An Improved Binary Particle Swarm Optimization for Unit Commitment Problem

Peng Li[1,3], *Senior Member*, *IEEE*, Peng Xi[1]
[1]School of Electrical and Electronic Engineering,
North China Electric Power University
Baoding 071003, China
[2]Shanxi Yuncheng Electric Power Supply Company
Yuncheng 044000, China

Liqiang Fei[1], Jiang Qian[2] and Jianjie Chen[2]
[3]Suzhou Institute of North China Electric Power University
Suzhou 215000, China
E-mail: ncepulp@gmail.com,xiruihan@126.com

Abstract—**This paper proposed a new approach combining priority list (PL) with binary particle swarm optimization (BPSO) to solve unit commitment (UC) problem. At first, PL method was used to determine the initial UC, and then the optimization window was determined according to the results, at last the BPSO method was adopted to solve the UC problem within the window. The window is to reduce the computing time and improve the optimization accuracy. In each iteration, the adjustment heuristic strategy was applied to revise the particle to meet the generators' constraints. This paper adopted Lambda-iteration method combining with dichotomy algorithm to solve the economic dispatch (ED) problem. The simulation results showed that the proposed method is indeed capable of obtaining higher quality solutions.**

Keywords-unit commitment; priority list; binary particle swarm optimization; heuristic adjustment

I. INTRODUCTION

The Unit Commitment (UC) can be defined as the scheduling of power production from generation units over a daily to weekly time horizon while respecting various generator constraints and system constraints. In solving the UC problem, generally two basic decisions are involved, namely, the "unit commitment" decision and the "economic dispatch" decision. The "unit commitment" decision involves the determination of the generating units to be running during each hour of the planning horizon, considering system capacity requirements, including the reserve, and the constraints on the start-up and shut-down of units. The "economic dispatch" decision involves the allocation of the system demand and spinning reserve capacity among the operating units during each specific hour of operation. The objective function includes costs associated with energy production and start-up and shut-down decisions, along with possible profits. The resulting problem is a large scale nonlinear optimization problem for which there is no exact solution technique.

Research efforts concentrated on efficient, suboptimal UC algorithms which can be applied to realistic power systems and have reasonable storage and computation time requirements. A literature survey on the unit commitment methods reveals that various numerical optimization techniques have been employed to approach the unit commitment problem.

This work was supported by National Natural Science Foundation of China (No. 50977029), Science and Technology Projects of Shanxi Electric Power Company Limited under State Grid Corporation of China, and the New Energy Foundation of North China Electric Power University, China (No. 200914002).

Specifically, there are traditional mathematical methods such as priority list (PL) [1,2] methods, dynamic programming (DP) [3], branch-and-bound (BB)[4] methods, mixed-integer programming (MIP)[5] and Lagrangian Relaxation (LR)[6,7] methods.

Recently, some methods based on meta-heuristics such as genetic algorithm (GA)[8,9], evolutionary programming (EP)[10], fuzzy logic (FL), artificial neural network (ANN), simulated annealing (SA) and swarm algorithms: particle swarm optimization (PSO) [11,12,13] and ant colony optimization (ACO) have also shown more promising results in term of computation time and cost minimization.

But, each of them has its own advantages and disadvantages.

Among these methods, PL method is simple and fast but the quality of the solution is not enough. PSO method is of better convergence and higher efficiency. This paper proposed a new approach combining priority list (PL) with binary particle swarm optimization (BPSO) to solve unit commitment (UC) problem. The results are compared each other and the effectiveness of the algorithms to solve the UC problem is discussed.

II. PROBLEM FORMULATION

The objective function of the UC problem is the minimization of the total production costs over the scheduling horizon. Therefore, the objective function is expressed as the sum of fuel and start-up costs of the generating units. Mathematically, the function is as follows:

$$\min E = \sum_{j=1}^{T}\sum_{i=1}^{Ng}[(u_{ij} f(P_{ij}^{g})) + S_{ij}u_{ij}(1-u_{i(j-1)})] \quad (1)$$

