Electrical Power and Energy Systems 75 (2016) 194–204

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

A two-point estimate method for uncertainty modeling in multi-objective optimal reactive power dispatch problem

Seyed Masoud Mohseni-Bonab [a], Abbas Rabiee [a,*], Behnam Mohammadi-Ivatloo [b], Saeid Jalilzadeh [a], Sayyad Nojavan [b]

[a] Department of Electrical Engineering, Faculty of Engineering, University of Zanjan, Zanjan, Iran
[b] Faculty of Electrical and Computer Engineering, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Article history:
Received 20 October 2014
Received in revised form 8 August 2015
Accepted 21 August 2015
Available online 25 September 2015

Keywords:
Monte Carlo simulation (MCS)
Multi objective optimal reactive power dispatch (MO-ORPD)
Real power loss (PL)
Two-point estimate method (TPEM)
Uncertainty
Voltage deviation (VD)

ABSTRACT

Due to nonlinear and discrete variables and constraints, optimal reactive power dispatch (ORPD) is a complex optimization problem in power systems. In this paper, the purpose is to solve multi objective ORPD (MO-ORPD) problem considering bus voltage limits, the limits of branches power flow, generators voltages, transformers tap changers and the amount of compensation on weak buses. The objectives of this paper are real power losses and voltage deviations from their corresponding nominal values, which are conflicting objectives. Because of the stochastic behavior of loads, the MO-ORPD problem requires a probabilistic approach. Hence, in this paper, a two-point estimate method (TPEM) is proposed to model the load uncertainty in MO-ORPD problem. Moreover, the proposed method is compared with some other methods such as deterministic approaches and Monte Carlo simulations (MCS). The obtained results approve the efficiency of the proposed methodology. The proposed models are implemented and solved using GAMS optimization package and verified using IEEE 14-bus and IEEE 30-bus standard test systems.

Introduction

Optimal power flow (OPF) is one of the main problems in power system operation, which was introduced by Carpentier for first time about 50 years ago [1]. Generally this problem categorized into two sub-problems, namely optimal reactive power dispatch (ORPD) and optimal real power dispatch [2]. ORPD is important for security and economy of power systems. The ORPD determines the optimal amount of reactive power generation at different places, which is used for minimization of real power transmission losses and total voltage deviation with considering different equality and inequality constraints. Nonlinear objective function and different type of constraints makes the ORPD problem a large-scale nonlinear optimization problem.

The ORPD problem is modeled for different objective functions and various methods are used for its solution. As presented in [3], the reactive power generation management can be employed to improve the voltage stability margin of power systems. A solution to the reactive power dispatch problem with a particle swarm optimization approach based on multi-agent systems is presented in [4]. In [5], a model for ORPD is presented for minimization of the total costs. The total cost is defined as cost of energy loss of transmission network and the costs of adjusting the control devices. In [6], a harmony search algorithm is implemented for solution of ORPD problem. In this paper, different objective functions including power transmission loss, voltage stability and voltage profile are optimized separately. Hybrid methods are also used for solution of ORPD problem to provide the advantage of different methods simultaneously. Hybridization of modified teaching learning algorithm and double differential evolution algorithm has been used in [7] for effective solution of ORPD problem. In [8], hybrid standard real-coded genetic algorithm and simulated annealing method is used to solve ORPD problem. In [9], application of chance-constrained programming method to handle the uncertainties in ORPD problem is studied. Uncertain nodal power injections and random branch outages are considered as uncertainty sources. The problem is solved by combining probabilistic power flow and genetic algorithm. The differential evolution algorithm for optimal settings of reactive power dispatch control variables is employed in [10].

ORPD problem is modeled as multi-objective optimization problem and solved using different methods in literature. A

---

* Corresponding author at: Department of Electrical Engineering, Faculty of Engineering, University of Zanjan, P.O. Box: 45371-38111, Zanjan, Iran. Tel.: +98 2433054208; fax: +98 2433052762.

E-mail addresses: s.m.mohsenibonab@ieee.org (S.M. Mohseni-Bonab), rabiee@znu.ac.ir (A. Rabiee), mohammadi@ieee.org (B. Mohammadi-Ivatloo), jalilzadeh@znu.ac.ir (S. Jalilzadeh), sayyad.nojavan@tabrizu.ac.ir (S. Nojavan).

http://dx.doi.org/10.1016/j.ijepes.2015.08.009
0142-0615/© 2015 Elsevier Ltd. All rights reserved.

