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An Improved PSO Approach for Profit-based Unit Commitment in Electricity Market

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***Abstract*--In this paper, we propose a formulation of the unit commitment problem based on the profit under the deregulated electricity market(PBUC). We express the unit commitment problem as a mixed integer nonlinear optimization problem in which the objective is to maximize profits for generation company and the decisions are required to meet all kinds of operating constraints. Under the assumption of competitive market and price forecasting, we developed an improved discrete binary particle swarm optimization(PSO) and standard value PSO to solve this PBUC problem iteratively. A generation company with 10 generating units is used to demonstrate the effectiveness of the proposed approach. Simulation results are compared with those obtained from reference method.**

keywords: particle swarm optimization, profit-based unit commitment, electricity market

I. Nomenclature

u_i^t The commitment state of unit i at time t.

P_i^t Generation of unit i at time t

P_D^t Forecasted demand at hour t

SR^t Forecasted reserve at hour t

Pimin Minimum generation of unit i

Pimax Maximum generation of unit i

R_i^t Reserve power of unit i at time t

T_i^{on} Minimum on time of unit i

T_i^{off} Minimum off time of unit i

$X_{i,t}^{on}$ Time duration for which unit i has been on at time t

$X_{i,t}^{off}$ Time duration for which unit i has been off at time t

ρ^t Forecasted spot price at time t

ρ_s^t Forecasted reserve price at time t

$f_i(P_i^t)$ Cost function of unit i at time t ,

$$f_i(P_i^t) = a_i(P_i^t)^2 + b_i P_i^t + c_i$$

STi Start up cost of unit i

Prob Probability that the reserve is called and generated.

N Number of generator units

T Number of hours

II. Introduction

THe task of Unit Commitment (UC) involves scheduling the on/off status, as well as the real power outputs, of thermal units for use in meeting all kinds of constraints. In a vertically integrated utility environment, the UC determines generating unit schedules in a utility for minimizing the operating cost over the time interval as a goal. The deregulation and restructuring of the electric power industry have created a competitive open market environment. Generation companies solve UC not for minimizing total production cost as before but for maximizing their own profit under deregulated environment. This problem is called profit-based UC problem(PBUC). PBUC is defined as a method to schedule generators economically based on the forecasted information, such as prices and demand/reserve with an objective to maximize profit of generation company. It is much more difficult problem to solve than traditional UC.

The PBUC problem is a mixed integer and continuous nonlinear optimization problem, which is very complex to solve because of its enormous dimension, a nonlinear objective function, and a large number of constraints. Many solution techniques [1-7], such as integer programming, dynamic programming, Lagrangian relaxation and genetic algorithm can be used to solve the PBUC. Because of the inherit limitation of these methods, which have some one or another drawback for solution the PBUC. More recently, meta-heuristic approach based on swarm intelligent called particle swarm optimization (PSO) is suit to solve PBUC for its good characteristic. This paper puts forth a new approach for solving PBUC, an improved particle swarm optimization (IPSO).

A PBUC model in the competitive electricity market environment is established in this paper, considering both power and reserve generations. To overcome the disadvantages of conventional optimization techniques and the drawbacks of PSO, an improved discrete binary PSO method is proposed to solve the PBUC problem in electricity market.

This paper is organized as follows. Part III describes the PBUC problem formulation in the competitive environment. Part IV describes the improved PSO method, which was used to solve the PBUC problem. Part V presents the results of

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illustrative example. Finally, Part VI provides some conclusions.

III. PROFIT-BASED UNIT COMMITMENT FORMULATION

The objective of PBUC is to maximize the generation company profit (revenue minus cost) subject to all kinds of constraints.

A. Objective function

$$\max Profit = Rv - Tc \quad or \quad \min Tc - Rv \qquad (1)$$

In this paper, reserve is paid when only reserve is actually used[5]. Therefore, revenue and costs in (1) can be calculated from the following equations:

$$Rv = \sum_{i=1}^{N}\sum_{t=1}^{T}[\rho^t \cdot P_i^t + prob \cdot \rho_s^t \cdot R_i^t] \cdot u_i^t \qquad (2)$$
$$Tc = \sum_{i=1}^{N}\sum_{t=1}^{T}\{[(1-prob) \cdot f_i(P_i^t) + prob \cdot f_i(P_i^t + R_i^t)] \cdot u_i^t + ST_i(1-u_i^{t-1}) \cdot u_i^t\}$$

