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A new quantum inspired chaotic artificial bee colony algorithm for optimal power flow problem

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ABSTRACT

This paper proposes a new artificial bee colony algorithm with quantum theory and the chaotic local search strategy (QCABC), and uses it to solve the optimal power flow (OPF) problem. Under the quantum computing theory, the QCABC algorithm encodes each individual with quantum bits to form a corresponding quantum bit string. By determining each quantum bits value, we can get the value of the individual. After the scout bee stage of the artificial bee colony algorithm, we begin the chaotic local search in the vicinity of the best individual found so far. Finally, the quantum rotation gate is used to process each quantum bit so that all individuals can update toward the direction of the best individual. The QCABC algorithm is carried out to deal with the OPF problem in the IEEE 30-bus and IEEE 118-bus standard test systems. The results of the QCABC algorithm are compared with other algorithms (artificial bee colony algorithm, genetic algorithm, particle swarm optimization algorithm). The comparison shows that the QCABC algorithm can effectively solve the OPF problem and it can get the better optimal results than those of other algorithms.

1. Introduction

In recent years, with the increase of fossil fuel price and increasingly acute environmental issues, rational development, full use of limited resources, operating efficiency improvement of the power system and optimization of the power system have attracted a growing concern. The optimal power flow (OPF) problem is first proposed by Carpentier in the early 1960s. Because the OPF can effectively solve economic operation problem with consideration of the security and stability of the power system, in the past few decades, it has attracted many scholars' attention. The purpose of the OPF problem is to determine the value of various control variables to minimize the fuel cost of power generation under the premise of meeting various constraints of the power system. The control variables of the OPF problem include active power output and voltage magnitude of all generator buses, shunt capacitor output and tap ratio of transformers [1]. Since the active power output and the voltage magnitude of all generators are continuous variables whereas the tap ratio and the shunt capacitor output are discrete variables, the OPF problem is a mixture of discrete and continuous variables problem.

Traditional optimization methods such as simplified gradient method [2], Newton method [3], interior point method [4] and decoupling method [5] have already been used in solving the OPF problem. But the convergence of the simplified gradient method is poor and its calculating time is long. Newton method is very limited to the continuity and differentiability of the problem's objective function and constraints, and it is difficult to solve the "curse of dimensionality" problem. Interior point method is slow and easy to converge to local optima. Therefore, traditional methods have many drawbacks in the solution of the OPF problem.

In order to overcome the shortcomings of the traditional methods, many scholars use genetic algorithms (GA) [6,7], evolutionary programming (EP) [8], gravitational search algorithm (GSA) [1], particle swarm optimization (PSO) [9], simulated annealing algorithm (SA) [10], shuffled frog leaping algorithm (SFLA) [11,12], differential evolution (DE) [13] and other heuristic search algorithms to solve the OPF problem. The results show that the heuristic search algorithm is a good way to solve the OPF problem with its apparent advantages over traditional methods. But practice also shows that the heuristic search algorithm still has a lot of problems: Many of them are easy to get premature convergence, the exploitation capability and the exploration capability of a heuristic search algorithm is often difficult to achieve a good balance and so

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Nomenclature

N_G	number of generators
N_L	number of transmission lines
N_B	total number of buses in the power system
N_{PQ}	number of load buses
T_{i-j}	transformer tap setting between the *i*-th and the *j*-th bus
Q_{C_i}	amount of reactive power compensation of the *i*-th bus
P_{G_i}	active power output of the *i*-th generator
Q_{G_i}	reactive power output of the *i*-th generator
V_i	voltage magnitude of the *i*-th bus
S_{L_i}	power flow in the *i*-th transmission line
G_{ij}	transmission line admittance between the *i*-th and the *j*-th bus
$B_{i,j}$	transmission line susceptance between the *i*-th and the *j*-th bus
$\theta_{i,j}$	voltage angle difference between the *i*-th and the *j*-th bus
Maxiter	maximum iteration number of an algorithm
N	number of employed bees in artificial bee colony algorithm
n	quantum bit number of each dimension
D	dimension of a problem
N_C	maximum iteration number of chaotic local search

on. To solve these problems, many scholars have proposed a lot of new heuristic search algorithms and processing mechanisms.

The artificial bee colony algorithm (ABC) is a bio-inspired optimization algorithm proposed by Karaboga in 2005, which is based on bees foraging behavior. It has been greatly developed in recent years. Since the ABC algorithm need not set too many parameters and easy to operate, it has been successfully used in many fields, such as artificial neural networks training [14], economic dispatch [15,16], data clustering analysis [17], heat exchanger design [18], stock price prediction [19], the UAV dynamic path selection [20], truss structure design [21] and image registration [22] and other fields. But practice shows that the local search ability of the ABC algorithm is not strong and easy to fall into local optima.

