Applied Soft Computing 12 (2012) 1477–1482

Contents lists available at SciVerse ScienceDirect

Applied Soft Computing

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

Artificial bee colony algorithm solution for optimal reactive power flow

Kürşat Ayan[a], Ulaş Kılıç[b,*]

[a] Sakarya University, Computer Engineering Department, Turkey
[b] Mehmet Akif Ersoy University, Bucak Emin Gülmez Vocational School, Turkey

ARTICLE INFO

Article history:
Received 24 November 2010
Received in revised form 15 June 2011
Accepted 15 January 2012
Available online 28 January 2012

Keywords:
Artificial bee colony
Optimal reactive power flow
Penalty function
Power system

ABSTRACT

Artificial bee colony (ABC) algorithm is an optimization algorithm based on the intelligent foraging behavior of honeybee swarm. Optimal reactive power flow (ORPF) based on ABC algorithm to minimize active power loss in power systems is studied in this paper. The advantage of ABC algorithm is that it does not require these parameters, because it is very difficult to determine external parameters such as cross over rate and mutation rate as in case of genetic algorithm and differential evolution. The other advantage is that global search ability of the algorithm is implemented by introducing a neighborhood source production mechanism which is similar to mutation process. Because of these features, ABC algorithm attracts much attention in recent years and has been used successfully in many areas. ORPF problem is one of these areas. In this paper, proposed algorithm is tested on both standard IEEE 30-bus test system and IEEE 118-bus test system. To show the effectiveness of proposed algorithms, the obtained results are compared with different approaches as available in the literature.

1. Introduction

Optimal reactive power flow (ORPF) that is a special case of the optimal power flow (OPF) problem is very important tool in terms of secure and economic operation of power systems. Control parameters of the optimal power flow (OPF) problem have a close relationship with the reactive power flow, such as voltage magnitudes of generator buses, shunt capacitors/reactors, output of static reactive power compensators, transformer tap-settings. In ORPF, the network active power loss is minimized and the voltage profile is improved while satisfying a given set of operating and physical constraints. Again in ORPF problem, the outputs of shunt capacitors/reactors and tap-settings of transformers are discrete variables and the other variables are continuous. Therefore, the reactive power flow problem is modeled as a large-scale mixed integer nonlinear programming (MINLP) problem.

For solving the ORPF problem, the classical methods such as linear programming, nonlinear programming, quadratic programming, the mixed integer programming, the Newton method have been successfully used [1–4]. Recently, methods based on interior point techniques have been presenting encouraging results to handle the large-scale ORPF/OPF problems because these methods offer much faster convergence and noticeable convenience in handling inequality constraints in comparison with other methods [5–7]. Nevertheless, these methods have severe troubles in handling the objective functions having multiple local minima. In all these practice, some simplification has been used to overcome the inherent limitations of the solution technique. Such simplifications frequently lead to a local minimum and sometimes result in a divergence.

Recently, many new stochastic search methods have been developed for solving the global optimization problems. Many salient stochastic methods such as evolutionary programming (EP) [8], genetic algorithm (GA) [9–11], evolutionary strategy (ES) [12], particle swarm optimization (PSO) [13], and tabu search (TS) [14] have been developed for solution of the ORPF problem since the mid-1990s. Such methods present extremely superiority in obtaining the global optimum and in handling discontinuous and non-convex objectives. However, many of these methods are not effective in managing optimization problems of integer and discrete nature. Such optimization problems can be solved by approximating the discrete and integer variables by continuous variables. Thus, the problem becomes an ordinary nonlinear programming one with continuous control parameters and the continuous values are reduced to the closest possible discrete or integer variable values. In practice, this method generally causes to the solutions that may be far from the globally optimal solution.

Artificial bee colony (ABC) algorithm is a search method, which is inspired by the foraging behavior of honeybee swarm, and target discrete optimization problems. The ABC algorithm that was developed by Karaboga [15] is a population-based heuristic algorithm. In this algorithm, bees are members of a family which live in organized honeybee swarm. The bees consist of two groups. ABC

* Corresponding author. Tel.: +90 248 325 99 00; fax: +90 248 325 99 00.
E-mail addresses: kayan@sakarya.edu.tr (K. Ayan), ulaskilic@mehmetakif.edu.tr (U. Kılıç).

1568-4946/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.asoc.2012.01.006

algorithm has been applied to various optimization problems such as compute-industrial engineering, hydraulic engineering, aviation and space science and electronic engineering since 2005 [16–18]. ABC algorithm was firstly applied to ORPF problem by Ozturk and is tested on IEEE 10 bus-test system in Ref. [19].

In this paper, various aspects of performance of ABC algorithm in solving the ORPF problem are analyzed using the IEEE 30-bus system and IEEE 118-bus system. The security constraints are also included in this study. The obtained results for two test systems confirm the superiority and efficiency of ABC algorithm in large-scale optimization problems with discontinuous objective functions and integer or discrete control variables.

2. ORPF formulation

The mathematical formulation of ORPF problems is a well-known optimization problem.

$$\begin{aligned} &\text{Minimize} && f(x,u) \\ &\text{Subjected to} && g(x,u)=0 \\ &&& h(x,u)\le 0 \end{aligned} \tag{1}$$

where the function $f(x, u)$ is the objective function, the function $g(x, u)=0$ is the equality constraint, and the function $h(x, u)\le 0$ is the inequality constraint.

In this study, the objective function is selected as the total energy generation cost, total network loss, corridor transfer power and total cost of compensation and so on, the equality constraints are selected as the power flow equalities and the inequality constraints are selected as the transmission line constraints and other security constraints Thus, the vector x is called as the vector of dependent variables and is given as follows:

$$x^T=[P_{gslack},\ V_L,\ Q_g] \tag{2}$$

P_{gslack} is the active power of slack bus, V_L is the voltage magnitudes of load buses, Q_g is the generator reactive power.

