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A new modified artificial bee colony algorithm for the economic dispatch problem

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ABSTRACT

In this paper a new modified artificial bee colony algorithm (MABC) is proposed to solve the economic dispatch problem by taking into account the valve-point effects, the emission pollutions and various operating constraints of the generating units. The MABC algorithm introduces a new relation to update the solutions within the search space, in order to increase the algorithm ability to avoid premature convergence and to find stable and high quality solutions. Moreover, to strengthen the MABC algorithm performance, it is endowed with a chaotic sequence generated by both a cat map and a logistic map. The MABC algorithm behavior is investigated for several combinations resulting from three generating modalities of the chaotic sequences and two selection schemes of the solutions. The performance of the MABC variants is tested on four systems having six units, thirteen units, forty units and fifty-two thermal generating units. The comparison of the results shows that the MABC variants have a better performance than the classical ABC algorithm and other optimization techniques.

1. Introduction

Economic dispatch (EcD) is an important optimizing problem in the electric power system operating. The aim of the EcD problem is to determine the power outputs of all generating units from a system, for a given time interval (one hour), in order to have minimum fuel cost, and to meet the required constrains.

Another problem that plays an important role in the operating of the power systems is the emission dispatch (EmD). The EmD problem is similar to the EcD problem, but in this case it aims determining the power outputs of the generating units that minimize the emissions' quantity – nitrogen oxides (NO_x), carbon dioxide (CO_x), sulfur oxides (SO_x) – released in the environment (caused by the burning of fossil fuels within thermal power plants), in certain imposed operating conditions. Searching for an optimal solution in the dispatching of the power outputs of the generators taking into consideration both fuel cost and the environmental emissions level, is known as Combined Economic and Emission Dispatch (CEED) problem. Basically, EcD and EmD problems aim to find a way to reduce operating costs and emissions levels for a power system without making investments in new equipment and/or technologies. The cost and emissions reduction is achieved by the optimal planning of the load dispatched among the system's generating units.

Solving EcD/EmD involves formulating a mathematical model of optimization and then selecting and/or developing an appropriate optimization technique. The simplest model for the EcD (EmD) problem is one in which the fuel cost (or the emissions level) of the generating units is defined by a quadratic function, and the constraints are limited to only two: the equality between the powers generated and demanded in the system, respectively the generating units operation between the minimum and maximum limits of power. However, in order to take into account more practical features of the operating units, the mathematical model has been improved by considering also the valve-point effects and by introducing the constraints regarding the ramp rate limits, prohibited zones of the units, the transmission losses. These additions determine a non-linear, non-smooth and non-continuous mathematical model of optimization. To solve the EcD/EmD or CEED problem, several methods, classic or based on artificial intelligence, have been used over time. Among the classical methods the following can be mentioned: quadratic programming [1], non-linear programming [2,3]. The classical methods may have difficulties in finding the optimal solution due to the non-linear and non-continuous nature of the optimization model [4,5].

As a result, several methods based on artificial intelligence were developed and applied for the above mentioned problems. These methods have the ability to identify higher quality solutions

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[4,6,7] and can be grouped into three categories. The first category consists of methods applied in their original version, the second refers to methods/algorithms derived from the original version by changing the relations to updating the solutions or by adapting some of the algorithm's parameters, and the third includes the hybrid methods.

From the first category several methods to solve the EcD/EmD or CEED problems were applied, such as: Genetic Algorithm (GA) [8,9], Particle Swarm Optimization (PSO) [4,8], Differential Evolution (DE) [5,8], Virus Optimization Algorithm (VOA) [8], Harmony Search (HS) [8], Seeker Optimization Algorithm (SOA) [8], Ant Colony Optimization (ACO) [10], Artificial Bee Colony (ABC) [11], Bacterial Foraging Optimization (BFO) [12], Gravitational Search Algorithm (GSA) [8,13], Firefly Algorithm (FA) [8,14], Imperialist Competitive Algorithm (ICA) [15].

In the second category of methods the following are included: Modified HS algorithm (MHSA) [16], Self-Adaptive Real Coded Genetic Algorithm (SARGA) [17], PSO with Time Varying Acceleration Coefficients (PSO_TVAC) [18], Improved Bacterial Foraging Algorithm (IBFA) [19], Modified Bacterial Foraging Algorithm (MBFA) [20], Improved Harmony Search with Wavelet Mutation (IHSWM) [21], Modified ABC (MABC) [22], Incremental ABC (IABC), ABC with Dynamic Population (ABCDP), ABCDP with Local Search (ABCDP-LC) [23], Modified Shuffled Frog Leaping algorithm (MSFL) [24].

