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Modified particle swarm optimization for nonconvex economic dispatch problems

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ABSTRACT

This paper presents modified particle swarm optimization to solve economic dispatch problems with non-smooth/non-convex cost functions. Particle swarm optimization performs well for small dimensional and less complicated problems but fails to locate global minima for complex multi-minima functions. This paper proposes Gaussian random variables in velocity term which improves search efficiency and guarantees a high probability of obtaining the global optimum without considerably worsening the speed of convergence and the simplicity of the structure of particle swarm optimization. The efficacy of the proposed method has been demonstrated on four test problems and four different non-convex economic dispatch problems with valve-point effects, prohibited operating zones with transmission losses, multiple fuels with valve point effects and the large-scale Korean power system with valve-point effects and prohibited operating zones. The results of the proposed approach are compared with those obtained by other evolutionary methods reported in the literature. It is found that the proposed modified particle swarm optimization based approach is able to provide better solution.

Introduction

Economic dispatch (ED) is an important optimization task in power system operation for allocating generation among the committed generating units in the most economical manner while satisfying various physical constraints. The cost function of a generator is approximated by using quadratic or piecewise quadratic functions [1]. But actual input–output characteristics of fossil fuel fired generating plants show high nonlinearities and discontinuities due to valve-point effects [2]. The valve-point effects [2,3] have been modeled by incorporating the sinusoidal function into the quadratic function, such as the one shown in Fig. 1.

Shaft bearing tremor caused by a steam admission valve or the machine fault or the associated auxiliary equipment fault can produce prohibited operating zones [4,5,7] in the input–output curve of a thermal unit. The silhouette of the input–output curve in the vicinity of a prohibited zone is tricky to find out by actual performance testing. The best economy is accomplished by circumventing operation in these areas [4,7]. Cost function taking into account prohibited operating zones, can be represented as in Fig. 2.

The valve-point effects, prohibited operating zones and other constraints create the non-convex decision space.

The calculus-based methods cannot handle these types of problems. The dynamic programming (DP) method [8] has no restriction on the shape of the objective function and can solve ED problems with non-smooth and discontinuous cost curves. However, this method suffers from the curse of dimensionality or local optimality.

The advent of meta-heuristic algorithms shows potential to solve complex ED problems. Genetic algorithms (GAs) [3–6], Hopfield neural network (HNN) [9], simulated annealing (SA) [10], evolutionary programming (EP) [11,12], improved tabu search (ITS) [2], particle swarm optimization (PSO) [1,13–16], evolutionary strategy optimization (ESO) [7], ant colony optimization (ACO) [17], differential evolution (DE) [18,19], artificial immune system (AIS) [20], bacterial foraging algorithm (BFA) [21], biogeography-based optimization (BBO) [22], continuous quick group search optimizer [23] etc. have been proposed to date and applied effectively to solve ED problems. Though these methods cannot attain the global optima, they often accomplish near global optimal solution.

Since the 1989, swarm intelligence algorithms inspired from the collective behavior of a group of social insect colonies and of other animal societies have emerged. Particle swarm optimization (PSO), introduced in 1995 by Kennedy and Eberhart [24], is inspired by social behavior of organisms such as bird herding and fish training. It is a flexible, robust and population based self-adaptive algorithm with inherent parallelism.

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PSO has been used for many power system problems such as distribution state estimation [30], optimal reactive power dispatch [31], optimal strategies for the electricity producers [32], optimal power flow [33], distribution system feeder reconfiguration [34], optimum location and sizing of distribution static synchronous series compensator [35] apart from ED due to its simplicity, superior convergence characteristics and high solution quality.

But, PSO suffers from premature convergence, particularly for complex functions having multiple minima. After the introduction of PSO, to improve its performance, many variations have been proposed for PSO by various researchers [25–29].

To overcome the problem of premature convergence, this paper proposes modified particle swarm optimization (MPSO). In this approach, Gaussian random variables are introduced in velocity term which improves search efficiency and guarantees a high probability of obtaining the global optimum without considerably worsening the speed of convergence and the simplicity of the structure of PSO.

In this study, modified particle swarm optimization (MPSO), self-organizing hierarchical particle swarm optimizer with time-varying acceleration coefficients (HPSO-TVAC) and particle swarm optimization with time-varying inertia weight (PSO-TVIW) have been applied to solve four test problems and four non-smooth/non-convex ED problems with valve-point effects, prohibited operating zones with transmission losses, multiple fuels with valve point effects and the large-scale Korean power system with valve-point effects and prohibited operating zones. The performance of the proposed method has been compared with other evolutionary methods. It is found that the proposed MPSO based approach provides better solution.

