Expert Systems with Applications 36 (2009) 5081–5086

Contents lists available at ScienceDirect

Expert Systems with Applications

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

Fuzzy and simulated annealing based dynamic programming for the unit commitment problem

S. Patra [a,*], S.K. Goswami [a], B. Goswami [b]

[a] Assam Engineering College, Guwahati, Assam 781013, India
[b] Jadavpur University, Kolkata, West Bengal, India

ARTICLE INFO

Keywords:
Dynamic programming
Unit commitment problem
Heuristic procedures
Fuzzy based unit selection
Simulated annealing

ABSTRACT

A dynamic programming technique with a fuzzy and simulated annealing based unit selection procedure has been proposed in this paper for the solution of the UC problem. The curse of dimensionality of the dynamic programming technique is eliminated by minimizing the number of prospective solution paths to be stored at each stage of the search procedure. Heuristics like priority ordering of the units, unit grouping, fast economic dispatch based on priority ordering, avoidance of repeated economic dispatch through memory action have been employed to make the algorithm fast. The proposed method produced comparable results with the best performing methods found in the literature.

1. Introduction

Unit commitment (UC) is a mixed integer multistage decision making problem where the objective is to determine the hourly ON–OFF schedule and generation level of each generating unit of a power system over a given time horizon. Generally, the hourly schedule is determined for 24 h such that the fuel cost and start-up/shut-down cost is minimized and the spinning reserve constraints, up time/down time constraints, ramp rate constraints and load balance equations are satisfied (Wood & Wollenberg, 1996). The problem is a difficult one because of the mixed integer nature of the variables and the complex cost function involved. Many optimization techniques have been tried to solve the UC problem including simple heuristic methods like priority list Burns & Gibson, 1975; Senjyu, Shimabukuro, Uezato, & Funabashi, 2003), linear programming (Carrion & Arroyo, 2006; Fu, Shahidehpour, & Li, 2005a), non-linear programming approaches like Lagrange relaxation method (Cheng, Liu, & Liu, 2000), dynamic programming (Hobbs, Hermon, Warner, & Sheble, 1988; Ouyang & Shahidehpour, 1991) and branch and bound technique (Cohen & Yoshimura, 1983). In recent years, metaheuristic techniques (Ouyang & Shahidehpour, 1992) have been extensively used to solve the problem. Successes have been reported with the methods like simulated annealing (SA) Huang & Galiana, 1990; Simopoulos, Kavatza, & Vournas, 2006 and Tabu search (Mantawy, Abdel-Majid, & Selim, 1998) as well.

One of the successful techniques for the solution of the unit commitment problem is dynamic programming (DP). But it suffers from large computation time that expands exponentially with the size of the problem. To reduce the computation time, heuristic strategies have been introduced which limit the dynamic search requirements. Like many problems in power system, fuzzy logic has been used in solving UC problem as well for better handling of parameters involving uncertainties. Fuzzy dynamic programming approaches have also been proposed to take care of the load forecast uncertainty in the UC problem (Saber, Senjyu, Miyagi, Urasaki, & Funabashi, 2006; Saneifard, Prasad, & Smolleck, 1997; Su & Hsu, 1991).

This paper develops a fast dynamic programming solution algorithm for the UC problem by minimizing the number of search paths to be explored and applying a fuzzy logic and simulated annealing based unit selection procedure. The solution speed has also been enhanced by applying memory action whereby the results of the economic dispatch solutions for different combinations of units are memorized to reuse in future decision making steps. Though in recent publications, UC problem has been solved considering additional constraints like system security (Fu, Shahidehpour, & Li, 2005b), frequency regulation (Restrepo & Galiana, 2005) etc., we for the time being have not incorporated these into our formulation as we, in this paper, are basically presenting a new solution approach. The proposed method will however be applicable in solving the UC problem considering the mentioned constraints. It also will be applicable for UC solution in case of the market environment. It may be pointed out that in the present paper, we have not considered the load forecast uncertainty in the UC solution. Fuzzy approach has been used to handle the unit costs in an approximate way.

* Corresponding author.
E-mail address: sarmilapatra@yahoo.com (S. Patra).

0957-4174/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.eswa.2008.06.039

Notation

N	number of units
T	total scheduling period
I	index of unit ($i = 1.2 \ldots\ldots N$)
T	index of hour ($t = 1.2 \ldots\ldots T$)
$U_i(t)$	ON/OFF status of unit i at hour t
$P_i(t)$	generation of unit i at hour t
P_i^{max}	maximum generation limit of unit i
P_i^{min}	minimum generation limit of unit i
PD(t)	system load demand in the hour t
RE(t)	spinning reserve requirement in the hour t
T_i^{off}	minimum up time of ith unit
T_i^{on}	minimum down time of ith unit
$X_i^{on}(t)$	duration during which unit i is continuously on
$X_i^{off}(t)$	duration during which unit i is continuously off
$SC_i(t)$	start-up cost of unit i at hour t
$F_i(P_i(t))$	fuel cost of unit i at hour t
CF	total cost
h-cost$_i$	ith unit hot start cost
c-cost$_i$	ith unit cold start cost
c-s-hr$_i$	cold start time of unit i
RAMPUP$_i$	ramp-up limit of unit i
RAMPDN$_i$	ramp-down limit of unit i

2. Unit commitment problem formulation

2.1. Formulation

Mathematically, the unit commitment problem can be formulated as a mixed integer non-linear programming problem. The objective function and constraints are formulated as given below.

(1) *Objective function*: The total cost, CF over the entire scheduling periods is the sum of the fuel cost and start-up cost for all the units. The overall objective function of the UC problem is given by

$$\min \text{CF} = \sum_{t=1}^{T}\sum_{i=1}^{N}[F_i(P_i(t)) + \text{SC}_i(t)]$$

where $F_i(P_i(t))$ is fuel cost of thermal unit expressed as a second order function of each unit output.$F_i(P_i(t)) = a_i + b_iP_i(t) + c_iP_i^2$, where a_i,b_i and c_i represent unit cost coefficients.$SC_i(t)$ = start-up cost of unit i.The generator start-up cost depends on the time the unit has been off to start-up. It is given by

$$\text{SC}_i(t) = \text{h-cost}_i : T_i^{off} \leqslant X_i^{off}(t) \leqslant H_i^{off} = c\text{-cost}_i : X_i^{off}(t) > H_i^{off}$$

$$H_i^{off} = T_i^{off} + \text{c-s-hour}_i$$

(2) *Constraints*: The UC problem has to be solved satisfying the following constraints:*Power balance*: Total power generated must supply the load demand.

$$\text{PD}(t) = \sum_{i=1}^{N} Pi(t)$$

Spinning reserve requirements: Hourly reserve requirements RE(t) must be met

$$\sum_{i=1}^{N} V_i(t)\cdot P_i\max \geqslant \text{PD}(t) + \text{RE}(t)$$

Generator capacity limits: Unit rated minimum and maximum capacities must not be violated

$$P_i\min \le Pi(t) \le P_i\max$$

Unit minimum up/down time: Minimum up/down time limits of the units must satisfy the following:

$$T_i^{on} \leqslant X_i^{on}$$

$$T_i^{off} \leqslant X_i^{off}$$

Ramp rate constraints: If a unit remains in operation for two successive hours, in that case $-\text{RAMPDN}_i \leqslant P_i(t) - P_i(t-1) \leqslant \text{RAMPUP}_i$.

3. The proposed method

In traditional dynamic programming technique for solving the UC problem, several states (which is an array of units with specified units ON and the rest OFF) are evaluated each hour with the intent to find the predecessor path which results in the lowest cumulative cost through that hour.

In this paper, a new fuzzy rule based fast dynamic programming technique is proposed to solve the unit commitment problem. The proposed method consists of a number of heuristics such as priority ordering of the units, unit grouping, fast economic dispatch based on priority ordering, avoidance of repeated economic dispatch (ED) solution through memory action and fuzzy based unit selection procedure. These heuristics and fuzzy selection procedure are described first, followed by the complete solution algorithm of the UC problem.

3.1. Priority ordering

All the generating units are sorted by their average incremental cost to form a priority list in ascending order.

3.2. Grouping of units in different levels

To speed up the computation, groups of the generating units are classified in to different clusters in respect of the total capacity level of each group. State consisting of the base units (which must run at any time and supply the base load) termed as zero level is placed at the bottom. As the level is increased, the remaining units are added one by one. This process is explained for a 10 unit system in Fig. 1. The bracketed sets of numbers represent different states. The numbers in the bracket represent the units which are ON.

3.3. Ordering of the states in each level

States in different levels are placed according to maximum generation capacity in an ascending order as shown in Table 1).

3.4. Search window

At each stage, search is restricted in a narrow window determined by the ordered capacity levels formed in step C. If at a particular hour, the load demand and spinning reserve requirements are fulfilled from state m belonging to level r, the search is restricted to the states within the level r and $r + 1$. All the states within this window which satisfies the minimum up time and down time constraints are considered for evaluation It is clear from