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Multi-objective optimal reactive power dispatch using multi-objective differential evolution

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ABSTRACT

This paper presents multi-objective differential evolution (MODE) to solve multi-objective optimal reactive power dispatch (MORPD) problem by minimizing active power transmission loss and voltage deviation and maximizing voltage stability while varying control variables such as generator terminal voltages, transformer taps and reactive power output of shunt VAR compensators. MODE has been tested on IEEE 30-bus, 57-bus and 118-bus systems. Numerical results for these three test systems have been compared with those acquired from strength pareto evolutionary algorithm 2 (SPEA 2).

Introduction

Optimal reactive power dispatch (ORPD) perks up power system economy and security. Reactive power generation has no production cost but in general it has an effect on the production cost related with active power transmission loss. Multi-objective optimal reactive power dispatch (MORPD) minimizes active power transmission losses and voltage deviation and maximizes voltage stability simultaneously by adjusting control variables such as generator voltages, transformer tap settings, reactive power output of shunt VAR compensators etc. at the same time satisfying several equality and inequality constraints.

A variety of classical optimization techniques [1–5] such as Newton method, linear programming, quadratic programming and interior point method have been pertained to solve ORPD problem. ORPD is a mixture of discrete and continuous variables with multiple local optima. So it is difficult to acquire global optima by using classical optimization techniques.

In recent times nature-inspired metheuristics such as evolutionary programming (EP) [6], adaptive genetic algorithm (AGA) [7], particle swarm optimization (PSO) [8], hybrid particle swarm optimization (HPSO) [9], bacterial foraging algorithm (BFA) [10], quantum-inspired evolutionary algorithm (QEA) [11], comprehensive learning particle swarm optimization (CLPSO) [12] and hybrid shuffled frog leaping algorithm (HSFLA) and Nelder-Mead simplex search (NMSS) [13] have been pertained to solve ORPD problem.

ORPD problem is formulated as multi-objective optimization problem [14]. The multi-objective problem can be transfer into a single objective problem by weighted sum of objectives [15,16] but it may cause the non-commensurable objectives to lose their importance on merging into a single objective function. Hence, this approach cannot be pertained to find Pareto-optimal solutions of MORPD problems. Classical optimization methods can unearth one solution in one simulation run and therefore these methods are inconvenient to solve multi-objective optimization problems. In case of multi-objective evolutionary algorithms (MOEAs) multiple solutions are unearthed in one simulation run [17].

Recent developed multi-objective evolutionary optimization techniques are non-dominated sorting genetic algorithm (NSGA-II) [22,23], multi-objective differential evolution (MODE) [24], strength pareto evolutionary algorithm (SPEA) [25], pareto archived evolution strategy (PAES) and others. In recent times, SPEA [14,18], NSGA-II [19], hybrid fuzzy multi-objective evolutionary algorithm [20], chaotic parallel vector evaluated interactive honey Bee mating optimization [21] have been pertained to solve multi-objective ORPD (MORPD) problem.

This paper proposes MODE for solving MORPD problem which is formulated by reckoning active power transmission loss minimization, voltage deviation minimization and voltage stability maximization as competing objectives. The proposed technique is validated by applying it to IEEE 30-bus, 57-bus and 118-bus test systems. Test results acquired from the proposed technique are

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compared with those acquired from strength pareto evolutionary algorithm 2 (SPEA 2).

Problem formulation

The MORPD problem is formulated as a true multi-objective optimization problem by reckoning minimization of active power transmission loss and voltage deviation and maximization of voltage stability as objectives at the same time fulfilling equality and inequality constraints. The objective functions and constraints can be stated as:

Objective functions

Minimization of active power transmission loss

The objective function can be stated as:

$$\text{Minimize } F_1 = P_{loss} = \sum_{k=1}^{NTL} g_k[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \tag{1}$$

where P_{loss} signifies active power transmission loss, NTL is the number of transmission lines, g_k is the conductance of branch k connected between ith bus and jth bus, V_i and V_j are the magnitude voltage of ith and jth busses, δ_i and δ_j are the phase angle of voltages of the ith and jth busses.

Minimization of voltage deviation

The objective is to minimize the voltage deviation of all load (PQ) busses from 1 p.u to perk up power system security and service quality. The objective function can be stated as:

$$\text{Minimize } F_2 = \sum_{i=1}^{NPQ} |V_i - 1.0| \tag{2}$$

where NPQ is the number of load busses.

