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A new approach for unit commitment problem via binary gravitational search algorithm

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ABSTRACT

This paper proposes a new gravitational search algorithm to solve the unit commitment (UC) problem, which is integrated binary gravitational search algorithm (BGSA) with the Lambda-iteration method. The proposed method is enhanced by priority list based on the unit characteristics and heuristic search strategies to repair the spinning reserve and minimum up/down time constraints. Furthermore, local mutation strategies are applied to improve the performance of BGSA. The implementation of the proposed method for UC problem consists of three stages. Firstly, the BGSA based on priority list is applied for solution unit scheduling when neglecting minimum up/down time constraints. Secondly, heuristic search strategies are used to handle minimum up/down time constraints and decommit excess spinning reserve units. Thirdly, local mutation strategies are raised to avoid premature convergence of the algorithm and prevent it from trapping into local optima. Finally, Lambda-iteration method is adopted to solve economic load dispatch based on the obtained unit schedule. The feasibility and effectiveness of the proposed method is verified by the systems with the number of units in the range of 10–100 and the results are compared with those of other methods reported in literatures. The results clearly show that the proposed method gives better quality solutions than other methods.

1. Introduction

Unit commitment (UC) is a very significant optimization task, which plays an important role in the economic operation planning of power systems. The unit commitment problem (UCP) in power systems refers to the optimization problem for determining the start-up and shut-down schedule of generating units over a scheduling period so that the total production cost is minimized while satisfying various constraints. The UCP can be considered as two linked optimization decision processes, namely the unit-scheduled problem that determines on/off status of generating units in each time period of planning horizon, and the economic load dispatch problem. Mathematically, the UCP has commonly been formulated as a complex nonlinear, mixed-integer combinational optimization problem with 0–1 variables that represents on/off status and continuous variables that represents unit power, and a series of prevailing equality and inequality constraints. Furthermore, the number of combinations of 0–1 variables grows exponentially as being a large-scale problem. Therefore, UCP is known as one of the problems which is the most difficult to be solved in power systems.

Many methods have been developed to solve the UCP in the past decades. The major methods include priority list method (PL) [1,2], dynamic programming (DP) [3], branch-and-bound methods (BBM) [4], integer and mixed integer linear programming (MILP) [5], Langrangian relaxation (LR) [6,7]. Among these methods, PL is simple and fast, but the quality of final solution is not guaranteed. DP is flexible but the disadvantage is the “curse of dimensionality”, which leads to more mathematical complexity and increases computation time if the constraints are taken into consideration. The shortcoming of BBM is the exponential growth in the execution time with the size of UCP. MILP adopts linear programming techniques to solve and check an integer solution, which is approximate to handle nonlinear characteristics of UCP. These methods are usually applied to solve small-scale UCP and require major assumptions that limit the solution space. The main problem of the LR is the difficulty encountered in obtaining feasible solutions. Due to the non-convexity nature of the UCP, optimality of the dual problem does not guarantee feasibility of the primal UCP. Furthermore, solution quality of LR depends on the method to update Lagrange multipliers.

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Aside from the above methods, meta-heuristic approaches such as artificial neural network (ANN) [8], ant colony optimization [9,10], genetic algorithm (GA) [11–16], evolutionary programming (EP) [17], memetic algorithm (MA) [18], chaos optimization (CO) [19], simulated annealing (SA) [20], greedy random adaptive search procedure (GRASP) [21,22], bacterial foraging (BF) [23], differential evolution [24,25] and particle swarm optimization (PSO) [26–34] have also been used to solve UCP since the last decades. These meta-heuristic optimization methods attract much attention because it implements simply to find the near-global minimum and can easily deal with various complex nonlinear constraints. However, these meta-heuristic methods have one or another drawback such as premature phenomena, parameter sensitivity, trapping into local optimum and taking too much computation time especially for a large-scale UCP. Thus, improving current optimization techniques and exploring new optimization methods to solve the UCP problem has great significance.

