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A novel multi-objective directed bee colony optimization algorithm for multi-objective emission constrained economic power dispatch

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ABSTRACT

In this paper, a multi-objective directed bee colony optimization algorithm (MODBC) is comprehensively developed and successfully applied for solving a multi-objective problem of optimizing the conflicting economic dispatch and emission cost with both equality and inequality constraints is showcased. Classical optimization techniques like direct search and gradient methods fail to give the global optimum solution. The proposed algorithm is an integration of the deterministic search, the multi-agent system (MAS) environment and the bee decision-making process. Thus making use of deterministic search, multi-agent environment and bee swarms, the MODBC realizes the purpose of optimization. The hybridization makes MODBC to obtain a unique and fast solution and hence generate a better pareto front for multi-objective problems. The above mentioned multi-objective evolutionary algorithms have been applied to the standard IEEE 30 bus six generator test system. Results of the proposed algorithm have been compared with traditional methods like linear programming (LP) and multi-objective stochastic search technique (MOSST). The performance of the introduced algorithm is also compared with other evolutionary algorithms like Non-dominated Sorting Genetic Algorithm (NSGA), Niched Pareto Genetic Algorithm (NPGA) and Strength Pareto Evolutionary Algorithm (SPEA) and Particle Swarm Optimization (PSO). The results show the robustness and accuracy of the proposed algorithm over the traditional methods and its other multi-objective evolutionary algorithm (MOEA) counterparts.

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1. Introduction

Economic dispatch is characterized as the procedure of allocating generation points to the generation units so that the entire system load is supplied, meeting all the system constraints economically. Real-world applications usually involve simultaneous optimization of multiple objectives, which are generally non-commensurable and conflicting with each other. The purpose of multi-objective optimization algorithms in the mathematical programming framework is to optimize different objective functions, subject to a set of system constraints. There are mainly two objectives for any power generation industry, one is to minimize the emission of pollutants and other is to curtail the cost of generation. It becomes very necessary to find an optimal solution for both the functions simultaneously.

Many researchers have studied the environmental/economic dispatch problem either by considering the emission as a second objective function or as additional constraints. Many techniques have been proposed to handle the problem such as taking emission as a constraint [1,2], goal programming [3]. If emission is taken as a constraint then it is difficult to obtain the relation between the cost and emission. The weighting method simply assigns different weights to each objective function based on its importance and combines different objectives into one single objective function. The result of solving the problem using this approach is highly dependent on the assigned weights. Goal programming is implemented by assigning a goal or value to be achieved for each objective function. These values are incorporated into the problem as additional constraints. If prior knowledge about the solution feasible space is known then only this algorithm can be applied. Goal programming becomes inefficient if any of the goals selected becomes infeasible.

Evolutionary algorithms exterminate some of the above mentioned difficulties. Some of the Algorithms discussed in this paper are: Non-dominated Sorting Genetic Algorithm (NSGA) [4], Niched Pareto Genetic Algorithm (NPGA) [5], Strength Pareto Evolutionary Algorithm (SPEA) [6] and Particle Swarm Optimization [7]. Collective behavior of decentralized, self-organized systems which mimic the natural behavior of organisms is the characteristics of Swarm Intelligence (SI). The agents follow very simple rules, and although there is no centralized control structure dictating how individual agents should behave, local interactions between such agents lead to the emergence of complex global behavior [9]. A

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natural example of SI includes ant colonies, bird flocking, animal herding, bacterial growth, and fish schooling. Various algorithms derive from SI are the Ant Colony Optimization (ACO), GA and Particle Swarm Optimization (PSO) [10,11,16]. Particle Swarm Optimization (PSO) algorithm is based on social behavior of groups like flocking of birds or schooling of fish. It is a stochastic, population-based evolutionary computer algorithm for problem solving. It is a kind of swarm intelligence that predicts everyone solution as "particles" which evolve or change their positions with time. Each particle modifies its position in search space in accordance with its own experience and also that of neighboring particle by remembering the best position visited by itself and its neighbors, then calculating local and global positions.