Subject to，

1) Power balance constraint

$$\sum_{i=1}^{N_g} u_{ij}P_i^g + \sum_{k=1}^{Nw} P_{kj}^{w} = P_D^j \quad (2)$$

2) Spinning reserve constraint

$$\sum_{i=1}^{N_g} u_{ij} P_i^{g\max} - P_D^j \geq R_j \quad (3)$$

3) Generation limit constraint

$$P_i^{g\min} \leq P_{ij}^g \leq P_i^{g\max} \quad (4)$$

4) Minimum up and down time constraints

$$\begin{cases} (X_{i,t-1}^{on} - T_i^{on})(u_i^{t-1} - u_i^t) \geq 0 \\ (X_{i,t-1}^{off} - T_i^{off})(u_i^t - u_i^{t-1}) \geq 0 \end{cases} \quad (5)$$

Where the notations used are as follows:

$f(P_{ij}^g)$ fuel cost function of the *i*th unit with generation output P_{ij}^g at the *j*th hour. Usually, it is a quadratic polynomial with coefficients a_i, b_i and c_i as follows:

$$f(P_{ij}^g) = a_i + b_i P_{ij}^g + c_i P_{ij}^{g2} \quad (6)$$

Ng number of generators;

T number of hours;

P_{ij}^g generation output of the *i*th unit at the *j*th hour;

S_{ij} start-up cost of the *i*th unit;

u_{ij} on/off status of the *i*th unit at the *j*th hour and $u_{ij} = 0$ when off, $u_{ij} = 1$ when on;

P_D^j load demand at the *j*th hour (set to 10% of);

R_j spinning reserve at the *j*th hour;

$P_i^{g\min}$ minimum generation limit of the *i*th unit;

$P_i^{g\max}$ maximum generation limit of the *i*th unit;

T_i^{on} minimum up-time of the *i*th unit;

T_i^{off} minimum down-time of the *i*th unit;

$X_{i,t-1}^{on}$ duration during which the *i*th unit is continuously on;

$X_{i,t-1}^{off}$ duration during which the *i*th unit is continuously off.

III. BINARY PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO)[14], first introduced by Kennedy and Eberhart, is one of the heuristic optimization algorithms which is derived from the social-psychological theory. The PSO technique has ever since turned out to be a competitor in the field of numerical optimization.

A. PSO

The position and velocity iteration formulas of stand PSO are as follows:

$$v_{i,d}^{k+1} = \omega v_{i,d}^k + c_1 \bullet rand1 \bullet (pbest_{i,d}^{k+1} - x_{i,d}^k) + c_2 \bullet rand2 \bullet (gbest_d^k - x_{i,d}^k); \quad (7)$$

$$x_{i,d}^{k+1} = x_{i,d}^k + v_{i,d}^{k+1} \quad (8)$$

where, $v_{i,d}^k$ is the velocity of individual i at iteration k, $v_d^{\min} \leq v_{i,d}^k \leq v_d^{\max}$, ω is the inertia weight factor, c_1 and c_2 are the acceleration constants, $rand1$ and $rand2$ are the uniform random number between 0 and 1, $x_{i,d}^k$ is the current position of individual i at iteration k, $gbest_i$ is the particle best of individual i and $gbest$ is the generation best of the group.

B. BPSO

The particle swarm works by adjusting trajectories through manipulation of each coordinate of a particle. However, many optimization problems are set in a space featuring discrete, qualitative distinctions between variables and between levels of variables. In the binary version of the PSO, the trajectories changes in the probability that a coordination will take on binary value (0 or 1). Therefore, the main difference between the original PSO and the BPSO is that equation (9) replace equation (8).

$$f\ (rand() < S(v_{i,d}^{k+1}))\ then\ x_{i,d}^{k+1} = 1;$$
$$else\ x_{i,d}^{k+1} = 0. \quad (9)$$

Where S(v) is a sigmoid limiting transformation function $(S(v) = 1/(1+e^{-v}))$,

and $rand()$ is a quasi-random number selected from a uniform distribution in [0.0,1.0]. In the discrete version, $V^{\max}$ is retained, that is $|v_{id}^{k+1}| < V^{\max}$, which simply limits the ultimate probability that bit x_{id} will take on a binary value. A smaller $V^{\max}$ will allow a higher mutation rate.

IV. PROPOSED PLBPSO METHOD

A. Priority List(PL) Method

PL methods mimic the scheduling practices followed by system operators. The units are committed in ascending order of the unit Average Full Load Cost so that the most economic base load units are committed first and the peaking units last in order to meet the load demand. PL methods are very fast but they are highly heuristic and give schedules with relatively high production costs.

