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Application of imperialist competitive algorithm with its modified techniques for multi-objective optimal power flow problem: A comparative study

Mojtaba Ghasemi [a], Sahand Ghavidel [a,*], Mohammad Mehdi Ghanbarian [b], Hamid Reza Massrur [a], Masihallah Gharibzadeh [a]

[a] *Department of Electronics and Electrical Engineering, Shiraz University of Technology, Shiraz, Iran*
[b] *Islamic Azad University, Kazerun Branch, Kazerun, Iran*

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ABSTRACT

One of the major tools for power system operators is Optimal Power Flow (OPF) problem which is designed to optimize a certain objective over power network variables under certain constraints. One of the simplest but most powerful optimization algorithms is imperialist competitive algorithm (ICA) outperforming many of the already existing optimization techniques. The original ICA method often converges to local optima. Therefore, in order to avoid this shortcoming, the interaction effects of colonies on each other are modeled to improve local search near the global optima. Also, a series of modifications is purposed to the assimilation policy rule of ICA method in order to further enhance algorithm's rate of convergence for achieving a better solution quality. This article investigates the possibility of using recently emerged evolutionary-based approach as a solution for the OPF problems which is based on ICA method with its modified techniques for optimal settings of OPF control variables. The performance of this approach is studied and evaluated on the standard IEEE 57-bus test system with different objective functions and is compared to methods reported in the literature recently. The proposed modified techniques for ICA method provide better results compared to the original ICA and other methods recently reported in the literature as demonstrated by simulation results.

1. Introduction

The problem of OPF has been in a focus of wide attention over past years. The OPF problem has established its position as one of the main tools for optimal operation and planning of modern power systems. Main objective of the OPF problem in the paper is to optimize a chosen objective function as fuel cost with voltage profile value improvement and minimization active power losses by optimal adjusting the power system control variables and satisfying various system operating such as power flow equations and inequality constraints, simultaneously [55].

Nodal power balance equations and restrictions of all control or state variables are examples of equality constraints and inequality constraints, respectively. The control variables include the tap ratios of transformer, the generator real powers, the generator bus voltages and the reactive power generations of VAR sources while state variables involve the generator

* Corresponding author. Tel.: +98 911 1480548
E-mail address: s.ghavidel@sutech.ac.ir (S. Ghavidel).

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reactive power outputs, load bus voltages and flow of the network lines. Accordingly, the OPF is considered as a basic tool allowing electric utilities to characterize secure and cost effective operating conditions for an electric power system [24,27].

In general view, the OPF problem is described as a highly constrained and large-scale nonlinear nonconvex optimization problem. Dommel and Tinney were the first authors to introduce the formulation of the OPF problem [24]. From then, this topic has been handled by many researchers. Generally, the OPF problem can be solved via many traditional optimization methods such as linear programming, non-linear programming, quadratic programming, Newton-based techniques and interior point methods [13,26,29,39,38,62]. However, the impossibility of employing these methods in practical systems because of nonlinear characteristics such as valve point effects prohibited operating zones and piecewise quadratic cost function remains to be a major drawback of the mentioned approaches. With regard to this, improvement of optimization methods which are capable of address these shortcomings are becoming increasingly vital [54].

In recent decades, various population-based optimization techniques have been applied to solve complex constrained optimization problems which also include optimization problems in field of power systems like economic dispatch, optimal reactive power flow and OPF. Generally, achieving optimal or near optimal solution for a specific problem will require multiple trials as well as accurate adjustment of associated parameters. Some of the proposed population-based methods such as tabu search (TS) [1], genetic algorithm (GA) [23], improved genetic algorithm (IGA) [34], particle swarm optimization (PSO) [2], differential evolution (DE) [61], simulated annealing (SA) [53], modified shuffle frog leaping algorithm (MSFLA) [41], improved harmony search (IHS) algorithm [56], multi-objective harmony search (MOHS) algorithm [57], a hybrid algorithm using ICA method and teaching learning algorithm (TLA) [25] and evolutionary programming (EP) [58] have proved to be successful in solving OPF problems.

Another approach to OPF problem was differential evolution algorithm introduced by Basu with use of Flexible Alternating Current Transmission System (FACTS) devices. Basu used multi-objective differential evolution algorithm to solve the OPF problem with FACTS devices in IEEE 30-bus and IEEE 57-bus systems and the results were compared with the literatures [12]. Mahdad et al. also investigated utilization of parallel genetic algorithm (PGA) in the OPF problem representing large-scale system with shunts FACTS devices [36]. Also, Azizipanah-Abarghooee et al. [8] investigated using of MSFLA method to solve the OPF problem with thyristor controlled series capacitor (TCSC) and static VAR compensator (SVC) devices for multi-objective OPF problem in the power system. Dynamic OPF problem constraints valve-point effects, prohibited zones and multi-fuel [48] and reserve constrained dynamic economic dispatch problems [7,49,50] using proposed population-based methods have proved to be successful in solving optimization problems in the power system.

Furthermore, Memetic Algorithms (MC) are hybrid algorithms composed of an evolutionary framework and one or more local search components activated within the generation cycle. Memetic Computing (MC) is a subject that studies algorithmic structures composed of heterogeneous operators. MC is a branch in computer science which regards with complicated structures as the combination of heterogeneous operators, named memes, whose contribute to intelligent structures for problem solving [15,30]. Caraffini et al. [15] introduces the concept of parallel structures in MC by revisiting the literature in computational intelligence optimization, named Parallel Memetic Structure (PMS). The proposed PMS approach appears to display an extraordinarily high performance for large scale problems. A fast adaptive MA for a design of controller of engineering drives is presented in [14], and a compact memetic differential algorithm has been developed for a robot control in [44]. In [16], a computational prototype for automatic design of MC structures and for the implementation of a fully functional computational prototype has been proposed for continuous optimization problems. In [31], a recently proposed single-solution MC optimization method, namely Three Stage Optimization Memetic Explorations (3SOME), is used to implement a self-tuning PID controller on board of a mobile robot.

In 2007, Atashpaz-Gargari and Lucas introduced a novel with inspiration from social and political relations [5]. The performance of this evolutionary optimization algorithm has been continuously reinstated by successful utilization in many engineering applications such as control [35], data clustering [47], and industrial engineering [42] in recent years and has demonstrated great effectiveness in both critical factors of convergence rate and capability in achieving global optimal. In [11], a new modified ICA method further has been improved the performance of ICA algorithm by taking advantage of chaotic maps to determine the movement angle of colonies towards imperialist's position in order to enhance the escaping capability from a local optimal trap.

In this paper, new ICA techniques and the performance of these approaches for OPF problem are studied and evaluated on the standard IEEE 57-bus test system with different objective functions and are compared to methods reported in the literature. Experimental results on the OPF problem show that the novel ICA techniques have better performance in both convergence and global best in comparison with original ICA method, and other methods reported in the literature.

The rests of this article are classified in four sections as follows: Section 2 covers the formulation of an OPF problem while Section 3 explains the standard structure of the new ICA techniques, Section 4 of the paper is allocated to present optimization results and undertaking comparison and analysis of the performance of the mentioned methods used to solve the case studies of OPF problem on IEEE 57-bus system and finally, in Section 5, the conclusion of the implementation for the modified and combined algorithms is presented.

2. Problem formulation

In general, the goal of a solution of the OPF problem is to optimize a selected objective function through optimal adjustment power system control parameters while satisfying equality and inequality constraints at the same time.