Electrical Power and Energy Systems 80 (2016) 325–332

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Kinetic gas molecule optimization for nonconvex economic dispatch problem

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ARTICLE INFO

Article history:
Received 3 November 2014
Received in revised form 28 November 2015
Accepted 4 February 2016
Available online 16 February 2016

Keywords:
Kinetic gas molecule optimization
Economic dispatch
Prohibited operating zones
Valve-point loading
Multi-fuel option

ABSTRACT

This paper presents kinetic gas molecule optimization (KGMO) algorithm to solve economic dispatch problems with non-smooth/non-convex cost functions. KGMO is based on kinetic energy and the natural motion of gas molecules. The effectiveness of the proposed method has been verified on 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. It is found that the proposed KGMO 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 input–output characteristics or cost functions of a generator are approximated by using quadratic or piecewise quadratic functions, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions [1]. However, real input–output characteristics show higher-order nonlinearities and discontinuities due to valve-point loading in fossil fuel fired generating plants [2]. The valve-point loading effect has been modeled in [2,3] as a recurring rectified sinusoidal function, such as the one shown in Fig. 1.

The discontinuous prohibited operating zones in the input–output performance curve for a typical thermal unit can be due to vibration in a shaft bearing caused by a steam valve or can be due to faults in the machines themselves or the associated auxiliary equipment, such as boilers and feed pumps [4,5,7]. In practice, the shape of the input–output curve in the neighborhood of a prohibited zone is difficult to determine by actual performance testing. In actual operation, the best economy is achieved by avoiding operation in these areas [4,7]. Cost function that takes into account prohibited operating zones, can be represented as in Fig. 2.

The valve-point loading, prohibited operating zones, ramp-rate limits and other constraints turn the decision space into disjoint subsets, transforming the ED problem into a difficult non-smooth, non-convex optimization problem.

The calculus-based methods fail to address these types of problems. The dynamic programming (DP) approach [8] imposes no restriction on the nature of the cost curves and can solve ED problems with non-smooth and discontinuous cost curves. However, this method suffers from the curse of dimensionality or local optimality.

Modern meta-heuristic algorithms are a promising alternative for solution of complex ED problems. Genetic algorithms (GAs) [3–6], Hopfield neural network (HNN) [9], simulated annealing (SA) [10–12], evolutionary programming (EP) [13,14], improved tabu search (ITS) [2], particle swarm optimization (PSO) [1,15–18], evolutionary strategy optimization (ESO) [7], ant colony optimization (ACO) [19], differential evolution (DE) [20–22], artificial immune system (AIS) [23], bacterial foraging algorithm (BFA) [24], biogeography-based optimization (BBO) [25], continuous quick group search optimizer [26], etc. have been developed so far and applied successfully to solve ED problems. Although these methods do not always guarantee global best solutions, they often achieve a fast and near global optimal solution.

Very recently, a new metaheuristic optimization concept, based on kinetic energy of gas molecules, has been proposed by Moein and Logeswaran [27].

In this study, the (KGMO) is applied to solve four non-smooth/non-convex ED problems with valve-point effects, prohibited

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http://dx.doi.org/10.1016/j.ijepes.2016.02.005
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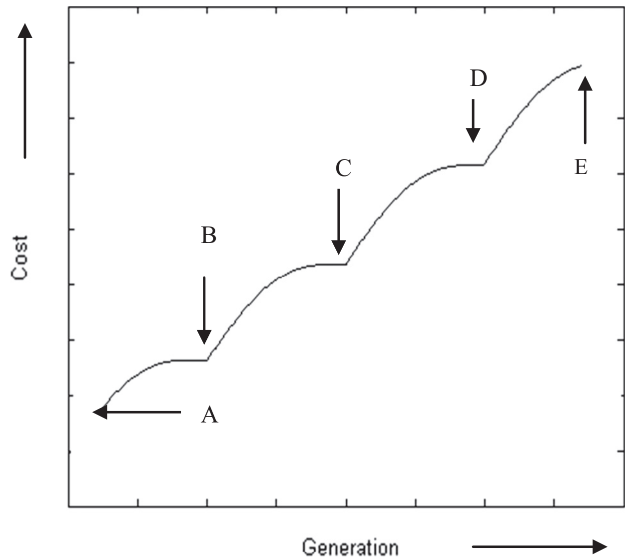

Fig. 1. Example of valve-point cost function with 5 valves. A – Primary Valve. B – Secondary Valve. C – Tertiary Valve. D – Quaternary Valve. E – Quandary Valve.

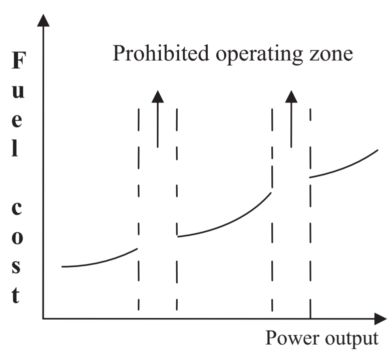

Fig. 2. Input–output curve with prohibited operating zones.

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 reported in the literature. It is found that the proposed KGMO based approach provides better solution.

Problem formulation

The objective of the ED is to minimize the total generation cost of a power system over some appropriate period while satisfying various constraints. The practical non-smooth/non-convex ED problem considers generator nonlinearities such as 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 process with the objective:

$$\text{Min} \sum_{i=1}^{N} F_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 \tag{1}$$

where $F_i(P_i)$ is the fuel cost function of ith unit. a_i, b_i and c_i are the fuel cost coefficients of ith unit. N is the number of committed units; P_i is the power output of ith unit.

Subject to the following constraints

(i) Power balance constraint:

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \tag{2}$$

The transmission loss P_L may be expressed by using B-coefficients as

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{3}$$

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

(ii) Generation capacity constraints
The power generated by each unit should be within its lower limit $P_i^{\min}$ and upper limit $P_i^{\max}$, so that

$$P_i^{\min} \leqslant P_i \leqslant P_i^{\max} \quad i \in N \tag{4}$$

(iii) Prohibited operating zone
The feasible operating zones of a unit with prohibited operating zones can be described as follows:

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

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

Economic dispatch problem considering valve-point effects and transmission losses

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

$$\text{Min} \sum_{i=1}^{N} F_i(P_i) = \sum_{i=1}^{N} a_i + b_i P_i + c_i P_i^2 + |d_i \times \sin\{e_i \times (P_i^{\min} - P_i)\}| \tag{6}$$

where d_i and e_i are the fuel cost coefficients of ith unit with valve-point effects.

The above objective function is to be minimized subject to constraints as mentioned in (2) and (4).

Economic dispatch problem considering valve-point effects and multiple fuels

Since generators are practically supplied with multi-fuel sources [6], each generator should be represented with several piecewise quadratic functions superimposed sine terms reflecting the effect valve-point effect of fuel type changes and the generator must identify the most economical fuel to burn. The fuel cost function of the ith generator with N_F fuel types is expressed as

$$F_i(P_i) = \alpha_{ij} + \beta_{ij} P_i + \gamma_{ij} P_i^2 + |\eta_{ij} \times \sin\{\delta_{ij} \times (P_{ij}^{\min} - P_i)\}| \tag{7}$$

if $P_{ij}^{\min} \leqslant P_i \leqslant P_{ij}^{\max}$ for fuel type j and $j = 1, 2, \ldots, N_F$