Electrical Power and Energy Systems 55 (2014) 731–740

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Modified Differential Evolution algorithm for multi-objective VAR management

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ARTICLE INFO

Article history:
Received 26 December 2012
Received in revised form 4 September 2013
Accepted 12 October 2013

Keywords:
Modified Differential Evolution algorithm
Pareto-optimal solution
Real power loss minimization
VAR management
Voltage deviation

ABSTRACT

Reactive power or VAR management is one of the most crucial tasks required for proper operation and control of a power system. Reactive power management is carried out to reduce losses and to improve voltage profile in a power system, by adjusting the reactive power control variables such as generator voltages, transformer tap-settings and other sources of reactive power such as capacitor banks or FACTS devices. VAR management provides better system security, improved power transfer capability and overall system operation. VAR management is a complex combinatorial optimization problem involving nonlinear functions having multiple local minima and nonlinear and discontinuous constraints. In this paper, the VAR management problem is formulated as a nonlinear constrained multi-objective optimization problem with equality and inequality constraints for minimization of real power losses and voltage deviation simultaneously. This multi-objective problem is solved using Differential Evolution (DE), which is a population based search algorithm. For avoiding the time and the effort in tuning the parameters of DE algorithm, a modified DE algorithm with time varying chaotic mutation and crossover is proposed for solving the multi-objective VAR management problem. Weighing factor method has been employed for finding Pareto optimal set for VAR management problem. Fuzzy membership function is used to obtain the best compromise solution out of the available Pareto-optimal solutions. Effectiveness of the proposed modified DE algorithm based approach has been demonstrated on IEEE 30-bus system and is found to be superior to classical DE and its variants Self-adaptive Differential Evolution (SaDE) and Ensemble of Mutation and Crossover Strategies and Parameters in Differential Evolution (EPSDE) in terms of convergence behavior and solution quality.

1. Introduction

The main objective of reactive power (VAR) management in a power system is to identify the reactive power control variables settings such as generator voltages, transformer tap-settings and other sources of reactive power such as capacitor banks or FACTS devices to reduce losses and to provide better voltage control resulting in improved voltage profile, system security, power transfer capability and overall system operation. Reactive power management is a sub-problem of optimal power flow (OPF) calculation. In general, OPF is a non-linear programming (NLP) problem that is solved to find out the optimal control parameters/circumstance to minimize or maximize a desired objective function, subject to certain system constraints. It was first introduced by Carpentier [1,2] in 1960s. Reactive power management provides the power system operator a set of control variables to minimize transmission losses and to preserve bus voltage within permissible limits by rescheduling the power flows.

In recent years, the issue of reactive power management for various objectives like voltage control and power losses reduction has received much attention. The main objective of VAR management is to improve the voltage profile and minimize real power losses through redistribution of reactive power in the system [3–5].

Though, the conventional optimization techniques like Gradient method, non-linear programming, Quadratic programming, Linear Programming, and Interior Point method can be applied to solve VAR management problem [6–10], but these techniques have several drawbacks, such as insecure convergence properties and excessive numerical iterations; resulting in huge computations and large execution time. Also, these methods are highly complex optimization techniques and inefficient for large-scale system applications [10]. Due to non-differential, non-linear, multi-modal and non-convex nature of the VAR management problem, most of these conventional techniques converge to a local optimum [10].

With the advent of Evolutionary Computing (EC) techniques like Genetic Algorithm (GA), Evolutionary Programming (EP), Differential Evolution (DE) algorithm, and Particle Swarm

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http://dx.doi.org/10.1016/j.ijepes.2013.10.015

