Energy Conversion and Management 52 (2011) 1334–1342

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Multiobjective bacteria foraging algorithm for electrical load dispatch problem

B.K. Panigrahi [a,*], V. Ravikumar Pandi [a], Renu Sharma [b], Swagatam Das [c], Sanjoy Das [d]

[a] Department of Electrical Engineering, IIT, Delhi, India
[b] Department of Electrical and Electronics Engg, ITER, SOA University, Bhubaneswar, Orissa, India
[c] Department of Electronics and Communication Engineering, Jadavpur University, Kolkata, India
[d] Department of Electrical and Computer Engineering, Kansas State University, USA

ARTICLE INFO

Article history:
Received 8 May 2009
Received in revised form 27 January 2010
Accepted 22 September 2010
Available online 27 October 2010

Keywords:
Environmental/economic dispatch
Pareto front
Multiobjective optimization
Bacterial foraging
Non-dominated sorting

ABSTRACT

In this paper the bacteria foraging meta-heuristic is extended into the domain of multiobjective optimization. In this multiobjective bacteria foraging (MOBF) optimization technique, during chemotaxis a set of intermediate bacteria positions are generated. Next, we use pareto non-dominance criterion to determine final set of bacteria positions, which constitute the superior solutions among current and intermediate solutions. To test the efficacy of our proposed algorithm we have chosen a highly constrained optimization problem namely economic/emission dispatch. Economic dispatch is a constrained optimization problem in power system to distribute the load demand among the committed generators economically. Now-a-days environmental concern that arises due to the operation of fossil fuel fired electric generators and global warming, transforms the classical economic load dispatch problem into multiobjective environmental/economic dispatch (EED). In the proposed work, we have considered the standard IEEE 30-bus six-generator test system on which several other multiobjective evolutionary algorithms are tested. We have also made a comparative study of the proposed algorithm with that of reported in the literature. Results show that the proposed algorithm is a capable candidate in solving the multiobjective economic emission load dispatch problem.

1. Introduction

The operations of electrical power systems are designed to meet the continuous variation of power demand. In essence, to ensure economic operation, power generation scheduling is performed based on two important tasks, unit commitment and economic dispatch, of which, later is the topic of present research. The purpose of traditional economic dispatch is to allocate generation levels to various generators in the system in order to meet the load demand in the most economic way. However, the optimum schedule obtained may not be the best, in case environmental criteria are also considered. The passage of the clean air act amendments in 1990 has forced the utilities to reduce their SO_2 and NO_X emissions by 40% from 1980 levels [1]. Therefore, apart from cost, emission objective must also be taken into account.

Environmental/economic dispatch (EED) is a multiobjective problem having conflicting objectives, as the minimization of cost maximizes the pollution, leads to the necessity of trade-off analysis to define admissible dispatch policies for any demand level [2]. There has been much research pertaining to EED problem. The influence of power pools on power dispatch with environmental consideration is analyzed by taking emission as the constraints of the model and power is dispatched by minimizing cost as single objective [3]. The constrained emission approach is considered in [4], and solved for dynamic power dispatch using Han-Powell algorithm. The multiobjective problem considering cost, emission and line over load index as objectives is solved using ε-constrained method in [5]. The method involves the optimization of most preferred objective while considering other objectives as constraints, which are bounded by some allowable level ε. However, the approach provided only weakly non-dominated solution and that too in considerably large time. The economic emission dispatch is solved by weighted min–max approach along with risk in expected power deviations as third objective [6]. The EED problem with line flow security constraint is solved by weighted sum method in [7] to convert the multiobjective EED problem in single objective optimization problem. These methods generate the non-dominated solution by varying the weights, thus requiring multiple runs to generate the desired Pareto set of solutions. Moreover, these methods are not efficient in solving problems having non-convex Pareto-optimal fronts. A linear programming based technique has been proposed in [8] which consider one objective at a time. But the approach failed to give any information regarding the trade-off front. The multiobjective EED problem with security constraints is solved for longitudinal power system by using weighted sum method and

* Corresponding author. Tel./fax: +91 11 2659 1078.
E-mail address: bkpanigrahi@ee.iitd.ac.in (B.K. Panigrahi).

0196-8904/$ - see front matter
doi:10.1016/j.enconman.2010.09.031

the combined objective is optimized by simulated annealing approach [9] and genetic algorithm [10].

Recently, the research focus has shifted towards handling both the objectives simultaneously. Over the past decade, this option has received much interest due to the development of a number of multiobjective evolutionary search strategies [11]. The combination of real coded genetic algorithm and simulated annealing techniques to solve the EED problem is given in [12] as Multiobjective Stochastic Search Technique (MOSST). The novel Non-dominated Sorting Genetic Algorithm (NSGA) [13], Niched Pareto Genetic Algorithm (NPGA) [14] and Strength Pareto Evolutionary Algorithm (SPEA) [15] was successfully applied to EED problem by Abido. Deb et al. [16,17] developed elitist multiobjective evolutionary algorithm called NSGA-II and applied to EED problem. The EED problem with three unit and six unit system is solved by Multiobjective Evolutionary Programming approach (MOEP) in [18]. Multiobjective Particle Swarm Optimization (MOPSO) [19], Fuzzified multiobjective particle swarm optimization (FMOPSO) [20], Fuzzy clustering based Particle swarm optimization (FCPSO) [21], Multiobjective chaotic particle swarm optimization (MOCPSO) [22], and an improved quantum-behaved particle swarm optimization method (QPSO) [23], etc., constitutes the pioneering multiobjective approaches based on particle swarm optimization that have earlier been applied to solve the multiobjective environmental/economic dispatch problem. These algorithms have been implemented on standard IEEE 30-bus 6-generator system in order to obtain the trade-off between the cost and emission. In this paper we have tried to develop a new multiobjective algorithm to obtain a pareto-optimal set of solutions for the above-mentioned problem. The multiattribute decision making (MADM) from the obtained Pareto-optimal front (POF) of multiobjective EED problem is given in [24]. The EED problem with the large penetration of wind energy is considered in [25]. In this paper the problem is solved using the simulated annealing liked particle swarm optimization (SA-PSO). The decision making tool has also been developed using Interactive Bi-objective programming with Valuable Trade-off (IBVT).

