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Optimal reactive power dispatch by particle swarm optimization with an aging leader and challengers

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ABSTRACT

This study presents a particle swarm optimization (PSO) with an aging leader and challengers (ALC-PSO) for the solution of optimal reactive power dispatch (ORPD) problem. The ORPD problem is formulated as a nonlinear constrained single-objective optimization problem where the real power loss and the total voltage deviations are to be minimized separately. In order to evaluate the performance of the proposed algorithm, it has been implemented on IEEE 30-, 57- and 118-bus test power systems and the optimal results obtained are compared with those of the other evolutionary optimization techniques surfaced in the recent state-of-the-art literature. The results presented in this paper demonstrate the potential of the proposed approach and show its effectiveness and robustness for solving the ORPD problem of power system.

1. Introduction

Optimal reactive power dispatch (ORPD) problem aims to allocate reactive power generation so as to minimize the real power transmission losses and/or to keep all the bus voltages within the limits, while satisfying a number of equality and inequality constraints including the power flow equations, upper and lower voltage limits and reactive power capacity restrictions in various reactive power sources such as generators, shunt capacitor banks and transformer taps [1].

Many classical optimization techniques such as linear programming [1], nonlinear programming (NLP) [2], quadratic programming [3,4], Newton approach [5] and interior point methods [6,7], etc. have been applied in the literature for solving ORPD problem of power system. These techniques are computationally fast. However, these techniques have severe limitations [8] like (i) need of continuous and differentiable objective functions, (ii) easy convergence to local minima and (iii) difficulty in handling a very large number of variables. Hence, it becomes essential to develop optimization techniques which are capable of overcoming these drawbacks.

To overcome these limitations, flexible evolutionary optimization techniques such as, simple genetic algorithm (GA) [9,10], improved GA [11], adaptive GA (AGA) [12], evolutionary strategies [13], evolutionary programming [14,15], differential evolution (DE) [16–19], harmony search (HS) algorithm [20], real-parameter GA [21], self-adaptive real coded GA (SARGA) [22], particle swarm optimization (PSO) [23], seeker optimization algorithm (SOA) [24], biogeography-based optimization (BBO) [25], gravitational search algorithm (GSA) [26], etc. have been applied in the literature for the solution of ORPD problem of power system. These evolutionary algorithms have shown success in solving ORPD problem since they do not need the objective and constraints as differentiable and continuous functions.

PSO and DE have received increased attention from researchers because of their simplicity and searching capability. However, it does not mean that these techniques do not have any limitations. In solving complex multimodal problems, these methods may be easily and early trapped into a local optimum. Furthermore, their searching performances depend on the appropriate parameter settings [27]. Premature convergence and local stagnation are frequently observed in many applications [28].

PSO algorithm is one of the swarm intelligence techniques based on simulating the food-searching behavior of birds [29]. Since its inception in 1995, constant emphasis is being given by the

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Nomenclature

B_{ij}	transfer susceptance between buses i and j
c_1 and c_2	positive coefficients that determine the influence of the personal and neighborhood best positions, respectively
g_k	conductance of branch k
G_{ij}	transfer conductance between buses i and j
$iter$	number of iteration for which the leading power of challenger is tested
J	objective function to be minimized
N_B	number of total buses
N_C	number of possible reactive power source installation buses
N_E	number of network branches
N_G	number of generator buses
N_i	number of buses adjacent to bus i (including bus i)
N_L	number of load buses
N_0	number of total buses excluding slack bus
N_P	number of particles in a population
N_{PQ}	number of PQ buses
N_T	number of transformer branches
$\text{NFFE}_{\max}$	maximum NFFEs
NFFE_S	number of fitness function evaluations or iteration cycles
P_{D_i}	demanded active power at bus i
P_{G_i}	injected active power at bus i
Q_C	shunt capacitor/inductor
Q_{D_i}	demanded reactive power at bus i
Q_G	generator reactive power
Q_{G_i}	injected reactive power at bus i
r_1 and r_2	random numbers uniformly distributed in [0, 1]
S_l	power flow in branch l
t	tth iteration
T_k	transformer tap
u	vector of control variables
V_G	generator voltage (continuous)
V_i	voltage at bus i
V_i^{ref}	reference value of the voltage magnitude of the ith bus which is equal to 1.0 p.u.
$\vec{V}_i(t)$	ith particle's velocity vector
V_L	load bus voltage
w	inertia weight
$w_{\max}$	maximum value of w
$w_{\min}$	minimum value of w
x	vector of dependent variables
$\vec{x}_{\text{gBest}}$	historically best position of the entire swarm
$\vec{x}_{\text{pBest}_i}$	historically best position of particle i ($i = 1, 2, \ldots, N_P$)
$\vec{X}_i(t)$	ith particle's position vector
θ_{ij}	voltage angle difference between buses i and j

