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Differential search algorithm for solving multi-objective optimal power flow problem

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ABSTRACT

In this paper, a simple and efficient nature inspired search method based on differential search algorithm (DSA) has been presented and used for optimal power flow (OPF) problem in power systems. By using the proposed DSA method, the power system parameters such as real power generations, bus voltages, load tap changer ratios and shunt capacitance values are optimized for the certain objective functions. Different types of single-objective and multi-objective functions on IEEE 9-bus, IEEE 30-bus and IEEE 57-bus power systems are used to test and verify the efficiency of the proposed DSA method. By comparing with several optimization methods, the results obtained by using the proposed DSA method are presented in detail. The results achieved in this work illustrate that the DSA method can successfully be used to solve the non-linear and non-convex problems related to power systems.

Introduction

Optimal power flow (OPF) calculations determine optimal control variables and system quantities for the most efficient power system planning and operation [1]. Besides, it has been a challenging task to operate a modern power system in an efficient way due to the necessity to compensate the system for continually changing load demand and provide energy of a high quality. The main objective of optimal power flow can be defined as optimizing a certain objective function while fulfilling the physical, operational and security constraints by determining the parameters of power system elements such as generators, capacitor banks and load tap changers.

In general, OPF can be defined as a non-linear, non convex, multi-dimensional and large-scale numerical problem depending on line and bus data, and further becomes complicated because of inclusion of variable constraints while optimizing and satisfying the system parameters for the objective functions such as fuel cost, fuel emission cost, voltage profile improvement, voltage stability enhancement and systems losses.

First examples of OPF algorithms were dependant on different classical mathematic based programming methods. Gradient based method [2], non-linear programming [3], linear programming (LP) [4,5], quadratic programming (QP) [6], Newton-based method [7,8], sequential unconstrained minimization technique [9] and interior point methods (IPMs) [10] have successfully proved their capabilities in this field.

The first method for the solution of OPF problem was the reduced gradient method, proposed by Carpentier [2]. It were Dommel and Tinney [3] who presented the formulation of optimal power flow and worked out the problem based on Kuhn–Tucker optimality criterion using a combination of the gradient method for a known group of independent variables and penalty functions.

Abou El-Ala and Abido [4] and Mota-Palomini [5] have used the linear programming method (LP) on account of its capability to output results in fast and secure ways than using nonlinear programming method due to its deficit of converging to unsuitable results on local minimum solution sets. Nevertheless, this methods was not adequate enough to solve non-smooth objective functions. In addition, quadratic programming (QP) based approaches are proposed by Burchett [6] and Newton based optimal power flow methods are used and applied successfully by Sun [7] and Santos [8].

The classical optimization methods require an initial point acceptable close to the solution in order not to be stuck in local minimum. Once the number of control parameters of the problem increase, the quality of solutions highly depends on the initial settings. Due to the disadvantages of these classical methods and additionally with the development of computer technologies, the interest in using the population based optimization methods for solving the power systems has rapidly grown during the last decades. The population based optimization methods use the random

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Nomenclature

f_{VD}	voltage deviation function
fc	quadratic fuel cost function
f_{PL}	transmission real power losses function
f_E	total emission function
f_{VSI}	voltage stability enhancement function
P_{Gi}	the generation of real power at bus i
P_{Gi}^{max}	upper limit of power generated by generator i
P_{Gi}^{min}	lower limit of power generated by generator i
Q_{Gi}	the generation of reactive power at bus i
Q_{Gi}^{max}	upper limit of reactive power generated by generator i
Q_{Gi}^{min}	lower limit of reactive power generated by generator i
P_{Di}	the active load demand of bus i
Q_{Di}	the reactive load demand of bus i
V_{Gi}	generator voltage magnitude at bus i
V_{Gi}^{max}	upper limit of generator voltage magnitude at bus i
V_{Gi}^{min}	lower limit of generator voltage magnitude at bus i
V_{Li}	voltage magnitude of the load bus at bus i
V_{Li}^{max}	upper limit of voltage magnitude of the load bus at bus i
V_{Li}^{min}	r limit of voltage magnitude of the load bus at bus i
T_i	settings of the tap changing transformers at bus i
T_i^{max}	upper limits of tap changing position of transformer i
T_i^{min}	lower limits of tap changing position of transformer i
Q_{Ci}	the output of shunt VAR compensator at bus i
Q_{Ci}^{max}	upper limit of the output of shunt VAR compensator at bus i
Q_{Ci}^{min}	lower limit of the output of shunt VAR compensator at bus i
S_{Li}	transmission line loading of ith branch
S_{Li}^{max}	upper limit of transmission line loading of ith branch
S_{Li}^{min}	lower limit of transmission line loading of ith branch
g_i	is the conductance of the ith line
θ_{ij}	the magnitude and angle of bus admittance element i, j
$\delta_k - \delta_m$	voltage phase angle difference between buses k and m
N_g	is the total generator number
N_{PQ}	the load bus number
N_L	the number of transmission lines
N_T	the number of load tap changer transformers
N_{QC}	the number of shunt capacitors
a_i, b_i, and c_i	the weighting factors of the generating unit i
α_i , β_i , γ_i , ξ_i and λ_i	the emission coefficients of the ith unit

