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경제급전 문제에의 개선된 PSO 알고리즘 적용

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An Improved Particle Swarm Optimization for Economic Dispatch Problems with Prohibited Operating Zones

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Abstract – This paper presents an efficient approach for solving the economic dispatch (ED) problems with prohibited operating zones using an improved particle swarm optimization (PSO). Although the PSO-based approaches have several advantages suitable to the heavily constrained nonconvex optimization problems, they still have the drawbacks such as local optimal trapping due to the premature convergence (i.e., exploration problem) and insufficient capability to find nearly-by extreme points (i.e., exploitation problem). This paper proposes an improved PSO framework adopting a crossover operation scheme to increase both exploration and exploitation capability of the PSO. The proposed method is applied to ED problem with prohibited operating zones. Also, the results are compared with those of the state-of-the-art methods.

1. INTRODUCTION

Many power system optimization problems including economic dispatch (ED) have nonconvex characteristics with heavy equality and inequality constraints [1]. The objective of ED is to determine the optimal combination of power output to meet the demand at minimum cost while satisfying the constraints. For simplicity, the cost function for each unit in the ED problems has been approximately represented by a single quadratic function and is solved using mathematical programming techniques [2]. Generally, these mathematical methods require the first or higher order derivative information of the cost function to find the optimal solution. Unfortunately, the input-output characteristics of generating units are nonconvex due to prohibited operating zones, valve-point loadings, and multi-fuel effects, etc. Thus, the practical ED problem should be represented as a nonconvex optimization one with the constraints, which cannot be directly solved by the mathematical methods. Over the past decade, to solve these problems, many salient methods have been developed [3]-[5].

Particle swarm optimization (PSO) is one of the modern heuristic algorithms suitable to solve nonconvex optimization problems with multiple minima. It is a population-based search algorithm and searches in parallel using a group of particles similar to other AI optimization techniques. The PSO suggested by Kennedy and Eberhart in 1995 is based on the analogy of swarm of bird and school of fish [6]. In PSO, each particle makes its decision using its own experience together with its neighbor's experiences. The main advantages of the PSO algorithm are summarized as simple concept and easy implementation, relative robustness to control parameters, and computational efficiency, etc. [1].

This paper proposes a PSO-based approach for the nonconvex ED problems with the heavy constraints. In order to overcome the existing drawbacks of PSO to some extents, this paper proposes an improved PSO framework combining the crossover operation (COPSO). The newly-introduced crossover operation inspired by GA can increase the diversity of the population in PSO mechanism. The employment of the crossover operation in the PSO framework can improve the global searching capability by preventing the premature convergence through increasing the diversity of the population. The suggested COPSO is applied to ED problem with prohibited operating zones and the solutions of COPSO are compared with those of the state-of-the-art AI methods.

2. FORMULATION OF ECONOMIC DISPATCH

2.1 Basic ED Formulation

The objective of the ED problem is to minimize the total fuel cost of thermal power plants subjected to the operating constraints of a power system. In general, it can be formulated mathematically with an objective function and two constraints [2].

$$F = \sum_{i=1}^{n} F_i(P_i) \tag{1}$$

$$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 \tag{2}$$

where F is the total generation cost, F_i the is cost function of generator *i*, a_i, b_i, c_i are the cost coefficients of generator *i*, P_i is the power output of generator *i*, and n is the number of generators.

For power balance, an equality constraint should be satisfied. The total generated power should be the same as the total load demand plus the total line loss. The transmission loss is not considered in this paper for simplicity. In addition, generation output of each generator should be laid between minimum and maximum limits. The corresponding inequality constraint for each generator is

$$P_{i,\min} \le P_i \le P_{i,\max} \tag{3}$$

where $P_{i,\min}$ and $P_{i,\max}$ are the minimum and maximum output of generator *i*, respectively.

2.2 ED Problem Considering Prohibited Operating Zones

In some cases, the entire operating range of a generating unit is not always available due to the physical operation limitations. Units may have the prohibited operating zones due to the faults in the machines themselves or the associated auxiliaries. Such faults may lead to instability in certain ranges of generator power output [3]. Therefore, for units with prohibited operating zones, there are additional constraints on the unit operating range as follows:

$$P_i \in \begin{cases} P_{i,\min} \le P_i \le P_{i,1}^{l} \\ P_{i,k-1}^{u} \le P_i \le P_{i,k}^{l} & k = 2,3,\cdots,pz_i \\ P_{i,pz_i}^{u} \le P_i \le P_{i,\max} & \qquad i = 1,2,\cdots,n_{PZ} \end{cases} \tag{4}$$

where $P_{i,k}^{l}$ and $P_{i,k}^{u}$ are the lower and upper boundary of prohibited operating zone of unit *i*, respectively. Here, pz_i is the number of prohibited zones of unit *i* and n_{PZ} is the number of units which have prohibited operating zones.

