Electric Power Systems Research 84 (2012) 109–119

Contents lists available at SciVerse ScienceDirect

Electric Power Systems Research

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

# Thermal unit commitment using binary/real coded artificial bee colony algorithm

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ARTICLE INFO

*Article history:*
Received 21 May 2010
Received in revised form
22 September 2011
Accepted 29 September 2011
Available online 11 November 2011

*Keywords:*
Unit commitment
Binary artificial bee colony
Economic dispatch
Valve-point effect
Prohibited operating zones
Multiple fuels

ABSTRACT

This paper presents a binary/real coded artificial bee colony (BRABC) algorithm to solve the thermal unit commitment problem (UCP). A novel binary coded ABC with repair strategies is used to obtain a feasible commitment schedule for each generating unit, satisfying spinning reserve and minimum up/down time constraints. Economic dispatch is carried out using real coded ABC for the feasible commitment obtained in each interval. In addition, non-linearities like valve-point effect, prohibited operating zones and multiple fuel options are included in the fuel cost functions. The effectiveness of the proposed algorithm has been tested on a standard ten-unit system, on IEEE 118-bus test system and IEEE RTS 24 bus system. Results obtained show that the proposed binary ABC is efficient in generating feasible schedules.



## 1. Introduction

Unit commitment is a nonlinear mixed integer optimization problem to schedule the operation of the generating units at minimum operating cost satisfying the demand and other equality and inequality constraints. UCP is to find the commitment schedule (on/off status of generators) and thereby the power output level of each committed generating unit. This scheduling has to be done daily for the time interval planned (hourly or for every five minutes) for dispatch in order to minimize the total fuel cost. Minimization of total cost which includes the fuel cost, start up, and shut down cost is carried out by satisfying various system and unit constraints. The UCP is formulated as a mixed integer-programming problem and it is computationally expensive to solve for large power systems.

Many solution strategies are available to solve the UCP and the ED problem. A literary review of UCP and the solution techniques are given in Refs. [1,2]. Techniques like priority list method [3], dynamic programming [4], mixed integer programming [5], branch and bound [6], [7] and Lagrangian relaxation [8] are the widely used conventional techniques. The priority list method is simple and fast. However, it produces suboptimal solution with higher operation cost. Dynamic programming method has dimensionality problem. That is with increase in problem size, the solution time increases rapidly with the number of generating units to be committed. Though LR method provides a fast solution, it suffers from numerical convergence and the solution quality due to the dual nature of the algorithm is poor. In branch-and-bound method, the computational time increases enormously for a large-scale power system. So, artificial intelligence techniques like, neural networks [9], expert systems [10], genetic algorithm [11,12] simulated annealing [13], evolutionary programming [14], tabu search [15], fuzzy logic [16], particle swarm optimization [17,18] and ant colony optimization [19] are used. These are population based search techniques and can search for the global or near global optimal solution for any large-scale system incorporating all system constraints with ease. In expert system, interaction with the plant operators are required making it inconvenient for a realistic system. Though GA, EP, SA and ACO are able to obtain near optimal solution, for a large power system the computational time is quiet high. Though many techniques are developed to solve UCP, no technique has been accepted as the best so far. In this context, an attempt is made to solve UCP using a newly developed novel binary artificial bee colony (ABC) algorithm.

In this paper, binary ABC algorithm is proposed to solve the UCP and the real-coded ABC algorithm is used to solve the economic dispatch problem. In addition to the quadratic cost functions generally used for representing the fuel cost functions, non-linearities due to valve-point loading, prohibited operating zone and multiple

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doi:10.1016/j.epsr.2011.09.022

fuel options are also incorporated. The algorithm presented in this paper is validated on a standard ten-unit system taken from the literature, IEEE 118-bus system and IEEE RTS 24 bus system. From the results, it can be inferred that the BRABC algorithm performs well.

## 2. Problem formulation

### 2.1. Objective function

The objective function of UC problem is the minimization of the total cost (TC) which is the sum of the fuel cost and the start-up cost of individual units for the given period subject to various constraints. Mathematically, the objective function of the UC problem can be formulated as follows:

$$\text{Minimize TC} = \sum_{t=1}^{T}\sum_{i=1}^{N}[F_i(P_{it}) + \text{SC}_i(1-u_{i(t-1)})]u_{it} \tag{1}$$

where TC is the total operating cost in \$, $F_i(P_{it})$ is the fuel cost of unit $i$ at hour $t$, $P_{it}$ is the output power of $i$th unit at hour $t$, $N$ is the number of units, $T$ is the scheduling period, $u_{it}$ is the on/off status of $i$th unit at hour $t$ and $SC_i$ is the start up cost in \$. The fuel cost function of a thermal unit is expressed as a second order quadratic function as shown in Eq. (2).

$$F_i(P_{it}) = a_i + b_iP_{it} + c_iP_{it}^2 \tag{2}$$

where $a_i, b_i, c_i$ are the unit cost coefficients of $i$th unit. However, for multi-valve steam turbines, due to valve-point loading [20] a sine term is used to model this and is given in Eq. (3).

$$F_i(P_{it}) = (a_i + b_iP_{it} + c_iP_{it}^2) + \left|e_i \sin(f_i(P_{i\min} - P_{it}))\right| \tag{3}$$

where $e_i, f_i$ are the valve-point coefficients of the $i$th unit and $P_{i\min}$ is the minimum generation limit of unit $i$. If multiple fuels are used, then the cost function is as given in Eq. (4).