B. PLBPSO Method

In this paper, we combine PL with BPSO to solve UC problem. At first, PL method was used to determine the initial

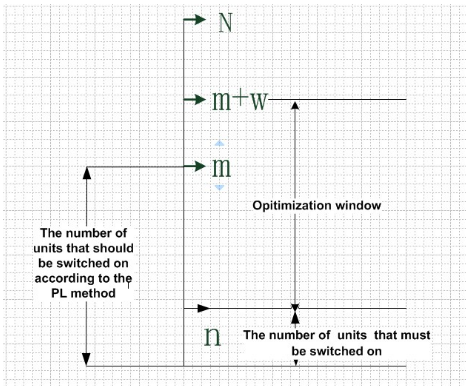

Figure 1. Optimization window

UC until the system load demand and spinning reserve are met. Then the optimization window was determined according to the results. At each dispatch moment, there will be m units assigned to be on. Then, according to the window, the m + w +1 to N generator units are set to shut down units. Suppose n is the number of the unit that must be switched on, then m+w-n is the width of optimization window. Fig.1 shows the optimization window.

C. Heuristic Adjustment Strategy

When BPSO was used to determine the generators' status (ON('1')/OFF('0')), because of the generators' and system's constraints such as the min-up(UP) and min-down(MD) time, the particle solution may be not feasible. Therefore, we need apply some heuristic adjustment strategy to repair the particle. The adjustment strategy is as follows:

1) determine the base-load units

The units that the operation cost is low can be on operate for 24 hours a day, the unit that the operation cost is high may be switched on at the peak periods and switched off at the valley periods. Set the units that could be operated for 24 hours continuously as the base-load units.

2) The adjustment to meet the reserve demand

When the unit commit plan was formed using the BPSO, at one dispatch moment, calculate the sum of the maximum of the generators that has been set switched on. If the value is smaller than the reserve demand of that moment., set the units which are off on operate according to the priority list from high to low until the reserve demand at that moment is satisfied. If the value is greater than the reserve demand of that moment, set the units which are on off *according to the priority list from low to high* until the reserve demand at that *moment is just satisfied.*

3) The adjustment to satisfy the Minimum Up and Down Time Constraints

Suppose the Minimum Up and Down Time is 2 hours. The adjustment strategy is as follows:

a) the adjustment of 101:

Change 101 into 111.

b) the adjustment of 010:

After step 'a', the state of the first units that after and before these 3 units is impossible for 1, that is 00100. Then calculate the number of consecutive 0s before and after 1, denoted by p,q. if q>2, then change 00100 into 00110; if q<3 and p>2, then change 00100 into 01100; if q<3 and p<3, change 00100 into 00111. After such adjustment, the unit commitment will satisfy he minimum up and down time constraints. If the original plan has met the constraint of load balancing, the new plan can still satisfy the reserving constraint.

D. Economic Load Dispatch

The UC problem can be considered as two linked optimization sub-problems, namely is the unit-scheduled problem, and the economic dispatch (ED) problem. After the unit commitment was calculated by the proposed PLBPSO method, use the classical Lambda-iteration method combining with dichotomy algorithm to solve the economic dispatch (ED) problem. The calculate time will be shorten greatly by the combination of Lambda-iteration method and dichotomy algorithm.

E. Elaborate Progress of PLBPSO for UC

Step 1: Input unit parameters, particle swarm parameters.

Step 2: Apply PL method to identify the UC that meet the power balance and spinning reserve constraints. Then determine the optimization window using the above method.

Step 3: Use BPSO method for optimizing within the window. If the particles can not meet the constraints, utilize the Heuristic adjustment method proposed by this paper to meet the constraints.

Step 4: Use Lambda-iteration method combing with dichotomy algorithm to solve the economic dispatch (ED) problem, then calculate the evaluation value of each individual. Modify the personal best (pg) and global best (gb).

Step 5 : If the number of the iteration is up to the number set before, go to next step; otherwise update the particle velocity and position, go back to Step3.

Step 6 : Output the best solution. Then stop.

V. SIMULATION RESULTS

The program was implemented in Matlab language and the simulation was carried out on a ten-generator system; the generators and demand data for this problem is from [9,15] . In implementing the proposed algorithms, some parameters must be determined in advance. In this paper the parameters were set through experiments as follows:

- Population Size =20 ; - Maximum Iterations=200 ;

- Dimension =Number of generators, N=10;

- Inertia Weight=1.0.