B. Subject to the following constraints

1） Energy constraint

$$\sum_{i=1}^{N} P_i^t u_i^t \le P_D^t \qquad t = 1,2,...T \qquad (3)$$

2） Reserve constraint

$$\sum_{i=1}^{N} R_i^t u_i^t \le SR^t \qquad t = 1,2,...T \qquad (4)$$

3) Unit generation and reserve limits constraint

$$\begin{aligned} &P_{i\min} \le P_i^t \le P_{i\max} \\ &0 \le R_i^t \le P_{i\max} - P_{i\min} \\ &P_i^t + R_i^t \le P_{i\max} \\ &i = 1,2,...N \end{aligned} \qquad (5)$$

4）Unit minimum ON/OFF duration constraint

$$\begin{cases} (X_{i,t-1}^{on} - T_i^{on})(u_i^{t-1} - u_i^t) \ge 0 \\ (X_{i,t-1}^{off} - T_i^{off})(u_i^t - u_i^{t-1}) \ge 0 \end{cases} \qquad (6)$$

IV. PROPOSED SOLUTION METHOD

A. Overview of the PSO

Particle swarm optimization (PSO), first introduced by Kennedy and Eberhart, is one of the modern heuristic optimization algorithms[8]. PSO provides a population based search procedure in which individuals called particles change their positions with time. The PSO can generate high quality solutions within shorter calculation time and stable convergence characteristic than other stochastic optimization methods.

The PSO model consists of a swarm of particles moving in an d-dimensional real-valued space of possible problem solutions. Every particle has a position $X_i = (x_{i1}, x_{i2}, ..., x_{id})$ and a flight velocity $V_i = (v_{i1}, v_{i2}, ..., v_{id})$. Moreover, each particle contains its own best position seen so far $P_i = (p_{i1}, p_{i2}, ..., p_{id})$ and a global best position $P_g = (p_{g1}, p_{g2}, ..., p_{gd})$ obtained through communication with its fellow neighbor particles.

At each time step t, the velocity is updated and the particle is moved to a new position. This new position is simply calculated as the sum of the previous position and the new velocity:

$$x_{ik}^{t+1} = x_{ik}^t + v_{ik}^{t+1} \qquad i = 1,2...n;\ k = 1,2,...d \qquad (7)$$

The update of the velocity from the previous velocity to the new velocity is determined by:

$$\begin{aligned} v_{ik}^{t+1} &= \omega v_{ik}^t + c_1 rand1(0,1)(p_{ik} - x_{ik}^t) + \\ &c_2 rand2(0,1)(p_{gk} - x_{ik}^t) \quad i = 1,2,...n;\ k = 1,2,...d \end{aligned} \qquad (8)$$

where

ω is inertia weight factor

c_1、c_2 are acceleration constant

rand1(0,1) and rand2(0,1) are uniform random value between[0,1]

v_{ik}^t is the velocity of particle i at iteration t

x_{ik}^t is the position of particle i at iteration t

B. An Improved PSO to PBUC

The original PSO is basically developed for continuous optimization problems. However, PBUC is formulated as mixed integer nonlinear programming problems. Kennedy and Eberhart proposed a discrete binary PSO(BPSO) to solve integer optimization problems[9]. However, with a simple modification, the PSO can be made to operate on binary problems, such as UC. In BPSO, *Xi* in (7) can take on values of 0 or 1 only. The velocity *Vi* will determine a probability threshold. If *Vi* is higher, the individual is more likely to choose 1, while lower values favour the 0 choice. Such a threshold requires staying in the range [0,1]. One of the functions accomplishing this feature is the sigmoid function, derived as follows:

$$s(V_i(t)) = 1/(1 + e^{-V_i(t)}) \qquad (9)$$

A random number (uniform distribution between 0 and 1) is first generated, whereby *Xi* is set to 1 if the random number is less than the value from the sigmoid function as illustrated below.

$$u_i(t+1)=\begin{cases}1 & if\ rand(0,1)<s(V_i(t+1)) \\ 0 & else\end{cases} \quad (10)$$

In PBUC problem, $u_i(t+1)$ represents the on or off state of the generator i at time t+1.

The PBUC is decomposed into two embedded optimization sub-problems: one the unit on/off status schedule problem with integer variables that can be solved by the improved discrete binary PSO and the other economic dispatch problem with continuous generated power that can be solved by the standard real value PSO. In calculating process, the real-valued PSO and BPSO are run in parallel, with each updated according to (8) and (10) separately.