$$F_i(P_i) = \begin{cases} a_{i1} + b_{i1}P_i + c_{i1}P_i^2, \ P_{i,1}^l \le P_i \le P_{i,1}^u & \text{for fuel } 1 \\ a_{i2} + b_{i2}P_i + c_{i2}P_i^2, \ P_{i,2}^l \le P_i \le P_{i,2}^u & \text{for fuel } 2 \\ \vdots & \\ a_{ik} + b_{ik}P_i + c_{ik}P_i^2, \ P_{i,k}^l \le P_i \le P_{i,k}^u & \text{for fuel } k \end{cases} \tag{4}$$

where $a_{ik}$, $b_{ik}$ and $c_{ik}$ are the fuel cost coefficients, $e_{ik}$ and $f_{ik}$ are the valve-point coefficients and $P_{i,k}^l$ and $P_{i,k}^u$ are the lower and upper bounds of the $i$th generator using the fuel type $k$.

Generating units may have certain regions where operation is undesired due to physical limitations of the machine components or issues related to instability. These regions produce discontinuities in the cost curve since the unit must operate under or over certain specified limits. This type of cost functions results in non-convex sets of feasible solution points, which are modeled as follows:

$$P_i = \begin{cases} P_{i\min} \le P_i \le P_{i,1}^l & \\ P_{i,j-1}^u \le P_i \le P_{i,j}^l & j = 2, \ldots n_i \\ P_{i,n_i}^u \le P_i \le P_{i\max} & \end{cases} \tag{5}$$

where $P_{i\max}$ is the maximum generation limit of unit $i$, $P_{i,j}^l$ and $P_{i,j}^u$ are the lower and upper bounds respectively of the $j$th prohibited zone of unit $i$ and $n_i$ is the number of prohibited zones in unit $i$.

The start-up cost, $\text{SC}_i$ for restarting a decommitted thermal unit depends on the time the unit has been off prior to start-up. Start-up cost will be high cold cost when down time duration exceeds cold start hour in excess of minimum down time. When down time duration does not exceed cold start hour in excess of minimum down time a hot start up cost can be considered. This is represented mathematically as follows:

$$\text{SC}_i = \begin{cases} \text{HSC}_i \text{ if } \text{MDT}_i \le X_{it}^{\text{off}} \le H_i^{\text{off}} \\ \text{CSC}_i \text{ if } \text{MUT}_i > X_{it}^{\text{off}} \end{cases} \tag{6}$$

$$H_i^{\text{off}} = \text{MDT}_i + T_{ci}$$

where $\text{HSC}_i$ is hot start cost of unit $i$; $\text{CSC}_i$ is cold start cost of unit $i$; $T_{ci}$ is cold start time of unit $i$; $\text{MUT}_i$ and $\text{MDT}_i$ are the minimum up and down times of unit $i$ respectively, $X_{it}^{\text{on}}$ and $X_{it}^{\text{off}}$ are the time duration for which unit $i$ has been continuously on and off at time $t$.

Increased awareness of limiting environmental pollution caused by thermal power plants due to $CO_2$, $SO_x$ and $NO_x$ emissions are crucial issues faced in the UCP. Many researchers treated emission as a constraint in a single objective UCP [28–30]. However the limitation of this approach is obtaining a trade-off solution between cost and emission which are conflicting in nature and cannot be minimized simultaneously. Hence the environmental/economic constrained UCP is formulated as a multi-objective UC problem. The emission from each unit depends on the power generated by that unit and can be modeled as sum of a quadratic and an exponential function.

$$E = \sum_{k=1}^{H}\sum_{i=1}^{N} E(P_{i,k}) = \sum_{k=1}^{H}\sum_{i=1}^{N}\begin{pmatrix} (\alpha_i + \beta_i.P_{i,k} + \gamma_i.P_{i,k}{}^2) \\ +\delta_i.\exp(d_i.P_{i,k}) \end{pmatrix} \tag{7}$$

The objective function of the EELD problem can be formulated as in Eq. (8) to consider the cost of generation Fc and the emission control level $E$ simultaneously.

$$\text{Minimize } F(\text{Fc}, E) \tag{8}$$

subject to the constraints (10)–(14). Since the fuel cost and emission functions conflict, in the sense that minimization of the fuel cost maximizes the emission cost and vice versa [31], solution to the combined function $F$ requires a compromise between them. Hence, the multi-objective problem in Eq. (8) is converted into single objective optimization problem by introducing price penalty factor $g$ and the new objective function can be expressed as in Eq. (9).

$$F = w\text{Fc} + (1-w)g \cdot E \tag{9}$$

where $w$ is a weighting factor of each of the objective function.

$g$ is a price penalty factor.

Here $g$ is calculated as per the steps given in Refs. [32–34].

In Section 5.5, two test systems are taken to show the effectiveness of the BRABC algorithm and environmental impact on UC problem.

### 2.2. Constraints

#### 2.2.1. Power balance constraint

The generated power from all the committed units must satisfy the load demand plus the system losses, which is defined as,

$$\sum_{i=1}^{N} P_{it}u_{it} = P_{Dt} + P_{Lt}, \quad t = 1, 2 \ldots T \tag{10}$$

#### 2.2.2. Spinning reserve constraint

To maintain system reliability, adequate spinning reserves are required.

$$\sum_{i=1}^{N} P_{i\max}u_{it} \ge P_{Dt} + P_{Lt} + P_{Rt}, t = 1, 2 \ldots T \tag{11}$$