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Evolutionary programming based optimal power flow and its validation for deregulated power system analysis

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Abstract

Optimal power flow (OPF) has been widely used in power system operation and planning. In deregulated environment of power sector, it is of increasing importance, for determination of electricity prices and also for congestion management. The classical methods are usually confirmed to specific cases of the OPF and do not offer great freedom in objective functions or the types of constraints that may be used. With a non-monotonic solution surface, classical methods are highly sensitive to starting points and frequently converge to local optimal solution or diverge altogether. This paper describes an efficient evolutionary programming based optimal power flow and compares its results with well known classical methods, in order to prove its validity for present deregulated power system analysis.

Keywords: Optimal power flow; Evolutionary programming; Deregulation; Steepest descent method; Genetic algorithm

1. Introduction

The OPF optimizes a power system operating objective function, while satisfying a set of system constraints. In general, OPF problem is a large dimension nonlinear, non-convex and highly constrained optimization problem. It is non-convex due to existence of nonlinear AC power flow equality constraints, non-convex unit operating cost functions and units with prohibited operating zones. This non-convexity is further increased when valve point loading effects of the thermal generators have to be included [16] or FACTS devices are included in the network.

Many classical techniques have been reported in the literature [9–12], such as nonlinear programming (NLP), quadratic programming (QP) and linear programming (LP). The gradient based methods [5,12] and Newton methods [15] suffer from the difficulty in handling inequality constraints. Moreover, these NLP and QP methods rely on convexity to obtain the global optimum solution and as such are forced to simplify relationships in order to ensure convexity. To apply linear programming [2], input–output function is to be expressed as a set of linear functions, which may lead to loss of accuracy. Moreover they are not guaranteed to converge to the global optimum of the general non-convex OPF problem. These days, genetic algorithm (GA) [3,7,8,16,19] and evolutionary programming techniques (EP) [6,17,18,20] has been suggested to overcome the above-mentioned difficulties of classical methods.

In these days, an evolutionary programming approach has been used to solve OPF for the analysis of deregulated model [13,14]. So it is necessary to validate the proposed approach with the help of well known basic classical technique likes gradient steepest descent method. In this paper, OPF algorithm of three approaches, steepest descent method, GA and EP have been developed and applied to IEEE-30 bus test system and their results are compared. In order to, further confirm the validity; the results of EP are also compared with results obtained using matlab optimization toolbox.

2. Optimal power flow problem

Let the objective function to be minimized, is given below

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$$f = \sum_i F_i(Pg_i) \tag{1}$$

which is the sum of operating cost over all controllable power sources.

$F_i(Pg_i)$ is the generation cost function for Pg_i generation at bus i

The cost is optimized with the following constraints.

- The inequality constraint on real power generation at bus i

$$Pg_i^{\min} \leqslant Pg_i \leqslant Pg_i^{\max} \tag{2}$$

where
$Pg_i^{\min}$ and $Pg_i^{\max}$ are respectively minimum and maximum values of real power generation allowed at generator bus i.

- The power flow equation of the power network

$$g(V, \phi) = 0 \tag{3}$$

where

$$g(V,\phi) = \begin{cases} P_i(V,\phi) - P_i^{\text{net}}\} & \leftarrow \text{For each } PQ \text{ bus } i \\ Q_i(V,\phi) - Q_i^{\text{net}}\} & \\ P_m(V,\phi) - P_m^{\text{net}}\} & \leftarrow \text{For each } PV \text{ bus } m, \\ & \text{not including the ref. bus.} \end{cases} \tag{4}$$

where
P_i and Q_i are respectively calculated real and reactive power for PQ bus i.
P_i^{net} and Q_i^{net} are respectively specified real and reactive power for PQ bus i.
P_m and P_m^{net} are respectively calculated and specified real power for PV bus m.
V and ϕ are voltage magnitude and phase angles at different buses.

- The inequality constraint on reactive power generation Qg_i at each PV bus

$$Qg_i^{\min} \leqslant Qg_i \leqslant Qg_i^{\max} \tag{5}$$

where $Qg_i^{\min}$ and $Qg_i^{\max}$ are respectively minimum and maximum value of reactive power at PV bus i.

- The inequality constraint on voltage magnitude V of each PQ bus

$$V_i^{\min} \leqslant V_i \leqslant V_i^{\max} \tag{6}$$

where $V_i^{\min}$ and $V_i^{\max}$ are respectively minimum and maximum voltage at bus i

- The inequality constraint on phase angle ϕ_i of voltage at all the buses i

$$\phi_i^{\min} \leqslant \phi_i \leqslant \phi_i^{\max} \tag{7}$$

where $\phi_i^{\min}$ and $\phi_i^{\max}$ are respectively minimum and maximum voltage angles allowed at bus i

- MVA flow limit on transmission line

$$\text{MVA}f_{ij} \leqslant \text{MVA}f_{ij}^{\max} \tag{8}$$

where $\text{MVA}f_{ij}^{\max}$ is the maximum rating of transmission line connecting bus i and j.

3. Steepest descent method

This is the most basic classical optimization method. The main features of this method are gradient procedure for finding the optimum and use of penalty functions to handle functional inequality constraints. This method provides bus increment cost directly, which is quite useful for cost analysis of power system under deregulated environment. The steepest descent (SD) method is well established and explained in detail in the literature [4,11].

Let the objective be

$$\text{Min}\, f(x,u) \tag{9}$$

Subject to equality constraints corresponding to power flow equations

$$[g(x,u,p)] = 0 \tag{10}$$

where

x is the unknown or state vector (such as voltage magnitude and its angle at load bus, voltage angle at PV bus),
u is the control parameters or independent variables (such as generator output and generator bus voltage),
p is the fixed parameters (such as real and reactive power at load buses).

This is equivalent to minimization of unconstrained Lagrangian function

$$L(x,u,p) = f(x,u) + [\lambda]^{\mathrm{T}} \cdot [g(x,u,p)] \tag{11}$$

The λ_i in $[\lambda]$ are called Lagrangian multipliers.

From above Eq. (11), follows the set of necessary conditions for a minimum:

$$\left[\frac{\partial L}{\partial x}\right] = \left[\frac{\partial f}{\partial x}\right] + \left[\frac{\partial g}{\partial x}\right]^{\mathrm{T}} \cdot [\lambda] = 0 \tag{12}$$

$$\left[\frac{\partial L}{\partial u}\right] = \left[\frac{\partial f}{\partial u}\right] + \left[\frac{\partial g}{\partial u}\right]^{\mathrm{T}} \cdot [\lambda] = 0 \tag{13}$$

$$\left[\frac{\partial L}{\partial \lambda}\right] = [g(x,u,p)] = 0 \tag{14}$$

Eqs. (12)–(14) are nonlinear algebraic equations and can only be solved by iterations. A simple yet efficient iteration scheme that can be employed is the steepest descent method. The basic technique is to adjust the control vector u, so as to move from one feasible solution point, in the direction of steepest descent (negative gradient) to a new feasible solution point with a lower value of objective function. By repeating these moves in the direction of negative gradient, the minimum will finally be reached.