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A new Optimal reactive power planning based on Differential Search Algorithm

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ABSTRACT

This paper proposes a new multi-level methodology based on the optimal reactive power planning. The developed methodology is designed to solve the problem of the non-feasibility solution of the fuel cost minimization problem (for a given operating point) where the classical method such as interior point method (IPM) is applied. The proposed solution to solve this problem is based on the application of the optimal reactive power planning problem considering voltage stability as the initial solution of the fuel cost minimization problem. To improve the latter the load voltage deviation problem is applied to improve the system voltage profile. For à good result improvement, the reactive power planning problem and the load voltage deviation minimization problems are solved using a new optimization method namely the Differential Search Algorithm (DSA). Moreover, the fuel cost minimization problem is solved using IPM. To identify the candidate placements of compensation devices for the optimal reactive power planning problem, a new voltage stability index namely: The Fast Voltage Stability Index (FVSI) is used. The methodology has been tested with the equivalent Algerian power system network, and the simulation results show the effectiveness of the proposed approach to improve the reactive power planning problem and to minimize the system voltage deviation.

Introduction

In order to maintain the desired levels of voltage profile and reactive power flow under various network configurations and operating conditions, power system operators may employ a number of control tools such as switching, power generator, VAr sources, FACTS devices, transformer tap-settings. By adjusting these controllers' tools, the redistribution of the reactive power would minimize several power system functions such as real power transmission losses, transmission reactive power flow, investment cost of shunt compensation devices, and load voltage deviation. This kind of problem in the literature is named optimal reactive power planning (ORPP) or optimal reactive power dispatch (ORPD), which has a significant influence on secure and economic operation of power systems. Therefore, it has been widely researched and many research papers have been published on this field [1–19].

This problem is modeled as a large-scale non-convex nonlinear programming problem (NLP). Many conventional optimization algorithms have been applied to solve the problem of reactive power planning. Among these methods: linear and successive linear programming (LP/SLP) [5,6], projected and augmented Lagrange method [7], quadratic and sequential quadratic programming (QP/SQP) [8,9], interior point method [10–14] and others. Unfortunately, these methods suffer from algorithmic complexity, poor computational time, sensitivity to initial search point and do not guarantee the convergence to the global optimum point. Recently, new optimization methods based on artificial intelligence have been developed to solve the problem of reactive power planning. Intelligent optimization techniques most commonly used in the reactive power planning are: genetic algorithm (GA) [15–17], particle swarm optimization (PSO) [18–21], Differential Evolution (DE) [22], artificial bee colony algorithm (ABC) [23–25] and others.

The methodology carried out in this work is deployed in two phases. In the first one, we consider that the power system network is secure and operates within its stability limits and the balance between consumption and generation is satisfied. Thus, the solution of optimization program of the fuel cost minimization problem using IPM gives a feasible solution where the reactive power planning problem is not considered. In the second phase, the power system network is unsecure and operates close to its

