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Multi Objective Differential Evolution approach for voltage stability constrained reactive power planning problem

J. Preetha Roselyn [a,*], D. Devaraj [b], Subhransu Sekhar Dash [a]

[a] SRM University, Kattankulathur 603203, India
[b] Kalasalingam University, Srivilliputhur 626190, India

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ABSTRACT

This paper presents the application of Multi Objective Differential Evolution (MODE) algorithm to solve the Voltage Stability Constrained Reactive Power Planning (VSCRPP) problem. Minimization of total cost of energy loss and reactive power production cost of capacitors and maximization of voltage stability margin are taken as the objectives in the Reactive Power Planning (RPP) problem. The *L*-index of the load buses is taken as the indicator of voltage stability. In the proposed approach, generator bus voltage magnitudes, transformer tap settings and reactive power generation of capacitor bank are taken as the control variables and are represented as the combination of floating point numbers and integers. The MODE emphasizes the non dominated solutions and simultaneously maintains diversity in the non dominated solutions. DE/randSF/1/bin strategy scheme of Differential Evolution with self tuned parameter which employs binomial crossover and difference vector based mutation is used for the VSCRPP problem. A fuzzy based mechanism is employed to get the best compromise solution from the pareto front to aid the decision maker. The proposed reactive power planning model is implemented on two test systems, IEEE 30 bus and IEEE 57 bus test systems. The simulation results of the proposed optimization approach show that MODE is better in maintaining diversity and optimality of solutions.

1. Introduction

Reactive power planning is one of the most challenging problems in power systems. It deals with the decisions of finding location and amount of reactive power resources in normal and stressed system conditions. It involves the simultaneous minimization of two objective functions; the first objective deals with the minimization of operation cost by reducing real power loss, the second objective minimizes the allocation cost of additional reactive power sources. The VAR planning aims at reduced VAR support to maintain feasible operation within acceptable voltage profile. When the transmission system is stressed due to various reasons, voltage instability limit the operation of the system and hence should be included in the VAR planning process. Ajjarapu et al. [1] proposed a method of determining the minimum amount of shunt reactive power support which indirectly maximizes the real power transfer before voltage collapse is encountered. A sequential quadratic programming algorithm is adopted to solve the optimal solution. Vaahedi et al. [2] proposed an algorithm for optimal VAR planning which takes into account voltage profile and voltage stability margins simultaneously. Wang et al. [3] proposed a flexible compensation method based on multi scenario and reactive power divisions to adapt the changes in future environment. The conventional optimization methods [4–6] may lead to local minimum and sometimes result in divergence in solving complex RPP problems.

Recently, evolutionary computation techniques like Genetic Algorithm (GA) [7] and Evolutionary Programming (EP) [8] have received greater attention to obtain global optimum for RPP problem. Lai and Ma [5] has proposed an evolutionary programming approach to RPP problem. The test results are compared with conventional gradient based optimization method. In [9], an integer-coded multi objective genetic algorithm is applied to reactive power planning problem considering both intact and contingent operating states. A modified Non Dominated Sorting Genetic Algorithm II (NSGA II) for multi objective RPP problem by incorporating dynamic crowding distance has been discussed in [10].

In this work, *L*-index proposed in [11] is used as the indicator of voltage stability. In this paper, VSCRPP problem is treated as multi objective optimization problem with minimization of cost of energy loss, reactive power production cost of capacitors and *L*-index (voltage stability index) as the objectives. Due to the presence of conflicting objectives, a multi objective optimization problem

* Corresponding author. Tel.: +91 8939916663.
E-mail addresses: preetha.roselyn@gmail.com (J. Preetha Roselyn), deva230@yahoo.com (D. Devaraj), munu_dash_2k@yahoo.com (S.S. Dash).

