Electrical Power and Energy Systems 53 (2013) 123–134

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal reactive power dispatch using quasi-oppositional teaching learning based optimization

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ARTICLE INFO

Article history:
Received 31 October 2012
Received in revised form 5 April 2013
Accepted 20 April 2013

Keywords:
Optimal reactive power dispatch
Teaching learning based optimization
Opposition based learning
Evolutionary algorithm
Voltage stability index
Voltage profile

ABSTRACT

This paper presents a newly developed teaching learning based optimization (TLBO) algorithm to solve multi-objective optimal reactive power dispatch (ORPD) problem by minimizing real power loss, voltage deviation and voltage stability index. To accelerate the convergence speed and to improve solution quality quasi-opposition based learning (QOBL) concept is incorporated in original TLBO algorithm. The proposed TLBO and quasi-oppositional TLBO (QOTLBO) approaches are implemented on standard IEEE 30-bus and IEEE 118-bus test systems. Results demonstrate superiority in terms of solution quality of the proposed QOTLBO approach over original TLBO and other optimization techniques and confirm its potential to solve the ORPD problem.

1. Introduction

Optimal reactive power dispatch (ORPD) is a useful tool in modern energy management system. It plays a significant role for secure operation of power systems. One of the main tasks of a power system operator is to manage the system in such a way that its operation be safe and reliable. The main purpose of ORPD is to find the optimal operating state of a power system and the corresponding settings of control variables such as voltage rating of generators, reactive power injection of shunt capacitors/reactors, tap ratios of the tap setting transformers in order to minimize the total power losses of the network while satisfying a given set of physical and operating constraints. However, due to the continuous growth in the demand of electricity with unmatched generation, voltage at heavily loaded may become less than its operating limit and it may cause voltage collapse. Therefore, improvement of voltage profile and enhancement of voltage stability should also be considered objectives of ORPD problem along with transmission loss.

Many classical optimization techniques such as gradient search (GS) [1], linear programming (LP) [2,3], Lagrangian approach (LA) [4], quadratic programming (QP) [5], and interior point methods (IP) [6], have been applied for solving ORPD problems. Zhu and Xiong [7] proposed a new approach to study the optimal reactive power (VAR) control problem using a modified interior point (MIP) method to minimize the system real power losses and to penalize any new VAR utilization. Granada et al. [8] approached a decentralized approach based on Lagrangian decomposition method for solving ORPD problem in multi-area power systems. From the literature survey, it may be observed that these classical methods suffer from many drawbacks, such as insecure convergence properties and excessive numerical iterations. These methods also suffer from the local optimality and resulting in huge computations and large execution time. These methods are also incapable of handling nonlinear, discontinuous functions and constraints and problems having multiple local minimum points.

In recent years, heuristic optimization techniques, such as simulated annealing (SA) [9], genetic algorithm (GA) [10], evolutionary programming (EP) [11], differential evolution (DE) [12], particle swarm optimization (PSO) [13], biogeography based optimization (BBO) [14], gravitational search algorithm (GSA) [15], seeker optimization algorithm (SOA) [16], and artificial bee colony optimization (ABC) [17], have generated intense interest to the researchers due to their flexibility, versatility and robustness in seeking global optimal solution. These methods present extremely superiority in obtaining the global optimum and in handling discontinuous and non-convex objectives. Roy et al. [18] presented BBO algorithm for solving multi-objective ORPD problems. Khazali et al. proposed harmony search algorithm (HSA) [19] to solve ORPD problem and produced better simulation results compared to other algorithms. Comprehensive learning particle swarm optimization (CPSO) was proposed by Mahadevan and Kannan [20] to generate higher quality solution for the ORPD problems. Hassan et al., introduced fully informed particle swarm optimization (FIPS) [21] to solve ORPD

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http://dx.doi.org/10.1016/j.ijepes.2013.04.011

problem. The authors implemented the proposed FIPS approach on standard 6-bus, IEEE 30-bus and IEEE 118-bus test systems to minimize the transmission loss. Badar et al. applied dynamic PSO (DPSO) [22] on ORPD problems to minimize the transmission loss of a 6-bus test system. Ramirez et al. [23] proposed DE algorithm to solve ORPD strategy that took care of steady state voltage stability implications. Yang et al. developed and successfully implemented hybrid DE (HDE) [24] to solve ORPD problem of IEEE 30-bus test system. Devaraj and Roselyn [25] presented an improved GA approach to solve voltage stability enhance ORPD problem. Jeyadevi et al. [26] addressed an application of modified NSGA-II (MNSGA-II) by incorporating controlled elitism and dynamic crowding distance (DCD) strategies in NSGA-II to solve multi-objective ORPD problem by minimizing real power loss and maximizing the system voltage stability.