transition rules rather than deterministic ones, do not employ the derivative information, have the ability of not being stuck in a local minimum, and cope with large-scaled non-linear problems. The most popular methods in this field such as differential evolution (DE) [11], particle swarm optimization (PSO) [12], stochastic weight trade-off particle swarm optimization (SWT-PSO) [13], genetic algorithm (GA) [14], enhanced genetic algorithm (EGA) [15], evolutionary programming (EP) [16,17], simulated annealing (SA) [18], biogeography-based (BBO) and quasi-oppositional biogeography-based optimization (QOBBO) [19,20], gravitational search algorithm (GSA) [21] and non-dominated sorting multi objective gravitational search algorithm (NSMOGSA) [22], harmony search algorithm (HS) [23], artificial bee colony algorithm (ABC) [24], modified imperialist competitive algorithm(MOMICA) [25*] and many more Grey Wolf Optimizer (GWO) [26*–30*] have been proposed to overcome the OPF problem. The classical optimization methods and the population based optimization methods aforementioned have been used with their own benefits and limitations in the power systems.

Abou El-Ala and Abido presented DE based approach and proposed optimization of different objective functions that reflect fuel cost minimization, voltage profile improvement, and voltage stability enhancement [11]. In [12,13] the results of proposed approaches based on PSO are compared with the results reported in the literature. The process of determining the optimal allocation and ratings of SVC is introduced using various types of GA [14]. In [15] it is combined a new decoupled quadratic load flow (DQLF) solution with EGA to solve the OPF problem. Yuryevich and Sood used EP to solve the OPF problems in order to increase to convergence speed in [16,17]. It is presented the solution of the OPF using the SA technique simultaneously composed by the load flow and the economic dispatch problem [18]. The BBO and QOBBO approaches has been implemented with three different objectives with the OPF embedded on IEEE 30 bus system respectively [19,20]. There are also various objective functions are minimized by using GSA [21]. In [22], The NSMOGSA is applied to solve different multi-objective OPF problems of power system network for the first time. The multi-objective harmony search algorithm was proposed for the OPF [23]. The multi objective optimization problem is solved by artificial bee colony (ABC) algorithm [24]. In [25*] The performance of a novel MOMICA approach is evaluated on the standard IEEE 30-bus and IEEE 57-bus power systems for the OPF.

Recently, a population based method, differential search algorithm (DSA), which is a new and effective evolutionary algorithm for solving real-valued numerical optimization problems is presented by Pinar Civicioglu [31]. The DSA simulates the Brownian-like random-walk movement used by an organism to migrate. In this paper, a novel DSA-based approach is proposed for the purpose of solving the OPF problem. The main contribution of this paper is applying DS algorithm in terms of solving OPF problem with various single and multi objective functions. Furthermore, the efficiency of the proposed DSA method is studied and tested on standard IEEE 9-bus, IEEE 30-bus and IEEE 57-bus systems. Different single objective functions such as total fuel cost, fuel emission, power loss, voltage deviation, voltage stability index minimization and also multi objective functions such as voltage deviation minimization along with the fuel cost and voltage stability index minimization along with the fuel cost are considered and achieved successfully.

Optimal power flow

In the OPF problem considered in this study, the main objective is optimizing single or multi objective functions while fulfilling the constraints such as load flow, generation bus voltages magnitudes, load bus voltage magnitudes, shunt VAR capacitances, reactive power generations and transformer taps settings.

The problem can be defined as:

$$\text{Optimize} : f(x,u)$$
$$\text{With subject of} : g(x,u) = 0 \text{ and } h(x,u) \leq 0$$

f and g represent the objective function and the load flow equations respectively, h indicates the parameter limits of the system.

In accordance with

$$x = [P_{Gslack}\ V_L\ Q_G\ S_l] \tag{1}$$

where x indicates the state variables including real generation power of the slack bus, voltage of the load bus, reactive generation power and transmission line loading.

$$u = [P_G\ V_G\ Q_C\ T] \tag{2}$$