researchers' pool towards its improvement in performance. Since the original PSO proposed in [29] is prone to suffer from the so-called "explosion" phenomena [30], two improved versions of PSO viz. PSO with a constriction factor (PSO-cf) and PSO with adaptive inertia weight (PSO-w), were proposed by Clerc et al. [30] and Shi et al. [31], respectively.

Application of PSO in diversified field of power system is reported in [32,33]. Recently, the use of PSO to solve ORPD problem is gaining more importance due to its effectiveness in handling the inequality constraints and discrete values compared with those of conventional gradient-based methods.

Yoshida et al. [23] have used PSO for reactive power and voltage control with voltage security assessment. Zhang and Sanderson [27] have proposed an adaptive PSO for reactive power optimization. Zhao et al. [34] have presented reactive power dispatch problem using a multi-agent-based PSO. Esmin et al. [35] have developed an approach to optimize the power loss by using a hybrid PSO with mutation operator. Kumari and Sydulu [36] have solved optimal reactive power control problem using an improved PSO. Vlachogiannis and Lee have proposed three new PSO algorithms in [37] for reactive power and voltage control. Cai et al. [38] have reported a modified PSO method to realize ORPD problem considering voltage stability improvement. A PSO with time varying acceleration is proposed in [39] for ORPD problem for reactive power cost allocation under deregulated environment of power system. Subbaraj and Rajnarayanan [22] have applied a two-phase hybrid PSO approach to solve ORPD problem. Mahadevan and Kannan have utilized a comprehensive learning PSO (CLPSO) in [40] for the solution of ORPD problem of power system. Vaisakh and Rao have proposed PSO with differentially perturbed velocity [41] for ORPD problem of power system. PSO with Cauchy and adaptive mutations have been applied for the solution of ORPD problem in [42]. Parallel PSO has been applied in dynamic ORPD problem of power system by Li et al. [43].

It is the general law of nature that every organism in the earth ages and has a limited lifespan. With the passage of time, leader of the colony becomes old and feeble. And this old leader has no longer the capability to lead the colony unless or otherwise it is challenged by a new and young challenger with great deal of enthusiasm and motivation to accomplish certain targets. Thus, aging provides opportunities for the other individuals of the colony to challenge the leadership capability of the leader. Based on these concepts, a modified PSO called as PSO with aging leader and challenges (ALC-PSO) has been presented in [44].

In ALC-PSO [44], the lifespan of the leader is adaptively tuned in accordance with the leader's leading power. If a leader shows strong leading power, it lives longer to attract the swarm toward better positions. Otherwise, if a leader fails to improve the swarm and gets old, new particles emerge to challenge and claim the leadership. This, in turn, brings diversity in the colony. In this way, the concept of "aging" in ALC-PSO actually serves as a challenging mechanism for promoting a suitable leader to lead the swarm. In this way, natural aging mechanism of the organism has been modeled into ALC-PSO.

In the present work, ALC-PSO is applied for the solution of ORPD problem of power system. Three IEEE standard test power systems like IEEE 30-, 57- and 118-bus power systems are adopted as standard power networks whose ORPD problem are solved with different objectives such as minimization of either active power transmission loss (P_{Loss}) or that of absolute value of total voltage deviations (TVD) and the results are compared with those of other computational intelligence-based techniques surfaced in the recent literature to, finally, establish the optimization efficacy of the proposed ALC-PSO algorithm.

The rest of this paper is organized as follows. In Section 2, mathematical problem of the ORPD work is presented. In Section 3, basic PSO is described. ALC-PSO is discussed in Section 4 with special emphasis on how it is applied to ORPD problem of power system. Simulation results are presented and discussed in Section 5. Finally, conclusions of the present paper are drawn in Section 6.

2. Mathematical problem formulation

The ORPD problem is concerned with optimization of steady-state performance of power system with respect to specified objective function, subject to various equality and inequality