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Economic load dispatch using krill herd algorithm

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ABSTRACT

Economic load dispatch (ELD) is an important topic in the operation of power plants which can help to build up effective generating management plans. The practical ELD problem has non-smooth cost function with nonlinear constraints which make it difficult to be effectively solved. This paper presents, a new and efficient krill herd algorithm (KHA) to solve both convex and non-convex ELD problems of thermal power units considering valve point loading, multiple fuel operation, transmission losses and constraints such as ramp rate limits and prohibited operating zones. To enhance the overall performance and effectiveness of the proposed algorithm, the crossover and mutation operation of differential evolution (DE) are integrated with the proposed method. The different versions of KHA are successfully applied to small, medium, and large-scale power systems for solving six different ELD problems. The simulation results obtained by the proposed algorithms are compared with the results obtained using other recently develop methods available in the literature. From numerical results, it is found that the proposed KHA with crossover and mutation operators approach is able to provide better solution than other reported techniques in terms of fuel cost. Furthermore, this algorithm is better in terms of robustness than most of the existing algorithms used in this study.

1. Introduction

During the last decade, the electrical power market became more and more liberal and highly competitive. The main goal is to generate of a given amount of electricity at the lowest possible cost. This need proper planning, operation and control of such large complicated systems. ELD is one of the most important problems to be solved for smooth and economic operation of a power system. A good load dispatch reduces the production cost, increases the system reliability and maximizes the energy capability of thermal units. ELD is a process for sharing the total load on a power system among various generating plants to achieve greatest economy of operation. The ELD, a nonlinear optimization problem is basically solved to generate optimal amount of generating power from the fossil fuel based generating units in the system by minimizing the fuel cost and satisfying all system constraints of power system. The careful and intelligent scheduling of the generating units can not only reduce the operating cost significantly but also assure higher reliability and security of power system. Thus, for last few decades, ELD has become an essential optimization area for economic operation and control of modern power system.

Previously, a number of derivative-based approaches such as gradient method [1], lambda iteration method (LIM) [2,3], linear programming (LP) [4], quadratic programming (QP) [5], Lagrangian multiplier method [6], classical technique based on co-ordination equations [7] were applied to solve ELD problems. However, in large practical thermal generation plants with large size turbines, the input–output characteristics of generators are highly nonlinear and discontinuous due to the presence of valve point loading effect. Because of highly nonlinear characteristics of the problem with many local optimum solutions and a large number of constraints, the classical calculus-based methods cannot perform satisfactorily for solving ELD problems. Recently, Yang et al. [8] presented a mathematical programming based method named quadratically constrained programming (QCP) to solve non-smooth and non-convex ELD problem.

Some traditional algorithms such as dynamic programming (DP) [9] impose no restrictions on the nature of the cost curves and therefore it can solve ELD problems with inherently nonlinear and discontinuous cost curves. However, DP method may cause the dimensions of the problem to become extremely large, thus requiring enormous computational efforts. Hopfield neural networks based method is another alternative to solve nonlinear ELD problems. An augmented Lagrange Hopfield network (ALHN) [10] for solving ELD problem was proposed by Dieu et al. Furthermore, Dieu et al. [11] introduced a hybrid method based on quadratic

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programming (QP) and augmented Lagrange Hopfield network (ALHN) for solving ELD problem with piecewise quadratic cost functions and prohibited zones. However, these methods suffer from excessive numerical iterations, resulting in huge computations.

Thus, developing a reliable, fast and efficient algorithm is still an active area for research in power systems. Various investigations on ELD have been explored till date, as better solutions would result in significant economical benefits. Modern meta-heuristic algorithms such as particle swarm optimization (PSO) [12–16], adaptive PSO [17], chaotic PSO [18], self-organizing hierarchical PSO [13], differential evolution (DE) [19], evolutionary programming (EP) [20], genetic algorithm (GA) [21,22], real coded GA (RCGA) [23], bacterial foraging optimization (BFO) [24], biogeography based optimization (BBO) [25], gravitational search algorithm (GSA) [26], pattern search method (PSM) [27], and clonal search algorithm [28] are promising alternative for solution of complex ELD problems. In addition to the above mentioned methods, few other methods have recently applied in ELD problems. Basu developed artificial bee colony (ABC) [29] optimization technique to solve multi-area economic dispatch (MAED) problem considering tie line constraints and nonlinearities like multiple fuels, valve-point loading and prohibited operating zones. The effectiveness of the proposed method was illustrated by applying it in three different test systems and its results were compared with the results of DE, EP and RCGA. Kumar et al. [30] proposed 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 satisfying both equality and inequality constraints. Cai et al. [31] developed a fuzzy adaptive chaotic ant swarm optimization (FCASO) algorithm for solving the ELD problems of thermal generators in power systems. A multi-objective mesh adaptive direct search (MOMADS) algorithm [32] was employed by Mohamed et al. for minimizing the cost and emissions simultaneously of a micro-grid.

