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Glowworm swarm optimization algorithm with topsis for solving multiple objective environmental economic dispatch problem

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ABSTRACT

A new glowworm swarm optimization (GSO) algorithm is proposed to find the optimal solution for multiple objective environmental economic dispatch (MOEED) problem. In this proposed approach, technique for order preference similar to an ideal solution (TOPSIS) is employed as an overall fitness ranking tool to evaluate the multiple objectives simultaneously. In addition, a time varying step size is incorporated in the GSO algorithm to get better performance. Finally, to evaluate the feasibility and effectiveness of the proposed combination of GSO algorithm with TOPSIS (GSO–T) approach is examined in four different test cases. Simulation results have revealed the capabilities of the proposed GSO–T approach to find the optimal solution for MOEED problem. The comparison with own coded weighted sum method incorporated GSO (WGSO) and other methods reported in literatures exhibit the superiority of the proposed GSO–T approach and also the results confirm the potential of the proposed GSO–T approach to solve the MOEED problem.

Introduction

The classical economic dispatch (ED) problem is to allocate generation among the committed units, while minimizing the fuel cost. Even, today the world major electric power demand is supplied with the help of fossil fuel power plants. This fossil fuel power plant produces atmospheric emission, whose nature and quantity depend on the fuel type and its quality. Particularly, coal fired thermal power plants produce gaseous pollutants such as carbon oxides (CO_x), sulphur oxides (SO_x) and oxides of nitrogen (NO_x) [1]. The U.S. clean air act amendments of 1990 and the increasing public awareness towards environmental protection have forced the generation companies to change their operating strategies. This insists the generation companies to minimize the gaseous emission of thermal power plants in addition to the conventional fuel cost minimization [2]. Various algorithms are presented and discussed to minimize the emission along with fuel cost by modifying the conventional ED problem into environmental economic dispatch (EED) problem [1,2]. Several techniques have been reported in the literatures to solve the EED problem. Combining the emission objective with fuel cost objective, combine economic emission dispatch (CEED) problem is formulated as a single objective problem and is solved by stochastic approach [3]. The bi-objective CEED problem is converted in to a single objective problem using a price penalty factor approach and weighted sum method, respectively, in [4,5] and both are solved by evolutionary programming (EP) algorithm.

Some researchers have formulated the CEED problem as MOEED Problem. A trade-off curve between the multiple objectives, known as Pareto Front has been found for the MOEED problem with the help of multi objective evolutionary algorithm (MOEA). In Ref. [6], non-dominated sorting genetic algorithm–II (NSGA-II) has been proposed to solve the MOEED problem. In this work, the author has solved the MOEED problem as a bi-objective problem and also a three objective problem by simultaneously optimizing the fuel cost, SO_x and NO_x as objectives. To provide a compromised solution for the decision maker, a fuzzy membership function is used to identify the best compromise solution (BCS) from the Pareto optimal solutions [6]. Strength Pareto evolutionary algorithm (SPEA) has been proposed to solve MOEED problem and compared with classical techniques such as linear programming and multi objective stochastic search technique [7]. Many MOEAs like NSGA, Niched Pareto genetic algorithm (NPGA) and SPEA have been successfully applied to MOEED problem and the results are compared with each other [7–9]. The author claims that the SPEA is superior in finding the uniformly distributed Pareto front compared to other MOEAs [7,8]. Further, the NSGA-II has been applied to MOEED problem and

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compared with other MOEAs like NSGA, NPGA and SPEA [9]. This work proves the superiority of the NSGA-II over the other MOEAs for solving MOEED problem.

In Ref. [10], particle swarm optimization (PSO) has been successfully implemented to solve the EED problem by considering the non-linear characteristics of a generator such as valve point loading. Abido proposed the multi objective PSO (MOPSO) for the MOEED problem and demonstrated its superiority compared with SPEA [11]. Hota et al. [12] proposed a fuzzy based modified bacterial foraging algorithm (MBFA) and applied it for the single objective EED problem. Multi-objective differential evolution (MODE) algorithm is proposed and applied to solve the MOEED problem with competing and non-commensurable objectives of fuel cost, emission and system loss [13]. Basu claimed that the MODE is better than NSGA–II and SPEA 2 for solving MOEED problem [14]. With the interest of combining the advantages of both PSO and differential evolution (DE) algorithm, a hybrid method called multi objective optimization algorithm based on PSO and DE (MO-DE/PSO) has been proposed for solving the constrained MOEED problem [15]. Hybrid DE with biogeography-based optimization (DE/BBO) has been proposed to solve the single objective EED problem and found that it outperforms the other method like PSO [16,17].

With the intention of developing a better algorithm to solve the ED & EED problem, various new heuristics search algorithms have been proposed in the literature. Those are firefly algorithm [18], Opposition based harmony search algorithm [19], gravitational search algorithm [20], biogeography based optimization (BBO) technique [21] and charged system search algorithm [22]. Each of this newly developed algorithm claims that they have the supreme qualities like finding the global optimal solution, minimum computation time and large scale power system applications.