The spinning reserve was assumed to be 10% of the hourly demand. To calculate easily the transition cost of each feasible combination, the shut-down cost as been taken to be equal to 0 for every unit.

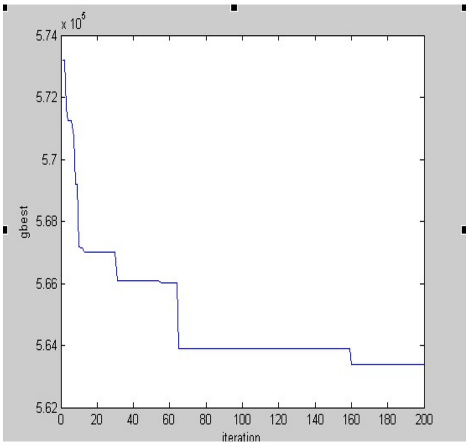

Figure.1 Convergence tendency of the evaluation value

Run the PLBPSO method 10 times. Fig.2 shows the convergence tendency of the best evaluation value in the population during PLBPSO processing. The best result is shown in Table I, the comparison of best result of each method is shown in Table II.

TABLE II. COMPARISON OF BEST RESULT OF EACH METHOD

Method	Cost of 10 units ($)
LR[9]	565,825
GA[9]	565,825
EP[10]	564,551
SA[16]	565,828
IPSO[17]	563,954
PL	564,340
BPSO	563,977
PLBPSO	563,390

TABLE I. COMMITMENT SCHEDULING FOR 10-UNIT SYSTEM OBTAINER BY PLBPSO

hour	Operation cost($)	Startup cost($)	State of generator	Generation Schedule(MW)									
				1	2	3	4	5	6	7	8	9	10
1	13,683	0	1100000000	455	245	0	0	0	0	0	0	0	0
2	14,555	0	1100000000	455	295	0	0	0	0	0	0	0	0
3	16,811	1,800	1100100000	455	370	0	0	25	0	0	0	0	0
4	18,599	0	1100100000	455	455	0	0	40.0706	0	0	0	0	0
5	20,020	1,120	1101100000	455	390.017	0	130	25	0	0	0	0	0
6	21,862	0	1101100000	455	455	0	130	60.074	0	0	0	0	0
7	23,261	1,100	1111100000	455	409.938	130	130	25	0	0	0	0	0
8	24,152	0	1111100000	455	455	130	130	30.068	0	0	0	0	0
9	26,591	340	1111110000	455	455	130	130	110.082	20	0	0	0	0
10	30,056	580	1111111100	455	455	130	130	162	32.911	25	10	0	0
11	31,917	60	1111111110	455	455	130	130	162	73.045	25	10	10	0
12	33,892	60	1111111111	455	455	130	130	162	80	25	43.065	10	10
13	30,056	0	1111111100	455	455	130	130	162	32.911	25	10	0	0
14	26,591	0	1111110000	455	455	130	130	110.082	20	0	0	0	0
15	24,152	0	1111100000	455	455	130	130	30.068	0	0	0	0	0
16	20,896	0	1101100000	455	440.034	0	130	25	0	0	0	0	0
17	20,020	0	1101100000	455	390.017	0	130	25	0	0	0	0	0
18	22,388	1,100	1111100000	455	360.065	130	130	25	0	0	0	0	0
19	24,152	0	1111100000	455	455	130	130	30.068	0	0	0	0	0
20	30,056	920	1111110000	455	455	130	130	162	32.912	0	0	0	0
21	26,591	0	1111110000	455	455	130	130	110.082	20	0	0	0	0
22	22,388	0	1111100000	455	360.065	130	130	25	0	0	0	0	0
23	17,684	0	1100100000	455	419.970	0	0	25	0	0	0	0	0
24	15,935	0	1100100000	455	319.937	0	0	25	0	0	0	0	0

VI. CONCLUSIONS

This paper proposes a new PLBPSO to solve the UC problem. The proposed method can generate better solutions than other methods.

The use of the optimization window is to reduce the computing time and improve the optimization accuracy. In each iteration, the heuristic adjustment strategy was applied to revise the particle to meet the generators' constraints. The simulation results showed that the proposed method is indeed capable of obtaining higher quality solutions.

ACKNOWLEDGMENT

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Limited under State Grid Corporation of China, and the New Energy Foundation of North China Electric Power University, China (No. 200914002).

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