Maximization of voltage stability

Voltage stability is the capacity of a power system to keep up suitable voltages at all bus bars beneath normal operating condition and even after disturbances such as change in load demand or system configuration. In recent times a number of major network collapses [28] have been taken place due to voltage instability. Improvement of voltage stability has been acquired by minimizing voltage stability indicator i.e. L – index value at each bus which signifies voltage collapse condition of that bus. L_j of jth bus [29] can be stated as:

$$L_j = \left|1 - \sum_{i=1}^{NPV} F_{ji}\frac{V_i}{V_j}\right| \quad \text{where} \quad j = 1, 2, \ldots\ldots, NPQ \tag{3}$$

$$F_{ji} = -[Y_1]^{-1}[Y_2] \tag{4}$$

where NPV is the number of PV bus and NPQ is the number of PQ bus. Y_1 and Y_2 are sub-matrices. YBUS acquired after segregating the PQ and PV bus parameters can be stated as:

$$\begin{bmatrix} I_{PQ} \\ I_{PV} \end{bmatrix} = \begin{bmatrix} Y_1 Y_2 \\ Y_3 Y_4 \end{bmatrix} \begin{bmatrix} V_{PQ} \\ V_{PV} \end{bmatrix} \tag{5}$$

L – index is computed for all PQ busses. L_j is zero or one depending upon no load condition or voltage collapse condition of jth bus. The objective function [27] can be stated as:

$$\text{Minimize} \quad F_3 = \max(L_j), \quad \text{where} \quad j = 1, 2, \ldots, NPQ \tag{6}$$

Constraints

Equality constraints

$$P_{Gi} - P_{Di} - V_i\sum_{j=1}^{NB} V_j\left[G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)\right] = 0,$$
$$i = 1, 2, \ldots, NB \tag{7}$$

$$Q_{Gi} - Q_{Di} - V_i\sum_{j=1}^{NB} V_j\left[G_{ij}\sin(\delta_i - \delta_j) - B_{ij}\cos(\delta_i - \delta_j)\right] = 0,$$
$$i = 1, 2, \ldots, NB \tag{8}$$

where NB is the number of busses, P_{Gi} and Q_{Gi} are active and reactive power generation at the ith bus, P_{Di} and Q_{Di} are active and reactive power demands at the ith bus, G_{ij} and B_{ij} are the transfer conductance and susceptance between ith bus and jth bus respectively.

Inequality constraints

Generator constraints. The generator voltage magnitudes and reactive power outputs curbed by their minimum and maximum limits can be stated as:

$$V_{Gi}^{\min} \leqslant V_{Gi} \leqslant V_{Gi}^{\max}, \quad i = 1, 2, \ldots, NG \tag{9}$$

$$Q_{Gi}^{\min} \leqslant Q_{Gi} \leqslant Q_{Gi}^{\max}, \quad i = 1, 2, \ldots, NG \tag{10}$$

Shunt VAR compensator constraints. Reactive power output of shunt VAR compensators curbed by their minimum and maximum limits can be stated as:

$$Q_{ci}^{\min} \leqslant Q_{ci} \leqslant Q_{ci}^{\max}, \quad i = 1, 2, \ldots, NC \tag{11}$$

Transformer constraints. Transformer tap settings curbed by their physical deliberation can be stated as:

$$T_i^{\min} \leqslant T_i \leqslant T_i^{\max}, \quad i = 1, 2, \ldots, NT \tag{12}$$

Security constraints. The voltage magnitude of each PQ bus curbed by its minimum and maximum limits and transmission line flow curbed by its maximum limit can be stated as:

$$V_{Li}^{\min} \leqslant V_{Li} \leqslant V_{Li}^{\max}, \quad i = 1, 2, \ldots, NPQ \tag{13}$$

$$S_{li} \leqslant S_{li}^{\max}, \quad i = 1, 2, \ldots, NTL \tag{14}$$

Principle of multi-objective optimization

Most of the real-world problems involve simultaneous optimization of several objective functions. These functions are non-commensurable and often competing and conflicting objectives. Multi-objective optimization having such conflicting objective functions gives rise to a set of optimal solutions, instead of one optimal solution because no solution can be considered to be better than any other with respect to all objective functions. These optimal solutions are known as pareto-optimal solutions.

Generally, multi-objective optimization problem consisting of a number of objectives and several equality and inequality constraints can be formulated as follows:

$$\text{Minimize} \quad f_i(x) \quad i = 1, \ldots\ldots, N_{obj} \tag{15}$$