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Solution of unit commitment problem using gravitational search algorithm

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ABSTRACT

In this article, gravitational search algorithm (GSA) is proposed to solve thermal unit commitment (UC) problem. The objective of UC is to determine the optimal generation of the committed units to meet the load demand and spinning reserve at each time interval, such that the overall cost of generation is minimized, while satisfying different operational constraints. GSA is a new cooperative agents' approach, which is inspired by the observation of the behaviors of all the masses present in the universe due to gravitation force. The proposed method is implemented and tested using MATLAB programming. The tests are carried out using six systems having 10, 20, 40, 60, 80 and 100 units during a scheduling period of 24 h. The results confirm the potential and effectiveness of the proposed algorithm compared to various methods such as, simulated annealing (SA), genetic algorithm (GA), evolutionary programming (EP), differential evolution (DE), particle swarm optimization (PSO), improved PSO (IPSO), hybrid PSO (HPSO), binary coded PSO (BCPSO), quantum-inspired evolutionary algorithm (QEA), improved quantum-inspired evolutionary algorithm (IQEA), Muller method, quadratic model (QM), iterative linear algorithm (ILA) and binary real coded firefly algorithm (BRCFF).

1. Introduction

The optimum economic operation and planning of electric power generation systems is an important issue in electric power industry. Unit commitment (UC) [1] plays a vital role in generation resource management. It is an optimization problem of determining the schedule of generating units within a power system in order to minimize fuel cost while satisfying a number of constraints such as unit capacity limit, ramp rate limits, spinning reserve constraints, minimum up time and down time constraints. However, UC problem not only minimizes the fuel cost (production costs) but also minimize the transition costs (start-up/shut-down costs). The spinning reserve constraint used in UC, describes the reliability requirement by taking the generator outages into consideration.

UC is essentially a combinatorial optimization problem, and it is quite challenging considering its nature of non-linearity and randomness. It is very complex to solve because of its enormous dimension, non-linear objective function and constraints. Researchers studied this complex problem for decades and many traditional techniques have been developed. The traditional techniques include priority list method [1–2], integer programming (IP) [3], dynamic programming (DP) [4–6], branch and bound [7], Benders' de-composition [8] and Lagrangian relaxation (LR) [9–11]. Among these methods, the priority list method is one of the earliest and simplest approaches to address the UC problem. However, this method is highly heuristic and gives schedules with relatively higher operation cost. The dynamic programming algorithm is an useful technique that provides optimal solutions in small power systems. However, the consideration of all combinations of units, as implemented in this technique, has proven impractical for large power system. Branch-and-bound method has the limitation of a deficiency of storage capacity and requires huge calculation time for large-scale problems. Lagrangian relaxation methods concentrate on finding an appropriate co-ordination technique for generating feasible primal solutions, while minimizing the duality gap. The main drawback with an LR method is its deficiency in obtaining feasible solutions.

Due to the high complexity and high nonlinearity of the UC problem, artificial intelligence methods are used as an alternative to traditional analytical approaches in recent years. These methods have the advantage of searching the solution space more thoroughly. Several artificial intelligence methods, such as Tabu search (TS) [12], simulated annealing (SA) [13–15], evolutionary programming (EP) [16], genetic algorithm (GA) [17–19], artificial neural networks (ANN) [20], particle swarm optimization (PSO) [21], hybrid PSO (HPSO) [22], and ant colony optimization (ACO) [23], have been developed and applied successfully to UC problems.

Recently, Chakraborty et al. presented a fuzzy controlled and multi-population based binary clustered PSO algorithm [24] to

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solve UC problem. In that paper a dynamic probabilistic mutation operator was used to improve the convergence speed of conventional PSO. A binary-real-coded DE applied to UC was reported by Datta et al. [25]. Chandrasekaran et al. proposed the binary real coded firefly algorithm (FA) [26] to solve network and reliability constrained unit commitment (UC) problem and the proposed algorithm was compared with other existing techniques by applying it on 10 unit and IEEE RTS 24 bus system. A harmony search algorithm (HSA) based combinatorial solution strategy for solving security constrained UC problem was introduced by Samiee et al. [27]. Tsai et al. proposed hybridization of Taguchi method and the immune algorithm (HTIA) [28] to solve UC problem. Hybridization was implemented to improve the global exploration capability of traditional IA algorithm.

A novel heuristic search algorithm, called gravitational search algorithm (GSA) motivated by the gravitational law and laws of motion, has been introduced very recently. It is characterized as a simple concept that is easy to implement. GSA has a flexible and well-balanced mechanism to enhance exploration and exploitation abilities. The application of GSA to solve optimization problems has been first presented by Rashedi et al. [29] in the year of 2009. In that article, authors applied GSA to optimize 23 standard benchmark functions and compared its performance with that of PSO, real coded GA (RGA) and central force optimization (CFO). However, except in economic load dispatch (ELD), optimal power flow (OPF) and optimal reactive power dispatch (ORPD), the GSA algorithm has not been applied to solve any other power system optimization problem so far. Affijulla et al. implemented GSA [30] to solve ELD problems. Bhattacharya et al. introduced multi-objective GSA [31] algorithm to solve large scale OPF problems. Roy et al. proposed GSA [32] to solve multi-objective ORPD problem and compared its results with those of other well established algorithms.