In 2002 K.M. Passino proposed a new optimization technique Bacteria Foraging Optimization Algorithm (BFOA) [26,27]. An individual *E. coli* bacterium in a foraging swarm takes necessary action to maximize the energy utilized per unit time spent for foraging, considering all the constraints presented by its own physiology such as sensing and cognitive capabilities, environment. This natural foraging strategy can lead to optimization and this forms the theoretical basis of BFOA. Based on this conception, Passino proposed an optimization technique known as the Bacterial Foraging Optimization Algorithm. Until date, single objective BFOA has successfully been applied to real world problems like parameter estimation of harmonic power signals using least square approach [28], transmission loss reduction based on optimally selecting the FACTS devices and its parameters [29], and active power filter synthesis by choosing the optimal PID parameters [30]. The hybrid combination of genetic algorithm and bacterial foraging algorithm is proposed in [31].

The objective of the proposed paper is to develope the multiobjective bacterial foraging algorithm and its application to environmental/economic load dispatch problem. The rest of the paper is organized as follows. In Sections 2 and 3, we outline the classical BFOA and multiobjective optimization respectively. Section 4 describes formulation of the novel multiobjective bacteria foraging (MOBF) algorithm. In Section 5, EED problem is briefly stated. Section 6 describes the simulation strategy for implementing the EED problem. Section 7 provides detailed experimental results comprising of final pareto-fronts obtained by MOBF as well as for competitive algorithms. Various numerical metrics are computed in order to evaluate performance of various algorithms. Best compromise solution is determined applying a fuzzy technique. Also comparisons are carried out with the results reported in standard literature.

2. The classical BFOA algorithm

The bacterial foraging system consists of four principal mechanisms, namely chemotaxis, swarming, reproduction and elimination-dispersal and all the above major four steps are nicely reported in [26].

3. Multiobjective optimization: a brief overview

Multiobjective optimization involves the simultaneous optimization of several incommensurable and often competing objectives [11]. In the absence of any preference information, a non-dominated set of solutions is obtained, instead of a single optimal solution. These optimal solutions are termed as Pareto optimal solutions.

Let us consider a minimization problem

$$\text{Minimize} \quad J(\vec{\theta}) = (J_1(\vec{\theta}), J_2(\vec{\theta}), \ldots J_M(\vec{\theta})) \tag{1}$$

Subjected to constraints

$$g_i(\vec{\theta}) = 0, i = 1, 2 \ldots m \tag{2}$$

$$h_j(\vec{\theta}) \leq 0, j = 1, 2, \ldots n \tag{3}$$

where $\vec{\theta}$ is called the decision vector, M is the number of objectives and m and n are the number of equality and inequality constraints respectively. Any solution vector a dominates b, if and only if a is partially less than b ($a <_p b$) i.e. $\forall i \in \{1, 2, \ldots M\}$

$$J_i(a) \leq J_i(b) \tag{4}$$

Those solutions, which are not dominated, by other solutions of a given set are considered non-dominated, regarding that set. The front obtained by mapping these non-dominated particles into objective space is called Pareto-optimal front, *POF*.

$$POF = \{\vec{J} = (J_1(\vec{\theta}), J_2(\vec{\theta}), \ldots J_M(\vec{\theta})) | \vec{\theta} \in S\} \tag{5}$$

where S is the set of obtained non-dominated particles. The determination of complete Pareto-optimal front is a very difficult task owing to the computational complexity involved in its computation due to the presence of a large number of suboptimal Pareto fronts. Considering the existing memory constraints, the determination of the complete Pareto front becomes infeasible, and thus requires the solutions to be diverse covering maximum possible regions of it.

During past decade, a variety of stochastic approaches like NSGA [13], NPGA [14], SPEA [15], NSGA-II [16,17], MOEP [18], MOPSO [19], FMOPSO [20], FCPSO [21], MOCPSO [22], and QPSO [23] etc., have been proposed. The NSGA is improved by Deb et al. [16] as NSGA-II with better elitism techniques which alleviates various shortcomings of NSGA and is found to be very efficient for multiobjective optimization. Zitler et al. [32] made a comparative study of multiobjective evolutionary algorithm with Strength Pareto Evolutionary Algorithm (SPEA). The improvement in SPEA algorithm is established and called as SPEA-II [33], which is also another robust algorithm. Coello et al. [34] came up with Multiobjective Particle Swarm Optimization, a powerful tool in multiobjective problem handling. Following the footsteps of these algorithms we have tried to develop a new multiobjective optimization algorithm using chemotactic operator of BFOA.