3. PSO WITH CROSSOVER OPERATION FOR ED PROBLEMS

3.1 Particle Swarm Optimization

Kennedy and Eberhart developed a PSO algorithm based on the behavior of individuals (i.e., particles or agents) of a swarm [6]. Particles in a swarm approach to the optimum through its present velocity, its previous experience, and the experience of its neighbors. In a *n*-dimensional search space, the position and velocity of particle *i* are represented as the vectors $X_i = (x_{i1}, \cdots, x_{in})$ and $V_i = (v_{i1,} \cdots, v_{in})$ in the PSO algorithm. Let $Pbest_i = (x_{i1}^{P}, \cdots, x_{in}^{P})$

and $Gbest = \left(x_1^G, \cdots, x_n^G\right)$ be the best position of particle *i* and its neighbors' best position so far, respectively. The modified velocity and position of each particle can be calculated using the current velocity and the distance from $Pbest_i$ to $Gbest$ as follows:

$$V_i^{k+1} = w V_i^k + c_1 rn_1 \left(Pbest_i^k - X_i^k\right) + c_2 rn_2 \left(Gbest^k - X_i^k\right) \tag{5}$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \tag{6}$$

where,

V_i^k	velocity of particle *i* at iteration *k*,
w	inertia weight factor,
c_1, c_2	acceleration coefficients,
rn_1, rn_2	random numbers between 0 and 1,
X_i^k	position of particle *i* at iteration *k*,
$Pbest_i^k$	best position of particle *i* until iteration *k*,
$Gbest^k$	best position of the group until iteration *k*.

In velocity updating process, the values of parameters such as w, c_1, and c_2 should be determined in advance. The constants c_1 and c_2 represent the weighting of the stochastic acceleration terms that pull each particle toward the $Pbest_i$ and $Gbest$ positions. The inertia weight w has a linearly decreasing dynamic parameter framework (i.e., Inertial Weights Approach [IWA] [1], [7]) descending from $w_{\max}$ to $w_{\min}$ to enhance the convergence characteristics as follows.

$$w^k = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times k \tag{7}$$

Here, $iter_{\max}$ is the maximum iteration number and k is the current iteration number.

3.2 Crossover Operation

In order to increase the diversity of a population, the crossover operation is newly introduced in the existing PSO, thereby can effectively explore and exploit the promising regions in a search space. The position of particle *i* modified by (10) is mixed with $Pbest_i$ to generate the trial vector $\widehat{X}_i = \left(\hat{x}_{i1}, \cdots, \hat{x}_{in}\right)$ as follows:

$$\hat{x}_{ij}^{k+1} = \begin{cases} x_{ij}^{k+1} & \text{if } r_{ij} \leq CR \\ x_{ij}^{P,k} & \text{otherwise} \end{cases} \tag{8}$$

for *j*=1,2,…,*n*. r_{ij} is the uniformly distributed random number between [0,1], and *CR* is the crossover rate in the range of [0,1]. When the value of *CR* becomes one, there is no crossover like as the conventional PSO. If the value of *CR* is zero the position of each position will always be experienced the crossover operation similar to the GA mechanism. The proper crossover rate *CR* will be determined by the empirical studies to improve the diversity of a population.

4. CASE STUDY

The experiments are performed on the 15-unit power system where four units have up to the three prohibited operating zones. The prohibited zones are existed in unit 2, 5, 6 and 12. The system supplies a load of 2,650MW with 200MW spinning reserve. All the system data and related constraints of the test system are provided in [3]. The population size *NP* and maximum iteration $iter_{\max}$ are set as 30 and 1,000, respectively. Since the performance of the proposed COPSO can depend on the parameters such as inertia weight w, two acceleration coefficients, and crossover rate, it is important to determine the suitable values of parameters. As for the linearly decreasing dynamic inertia weight, the starting value (i.e., $w_{\max}$) is set as 0.9 and the ending value (i.e., $w_{\min}$) as 0.4 since these values are widely accepted in solving various optimization problems [7]. The values for c_1, c_2, and *CR* are determined as 2.0, 2.0, and 0.2, respectively.

In Table 1, the results obtained by the proposed COPSO are compared with those from previous works. The proposed COPSO method always provides the same solution in 100 independent trials. Although the acquired best solution from COPSO is not guaranteed to be the global solution, the proposed algorithm has shown the superiority to the previous researches as described in Table 1.

<Table 1> Comparison of Results of Various Methods

Unit	DCGA [6]	IFEP [11]	ETQ [19]	COPSO
1	406.1	455	450	455
2	453.8	450.845	450	455
3	130	130	130	130
4	130	130	130	130
5	355	259.791	335	260
6	456.8	460	455	460
7	459.8	15.002	465	465
8	60	60.014	60	60
9	26.6	25.008	25	25
10	21.6	20.045	20	20
11	36.2	62.109	20	60
12	59	77.172	55	75
13	25	25	25	25
14	15	15.008	15	15
15	15	465	15	15
TP	2649.9	2649.994	2650	2650
TC	32515	32507.46	32507.5	32506.139

5. CONCLUSION

This paper proposes a new PSO-based approach for solving the nonconvex ED problems. The proposed PSO employs the crossover operation to enhance the performance of the conventional PSO. The crossover operation is introduced to increase the diversity of the population. The application of crossover operation in PSO is an efficient strategy not only to improves the global searching ability but also to prevents the solution from trapping into a local optimum point. The proposed COPSO algorithm has been successfully applied to ED problem considering prohibited operating zones and found better solutions for the test system than other solutions investigated until now. The results clearly show that the suggested PSO framework can be used as an efficient optimizer providing satisfactory solutions for the nonconvex ED problems.

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