Applied Energy 181 (2016) 375–390

Contents lists available at ScienceDirect

Applied Energy

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

An improved differential evolution algorithm for the economic load dispatch problems with or without valve-point effects

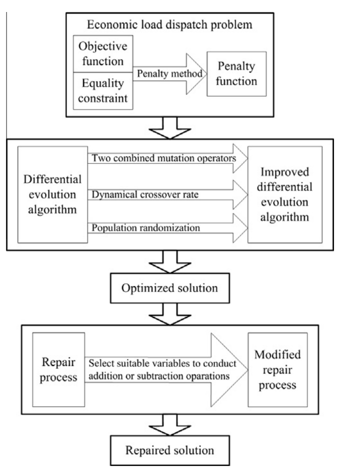
Dexuan Zou [a,*], Steven Li [b], Gai-Ge Wang [c], Zongyan Li [d], Haibin Ouyang [e]

[a] School of Electrical Engineering and Automation, Jiangsu Normal University, Xuzhou, Jiangsu 221116, PR China
[b] Graduate School of Business and Law, RMIT University, 379-405 Russell St, Melbourne, VIC 3000, Australia
[c] School of Computer Science & Technology, Jiangsu Normal University, Xuzhou, Jiangsu 221116, PR China
[d] School of Information and Electrical Engineering, China University of Mining and Technology, Xuzhou 221116, China
[e] School of Mechanical and Electric Engineering, Guangzhou University, Guangzhou, Guangdong 510006, PR China

HIGHLIGHTS

- An improved differential evolution (IDE) is developed to solve economic load dispatch problems.
- IDE has strong stability and good accuracy.
- IDE has the potential to be applied to many other energy-related problems.
- A modified repair process is introduced to handle equality constraints.
- The modified repair process can help IDE to rapidly find feasible solutions.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 22 March 2016
Received in revised form 12 August 2016
Accepted 13 August 2016

Keywords:
Improved differential evolution
Economic load dispatch
Valve-point effects
Mutation
Modified repair process
Equality constraint

ABSTRACT

This paper presents an improved differential evolution (IDE) algorithm for economic load dispatch (ELD) problems with or without valve-point effects (VPE). The proposed IDE is different from the traditional differential evolution (DE) algorithm in three aspects: first, two mutation operators are used to generate mutant vectors; second, a dynamical crossover rate is used to update trail vectors; third, a useful population randomization is adopted to overcome the premature convergence. In addition, a modified repair process is introduced to handle the constraint violations. Eight cases are selected to testify the performance of four DE approaches on solving ELD problems. According to our empirical results, IDE makes slight improvements on the objective function values from the literature. However, it can always find the solutions satisfying the equality constraints. Most importantly, the IDE can achieve much smaller variances than other DEs on the majority of the test problems, indicating that it has strong stability on solving ELD problems.

* Corresponding author.
E-mail address: zoudexuan@163.com (D. Zou).

http://dx.doi.org/10.1016/j.apenergy.2016.08.067
0306-2619/

1. Introduction and literature review

Economic load dispatch (ELD) [1] is a complex issue in power system operation, and it requires scheduling generation among the specified units. The goal of ELD is to minimize the total fuel cost under the conditions of meeting the load demand and operational constraints. Thus a complete and accurate mathematical model is often needed for solving the ELD problems in practice. Until now, the quadratic function has been the most commonly used function for approximately evaluating the generation cost of the ELD problems with a variety of intensified versions such as the valve-point effects [1–4], transmission line losses [5–8], prohibited operating zones [7–9], the environmental emissions of power plants [10–14].

The original ELD problems can be solved by the traditional approaches based on mathematical programming techniques [1,15,16] because the quadratic functions are used as the cost functions which are monotonically increasing. However, these approaches can hardly work for the ELD problems with additional considerations as the quadratic functions are no longer suitable for characterizing these ELD problems. For example, for the ELD problems with the valve-point effects, the sinusoidal functions and quadratic functions are combined to construct cost functions. Moreover, the cost functions can be inherently nonlinear, and may contain a number of local optima. Thus more and more researchers are turning to stochastic search algorithms for solving the ELD problems with various additional constraints.