In order to increase the diversity of the individuals and accelerate the speed of the ABC algorithm, the paper adds the idea of quantum computing theory [23] into the basic ABC algorithm: Encoding the individuals with the quantum bit to increase the diversity of the individuals; Using the quantum rotation gate to process all quantum bits of each individual at the end of the ABC algorithm, in which all the individuals update toward the direction of the best one, thus accelerate the optimization speed. In order to strengthen local search ability of the ABC algorithm, a chaotic local search operator [24] is joined at the end of the scout bee stage. In each iteration, the proposed algorithm begin local search around the best food source found so far. With the help of the characteristics of chaos, such treatment can effectively help the ABC algorithm to jump out from local optima easily. Together with the quantum theory and the chaotic local search, the quantum inspired chaotic artificial bee colony algorithm (QCABC) is generated. Due to the good individual diversity and local search capability of the QCABC algorithm, it can be seen as a better method to deal with the high-dimensional, non-linear, non-continuous OPF problem than other traditional methods. Finally, the IEEE 30-bus and the IEEE 118-bus standard test systems are used to test the effects of the QCABC algorithm for the OPF problem. Simultaneously, the particle swarm optimization (PSO) [9], genetic algorithms (GA) [25] and artificial bee colony algorithm (ABC) [26] are used to simulate the same OPF problem in the two systems. The results show that the QCABC algorithm can accelerate the convergence speed of the ABC algorithm. The stability and convergence result of the QCABC algorithm is the best among these algorithms.

The rest of this paper is organized as follows: Section 2 describes the mathematical model of the OPF problem. Section 3 declares the principles and steps of the basic ABC algorithm, introduces the principle of the quantum computing and the chaotic local search steps and describes the improving method for the ABC algorithm. Section 4 introduces the steps of the QCABC algorithm for the OPF problem. The simulation results analysis of different algorithms in the OPF problem are given in Section 5. Section 6 is the summary of this paper. Acknowledgements are listed in the end.

2. Problem formulation

The OPF problem can be described as under the given conditions of the power system's structure, parameters and load, the value of the control variables are determined to minimize the total fuel cost while satisfying the total load requirement and various equality and inequality constraints of the power system. Therefore, the OPF problem is a typical nonlinear programming problem.

The control variables include: Active power output of each generator except the slack bus active power P_G, voltage magnitude of generator bus V_G, transformers tap ratio T, shunt VAR compensation Q_c. Use u to represent the control variables vector, then:

$$u = [P_{G_2} \ldots P_{G_{NG}}, V_{G_1} \ldots V_{G_{NG}}, T_1 \ldots T_{NT}, Q_{C_1} \ldots Q_{C_{NC}}] \tag{1}$$

The dependent variables include: Active power output at slack bus P_{Gslack}, the voltage magnitude of each load bus V_L, the reactive power of generator Q_G, transmission line flow S_L.

Use x to represent the dependent variables vector, then x can be described as:

$$x = \left[P_{G_{slack}}, V_{L_1} \ldots V_{L_{NL}}, Q_{G_1} \ldots Q_{G_{NG}}, S_{L_1} \ldots S_{L_{NL}}\right] \tag{2}$$

Note: we usually treat the first generator bus of the power system as the slack bus, then $P_{G_{slack}} = P_{G_1}$.

2.1. Objective function

In this paper, the objective function is the minimization of the total fuel cost of power generation:

$$\text{Min } FC = \text{Min}\left\{\sum_{i=1}^{N_G}\left[a_i + b_i \cdot P_{G_i} + c_i \cdot P_{G_i}^2\right]\right\} \tag{3}$$

where FC is the total fuel cost function [27]. When considering the valve point effect of the generator, each generator's fuel cost function should add $|d_i \times \sin(e_i \times (P_{G_{i\min}} - P_{G_i}))|$, where a_i, b_i, c_i, d_i, e_i are the fuel cost coefficients of the i-th generator, which are constants to each generator. After considering the valve point effect of each generator, it is obvious that each generator's fuel cost will increase, and the fuel cost function will become more complicated. In other words, the OPF problem with the valve point effect of each generator is more complicated to solve and will have higher fuel cost than the one without considering the valve point effect. Fig. 1 shows the two kinds of fuel cost function.