Among the hybrid methods a few are mentioned: Hybrid Differential Evolution algorithm (HDE) [25], Hybrid Genetic Algorithm based on differential evolution (HGA) [26], hybrid PSO with Sequential Quadratic Programming (PSO-SQP), Evolutionary Programming-SQP (EP-SQP) [27], hybrid GA–Pattern Search–SQP (GA–PS–SQP) [28], Fuzzy Adaptive PSO with Variable Differential Evolution (FAPSO-VDE) [29], Hybrid Multi-Agent based PSO (HMA-PSO) [30], hybrid Chaotic PSO algorithm and SQP technique (CPSO–SQP) [31], hybrid that combines Shuffled frog leaping algorithm and Differential Evolution (SDE) [32], Hybrid swarm intelligence based Harmony Search (HHS) [33], hybrid Simulated Annealing with PSO (SA-PSO) [34].

Each of the methods above have their advantages and disadvantages regarding the quality and stability of the solution, the convergence of iterative process, the calculus efficiency or the simplicity of implementation. This paper proposes a method from the second category, being a modified ABC method.

The ABC algorithm is a biological-inspired optimization technique, based on population which imitates the foraging behavior of the real honey bee, being introduced by Karaboga in 2005 [35]. Initially, the ABC algorithm has been used in solving unimodal and multi-modal numerical optimization problems on a limited set of test functions [35]. Due to its many positive features – simple in concept and easy to implement, flexible, the possibility of using chaotic maps and of developing hybrids from combinations with other techniques – the ABC algorithm has been successfully applied to the optimization of complex mathematical functions with or without constraints [36–43], or solving engineering problems, such as: the optimization of truss structures [44], engineering design optimization [45], automatic voltage regulator system [46], design and economic optimization of shell and tube heat exchangers [47], fault section estimation in power systems [48], optimal reactive power flow [49], economic dispatch [50].

Several studies show that the ABC algorithm performs better or just as good as other biological-inspired algorithms, such as genetic algorithm, differential evolution and particle swarm optimization [36–38]. Besides the already mentioned advantages, ABC algorithm may encounter a number of challenges (sub-optimal solutions, low robustness, slow convergence) in the optimization of composite functions, non-separable functions or problems that require constraints [51]. Also, in [41] is concluded that ABC algorithm is good at exploration but poor at exploitation.

To overcome these problems several variants of ABC algorithm have recently been proposed in order to enhance the performance of the original version.

Some of the ways used to achieve this purpose are: the introduction of new relations (inspired by other algorithms such as DE or PSO) to update the solutions in the search space [39–43,51], ABC algorithm hybridization with other classical algorithms (derivative methods [52]) or metaheuristics (PSO, DE) [53,54], using chaotic maps [55], fuzzy theory [56], contraction strategies of the solutions' search space [57], multi-objective ABC [58], self-adaptation of mutation step size [59].

In this paper, a modified ABC algorithm (called MABC) is proposed, to solve the economic dispatch problem, taking into account systems having various characteristics (different operating constraints, the emission pollutions, the valve-point effects). The MABC algorithm has the structure of the original ABC algorithm, but relies on a new relation for the update of the solutions in the search space, based on the relations presented in [42] and [51]. In [42] an ABC variant it is proposed – Global best artificial bee colony algorithm – that updates the solutions using the information from the neighborhood of the best solution. To improve the convergence rate of the basic ABC algorithm, in [51] two parameters are introduced to control the frequency and magnitude of the perturbation in the update process of the solutions.

The MABC algorithm behavior is also investigated under two conditions: (i) incorporation of chaotic components (generated by cat and logistic maps) in the relation used for the solutions update; (ii) the introduction of two schemes for the solutions selection (disruptive selection and classical proportional selection). It must be mentioned that the cat map and disruptive potential selection scheme have not been investigated when solving the economic/emission dispatch problem. The performance of the MABC method was tested on systems with different characteristics and then compared with several other optimization techniques from the solutions stability and quality point of view.

2. Formulation of the problems (EcD, EmD, CEED)

2.1. The economic dispatch (EcD) problem

The mathematic optimization model for the EcD problem includes three elements – optimizing variables, the objective function and constraint relations – listed below.

The optimizing variables are the real output powers P_j, $j = 1,2,\ldots n$ of the generating units, presented as a solution vector $P = [P_1, P_2, \ldots P_j, \ldots, P_n]$, where n is the total number of units from the analyzed system.

The objective function $F[P]$ aims to minimize the fuel total cost for the entire system:

$$\min F = \sum_{j=1}^{n} F_j(P_j) \tag{1}$$

where $F_j(P_j)$ is the fuel cost, in \$/h, for the jth unit, which is modeled by a quadratic polynomial function such as:

$$F_j(P_j) = c_j P_j^2 + b_j P_j + a_j \tag{2}$$

If the valve-point effects are taken into consideration, then the cost function for unit j includes a sine factor, besides the quadratic polynomial function [19,27,60]:

$$F_j(P_j) = c_j P_j^2 + b_j P_j + a_j + |e_j \sin(f_j(P_{j,\min} - P_j))| \tag{3}$$