Recently, modifications of conventional population based methods are made for getting better quality solutions of ELD problem. Barisal implemented an improved PSO (IPSO) [33] to solve non-smooth ELD problem. In this proposed IPSO method, the dynamic search space squeezing strategy is incorporated in conventional PSO to improve the convergence speed and to efficiently handle inequality constraints, of ELD problem. Hosseinnezhad and Babaei implemented θ-PSO [34] method on 6, 13, 15 and 40 generating units test systems to solve ELD problems considering various nonlinear constraints like ramp rate limits, valve point loadings, prohibited operating zone and proposed method was compared with few modified versions of PSO and other optimization techniques. Aydın and Ozyon applied incremental artificial bee colony (IABC) and incremental ABC with local search (IABC_LS) algorithms [35] to solve ELD problem of 3, 5, 6 and 40 generating unit systems. Shaw et al. [36] applied oppositional based learning (OBL) concept to accelerate the performance of the GSA. Chatterjee et al. [37] proposed opposition-based harmony search algorithm (OHSA) to employ opposition-based learning for harmony memory initialization and also for the generation jumping. Liao presented isolation Niche immune based GA algorithm [38] for solving dynamic ELD (DELD) problem. Peng et al. proposed bi-population chaotic differential evolution (BPCDE) algorithm [39] to solve DELD problem of a power system integrated with large scale wind farms. In the proposed algorithm, chaotic map update mechanism and metropolis rule are used to improve the performance of standard differential evolution algorithm.

Various researchers were looking for better alternatives, and therefore, hybrid methods combining different conventional techniques were identified. Recently, different hybridization techniques such as GA-SQP [40], PSO-SQP [41,42], hybrid EP-PSO-SQP [43], hybrid DE (HDE) [44,45], hybrid DE-PSO [46], hybrid shuffled differential evolution (SDE) [47], hybrid differential harmony search [48] are proposed for getting better quality solutions of ELD problems. Recently, Roy et al. proposed modified shuffled frog leaping algorithm (MSFLA) [49] with genetic algorithm (GA) for the ELD problem. To test the effectiveness, the proposed method was implemented on IEEE standard 30-bus [30], 13 [20] and 40 [20] thermal units systems. Mohammadi-Ivatloo et al. [50] presented a novel heuristic algorithm for solving ELD problems, by employing iteration based PSO with time varying acceleration coefficients (IPSO-TVAC) method. Saber [51] presented a novel modified PSO (MPSO), which includes advantages of bacterial foraging (BF) and PSO for constrained DELD problem. Vaisakh et al. implemented bacterial foraging PSO-DE (BPSO-DE) algorithm [52] by integrating BFO, PSO and DE for solving static and dynamic ELD problems of various test systems.

Krill herd algorithm (KHA) is a recently developed powerful evolutionary algorithm proposed by Gandomi and Alavi [53] to solve non-convex optimization problem. The proposed KHA method is based on the herding behavior of krill individuals. Each krill individuals modify its position using three process namely, (1) movement induced by other individuals (2) foraging motion, and (3) random physical diffusion. The foraging motion and the motion induced by other individuals contain global and local strategies, respectively which make KHA a powerful technique. However, sometime, conventional KHA is unable to generate global optimal solutions on some high-dimensional nonlinear optimization problems. To improve the performance of the KHA, adaptive crossover and mutation mechanisms are incorporated into the algorithm. The crossover operator helps to avoid premature convergence in the early run phase, and refine the final solutions in the later. Due to these excellent properties of this new algorithm and as it does not have any tendency to stick in local optimum points in the nonlinear optimization problem, the present authors applied this newly developed algorithm, to solve non-convex complex ELD problems. The different version of KHA techniques are applied on six different test cases (6-unit, 10-unit, 15-unit, 40-unit without transmission loss, 40-unit with transmission loss and 80 unit systems) with varying degree of complexity for verifying its performance with other established methods such as simulated annealing (SA), GA, PSO, DE, self-organizing hierarchical PSO (SOH-PSO), GAAPI, new PSO (NPSO), fuzzy adaptive PSO (FAPSO), passive congregation based PSO (PC_PSO), tabu search (TS), multiple TS (MTS), NPSO with local random search (NPSO-LRS), teaching learning based optimization (TLBO), and quasi-oppositional TLBO (QOTLBO).

The rest of this paper is organized as follows: Section 2 presents the problem formulation. The key points of the proposed KHA technique are described in Section 3. In Section 4, the proposed method applied to ELD problem is illustrated. Six cases based on five different power systems are studied and the simulation results are discussed in Section 5. The conclusion is summarized in Section 6.

2. Problem formulation

2.1. Objective function

The ELD problem is addressed as to simultaneously minimize the power production cost and meet the load demand of a power system while satisfying the equality and inequality constraints. Main production cost of thermal generator is fuel cost. Therefore, the objective function of ELD problem may be expressed as under: