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Evolving ant colony optimization based unit commitment

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ABSTRACT

Ant colony optimization (ACO) was inspired by the observation of natural behavior of real ants' pheromone trail formation and foraging. Ant colony optimization is more suitable for combinatorial optimization problems. ACO is successfully applied to the traveling salesman problem. Multistage decision making of ACO gives an edge over other conventional methods. This paper proposes evolving ant colony optimization (EACO) method for solving unit commitment (UC) problem. The EACO employs genetic algorithm (GA) for finding optimal set of ACO parameters, while ACO solves the UC problem. Problem formulation takes into consideration the minimum up and down time constraints, startup cost, spinning reserve, and generation limit constraints. The feasibility of the proposed approach is demonstrated on two different systems. The test results are encouraging and compared with those obtained by other methods.

1. Introduction

Unit commitment (UC) is used to schedule the generating units for minimizing the overall cost of the power generation over the scheduled time horizon while satisfying a set of system constraints. UC problem is a nonlinear, combinatorial optimization problem. The global optimal solution can be obtained by complete enumeration, which is not applicable to large power systems due to its excessive computational time requirements [1]. Up to now, many methods have been developed for solving the UC problem such as priority list methods [2,3], integer programming [4,5], dynamic programming (DP) [6–8], branch-and-bound methods [9], mixed-integer programming [10] and Lagrangian relaxation (LR) [11–13].

These methods have only been applied to small UC problems and have required major assumptions which limit the solution space [14,15]. Lagrange relaxation for UC problem was superior to dynamic programming due to its faster computational time. However, it suffers from numerical convergence and solution quality problems in the presence of identical units. Furthermore, solution quality of LR depends on the method to initialize and update Lagrange multipliers [16].

Ant colony optimization (ACO) was proposed by Dorigo et al. to solve difficult combinatorial optimization problems. ACO is a random stochastic population based algorithm that simulates the behavior of ants for cooperation and learning in finding shortest paths between food sources and their nest [17–20]. In ACO, the ants' behavior is simulated to solve the combinatorial problems such as traveling salesman problem and quadratic assignment problem [19,20]. Artificial ant colony search algorithm is applied to solve large-scale economic dispatch problem in Ref. [21]. In Ref. [22], economic dispatch of power systems was solved by generalized ant colony optimization. Ant colony search algorithm is applied to distribution network reconfiguration for loss reduction in Ref. [23]. Ant colony search algorithm for Optimal Reactive Power Optimization is given in Ref. [24]. The ACO is applied to solve the UC problem by Refs. [25,26].

This paper proposes a new method, evolving ant colony optimization (EACO) for solving UC problem for a period of 24 h. In this approach, the ACO is used to obtain the unit commitment schedule and genetic algorithm technique is used to find optimal set of parameters required for ACO. The Lagrangian multiplier method is applied to obtain the economic dispatch for the 24-h schedule. To illustrate the effectiveness of the proposed method, it is tested on two different systems one with 10 and 20 units and the other with 10 units. Simulation results are presented and compared with other methods.

2. Problem formulation

The objective of unit commitment problem is to minimize the production cost over the scheduled time horizon (24 h) under the generator operational and spinning reserve constraints. The objec-

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Nomenclature

CSC_i cold startup cost of unit i
F_i^t generator fuel cost in quadratic form
$F_i^t = a_i + b_i P_i^t + c_i (P_i^t)^2$ fuel cost in $/h
HSC_i hot startup cost of unit i
N total number of generator units
$P_{i,\min}$ minimum real power generation of unit i (in MW)
$P_{i,\max}$ maximum real power generation of unit i (in MW)
P_i^t real power generation of unit i at hour t (in MW)
P_D^t load demand at hour t (in MW)
R^t spinning reserve at hour t (in MW)
ST_i^t startup cost of unit i at hour t
T total number of hours
$T_{i,cold}$ cold start hours of unit i (in h)
$T_{i,down}$ minimum down time of unit i (in h)
$T_{i,off}$ continuously off time of unit i (in h)
$T_{i,on}$ continuously on time of unit i (in h)
$T_{i,up}$ minimum up time of unit i (in h)
$U_{i,t}$ status of unit i at hour t (on = 1, off = 0)
m number of ants
τ pheromone intensity
C_{ij} production cost occurred during a stage
η_{ij} heuristic function for visibility
n number of eligible states (size of pheromone matrix)

tive function to be minimized is

$$F(P_i^t, U_{i,t}) = \sum_{t=1}^{T} \sum_{i=1}^{N} [F_i(P_i^t) + ST_{i,t}(1 - U_{i,t-1})] U_{i,t} \quad (1)$$

subject to the following constraints:

power balance constraint

$$\sum_{i=1}^{N} P_i^t U_{i,t} = P_D^t \quad (2)$$

spinning reserve constraint

$$\sum_{i=1}^{N} P_{i,\max} U_{i,t} \geq P_D^t + R^t \quad (3)$$

generator limit constraints

$$P_{i,\min} U_{i,t} \leq P_i^t \leq P_{i,\max} U_{i,t}, \quad i = 1, \ldots, N \quad (4)$$

minimum up and down time constraints

$$U_{i,t} = \begin{cases} 1, & \text{if } T_{i,on} < T_{i,up} \\ 0, & \text{if } T_{i,off} < T_{i,down} \\ 0 \text{ or } 1, & \text{otherwise} \end{cases} \quad (5)$$

startup cost

$$ST_{i,t} = \begin{cases} HSC & \text{if } T_{i,down} \leq T_{i,off} \leq T_{i,cold} + T_{i,down} \\ CSC_i & \text{if } T_{i,off} > T_{i,cold} + T_{i,down} \end{cases} \quad (6)$$

3. Implementation of the proposed method

The implementation of EACO algorithm for solving UC problem involves two phases. In the first phase, all possible states of the tth hour (using exhaustive enumeration) that satisfy the load demand with spinning reserve constraints are found. For 10-unit system, a maximum of 256 eligible states are found in any hour by taking first two generators as base units. i.e. first two generators are in 'on' condition for 24 h and only 256 feasible states are available for remaining eight generators. In 20-unit case exhaustive enumeration is not possible. First four units are base units and in the remaining 16 units, last six peak units are not considered for light load conditions to try the combinations. In that way, a maximum of 1024 feasible states are found in any hour. Economic dispatch using Lagrangian multiplier method is carried out for all feasible states to calculate the optimal generator output and production cost for each hour and startup cost is added to production cost to get transition cost for each hour. This process is continued for the complete scheduling period of 24 h to get total cost for each state of all feasible states which constitutes the ant search space (ASS). The ASS which involves multi decision states is shown in Fig. 1. S_t is the eligible state satisfying load demand and spinning reserve at tth hour.

Once the search space is identified, the second phase involves the artificial ants allowed to pass continuously through the ASS. Each ant starts its journey from the starting node (initial condition, i.e. 1st hour), reaches the final node (24th hour) to complete its tour. Whenever an ant reaches the final node, overall generation cost for 24 h including startup cost is calculated. For each transit stage (t to t + 1 h), the ant selects a state satisfying minimum uptime, minimum down time, ramp rate constraints, etc. The generation cost together with startup cost is calculated for all units which becomes transition cost.

This process is continued till the time period becomes T (24 h) and a tour is completed for that particular ant. Whenever a tour is completed by an individual ant and if the total generation cost is found is lesser than the minimum cost paths taken by the previous

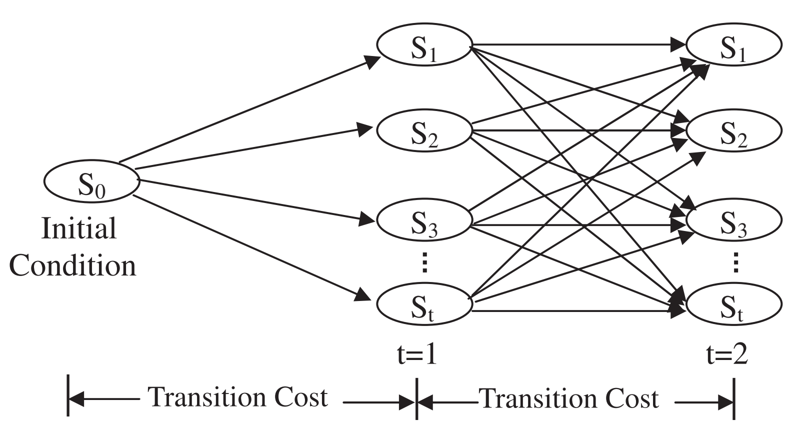

Fig. 1. Multi decision space.