Nomenclature

Sets

N_B/N_j	set of buses
N_L	set of branches (transmission lines)
N_G	set of generating units
N_D	set of load buses
ψ_ℓ	set of buses adjacent to ℓ-th branch
N_T	set of tap changing transformers
N_{sh}	set of VAR compensators
N_O	set of objective functions
N_P	set of Pareto optimal solutions

Indices

k	index of Pareto optimal solutions
i/j	index of bus number where $i = 1, 2, \ldots, N_B$
ℓ	index of transmission lines
sl	index of slack bus
r	index of objective functions
t	index of on-load tap changing transformers

Parameters

w_1	weight of objective 1 (real power loss)
w_2	weight of objective 2 (voltage deviation)
$y_\ell/g_\ell/b_\ell$	Admittance/conductance/susceptance of ℓ-th line
$Y_{ij} = G_{ij} + jB_{ij}$	ij-th element of system Y_{BUS} matrix
P_{Gi}	active power production at bus i
$P_{G_i}^{\min}/P_{G_i}^{\max}$	minimum/maximum value for active power
$T_t^{\min}/T_t^{\max}$	minimum/maximum value for t-th tap changer settings
P_{D_i}	real power of the i-th bus
Q_{D_i}	reactive power of the i-th bus
$Q_{G_i}^{\min}/Q_{G_i}^{\max}$	minimum/maximum value for reactive power of the i-th bus
$V_i^{\min}/V_i^{\max}$	minimum/maximum value for voltage magnitude of the i-th bus
$S_\ell^{\max}$	maximum value of power flow of ℓ-th transmission line
Q_{C_i}	VAR compensation capacity in each step at bus i
$A_i^{\min}/A_i^{\max}$	minimum/maximum reactive power compensation step at bus i

Variables

x	vector of dependent variables
u	vector of control variables
T_t	value of t-th tap changer setting
V_i/V_j	voltage magnitude of bus i/j
θ_i/θ_j	voltage angle at bus i/j
S_ℓ	power flow of ℓ-th transmission line
Q_{G_i}	reactive power generation in bus i
A_i	reactive power compensation step at bus i
Q_{sh_i}	reactive power compensation at bus i

Functions

J	total objective function
J_1	first objective function (PL = real power loss)
J_2	second objective function (VD = voltage deviation)
J_{pu}	normalized objective function (PL_{pu} and VD_{pu})
$J_r^{\max}/J_r^{\min}$	maximum/minimum value for r-th objective function
$PL^{\min}/PL^{\max}$	minimum/maximum value for PL
$VD^{\min}/VD^{\max}$	minimum/maximum value for VD

strength Pareto evolutionary algorithm is proposed in [11] to handle the ORPD problem considering the real power loss and the bus voltage deviations as objective functions. In [12], real power loss, voltage deviation and voltage stability index are considered as objective functions and the obtained multi-objective problem is solved using teaching learning based optimization algorithm. Improving voltage stability margin of power system [13] by controlling VAR sources is studied in [14,15]. In [15], *L-index* is used as voltage stability index and is incorporated in multi-objective ORPD problem considering active power losses as another objective. The problem is solved using chaotic PSO based multi-objective optimization method. In [16], ORPD problem is modeled as fuzzy goal programming problem and solved using genetic algorithm. ORPD problem considering static voltage stability and voltage deviation is solved using a seeker optimization algorithm (SOA) in [17]. The multi-objective ORPD problem considering active power losses and voltage stability index as objective functions is solved using modified NSGA-II in [18]. In [19], a hybrid fuzzy multi-objective evolutionary algorithm based approach is proposed for solution of multi-objective ORPD problems. Hybrid modified imperialist competitive algorithm and invasive weed optimization is implemented in [20] for multi-objective ORPD (MO-ORPD) problem solution. In [21], different constraint handling methods in ORPD problem including feasible solutions, self-adaptive penalty, ε-constraint, stochastic ranking, and the ensemble of constraint handling techniques is evaluated. A multi objective chaotic parallel vector evaluated interactive honey bee mating optimization algorithm is presented in [22] to solve the MO-ORPD problem with considering operational constraints of the generators.

Therefore, it is observed that the MO-ORPD problem has been solved so far with many intelligent algorithms but none of them solve multi objective reactive power dispatch considering load uncertainty. Load forecast can be obtained using historical load data and whether forecast data using different methods. But, always the forecast is not perfect and there is an inaccuracy in the forecasted data. Therefore it is necessary to consider the effect of uncertain loads in the problem.

Uncertain parameters in power systems can be divided into two categories: The first one is technical parameters like outages, demand and generation and second one is economical parameters like as inflation rate or price levels. There are different methodologies for handling uncertainties in power systems that is based on aforementioned parameters. Stochastic programming is widely used in power system planning and operation for uncertainty modeling [23–25]. In stochastic programming based methods, the uncertain parameters are modeled using discrete scenarios with their occurrence probability. Information gap decision theory (IGDT) is a non-possibilistic uncertainty modeling method, which does not require probability distribution of the uncertain parameters. IGDT method is used for modeling wind power generation uncertainty in OPF problem in presence of HVDC lines [26]. This method is also used for modeling price uncertainty in operation of generation companies [27] and distribution companies [28]. Robust optimization is another decision making tool in uncertain environments. This method is utilized in [29] for market price uncertainty modeling in optimal self-scheduling of a hydro-thermal generating company. In [30], robust optimization method is used for decision making of a retailer in energy market. An updated review of the uncertainty modeling methods in energy systems are provided in [31].

The aim of this paper is determining optimal values of control variables in order to achieve the objectives such as reducing real power losses and minimizing voltage deviation considering the