In this paper, GSA algorithm has been employed which is more effective and capable of solving nonlinear optimization problems faster and with better accuracy in detecting the global best solution. Six sample cases with and without ramp rate constraint are presented to investigate the efficiency of the proposed method. With the proposed method, the total generation cost can be remarkably reduced while considering various constraints reflecting the practical system.

The rest of the paper is organized as follows: In Section 2, mathematical problem formulation of UC problem is defined. The proposed GSA algorithm is discussed in Section 3. In Section 4, the GSA based UC algorithm is investigated. Input parameters of GSA algorithm are presented in Section 5. In Section 6, GSA is compared with the best previously known algorithms for seven UC test cases. In Section 7, a brief conclusion is given.

2. Mathematical problem formulation of unit commitment

2.1. Objective function

The objective of the UC problem is to minimize the sum of fuel cost, the start up and shut down cost of all individual units for the given period of time subjected to various constraints [33].

$$F = \sum_{i=1}^{ng}\sum_{t=1}^{th}[FC_i U_{i,t} + SUC_i\{U_{i,t}(1-U_{i,t-1})\} + SDC_i\{U_{i,t}(1-U_{i,t-1})\}] \tag{1}$$

where

$$FC_i = \alpha_i P_{g_{i,t}}^2 + \beta_i P_{g_{i,t}} + \gamma_i \tag{2}$$

and

$$SUC_i = \begin{cases} HSC_i; & if \quad T_{off_i}^t \leqslant T_{down_i} + T_{cold_i} \\ CSC_i; & if \quad T_{off_i}^t > T_{down_i} + T_{cold_i} \end{cases} \tag{3}$$

where FC_i is the fuel cost of the ith unit which is taken as quadratic function; ng is the number of generating units; th is the total number of hours; $\alpha_i, \beta_i, \gamma_i$ are the fuel cost coefficients of the ith unit; $P_{g_{i,t}}$ is the power output of the ith generating unit at the tth hour; SUC_i is the startup cost of the ith unit; HSC_i, CSC_i are the hot start up cost and cold start up cost of the ith unit; T_{off_i} is the continuous off time duration of the ith unit; T_{down_i} is the minimum down time of the ith unit; T_{cold_i} is the cold start hours of the ith unit; $U_{i,t}$ is the status of the ith generating unit at the tth hour; and SDC_i is the shutdown cost of the ith generating unit.

2.2. Constraints

Depending on the nature of the power system under study, the UC problem is subject to equality and inequality constraints. The equality constraints being the load balance constraints. The inequality constraints include the unit capacity constraints, the spinning reserve constraints, UP/DOWN time constraints and ramping constraints. However, in the simulation results of this article, the ramping constraints are not taken into consideration. The mathematical formulation of the above mentioned constraints are described below [33]:

2.2.1. Equality constraint

For, each tth hour, the sum of the output powers of the committed generators is equal to the forecasted power demand and is given by

$$\sum_{i=1}^{ng} P_{g_{i,t}} U_{i,t} = P_{D_t} \tag{4}$$

where P_{D_t} is the power demand at the tth hour.

2.2.2. Inequality constraints

2.2.2.1. Generating units constraints. Each committed unit must operate within its operating limits as shown below:

$$P_i^{\min} \leqslant P_{i,t} \leqslant P_i^{\max} \tag{5}$$

where $P_i^{\min}, P_i^{\max}$ are the minimum and maximum operating limits of the ith generating unit.

2.2.2.2. Spinning reserve constraints.

$$\sum_{i=1}^{ng} P_i^{\max} U_{i,t} \geqslant P_{D_t} + SR_t \tag{6}$$

where SR_t is the maximum reserve at the tth hour and P_{D_t} power demand at the tth hour.

2.2.2.3. Minimum up time constraint. Once a unit is started up, it should not be shut-down before a minimum up-time period is met and it mathematically expressed for ith generating unit as follows:

$$T_{ON_i} \geqslant T_{UP_i} \tag{7}$$

where T_{ON_i} is the ON time duration of the ith generating unit and T_{UP_i} is the minimum up time of the ith generating unit.

2.2.2.4. Minimum down time constraint. Once a unit is started down, it should not be shut-up before a minimum down-time period is met and it mathematically expressed for ith generating unit as follows:

$$T_{OFF_i} \geqslant T_{DOWN_i} \tag{8}$$