Problem formulation

The objective of the ED is to minimize the total fuel cost of a power system while satisfying various constraints. The non-smooth/non-convex ED problem takes into account valve-point loading effects, prohibited operating zones and multi-fuel options along with system power demand, transmission loss and operational limit constraints.

Economic dispatch problem considering prohibited operating zones and transmission losses

The ED problem can be described as a minimization problem with the objective:

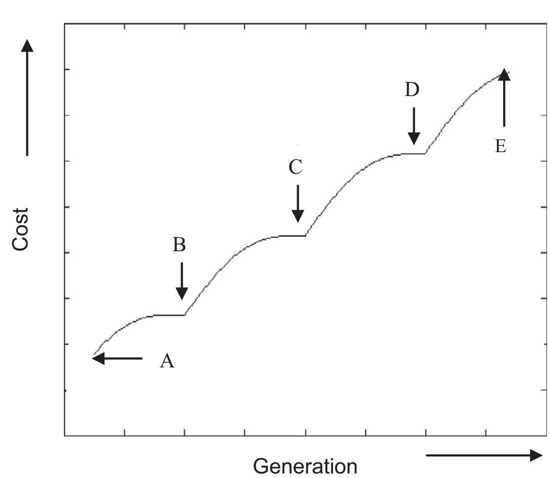

Fig. 1. Example of valve-point cost function with 5 valves. A – primary valve, B – secondary valve, C – tertiary valve, D – quaternary valve, E – quandary valve.

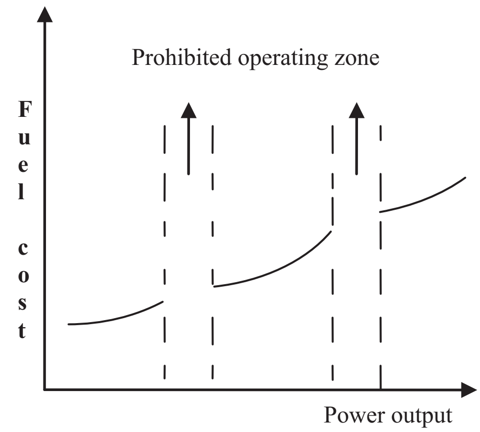

Fig. 2. Input–output curve with prohibited operating zones.

$$\mathrm{Min}\sum_{j=1}^{N}F_j(P_j) = \sum_{j=1}^{N}a_j + b_jP_j + c_jP_j^2 \tag{1}$$

where $F_j(P_j)$ is the fuel cost function of jth unit. a_j, b_j and c_j are the fuel cost coefficients of jth unit. N is the number of committed units; P_j is the power output of jth unit.

Subject to the following constraints

(i) Power balance constraint:

$$\sum_{j=1}^{N}P_j - P_D - P_L = 0 \tag{2}$$

The transmission loss P_L is a function of real power outputs of all units. There are two approaches to calculate transmission loss, i.e. load flow approach and Kron's loss formula. Kron's loss formula known as B-coefficient loss formula is used in this work. The transmission loss P_L can be stated as follows

$$P_L = \sum_{l=1}^{N}\sum_{j=1}^{N}P_lB_{lj}P_j + \sum_{j=1}^{N}B_{0j}P_j + B_{00} \tag{3}$$

where P_D is the system load demand. B_{lj}, B_{0j} and B_{00} are B-coefficients.

(ii) Generating limit constraints

Each generator power output should be within its lower limit $P_j^{\min}$ and upper limit $P_j^{\max}$ such that

$$P_j^{\min} \leqslant P_j \leqslant P_j^{\max} \quad j \in N \tag{4}$$

(iii) Prohibited operating zone

The feasible operating zones of a unit with prohibited operating zones can be described as follows:

$$\begin{aligned} &P_j^{\min} \leqslant P_j \leqslant P_{j,1}^{l} \\ &P_{j,r-1}^{u} \leqslant P_j \leqslant P_{j,r}^{l}, \quad r = 2,3,\ldots,n_j \\ &P_{j,r_i}^{u} \leqslant P_j \leqslant P_j^{\max}, \quad j \in N \end{aligned} \tag{5}$$

where r represents the number of prohibited operating zones of $i$the unit. $P_{j,r-1}^{u}$ is the upper limit of $(r-1)$th prohibited operating zone of j the unit. $P_{j,r}^{l}$ is the lower limit of rth prohibited operating zone of j the unit. Total number of prohibited operating zone of j the unit is n_j.