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Nomenclature

List of symbols

f_{VAR}	cost function of *SVC*
C_{fi}	is the fixed installation cost of the reactive power sources at the *i*th bus
C_{ci}	the cost by MVAR of the compensation devices at the *i*th bus
Q_{VARi}	the compensation at the *i*th bus
$Q_{VARi}^{\min}$	minimum of shunt compensation devices reactive power
$Q_{VARi}^{\max}$	maximum of shunt compensation devices reactive power
N_{VAR}	the number of installed compensation devices
f_{OPF}	objective function of the fuel cost problem
f_p^i	polynomial cost functions of real power injections
P_{loss}	transmission real power losses
F_G	global objective function
Q_{loss}	transmission reactive power losses
G_c	equality constraints of the system
H_c	inequality constraints of the system
U	vector of controls variables
$U^{\min}$	minimum limit of controls variables
$U^{\max}$	maximum limit of controls variables
X	vector of state variables
$X^{\min}$	minimum limit of state variables
$X^{\max}$	maximum limit of state variables
V_G	generator thermal voltage
$V_{Gi}{}^{\min}$	minimum generator thermal voltage
$V_{Gi}{}^{\max}$	maximum generator thermal voltage
T_R	transformer tap ratio
$T_{Ri}^{\min}$	minimum transformer tap ratio
$T_{Ri}^{\max}$	maximum transformer tap ratio
V_L	load bus voltage
$V_{Li}^{\min}$	minimum load bus voltage
$V_{Li}^{\max}$	maximum load bus voltage
V_{bus}	buses voltage
V_i, V_j	voltage magnitude at bus *i* and *j* respectively
$V_i^{\max}$	maximum bus voltage magnitude
$V_i^{\min}$	minimum bus voltage magnitude
S^t, S_i^t	power transmission lines
$S_i^{\max}$	power transmission lines maximum
$S_i^{\min}$	power transmission lines minimum
V_i^{lim}	load voltage limits
Q_{Gi}^{lim}	reactive power generator limit
S_i^{lim}	power transmission lines limits
P_G and Q_G	real and reactive power generator
$Q_{Gi}{}^{\max}$	maximum reactive power generator
$Q_{Gi}{}^{\min}$	minimum reactive power generator
a_i, b_i, c_i	fuel cost coefficients of the *i*th generating units
P^t, Q^t	active and reactive of power transmission lines
P_{Di}, Q_{Di}	real and reactive power at bus *i*
G, B	real and reactive part of the bus admittance matrix
θ_{ij}	voltage angle difference between buses *i* and *j*
θ_{ji}	voltage angle difference between buses *j* and *i*
N_{bus}	set of numbers of total buses
N_G	set of number of generator buses
N_{VAR}	set of numbers of compensation devices installed
N_T	set of number of transformers
N_{PQ}	set of number of *PQ* buses
N_{Li}	set of number of transmission lines
σ_{vi}	penalty factors for the bus voltage limit violation
σ_{QGi}	penalty factors for the generator reactive power limit violation
$\sigma_{S_i^t}$	penalty factors for the transmission lines power flow
Z_{ij}	line impedance
X_{ij}	line reactance
Q_{jr}	reactive power flow at the receiving end
V_{is}	sending end voltage
δ	the angle difference between the supply voltage and the receiving voltage

secure limits. Though, the optimization program of the fuel cost minimization problem [26] gives a non-feasible solution, the optimal reactive power planning problem by considering voltage stability in this case is introduced to solve the problem by setting the network constraints (buses voltages, reactive power generators and power flow constraints) in the acceptable range. The load voltage deviation minimization problem is applied after each phase to improve the solution of the problem by minimizing the load buses voltage deviation. The choice of the IPM [26–29] to solve the fuel cost minimization problem is motivated by the robustness of this technique widely used by most of the power system software tools, such as: CYME [30], ETAP [31], MATPOWER [32], and PSAT [33].

In this paper, a new algorithm, the Differential Search Algorithm (DSA), is presented to solve the reactive power planning and the load voltage deviation minimizations problems. DSA is a new and effective evolutionary algorithm for solving real-valued numerical optimization problems, which has been found to be robust and flexible in solving optimization problem, because it can generate a high-quality solution within shorter calculation time and stable convergence characteristic than other stochastic methods. DSA was inspired by migration of superorganisms utilizing the concept of Brownian like motion in [34].

In power system domain, the slow variation of reactive power loading towards its maximum point causes the load flow solution to reach its non-convergence point which forces the system to reach the voltage stability limit. The margin measured from the base case to the maximum convergence point determines the maximum loadability at a particular bus [35,36]. In this paper, a new voltage stability index namely, FVSI (Fast Voltage Stability Index) is used to estimate the maximum loadability and to identify the critical lines and buses to install the compensation devices. For this purpose, the reactive power at a specific load bus is augmented until it reaches the instability point at bifurcation. At this point, the connected load at the particular bus is considered as the maximum loadability. The smallest maximum loadability is ranked the highest, implying the critical bus [37,38].

Using the voltage stability study to locate the compensation devices, the system becomes more stable and secure (in term of voltage and reactive power). And by installing the compensation devices in the most sensitive buses, the margin measured becomes far from the maximum convergence point. This study is essential to improve the voltage profile and to ensure the power flow constraints even in critical conditions, with the convergence of the fuel cost problem.

The proposed methodologies have been applied in the equivalent Algerian electric power system network system for two operating function point. This paper is organized as follow: The methodology formulation is first reviewed in Section 'Problem formulation', then, Section 'Proposed methodology' the problem formulation, Section 'Voltage stability index' a brief review of the stability index FVSI, Section 'Differential Search Algorithm (DSA)' an introduces the proposed DSA algorithm. In Section 'Simulation results', the effectiveness of DSA is verified by several simulations carried out on the Algerian electric power system 114-bus. Finally, Section 'Conclusion' concludes the paper.