Nomenclature

f_1	active power loss
ntl	the number of transmission lines
g_k	is the conductance of the kth line
$V_i\angle\delta_i$ and $V_j\angle\delta_j$	are the voltages at the end buses i and j of the kth line in a power system, respectively
f_2	Voltage deviation
NLB	the number of load buses
V_k^{ref}	is the pre-specified reference value of the voltage magnitude at the kth load bus
V_k^{ref}	is usually set to be 1.0 pu
NB	is the number of buses
P_G and Q_G	are the generator real and reactive power, respectively
P_D and Q_D	are the load real and reactive power, respectively
G_{ij} and B_{ij}	are the transfer conductance and susceptance of the line between bus i and bus j, respectively
NG	is the number of generators
NT	is the number of transformers
NC	is the number of switchable VAR sources
x	is the vector of dependent variables consisting of load bus voltages V_L, generator reactive power outputs Q_G, and transmission line loadings S_L
u	is the vector of control variables consisting of generator voltages V_G, transformer tap settings T, and shunt VAR compensations Qc
w	is a weighing factor
$f_i^{\min}$ and $f_i^{\max}$	are the minimum and maximum value of the ith objective function among all non-dominated solutions, respectively
x_j^l and x_j^u	are the lower and upper bounds of the jth variable, respectively
$f(\cdot)$	is the function to be minimized
t	is the iteration count and μ is a control parameter

Optimization (PSO), these techniques have been applied for reactive power dispatch problem [11–21].

These nature inspired stochastic search based methods are increasingly being proposed for solving power system optimization problems in recent years. The random parallel search capability and non-dependency on nature of the optimization problem has contributed to their popularity for handling various complex optimization problems. The ease of formulating the equality and inequality constraints and stable convergence behavior also add to their merits. In recent years, several Evolutionary Computing based algorithms, their modified versions and hybrid EC algorithms have been developed and proposed for various optimization problems in power system [22,23]. The modified versions and hybrid EC algorithms are claimed to provide better solution for some functions and the problem under consideration, but there is no algorithm available which outperforms other algorithms for all the optimization problems. The reason is that, these methods do not converge to the global best solution in every trial run but are able to produce a feasible near global solution quite fast and are highly dependent on parameter tuning.

DE is a simple population based search algorithm, which is highly efficient in handling constrained optimization problems and is supposed to be an improved version of Genetic Algorithm. This algorithm can be applied for optimization of a non-smooth, discontinuous and multi-modal function. Differential Evolution algorithm can find near optimal solution regardless the initial parameters, its convergence is fast and it requires few number of control parameters. In addition to this, its coding is simple and it can handle integer and discrete optimization [24,25].

The performance of the Differential Evolution algorithm was compared with various heuristic techniques. It has been observed that DE is significantly better than that of other heuristic methods like GA, Particle Swarm Optimization and Evolutionary Algorithm. DE algorithm is found to be robust and able to provide the same results consistently over several trials [26,27]. In addition to this, DE algorithm has been used to solve high dimensional function optimization [28]. It is found that, it has superior functioning on a set of widely used bench-mark functions. Thus, DE algorithm seems to be a promising approach for various engineering optimization problems including reactive power management [29–32].

Differential Evolution algorithm has been applied for single objective VAR management problem [18,19], and the results obtained are found to be better than those already reported earlier by using other such techniques. In this paper, a modified DE algorithm with time varying chaotic mutation and crossover has been proposed for solving the multi-objective VAR management problem. The problem has been formulated as a non-linear constrained multi-objective optimization problem, where the real power loss and the bus voltage deviations are to be optimized (minimized) simultaneously. These two objectives are converted to a single objective by linear combination of these objectives as a weighted sum. Modified DE algorithm has been employed to obtain the Pareto-optimal set of the solution. Moreover, a fuzzy based method has been applied to extract the best compromise solution over the trade-off curve. Effectiveness of the proposed modified DE based approach to solve multi-objective VAR management problem has been demonstrated and compared on the standard IEEE 30-bus system [6].

2. Problem formulation

The optimal VAR management problem is to optimize the steady state performance of a power system in terms of one or more objective functions while satisfying several equality and inequality constraints. The VAR management problem can be formulated as follows [4].

2.1. Objective functions

(1) *Minimization of real power loss (P_L)*

This objective is to minimize the real power loss in transmission lines of a power system by managing reactive power and is expressed as

$$f_1 = PLoss = \sum_{k=1}^{ntl} g_k[V_i^2 + V_j^2 - 2V_iV_j\cos(\delta_i - \delta_j)] \quad (1)$$

(2) *Minimization of voltage deviation (V_D)*

This objective is to minimize the deviations in voltage magnitudes at load buses that can be expressed as

$$f_2 = V_D = \sum_{k=1}^{NLB} |V_k - V_k^{ref}| \quad (2)$$

2.2. Problem constraints

(1) *Equality constraints*