In order to obtain high precision solution for PBUC, two operators which are repair strategy and swap mutation operator were adopted to improved BPSO performance:

1) Repair strategy operator

This operator repairs solutions that are infeasible regarding the minimum up/down constraints of unit. The process of fixing a solution is done by evaluating the state of each unit $X_{i,t}^{on}$ and $X_{i,t}^{off}$. As it was previously defined $X_{i,t}^{on}$ and $X_{i,t}^{off}$ denotes the consecutive time that unit *i* has been up and down at time *t* separately. The state of a unit is evaluated starting from hour 0. If at a given hour *t* the minimum up or down time constraint is violated, the state (on/off) of the unit at that hour is reversed and $X_{i,t}^{on}$ or $X_{i,t}^{off}$ is updated. The process continues until the last hour has been reached. This operator can be effectively dealt with the minimum up/down time constraints of unit

2) Swap mutation operator

The swap operator uses the full-load average costs (α) of the generating units to perform a swap of unit states. The α of a unit is defined as the cost per unit of power when the generator is at its full capacity. The generating units are ranked by their α in ascending order. This means that for any two generating units *i* and *j* where *i<j* the inequality $\alpha_i < \alpha_j$ holds. Units with lower α should have higher priority to be dispatched. At a given hour, the operator probabilistically swaps the states of two units *i* and *j* only if the unit *i* is ranked better than unit *j* and the state of the units are off and on respectively. This operator enhanced the algorithm's global optimal performance.

In PSO, the evaluation function value is mainly used to provide a measure of how the particle performed in the problem domain. The best particle in swarm should have the highest profit and also satisfy constraints of the PBUC. Therefore, in the improved PSO, Energy and reserve constraints can be dealt with through penalty function, so we define the evaluation function F as following equation (11). After some treatment for these constraints, the following objective functions can be obtained:

$$\min F=-\mathrm{Pr}ofit+\sigma\{\sum_{t=1}^{T}(\phi_t)^2+\sum_{t=1}^{T}(\varphi_t)^2\} \quad (11)$$

$$\phi_t=\min\{0,(P_D^t-\sum_{i=1}^{N}P_i^t u_i^t)\} \quad (12)$$
$$t=1,2,...T$$

$$\varphi_t=\min\{0,(SR^t-\sum_{i=1}^{N}R_i^t u_i^t)\} \quad (13)$$
$$t=1,2,...T$$

where σ is the constraints penalty coefficient.

It is of crucial importance to select the penalty coefficient in the search process of the PSO. Overlarge penalty coefficient will possibly lead to converge at the local optimum solution. On the other hand, the convergence of algorithm will be poor. Therefore, this paper adopts self-adaptive adjusted strategy to choose penalty factor σ, which is computed at the kth generation defined as $\sigma=\sigma_0+\log(k+1)$.where σ_0 is a given constant. The pressure on the infeasible solution can be increased with the number of generations based on the Kuhn-Tucker optimality theorem and penalty function theorem providing guidelines to choose the penalty term. Thus σ increases gradually which ensures the satisfaction of constraints with the process of the PSO.

V. NUMERICAL EXPERIMENTS

The PBUC problem solution method is implemented in Visual C++6.0. We use a generation company with 10 generating units to illustrate the proposed method. In our implementation, energy and reserve are considered simultaneously in the formulation. 24 h scheduling period is considered. Fuel cost function of each generating unit is estimated into quadratic form as shows in nomenclature. Unit data, forecasted demand, reserve and market prices were given in Tables 1,2 and figure 1 as following, which obtained from Reference [7].

TABLE 1 Generators Data

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Pmax	455	455	130	130	162
Pmin	150	150	20	20	25
a	0.00048	0.00031	0.00200	0.00211	0.00398
b	16.19	17.26	16.60	16.50	19.70
c	1000	970	700	680	450
min up	8	8	5	5	6
min down	8	8	5	5	6
ST	4500	5000	550	560	900
Ini.	8	8	-5	-5	-6

	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Pmax	80	85	55	55	55
Pmin	20	25	10	10	10
a	0.00712	0.00079	0.00413	0.00222	0.00173
b	22.26	27.74	25.92	27.27	27.79
c	370	480	660	665	670
min up	3	3	1	1	1
min down	3	3	1	1	1
ST	170	260	30	30	30
Ini.	-3	-3	-1	-1	-1

TABLE 2 Forecasted demand and reserve

Hour	Forecasted Demand (MW)	Forecasted Reserve (MW)
1	700	70
2	750	75
3	850	85
4	950	95
5	1000	100
6	1100	110
7	1150	115
8	1200	120
9	1300	130
10	1400	140
11	1450	145
12	1500	150
13	1400	140
14	1300	130
15	1200	120
16	1050	105
17	1000	100
18	1100	110
19	1200	120
20	1400	140
21	1300	130
22	1100	110
23	900	90
24	800	80

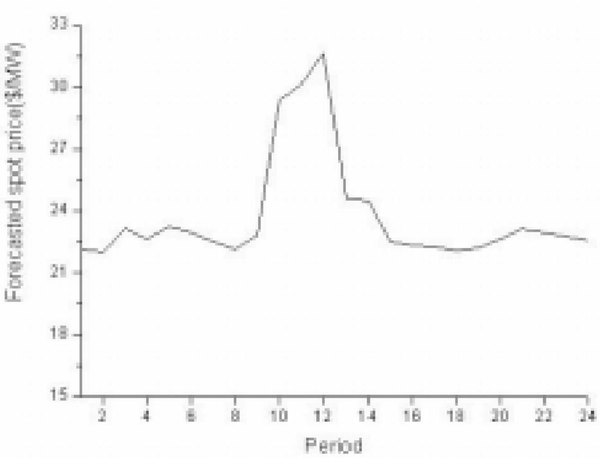

Fig. 1. Forecasted spot price for 24 period

In order to overcome the stochastic nature of the improved PSO for obtaining better result, each experiment was run 10 times, starting with an different random initial population particles. The best result is selected as the final result, under the control parameter settings of the approach are population size 30 and maximize iterative generation 2000.

The profit using the improved PSO method is $113018.7 and the corresponding profit using the hybrid approach between Lagrangian Relaxation (LR) and Evolutionary Programming (EP) in Reference [7] is $112818.9. The profit using the improved PSO approach is 0.2% higher than that of hybrid method between LR and EP.

VI. Conclusions

In this paper, we have established an model of the unit commitment problem based on profit under the deregulation electricity market environment, which generation company is responsible for unit commitment in a restructured market structure. We have shown that when a competitive market and price forecasting are assumed the unit commitment problem can be solved by improved particle swarm optimization. The proposed method helps generation company to make a decision, how much power and reserve should be sold in markets and how to schedule generators in order to receive the maximum profit. The numerical results on the generation company with 10 units demonstrate the quick-speed convergence and higher accuracy of the proposed approach, so it provides a new effective method for solution of the PBUC problem in electricity market.

VII. References

[1] Sheble G.B., Fahd G.N. "Unit commitment literature synopsis," *IEEE Trans. on power systems*, vol.9, pp.128-135, Jan., 1994.

[2] K. S. Swarup, S. Yamashiro. "Unit commitment solution methodology using genetic algorithm,"*IEEE Trans. on power systems*, vol.17, pp.87-91, Jan.2002.

[3] Chuan-Ping Cheng, Chih-Wen Liu, Chun-Chang Liu."Unit commitment by Lagrangian relaxation and genetic algorithms,"*IEEE Trans. on power systems*, vol.15, pp.707-714, April 2000.

[4] Chung-Ching Su, Yuan-Yih Hsu. "Fuzzy dynamic programming: an application to unit commitment,"*IEEE Trans. on power systems*, vol.6, pp.1231~1237,July 1991.

[5] Eric H. Allien, Marija D. Ilic. "Reserve markets for power systems reliability," *IEEE Trans. on power systems*, vol.15, pp.228-233, Jan. 2000.

[6] H. Y. Yamin,S.M. Shahidehpour. "Unit commitment using a hybrid model between Lagrangian relaxation and genetic algorithm in competitive electricity markets,"*Electric Power System Research*, vol.68, pp.83-92, 2004.

[7] Pathom A., Hiroyuki, K., Eiichi, T. "A hybrid LR-EP for solving new profit-based UC problem under competitive environment," *IEEE Trans. on power systems*, vol.18, pp. 229-237,Jan. 2003.

[8] Kennedy J. and Eberhart R.,"Particle swarm optimization,"in Proceedings of IEEE Conference on Neural Networks, 1995,pp.1942-1948

[9] Kennedy J.,Eberhart R., "A discrete binary version of the particle swarm optimization algorithm," in Proc. of the 1997 conference on Systems, Man, and Cybernetics,1997, pp.4104-4109

VIII. Biographies

Yuan Xiaohui was born in Hubei province in People's Republic of China, on Dec. 18, 1971. He received PH.D degree from Huazhong University of Science & Technology in China in 2002.He works as a post-fellow researcher of the Department of Hydropower Engineering of Huazhong University of Science & Technology, Wuhan, China. His researchs are in the field of artificial intelligent with application to power system operation and electricity market.

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