This paper proposes teaching learning based optimization (TLBO) and quasi-oppositional TLBO (QOTLBO) to solve ORPD problems of power systems. The proposed algorithms are implemented on IEEE 30-bus and IEEE 118-bus test systems to solve different single and multi-objective functions. The different single objectives are minimization of transmission loss, voltage deviation and voltage stability index and the multi-objective problem includes simultaneous minimization of transmission loss, voltage deviation and voltage stability index. The simulation results of the proposed methods are compared with other well popular algorithms like strength pareto evolutionary algorithm (SPEA) [27], GA-1 [28], GA-2 [25], DE-1 [12], DE-2 [29], PSO-1 [30], PSO-2 [31], fully informed PSO (FIPS) [31], quantum-inspired evolutionary algorithm (QEA) [32] and ACS [32].

This rest of the paper is organized as follows: ORPD problem is formulated in Section 2. In Section 3, the original TLBO algorithm is described briefly. The quasi-opposition based learning (QOBL) is described in Section 4. QOTLBO algorithm is briefly explained in Section 5. The system simulation is given in Section 6. The conclusion is made in Section 7.

2. Problem formulation

2.1. Objective functions

2.1.1. Single objective function

The objective of voltage stability constraint ORPD is to minimize the active power loss, voltage stability index (L-index) and at the same time keeping the voltage profile within the defined limits while satisfying various equality and inequality constraints. Minimization of voltage stability index helps to enhance the system security.

(i) Minimization of active power loss

The main objective of the ORPD is to minimize the network active power loss while satisfying a number of operating constraints. The objective function may be expressed as:

$$f_1 = \min(P_{loss}) = \min\left[\sum_{k=1}^{N_{TL}} G_k\left(V_i^2 + V_j^2 - 2V_iV_j\cos\alpha_{ij}\right)\right] \tag{1}$$

where P_{loss} is the total active power loss; G_k is the conductance of the kth branch connected between the ith and the jth bus; α_{ij} is the admittance angle of the transmission line connected between the ith and the jth bus; N_{TL} is number of transmission lines; V_i, V_j are the voltage magnitude of the ith and the jth bus, respectively.

(ii) Improvement of voltage stability index

Both reactive and real power losses increase rapidly as the system approaches the maximum loading point or voltage collapse point. Voltage stability problem has a close relationship with the reactive power of the system. Voltage stability can be improved by minimizing the voltage stability indicator L-index. In order to enhance the voltage stability and move the system far from the voltage collapse point, improvement of the voltage stability margin is used as an objective for voltage stability enhance based ORPD problems. Voltage stability index objective may mathematically be expressed as:

$$f_2 = \min(L_{\max}) = \min[\max(L_K)] \quad K = 1, 2, \ldots, N_L \tag{2}$$

where N_L is the number of load buses; L_K is the voltage stability indicator (L-index) of the kth node and may be formulated as [25]:

$$L_K = \left|1 - \sum_{i=1}^{N_G} F_{ji}\frac{V_i}{V_j}\angle\{\theta_{ij} + (\delta_i - \delta_j)\}\right| \tag{3}$$

F_{ji} is the (i,j)th components of the sub matrix obtained by the partial inversion of Y_{Bus} and is given by [26]:

$$F_{ji} = -[Y_{jj}]^{-1}[Y_{ji}] \tag{4}$$

where Y_{jj} is the self-admittance of the jth bus; Y_{ji} is the mutual-admittance between the jth bus and the ith bus; θ_{ij} is the phase angle of the term F_{ij}; δ_i, δ_j are the phase angle of the ith and the jth bus voltages, respectively; N_G is the number of generated buses.

(iii) Improvement of voltage profile

Bus voltage is one of the most important security and service quality indexes. Minimizing the deviations of voltages from desired values is widely used. The objective of voltage profile improvement or the voltage deviation minimization at load buses of the power system may be expressed as follows:

$$f_3 = \min\left(\sum_{i=1}^{N_L}\left|V_{L_i} - V_{L_i}^{sp}\right|\right) \tag{5}$$

where V_{L_i} is the voltage at ith load bus; $V_{L_i}^{sp}$ is the desired voltage at ith load bus which is usually set to 1.0 p.u. The minimization of the objective function is subjected to a number of equality and inequality constraints as given below.

2.1.2. Multi-objective function

Most engineering optimization problems are concerned with several objectives. Very often, these objectives are conflicting with each other. Thus, simultaneous optimization of the opposing objectives has become challenging task for researchers. Many researchers proposed multi-objective evolutionary algorithms such as the non-dominated sorting genetic algorithm (NSGA) [26], the strength pareto evolutionary algorithm (SPEA) [27] to solve the ORPD problem by simultaneously considering the individual objective as competing objectives. Few researchers [33] proposed price penalty factor approach to solve multi-objective optimization problem. In this article also, the multi-objective ORPD problem is converted to a single objective function by introducing price penalty factors approach as follows:

$$f = f_1 + PF_1 \times f_2 + PF_2 \times f_3 \tag{6}$$

where PF_1, PF_2 are the price penalty factor for voltage stability index and voltage profile respectively. In this simulation study, the

2.2. System constraints

(i) Equality constraint

The real and reactive power balance equations are the equality constraints of ORPD problem and are expressed as follows: