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A novel hybrid algorithm of imperialist competitive algorithm and teaching learning algorithm for optimal power flow problem with non-smooth cost functions

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ABSTRACT

One of the major tools for power system operators is optimal power flow (OPF) which is an important tool in both planning and operating stages, designed to optimize a certain objective over power network variables under certain constraints. Without doubt one of the simple but powerful optimization algorithms in the field of evolutionary optimization is imperialist competitive algorithm (ICA); out-performing many of the already existing stochastic and direct search global optimization techniques. The original ICA method often converges to local optima. In order to avoid this shortcoming, we propose a new method that profits from teaching learning algorithm (TLA) to improve local search near the global best and a series of modifications is purposed to the assimilation policy rule of ICA in order to further enhance algorithm's rate of convergence for achieving a better solution quality. This paper investigates the possibility of using recently emerged evolutionary-based approach as a solution for the OPF problem which is based on hybrid modified ICA (MICA) and TLA (MICA–TLA) for optimal settings of OPF control variables. The performance of this approach is studied and evaluated on the standard IEEE 30-bus and IEEE 57-bus test systems with different objective functions and is compared to methods reported in the literature. The hybrid MICA–TLA provides better results compared to the original ICA, TLA, MICA, and other methods reported in the literature as demonstrated by simulation results.

1. Introduction

The problem of OPF has been in the focus of wide attention over past years and 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 is to optimize a chosen objective function such as piecewise quadratic cost function, fuel cost with valve point effects, fuel cost with prohibited zones, or fuel cost with voltage profile improvement by optimal adjusting the power system control variables and satisfying various system operating such as power flow equations and inequality constraints, simultaneously (Niknam et al., 2011; Sayah and Zehar, 2008). OPF problem is one of them which help the operators in running the system optimally under specific constraints. In order to guide the decision making of power system operators a more robust and global optimization of any OPF problems is needed.

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 reactive power outputs, load bus voltages and flow of the network lines. Accordingly, the OPF problem is considered a basic tool allowing electric utilities to characterize secure and cost effective operating conditions for an electric power system (He et al., 2004; Dommel and Tinney, 1968).

In general view, the OPF problem is described as a highly constrained, large-scale non-linear non-convex optimization problem. Dommel and Tinney (1968) were the first authors to introduce the formulation of the OPF problem. 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 (LP), non-linear programming (NLP), quadratic programming (QP), Newton-based techniques and interior point methods (IPM) (Yan and Quantana, 1999; Habiabollahzadeh et al., 1989; Burchet et al., 1984; Momoh et al., 1999; Momoh 1999; Huneault and Galina, 1991). However, in some

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cases, the foregoing methods failed to provide the global minima and only reached the local one. Therefore, some classical methods cannot handle the integer problems. To guide the decision making of the power system operator, the OPF solution should not be sensitive to selected starting points. Complexity of OPF problem must be reduced. OPF problem programs must be user friendly. Therefore, there is a need for more robust and faster OPF algorithm. With regard to this, improvement of optimization methods, capable of address these shortcomings are becoming increasingly vital (Roy et al., 2010).

In recent decades, various population-based optimization techniques have been applied to solve complex constrained optimization problem which also include optimization problem 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) (Abido, 2002), genetic algorithm (GA) (Deveraj and Yegnanarayana, 2005), improved genetic algorithm (IGA) (Lai et al., 1997), particle swarm optimization (PSO) (Abido, 2002), differential evolution (DE) (Varadarajan and Swarup, 2008), simulated annealing (SA) (Roa-Sepulveda and Pavez-Lazo, 2003), evolutionary programming (EP) (Somasundaram et al., 2004), a multi-objective PSO (Hazra and Sinha, 2010), fuzzy multi-objective PSO considering UPFC (Aghaei et al., 2012), modified honey bee mating optimization (MHBMO) considering generator constraints (Niknam et al., 2011), modified artificial bee colony (MABC) algorithm (Khorsandi et al., 2013), and improved harmony search (IHS) algorithm (Sinsuphan et al., 2013) have proved to be successful in solving OPF problem with different objectives. The results reported were for different test systems promising and encouraging for further research in this direction.