In this paper, we use our own developed a new algorithm renamed as MODBC for multi-objective problems [13–15], which is a hybrid version on MAS, which mimics its structure and modified Nelder–Mead method to find an optimal solution. The decision making technique is mimicked from bee decision-making process. The decision-making process is based on the algorithm used by bees for finding a suitable place for establishing new colony. The experimental results show the robustness and accuracy of MODBC over genetic algorithm and PSO. Due to its hybrid nature, this algorithm provides only deterministic solutions. Making use of these agents–agent interactions and evolution mechanism of bee swarms in a lattice-like environment, the proposed method can find high-quality solutions reliably with the faster convergence characteristics in a reasonably good computation time.

This paper is organized as follows. The hybrid algorithm is comprising of two parts search algorithm and other as the decision making process. Section 2 details, the problem formulation and the related issues. The development and working of the MODBC is elaborated in Section 3. The starting point and the number of agents are important issues while handling such algorithms. The choice of the number of agents and the starting point of search are also presented and discussed. The decision making process in the honey bees makes them an interesting swarm research area to work. Section 4 also discusses the decision making method used by the bees in the proposed algorithm. Section 5 discusses simulation and experimental results made on the problem formulated. Two different cases with different conditions have been considered in this paper. Above reported techniques have been applied to the standard IEEE 30-bus six-generator test system. A comparative study of the performance of the proposed algorithm with SPEA NSGA, and NPGA has been carried out for solving the multi-objective economic/environmental dispatch problem. MOEA techniques have also been compared with classical methods. The effectiveness of MODBC techniques to handle the EED problem over the classical methods and other MOEA counterparts is demonstrated. Finally, Section 6 concludes the paper.

2. Economic/emission power dispatch problem

The economic dispatch problem is addressed as to simultaneously minimize the overall cost rate and meet the load demand of a power system while satisfying an equality and inequality constraints. Assuming the power system includes N generating units. The aim of economic power dispatch is to determine the optimal share of load demand for each unit in their operational range [8]. Nomenclature of the symbols used has been tabulated in Table 11.

2.1. Minimization of fuel cost and emission

The total fuel cost function of all generating units can be modeled by the following quadratic function

$$F(P_i) = \sum_{i=1}^{N} (a_i + b_i P_i + c_i P_i^2)\ \$/\mathrm{h} \tag{1}$$

where a_i, b_i and c_i are the cost coefficients of the ith generator and N is the number of generators committed to the operating system. P_i is the power output of the ith generator.

Many techniques were proposed to represent the emission function. One of those is being formulated as given below [9].

$$E(P) = \sum_{i=1}^{N} (\alpha_i + \beta_i P_i + \gamma_i P_i^2) + \varsigma e^{\lambda_i P_i}\ \mathrm{ton/h} \tag{2}$$

where α_i, β_i, γ_i, ζ and λ_i are the emission coefficients of ith generator and N is the number of generators committed to the operating system. P_i is the power output of the ith generator.

2.2. Constraints

1. Maximum and minimum constraints in generation capacity

The power generated P_i by each generator should be bound by upper and lower limits

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

where $P_{i\max}$ and $P_{i\min}$ are the upper and lower limits of the generation capacity of ith generator.

1. Power balance constraints

Total electric power generation (P_i) must be distributed between power demand (P_d) and the power loss in the transmission lines (P_l).

$$\sum_{i=1}^{N} P_i - P_l - P_d = 0 \tag{4}$$

The loss component (P_l) can be calculated using the following formula [7].

$$P_l = \sum_{i=1}^{N}\sum_{j=1}^{N} (P_i B_{ij} P_j) \tag{5}$$

where B_{ij} is the element of loss coefficient.

2.3. EED multi-objective problem formulation

The economic/emission dispatch problem can be formulated as multi-objective optimization problem as follows:

$$Min\ z = [F(P), E(P)] \tag{6}$$

Subjected to

$$\begin{aligned} g(P_i) &= 0 \\ h(P_i) &\leqslant 0 \end{aligned} \tag{7}$$

where g represents the power balance constraint and h represents the generation capacity constraint.

2.4. Best compromise solution

The minimum and maximum values of fuel and emission costs are considered as the lower and upper bounds respectively and these are employed then to characterize the corresponding fuzzy utility functions of the two objectives, concerned. Thereby, a fuzzy satisfaction-maximizing approach is relied on to obtain a set of non-inferior solutions [8]. To help the operators in determining the best compromise solution out of the Pareto-set obtained the ith objective function (F_i) is represented as a membership function μ_i as given below [8].

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