In recent years, a new optimization method known as gravitational search algorithm (GSA) proposed by Esmat Rashedi et al. [35] in 2009 has become a candidate for optimization application due to its flexibility and efficiency, which is based on the Newton's law of gravity and law of motion. GSA has been verified high quality performance in solving different optimization problems, such as optimal power flow in power system [36], parameter identification of water turbine regulation system [37], future oil demand forecasting [38] and prototype classifier [39]. The most substantial feature of GSA is that gravitational constant adjusts the accuracy of the search, so it speeds up solution process. Furthermore, GSA is memory-less, it works efficiently like the algorithms with memory, and it can be considered as an adaptive learning algorithm, respectively. However, application of GSA in combinatorial optimization problems is still limited. The major obstacle of successfully applying GSA to combinatorial problems is due to its continuous nature. To remedy this drawback, this paper proposes an enhanced gravitational search algorithm to solve UCP, which is integrated binary gravitational search algorithm (BGSA) with the Lambda-iteration method. The proposed method is enhanced by priority list based on the unit characteristics and heuristic search strategies to repair the spinning reserve and minimum up/down time constraints. To improve the performance of the method, local mutation strategies are raised to avoid premature convergence and trapping into local optima. In the proposed method, BGSA is used to solve the unit-scheduling problem and the Lambda-iteration method is used to solve the economic load dispatch problem. Finally, the proposed method is tested on the UCP systems with the number of units in the range of 10–100. Simulation results demonstrate the feasibility and effectiveness of the proposed method in terms of solution quality compared with those of other optimization methods reported in the literatures.

This rest of the paper is organized as follows. Section 2 provides the mathematical formulation of the UCP. Section 3 briefly introduces the basics of binary gravitational search algorithm. Section 4 proposes an improved binary gravitational search algorithm for solving UCP. Section 5 gives the numerical example. Section 6 outlines the conclusions. Finally, acknowledgements are given in Acknowledgements Section.

2. Formulation of unit commitment problem

2.1. Objective function

The objective of UCP is to find the generation scheduling over the scheduled time horizon such that the total production cost can be minimized while satisfied all kinds of constraints. The total production cost over the entire scheduling periods is the sum of the operating cost and startup cost for all of the units. Thus, the objective function of the UC problem is to minimize

$$\sum_{t=1}^{T}\sum_{i=1}^{N}[f_i(P_i^t) + ST_i^t(1-u_i^{t-1})]u_i^t \tag{1}$$

where N is number of generators; T is total scheduling period; P_i^t is generation of unit i at time t; u_i^t is on/off status of unit i at time t (on = 1 and off = 0); ST_i^t is startup cost of unit i at time t.

Generally, the fuel cost, $f_i(P_i^t)$ per unit is a function of the generator power output. Most frequently used cost function is in the form of

$$f_i(P_i^t) = a_i + b_iP_i^t + c_i(P_i^t)^2 \tag{2}$$

where a_i, b_i and c_i represent the unit cost coefficients.

2.2. Constraints

(1) System power balance

The generated power from all committed units must be sufficient enough to meet the system power demand.

$$\sum_{i=1}^{N}P_i^tu_i^t = P_D^t \tag{3}$$

where P_D^t is system load demand at time t.

(2) System spinning reserve requirement

Spinning reserve requirements are necessary in the operation of a power system. This necessity is due partly to certain outages of equipment. The reserve is considered to be a prespecified value or a given percentage of the forecasted demand.

$$\sum_{i=1}^{N}u_i^tP_{i\,\max} \geq P_D^t + P_R^t \tag{4}$$

where P_R^t is spinning reserve at time t.

(3) Generation power limits

Each unit has generation range, which is represented as

$$u_i^t \cdot P_{i\,\min} \leq P_i^t \leq u_i^t \cdot P_{i\,\max} \tag{5}$$

where $P_{i\min}$ and $P_{i\max}$ are minimum and maximum generation limit of unit i, respectively.

(4) Unit minimum up time

A unit must be on for a certain number of hours before it can be shut down.

$$T_{i,on}^t \geq T_{i,up} \tag{6}$$

where $T_{i,on}^t$ is continuously on time of unit i up to time t; $T_{i,up}$ is unit i minimum up time.

(5) Unit minimum down time

A unit must be off for a certain number of hours before it can be brought online.

$$T_{i,off}^t \geq T_{i,down} \tag{7}$$

where $T_{i,off}^t$ is continuously off time of unit i up to time t; $T_{i,down}$ is unit i minimum down time.

(6) Unit initial status