorithm. The total demand of 40-unit system are set to 10500MW.

Table 1 shows the minimum, mean, maximum, and standard deviation achieved by the simulator.

Minimum Cost ($)	Average Cost($)	Maximum Cost($)	Standard Deviation
121452.6785	121549.6149	121741.609	114.7923

Table 1. Convergence Results for 40-Unit System

In Table 2, the best results fo 40-unit system achieved by CR-PSO are compared with those from evolutionary programming (EP) [5], modified particle swarm optimization (MPSO) [8], PSO-SQP [9], DEC-SQP [10]. Although the acquired best solution is not guaranteed to be the global solution, the CR-PSO has shown the superiority to the existing methods as shown in Table 5.

Methods	Best Cost ($)	Mean Cost ($)
EP[5]	122624.35	123382.00
MPSO[8]	122252.27	N/A
PSO-SQP[9]	122094.67	122245.25
DEC-SQP[10]	121741.98	122295.13
CR-PSO	121452.68	121549.61

Table 2. Comparison of Results of Each Method for 40-Unit System

It is clear from numerical results that the proposed CR-PSO method outperform other state-of-the-art methods in solving the ED problems with nonsmooth cost functions.

7. Conclusions

This paper presents a development of an educational simulator of particle swarm optimization (PSO) and application for solving the test functions and economic dispatch (ED) problems with nonsmooth cost functions. In developed simulator, lecturers and students can select the functions for simulation and set the parameters that have an influence on PSO performance. To improve searching capability for ED problems, a crossover operation is proposed to the position update of each individual (CR-PSO). These strategies not only improve the global searching ability but also prevent the solution from trapping into a local optimum point. To verify the feasibility of CR-PSO method, numerical studies have been performed for one sample systems. The simulation results have been compared with other state-of-the-art methods, whereby the superiority of proposed algorithm has been proven. Finally, this simulator will be expected to increase understanding of PSO algorithm.

[References]

[1] J. Kennedy and R. Eberhart, "Particle swarm optimization", in Proc. IEE Int. Conf. Neural Networks (ICNN'95), vol. IV, Perth, Australia, 1995, pp.1942-1948.

[2] M. Clerc and J. Kennedy, "The particle swarm-expolsion, stability, and convergence in a multidimensional complex space," IEEE Trans. Evol. Comput., vol. 6, no. 1, pp. 58-73, Feb. 2002.

[3] H. Yoshida, K. Kawata, Y. Fukuyama, S. Takayama, and Y. Nakanishi, "A particle swarm optimization for reactive power and voltage control considering voltage security assessment," IEEE Trans. Power Syst., vol. 15, pp. 1232-1239, Nov. 2000.

[4] J. Kennedy and R. C. Eberhart, Swarm Intelligence. San Francisco, CA: Morgan Kaufmann, 2001.

[5] H. T. Yang, P. C. Yang, and C. L. Huang, "Evolutionary programming based economic dispatch for units with nonsmooth fuel cost functions," IEEE Trans. Power Syst., vol. 11, no. 1, pp. 112-118, Feb. 1996.

[6] N. Sinba, R. Chakrabarti, and P. K. Chattopadhyay, "Evolutionary programming techniques for economic load dispatch," IEEE Trans. Evol. Comput., vol. 7, pp. 83-94, Feb. 2003.

[7] D. C. Walters and G. B. Sheble, "Genetic algorithm solution of economic dispatch with the valve point loading," IEEE Trans. Power Syst., vol. 8, pp. 1325-1332, Aug. 1993.

[8] J. B. Park, K. S. Lee, J. R. Shin, and K. Y. Lee, "A particle swarm optimization for economic dispatch with nonsmooth cost functions," IEEE Trans. Power Syst., vol. 20, no. 1, pp. 34-42, Feb. 2005.

[9] T. A. A. Victoire and A. E. Jeyakumar, "Hybrid PSO-SQP for economic dispatch with valve-point effect," Electric Power Syst. Research, vol. 71, pp. 51-59, Sep. 2004.

[10] T. A. A. Victoire and A. E. Jeyakumar, "Reserve constrained dynamic dispatch of units with valve-point effects," IEEE Trans. Power Syst., vol. 20, No. 3, pp. 1273-1282, Aug. 2005.