Recently, a novel algorithm, to find the optimal points in the multimodal functions, glowworm swarm optimization (GSO) has been proposed by Krishnanand and Ghose [23,24]. This algorithm shares a few features with some well-known swarm intelligence based optimization algorithms such as ant colony optimization and PSO. The performances of the GSO on various benchmark multi model functions are analysed and the results prove that the GSO outperforms PSO [25]. Presently, some improvements have been proposed in GSO [26]. GSO has been applied for sensor deployment scheme in wireless sensor networks [27].

This paper presents the combination of GSO algorithm with TOPSIS (GSO–T) to solve the MOEED problem. In the proposed approach, a multi-criteria decision making method called TOPSIS is proposed as a fitness evaluation tool. In this work, TOPSIS is utilized as an overall ranking tool, since the TOPSIS continues to work satisfactorily across different application areas in evaluating, assessing and ranking alternatives across diverse industries [28,29]. A time varying step size is also incorporated in GSO to improve its performance. The proposed GSO–T approach is implemented on four different standard test cases to explore its capability and effectiveness. Results of the proposed GSO–T approach are compared with own coded WGSO approach and also with other leading algorithms, which are reported by various researchers.

The rest of the paper is organised as follows: The MOEED problem formulation is presented in the "Problem formulation" section. Detailed concept of GSO algorithm is described in the "Glowworm swarm optimization algorithm" section, followed by description about TOPSIS in the "TOPSIS" section. Implementation of proposed GSO–T approach for MOEED problem is illustrated in the "Implementation of GSO–T for multiple objective EED problem" section. In the "Numerical examples and simulation results" section", numerical examples and simulation results are presented. Finally, conclusions are drawn in the "Conclusion" section.

Problem formulation

Conventionally, the MOEED problem is formulated to minimize the two competing objective function such as fuel cost and emission, while satisfying the system equality and inequality constraints. Here, the problem is formulated as described below:

Problem objectives

Minimization of fuel cost

Similar to the classical ED problem, the simplified form of the total fuel cost function of the system can be stated as follows [30]:

$$F_1 = F_C(P_G) = \sum_{i=1}^{N_G} \left(a_{ci} + b_{ci}P_{Gi} + c_{ci}P_{Gi}^2\right) \qquad (\$/\mathrm{h}) \tag{1}$$

where $F_C(P_G)$ is the generator fuel cost function; a_{ci}, b_{ci} and c_{ci} are the cost coefficients of the ith generator; N_G is the number of committed generators in the power system; P_{Gi} is the power output of the ith generator.

Minimization of fuel cost with valve point loading effect

To involve the valve point loading effect, a sinusoidal function can be added to the quadratic cost function given in Eq. (1) [31]. Now, the total fuel cost function with valve point loading can be stated as follows;

$$F_2 = F_C(P_G) = \sum_{i=1}^{N_G} \left(a_{ci} + b_{ci}P_{Gi} + c_{ci}P_{Gi}^2\right) + \left|e_{ci} \times \sin\left(f_{ci} \times \left(P_{Gi}^{\min} - P_{Gi}\right)\right)\right| \qquad (\$/\mathrm{h}) \tag{2}$$

where e_{ci} and f_{ci} are the valve-point loading effect coefficients of the ith generator; $P_{Gi}^{\min}$ is the minimum power output limit of the ith generator.

Inclusion of valve point loading effect in the fuel cost function increases the number of local optima in the problem, which widen the complication of finding global or near global optimal solutions.

Minimization of emission objective

The emission function can be formulated in two different approaches. In the first approach, the SO_x and NO_x emission objectives are considered as separate quadratic functions [1]. They are given in the following equations:

$$F_3 = E_{SO_X}(P_G) = \sum_{i=1}^{N_G} \left(\alpha_{si} + \beta_{si}P_{Gi} + \gamma_{si}P_{Gi}^2\right) \qquad (\mathrm{t/h}) \tag{3}$$

$$F_4 = E_{NO_X}(P_G) = \sum_{i=1}^{N_G} \left(\alpha_{ni} + \beta_{ni}P_{Gi} + \gamma_{ni}P_{Gi}^2\right) \qquad (\mathrm{t/h}) \tag{4}$$

where $E_{SO_X}(P_G)$ is the SO_x emission function; $E_{NO_X}(P_G)$ is the NO_x emission function; α_{si}, β_{si} and γ_{si} are the SO_x emission coefficients of the ith generator; α_{ni}, β_{ni} and γ_{ni} are the NO_x emission coefficients of the ith generator.

In the second approach, the emission function is formulated as a combination of both the SO_x and the NO_x emission objectives as given in [11]. The total emission of these pollutants can be expressed with both quadratic and exponential functions as stated below.

$$F_5 = E(P_G) = \sum_{i=1}^{N_G} 10^{-2} \times \left(\alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2\right) + \xi_i \exp(P_{Gi}\lambda_i) \qquad (\mathrm{t/h}) \tag{5}$$