Sinha et al. [1] improved the basic evolutionary programming (EP) method for the ELD problems. First, they modified the basic technique using the adaptation based on scaled cost. Second, they developed an EP method according to an empirical learning rate. The improved version of EP was recommended for solving ELD problems with large-scale systems as it can improve the convergence rate and probability of obtaining desirable solutions. Thanushkodi et al. [2] proposed an efficient particle swarm optimization (EPSO) method to solve ELD problems in power system. In their EPSO, all personal best particles are updated using two different formulas, and the global best particle is updated according to these personal best particles. Moreover, a new method is used to search candidate solutions meeting the equality and inequality requirements. Labbi et al. [3] used an artificial bee colony optimization (ABC) to handle ELD problems. Three useful phases are adopted in ABC: employed bee phase, onlooker bee phase and scout bee phase. In the employed bee phase, each solution is mutated in terms of its randomly selected neighbor, and a greedy selection is used to decide whether the original solution can be replaced by the mutant. In the onlooker bee phase, the onlooker bees in the hive search a food source according to the information from the employed foragers. A food source (candidate solution) is chosen with the probability which is proportional to its food (solution) quality. In the scout bee phase, a solution (scout bee) is randomly generated to explore solution space. Moreover, an employed bee would be replaced by the scout bee if the trials of mutation failed. Therefore, the scout bee phase is necessary and very helpful to facilitate the exploration of potential solution space. Bhattacharya and Chattopadhyay [8] introduced a hybrid method combining DE with biogeography-based optimization (DE/BBO) algorithm to deal with both convex and nonconvex ELD problems. DE/BBO facilitates the exploration of DE using BBO. Moreover, BBO [17] adopts three types of efficient movements for a species: arising, migration, and extermination. These three movements are helpful to enhance the information sharing among different candidate solutions. Chaturvedi et al. [9] developed a particle swarm optimization with time varying acceleration coefficients (PSO_TVAC) for solving ELD problems. This method improves PSO by using a novel parameter automation strategy where time varying acceleration coefficients (TVAC) are introduced to suitably control the local and global search. Based on the dynamically adjusted acceleration coefficients, the global optimal solutions can be achieved by avoiding the premature convergence. Niknam [18] proposed an efficient hybrid evolutionary approach to handle the ELD problems with VPE. The approach combines a fuzzy adaptive particle swarm optimization (FAPSO) algorithm with the Nelder-Mead (NM) simplex search called FAPSO-NM. The NM method is utilized to carry out local search for the global solution obtained by FAPSO at each generation. As a result, FAPSO-NM improves the performance of the FAPSO algorithm. Xiong et al. [19] presented a multi-strategy ensemble biogeography-based optimization (MsEBBO) for solving the ELD problems. In order to maintain a proper balance between exploration and exploitation, MsEBBO improves the three components of biogeography-based optimization (BBO) by the no free lunch theorem. Besides, an effective repair technique is proposed to deal with different constraints of the ELD problems. Adarsh et al. [20] introduced the chaotic bat algorithm (CBA) for solving the ELD problems with equality and inequality constraints. The CBA employs the sinusoidal chaotic map to control the loudness A^i of each bat to enhance the performance of the original BA algorithm. Experimental results show that the CBA is able to cope with high dimensional ELD problems with several constraints. Basu and Chowdhury [21] introduced cuckoo search algorithm (CSA) for solving the ELD problems. CSA is a nature-based optimization method, and it is derived from the obligate brood parasitism of some cuckoo species by laying their eggs in the nests of other host birds of other species. Experimental results show that CSA is capable of achieving desirable solutions. Sekhar and Mohanty [22] presented an enhanced cuckoo search (ECS) algorithm for the ELD problems. In ECS, dynamical variable values of the step size and the probability are adopted to improve solutions. Simulation results indicate that the ECS algorithm can obtain minimum fuel cost with minimum severity index under contingency scenario. Coelho and Mariani [23] introduced an improved harmony search (IHS) algorithm to solve the ELD problems. The key feature of the IHS is the modification of the pitch adjustment step of HS. The pitch adjusting rate PAR(t) is dynamically updated, and the coefficient r of arbitrary distance bandwidth bw is replaced by a random number e using an exponential probability distribution [24]. This modification helps to maintain a good balance between the low-amplitude and high-amplitude searchings. The experimental results reveal that IHS can achieve better solutions with rapid convergence compared to HS. Jayabarathi et al. [25] solved the ELD problems by a HBFA algorithm based on particle swarm optimization (PSO) [26] and bacterial foraging algorithm (BFA). This hybrid algorithm integrates the biased velocity of PSO with the chemotaxis, swarming and reproduction steps of BFA. The best bacterium is adopted in velocity to restrain the randomness and to enhance the swarming effect. HBFA has the advantage of sharing and conveying more sufficient information than other evolutionary methods. Moreover, HBFA converges faster than the other methods, because a dynamic decreasing function is used to carry out the swim walk instead of the constant step for updating the solution vector. The experimental results show that the HBFA is better than the BFA. Banerjee et al. [27] introduced a teaching learning based optimization (TLBO) method to solve the ELD problems without considering transmission losses. This optimization method is inspired by the relationship between teacher and students, and it is based on two basic concepts of education: teaching phase and learning phase. Learners firstly improve their knowledge according to the teaching experience of a teacher, and then they expand their knowledge through information sharing among themselves. For any candidate solution in TLBO, its