And the vector u is called as the vector of control variables and is given as follows:

$$u^T=[P_g,\ V_g,\ T,\ Q_c] \tag{3}$$

P_g is the active power of generation buses except the slack bus, V_g is the generator voltage magnitudes, T is the transformer tap ratio, Q_c is the shunt compensation.

Power system loss is the function of dependent and independent variables (control variables).

$$P_{loss}=\sum_{k=1}^{N_l}P_{lossk}=\sum_{i=1}^{N}\sum_{j=1}^{N}g_{ij}[V_i{}^2+V_j^2-2V_iV_j\cos\theta_{ij}] \tag{4}$$

N is total number of buses, N_l is the number of transmission lines, g_{ij} is the conductance of ijth transmission line, V_i is the voltage magnitude of ith bus, θ_{ij} is the angle difference of ijth transmission line.

Power flow equalities in the optimal power flow are given as follows:

$$P_{gi}-P_{li}-V_i\sum_{j=1}^{N}V_j(G_{ij}\cos\theta_{ij}+B_{ij}\sin\theta_{ij})=0 \tag{5}$$

$$Q_{gi}+Q_{ci}-Q_{li}-V_i\sum_{j=1}^{N}V_j(G_{ij}\sin\theta_{ij}-B_{ij}\cos\theta_{ij})=0 \tag{6}$$

P_l is the active load demand, Q_l is the reactive load demand, G_{ij} is the conductance between bus i and bus j, B_{ij} is the susceptance between bus i and bus j.

Active power outputs, reactive power outputs, and generation bus voltages are restricted by their lower and upper limits and the generator constraints are given as follows:

$$P_{gi}^{\min}\le P_{gi}\le P_{gi}^{\max}\quad i=1,\ldots,N_g \tag{7}$$

$$Q_{gi}^{\min}\le Q_{gi}\le Q_{gi}^{\max}\quad i=1,\ldots,N_g \tag{8}$$

$$V_i^{\min}\le V_i\le V_i^{\max}\quad i=1,\ldots,N \tag{9}$$

Transformer tap settings are restricted by their lower and upper limits and the transformer constraints are given as follows:

$$T_i^{\min}\le T_i\le T_i^{\max}\quad i=1,\ldots,N_T \tag{10}$$

N_T is the number of transformers.

Shunt VAR compensations are restricted by their limits and the shunt VAR constraints are given as follows:

$$Q_{ci}^{\min}\le Q_{ci}\le Q_{ci}^{\max}\quad i=1,\ldots,N_c \tag{11}$$

N_c is the number of shunt VAR compensations.

The load of ith transmission line is restricted by its limits and the apparent power constraints are given as follows:

$$S_{li}\le S_{li}^{\max}\quad i=1,\ldots,N_l \tag{12}$$

The objective function in the statement (4) should be minimized with the power balance equations given in the statements (5)–(12). The above-mentioned problem can be generalized as follows:

$$\begin{aligned} f(x,u)={}&R_1P_{loss}+R_2(P_{g,slack}-P_{g,slack}^{\lim})^2+R_3\sum_{i=1}^{N_{PQ}}(V_i-V_i^{\lim})^2 \\ &+R_4\sum_{i=1}^{N_g}(Q_{gi}-Q_{gi}^{\lim})^2+R_5\sum_{i=1}^{N_l}(S_{li}-S_{li}^{\lim})^2 \end{aligned} \tag{13}$$

R_1, R_2, R_3, R_4 and R_5 are the penalty functions having large positive value, N_{PQ} is the total number of load buses.

$P_{g,slack}^{\lim}$, $V_i^{\lim}$, and $Q_{gi}^{\lim}$ are defined as follows;

$$P_{g,slack}^{\lim}=\begin{cases}P_{g,slack}^{\max};P_{g,slack}>P_{g,slack}^{\max}\\ P_{g,slack}^{\min};P_{g,slack}<P_{g,slack}^{\min}\end{cases} \tag{14}$$

$$V_i^{\lim}=\begin{cases}V_i^{\max};V_i>V_i^{\max}\\ V_i^{\min};V_i<V_i^{\min}\end{cases} \tag{15}$$

$$Q_{gi}^{\lim}=\begin{cases}Q_{gi}^{\max};Q_{gi}>Q_{gi}^{\max}\\ Q_{gi}^{\min};Q_{gi}<Q_{gi}^{\min}\end{cases} \tag{16}$$

$$S_{li}^{\lim}=\begin{cases}0\quad;S_{li}\le S_{li}^{\max}\\ S_{li}^{\max};S_{li}>S_{li}^{\max}\end{cases} \tag{17}$$

$P_{slack}^{\lim}$ is the lower and upper limits of active power, $V_i^{\lim}$ is the lower and upper limits of the bus voltage magnitudes, $Q_{gi}^{\lim}$ is the lower and upper limits of the reactive power outputs, $S_{li}^{\lim}$ is the lower and upper limits of apparent power.

3. Artificial bee colony (ABC) algorithm

ABC algorithm was proposed by Karaboga in 2005 [15] and the flow chart of this algorithm is shown in Fig. 1. ABC algorithm is a population-based algorithm to be developed by taking into consideration the thought that how honeybee swarm finds food. The honeybee swarm in this algorithm is divided into two groups: worker bees and non-worker bees including onlooker bees and explorer bees. The onlooker bees are produced with certain intervals around the worker bees. If the produced onlooker bees find