The power system academic has made considerable efforts to provide scientific community with simulation tools that cover different aspects of power systems analysis. Matpower developed by Zimmerman and Gan (1997), Power Systems Analysis Toolbox (PSAT) introduced by Milano (2005) and utilized enhanced genetic algorithm (EGA) for solving OPF by Bakistzis et al. (2002) are some examples of these efforts. The mentioned approaches have been tested on IEEE 30-bus system and the three areas IEEE RTS-96 which is a 73 bus, 120-branch system.

Another approach to OPF problem was DE algorithm introduced by Basu with use of flexible alternating current transmission system (FACTS) devices. Basu used multi-objective DE algorithm to solve the OPF problem with FACTS devices in IEEE 30-bus and IEEE 57-bus systems, the results were compared with the literature by the author (Basu, 2011). Madhad et al. also investigated use of efficient parallel genetic algorithm (EPGA) in the OPF problem representing large-scale system with shunts FACTS devices. Authors presented three test systems IEEE 30-bus, IEEE 118-bus and 15 generation units with prohibited zones and compared with the results of other literatures (Madhad et al., 2010).

Atashpaz-Gargari and Lucas (2007) introduced a novel with inspiration from social and political relations. The performance of this evolutionary optimization algorithm has been continuously reinstated by successful utilization in many engineering applications such as control (Lucas et al., 2010), data clustering (Niknam et al., 2011), and industrial engineering (Nazari-Shirkouhi et al., 2010) in recent years and has demonstrated great effectiveness in both critical factors of convergence rate and capability in achieving global optimal. In Bahrami et al. (2011) 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, we present a new hybrid algorithm, called a MICA–TLA, which is based on merging MICA with TLA algorithms. The performance of this approach for OPF problem with non-smooth cost functions such as piecewise quadratic cost function, fuel cost with valve point effects, fuel cost with prohibited zones is studied and evaluated on the standard IEEE 30-bus and IEEE 57-bus test systems with different objective functions and is compared to methods reported in the literature. Experimental results on the OPF problem show that the novel hybrid algorithm has better performance in both convergence and global best, compared with original ICA, TLA, MICA, and other methods reported in the literature. We believe that the proposed method has good performance and ability to obtain the solution of the OPF problem. This proposed method can optimize number of different objectives and may be helpful to the system operators in choosing judicious decision in running the system efficiently.

The rest of this paper is classified into four sections as follows: Section 2 covers formulation of an OPF problem while Section 3 explains the standard structure of the ICA, TLA, MICA and hybrid MICA–TLA algorithms, Section 4 of the paper is allocated to presenting 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 30-bus and IEEE 57-bus systems and finally, in Section 5, the conclusion of the implementation for the hybrid method is presented.

2. Problem formulation

In general view, the goal of a solution of optimal power flow 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.

The OPF problem can be mathematically formulated as follows:

$$\text{Min}\, J(x,u) \tag{1}$$

$$\text{Subject to}: \; g(x,u) = 0 \tag{2}$$

$$h(x,u) \le 0 \tag{3}$$

In the above equation, J is the objective function to be minimized and x is the vector of dependent variables (state vector) consisting of:

1. Generator active power output at slack bus P_{G1}.
2. Load bus voltage V_L.
3. Generator reactive power output Q_G.
4. Transmission line loading (or line flow) S_l.

Accordingly, the x vector can be illustrated as the following:

$$x^T = [P_{G1}, V_{L1} \ldots V_{LNPQ}, Q_{G1} \ldots Q_{GNG}, S_{l1} \ldots S_{lNTL}] \tag{4}$$

where NG defines the number of generators; NPQ and NTL depict the number of PQ buses and the number of transmission lines, respectively.

u is the vector of independent variables (control variables) consisting of:

1. Generation bus voltages V_G.
2. Generator active power output P_G at PV buses except at the slack bus P_{G1}.
3. Transformer taps settings T.
4. Shunt VAR compensation Q_C.

Therefore, u can be expressed as follows:

$$u^T = [P_{G2} \ldots P_{GNG}, V_{G1} \ldots V_{GNG}, Q_{C1} \ldots Q_{CNC}, T_1 \ldots T_{NT}] \tag{5}$$