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Nomenclature

G_{ij}, B_{ij}	conductance and susceptance of transmission line connected between *i*th and *j*th bus
P_i, Q_i	real and reactive power injection of *i*th bus
P_s	real power generation of slack bus
Q_{ci}	reactive power generation of *i*th VAR source installment
V_{gi}	generator voltage magnitude at bus *i*
t_{ki}	tap setting of transformer at branch *k*
N_l	number of transmission lines
N_C	number of reactive power source installation buses
N_T	number of tap-setting transformer branches
N_{PV}	number of voltage buses
N_B	total number of buses
N_{PQ}	number of load buses
N_{B-1}	total number of buses excluding slack bus
N_d	number of load level durations
d_l	duration of load level (h)
h	per unit energy cost
e_i	fixed VAR source installment cost at bus *i*
C_{ci}	per unit VAR source purchase cost at bus *i*
V_i	voltage magnitude of *i*th generator
V_j	voltage magnitude of *j*th generator
θ_{ji}	phase angle of the term F_{ji}
δ_i	voltage phase angle of *i*th generator unit
δ_j	voltage phase angle of *j*th generator unit
N_g	number of generating units
$L_{\max}$	maximum value of *L*-index in load buses

results in a number of optimal solutions known as pareto optimal solutions [12]. In multi objective optimization, effort must be made in finding the set of trade off pareto solutions by considering all objectives to be important. The ability of evolutionary techniques like Differential Evolution (DE) to find multiple solutions in one single simulation run makes them unique in solving multi objective optimizations. This paper proposes a Multi Objective Differential Evolution (MODE) with self tuned parameters for VSC-RPP problem. DE/randSF/1/bin scheme [13] is used for the RPP problem in which mutation scheme uses a randomly selected vector and only one weighted difference vector is used to perturb it. The mutation scheme is combined with binomial type crossover and with random scale vector. Due to the convergence speed, simplicity and robustness by MODE to reach the optimal solutions makes it suitable for large scale optimization problem like VSCRPP. The effectiveness of the proposed approach to solve the multi objective voltage stability constrained reactive power planning problem has been demonstrated in IEEE 30 bus and IEEE practical 57 bus test systems.

2. Problem formulation

Generally, the RPP problem is formulated as an optimization problem in which cost of energy loss and cost of reactive power production of capacitors are minimized satisfying a number of equality and inequality constraints. In this work, in addition to the above objective, minimization of $L_{\max}$ in the contingency state is included as additional objective of the RPP problem. The control variables of the problem are generator bus voltage magnitudes, tap settings of transformers and reactive power generation of capacitor banks. The mathematical formulation of the multi-objective RPP problem is given below:

2.1. Minimization of cost of energy loss and cost of reactive power production of capacitors

The objective function in RPP problem comprises of two terms, namely, the total cost of energy loss, W_C and the cost of reactive power production, I_C which is given by:

$$\text{Minimize } F_C = W_C + I_C \tag{1}$$

The first term W_C represents the total cost of energy loss as follows:

$$W_C = h\sum_{l\varepsilon N_l} d_l P_{loss,l} \tag{2}$$

where $P_{loss,l}$ is the network real power loss during the period of load level d_l and is given by equation:

$$P_{loss,l} = \sum_{\substack{k\in N_l \\ k=(i,j)}} g_k\left(V_i^2 + V_j^2 - 2V_iV_jCos\theta_{ij}\right) \tag{3}$$

The second term I_C represents the cost of VAR production of capacitors which has two components namely a fixed installation cost, e_i and variable cost, C_{ci}.

$$I_C = \sum_{i\in N_C} e_i + C_{ci}|Q_{ci}| \tag{4}$$

where Q_{ci} is reactive power source installation at bus *i* and Q_{ci} can be either positive or negative, depending on whether the installation is capacitive or reactive. Therefore, absolute values are used to compute the cost. The above two equations are put in one equation to obtain a comprehensive one.

2.2. Minimization of L-index

Static voltage stability analysis involves determination of an index called voltage stability index. This index is an appropriate measure of closeness of the system to voltage collapse. There are various methods of determining voltage stability index. One such method is *L*-index proposed in [11] which is based on load flow analysis. The bus with the highest *L* index value will be the most vulnerable bus in the system. The *L*-indices for a given load condition are computed for all the load buses and the maximum of the *L*-indices ($L_{\max}$) gives the proximity of the system to voltage collapse. The *L*-index has an advantage of indicating voltage instability proximity of current operating point without calculation of the information about the maximum loading point. Hence the minimization of *L*-index makes the system less prone to voltage collapse. The *L*-index of the *j*th node is given by the expression,

$$L_j = \left|1 - \sum_{i=1}^{N_g} F_{ji}\frac{V_i}{V_j}\angle(\theta_{ji} + \delta_i - \delta_j)\right| \tag{5}$$

The detailed calculation of *L* index is given in Appendix A.1.

2.3. System constraints

The RPP problem is subjected to the following equality and inequality constraints: