Profit Based Unit Commitment Using Evolutionary Particle Swarm Optimization

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***Abstract*—The profit based unit commitment (PBUC) problem determines an optimal unit commitment schedule for a generation company (GENCO) participating in a deregulated environment with the aim of maximizing its profit. This is done using predicted prices of energy and other ancillary services including supply of reserve power. Several techniques have been proposed in literature to solve the optimization problem and this paper applies the evolutionary particle swarm optimization (EPSO) algorithm. Simulation results carried out in MATLAB software for a test GENCO with 10 thermal units shows that the EPSO algorithm provides better solutions and has better convergence characteristics than the classic PSO algorithm.**

I. Introduction

Over the last few decades the electric energy sub-sector has been undergoing significant changes. Probably the biggest change has been deregulation of many power systems especially in the developed world; though aspects of deregulation are also beginning to take root in developing nations. The main aim of deregulation is to create competition among Generation Companies (GENCOs) and hence provide different choices of generation options at lower prices to consumers [1], [2].

Unit Commitment has always been a significant task in power systems. However, the approach in the deregulated environment is significantly different form that in the regulated environment. Here, the GENCO is not the system operator hence, unlike the regulated market where the objective of the utility in unit commitment is the minimization of operating cost, in the deregulated environment the objective of the GENCO is the maximization of profit. This has led to what is now referred to as Profit Based Unit Commitment (PBUC) in deregulated markets [3]–[5]. From the GENCO's point of view, an optimal solution to the PBUC problem is very important because of the potential economic consequences. Reducing the fuel cost by as little as 0.5 percent can result in savings of millions of dollars per year for large GENCOs which would translate to significant gains in profit [3].

Various solution methodologies for solving the PBUC problem have been proposed in literature [6]–[9]. This paper proposes a solution methodology incorporating reserve payments as well as spot market energy prices. The proposed methodology is based on the EPSO technique [10]. The Lagrangian relaxation technique is used to simplify the PBUC problem and the EPSO algorithm plays the significant role of updating the Lagrange multipliers. The obtained optimal UC schedule satisfies all operational constraints including meeting bilaterally agreed energy supply commitments.

EPSO is preferred to the classic PSO algorithm because of its better performance. With classic PSO there is a challenge in the choice of the weight parameters at the beginning of the solution algorithm. However, the mutation and selection processes of the EPSO algorithm provides an aspect of parameter tuning resulting in better solutions and convergence characteristics [10] which is confirmed by the simulation results in this paper.

The rest of this paper is organized as follows: section II introduces the EPSO algorithm; section III outlines the PBUC problem formulation; section IV explains the proposed solution methodology; section V presents simulation results on a test IEEE system; while conclusions are given in section VI.

II. Evolutionary Particle Swarm Optimization

Evolutionary particle swarm optimization (EPSO) is an optimization algorithm based on a combination of the evolutionary programming (EP) and particle swarm optimization (PSO) concepts [10]. In simple terms, a population (swarm) of processing elements called particles, each of which representing a candidate solution forms the basis of computation in the EPSO algorithm. A possible solution to the existing optimization problem is represented by each particle in the swarm. A population of random solutions is used to initialize the EPSO algorithm and the optimal solution is searched by updating the solutions in each iteration.

Similar to the classic PSO algorithm, during an EPSO iteration, every particle moves towards its own personal best solution that it achieved so far ($pBest$), as well as towards the global best ($gBest$) solution which is best among the best solutions achieved so far by all particles present in the population. The EPSO algorithm works to handle the parameter tuning challenge of the classic PSO algorithm by progressively "mutating" the weight parameters with successive iterations. The basic structure of EPSO as originally explained in [10] carries out the following processes at each iteration:

- REPLICATION - each particle is replicated a number of times.
- MUTATION - each particle has its weights mutated.

- REPRODUCTION - each mutated particle generates an offspring according to the *particle movement rule*.
- EVALUATION - each offspring has its fitness evaluated.
- SELECTION - the best particles between the original set and the mutated set survive based on a stochastic tournament to form a new generation.

Usually, after a certain pre-set number of iterations (generations), the particle with the global best solution is stored as the optimal solution. Incorporation of the Darwinistic characteristics of mutation and selection allows the EPSO algorithm to take advantage of the faster convergence characteristics of Evolutionary Programming (EP) strategies.

III. PBUC Problem Formulation

The PBUC problem is formulated as a maximization of a GENCO's profit. Mathematically, we seek to determine a GENCO's optimal unit commitment schedule i.e. generation units turn ON - turn OFF and power output schedule based on predicted energy and reserve prices. In this paper, the GENCO's bilateral contract commitments are also considered. The objective function and the operational constraints are explained in the following subsections. The variables used in the equations are listed in Table I.

A. Objective Function

Profit (PF) is defined as the difference between revenue (RV) obtained from sale of energy and reserveand the total operating cost (TC) of the GENCO. Mathematically, the PBUC problem objective function is given as:

$$\text{Maximize} \qquad PF = RV - TC \tag{1}$$

1) GENCO Revenue: In (1), RV is given by:

$$RV = \sum_{h=1}^{H} \left(RVp^h + RVr^h \right) \tag{2}$$

Revenue from the energy market at a given hour RVp^h is calculated as:

$$RVp^h = \alpha_b^h P_b^h + \alpha_s^h \left(\sum_{i=1}^{N} P_i^h - P_b^h \right) + \kappa \left(\alpha_s^h - \alpha_b^h \right) P_b^h \tag{3}$$

The first term in (3) represents revenue from bilateral contracts, the second term represents revenue from the energy sold at the spot market, while the third term represents revenue from contracts of differences. Contracts of differences are usually included in bilateral contracts to compensate suppliers and consumers for differences between the bilaterally agreed prices and the prevailing market price [11].

Revenue from sale of reserve power at hour h is given by:

$$RVr^h = \alpha_r^h \sum_{i=1}^{N} \left(P_i^{max} - P_i^h \right) \tag{4}$$

In (4), it is assumed that both spinning and standing reserve are paid at the same rate. If the pricing is different, the equation could be split to have two terms accounting for each type of reserve.

TABLE I
NOMENCLATURE

h	hour index
i	generator index
j	EPSO particle index
k	iteration number index
r	EPSO replicated particle index
H	number of scheduling hours
J	number of EPSO particles
K	maximum number of EPSO algorithm generations
N	total number of generators
R	number of replications for an EPSO particle
PF	GENCO Profit
$RV,\ TC$	GENCO revenue and costs respectively
RVp^h	revenue from energy (MWh) sales at hour h
RVr^h	revenue from reserve capacity (MW) sales at hour h
FC_i^h	fuel cost of generator i at hour h
SC_i^h	start up cost of generator i at hour h
a_i, b_i, c_i	fuel cost curve constants for generator i
CSC_i	cold start-up cost of generator i
HSC_i	hot start-up cost of generator i
$CShr_i$	Number of hours after which generator i is considered cold
α_s^h	unit price for spot market energy sales at hour h
α_b^h	unit price for bilateral contracts energy sales at hour h
α_r^h	unit price for reserve capacity sales at hour h
κ	factor for contract of differences
P_b^h	scheduled power generation for bilateral contracts at hour h
P_i^h	power output from generator i at hour h
U_i^h	state of generator i at hour h
P_i^{min}, P_i^{max}	minimum and maximum outputs of generator i respectively
RU_i, RD_i	ramp up and ramp down limits of generator i respectively
MUT_i, MDT_i	minimum up time and minimum down time limits of generator i respectively
$\lambda_{j,k}^{h,r}$	Lagrange Multiplier for the r^{th} replica of particle j hour h and iteration k
$v_{j,k}^{h,r}$	velocity of the r^{th} replica of particle j for hour h and iteration k
$w_{j,k}^{0,r}, w_{j,k}^{1,r}, w_{j,k}^{2,r}$	weighting factors corresponding to the r^{th} replica of particle j at iteration k
$pBest_{j,k}$	personal best solution of particle j at iteration k
$gBest_k$	global best solution for all particles at iteration k
τ_λ	standard deviation of the random initial value of Lagrange multipliers
τ_g	standard deviation of the random disturbance of the value of $gBest$
τ_w	standard deviation of the random mutation of a weight parameter
p_{luck}	probability of the best offspring of a particle surviving after an iteration

2) GENCO Costs: In (1), the total costs TC is a sum of fuel costs(FC) and start up costs(SC) for all generators over the entire scheduling period given as:

$$TC = \sum_{h=1}^{H} \sum_{i=1}^{N} \left(FC_i^h + SC_i^h \right) \tag{5}$$

where

$$FC_i^h = a_i + b_i P_i^h + c_i \left(P_i^h\right)^2 \tag{6}$$

$$SC_i^h = \gamma_i \left(1 - U_i^{h-1}\right) U_i^h \tag{7}$$

where

$$\gamma_i = \begin{cases} CSC_i & \text{if } \sum_{t=h-CShr_i}^{h} U_i^t \geq CShr_i \\ HSC_i & \text{if } \sum_{t=h-CShr_i}^{h} U_i^t < CShr_i \end{cases} \tag{8}$$

B. Operational Constraints

The GENCO operational constraints are given as:

(a) Power balance for bilateral contracts

$$\sum_{i=1}^{N} P_i^h \geq P_b^h \qquad \forall h \tag{9}$$

(b) Generation limit constraints

$$U_i^h P_i^{min} \leq U_i^h P_i^h \leq U_i^h P_i^{max} \qquad \forall i, \forall h \tag{10}$$

(c) Generator ramp up constraints

$$P_i^h - P_i^{h-1} \leq RU_i \qquad \forall i, \forall h \tag{11}$$

(d) Generator ramp down constraints

$$P_i^{h-1} - P_i^h \leq RD_i \qquad \forall i, \forall h \tag{12}$$

(e) Generator minimum up time constraints

$$U_i^h = 1 \text{ if } U_i^t - U_i^{t-1} = 1, \quad \text{for } h = t, ..., t + MUT_i - 1 \tag{13}$$

(f) Generator minimum down time constraints

$$U_i^h = 0 \text{ if } U_i^{t-1} - U_i^t = 1, \quad \text{for } h = t, ..., t + MDT_i - 1 \tag{14}$$

Constraints (10)−(14) are similar to the traditional UC formulation [4]. However, constraint (9) dictates that the GENCO's total generation must be greater than its bilateral contracts commitments. This is in contrast with the traditional case where generation must equal total system demand and losses. Also, unlike the traditional UC formulation, there is no spinning reserve constraint as this is not the GENCO's responsibility. The GENCO only gets payments for supplying part of the reserve.

IV. PBUC Solution Methodology

The proposed solution methodology involves the solution of a relaxed form (Lagrangian) of the PBUC problem. The Lagrangian function is formed by relaxing constraint (9) into the objective function. Possible solutions to the relaxed problem are then initialized and the solutions are iteratively updated using a two-step process.

The first step involves solving the relaxed problem for each possible solution (sets of Lagrange multipliers). With the relaxation, optimal schedules of individual generation units are determined by breaking down the relaxed function into subproblems for each unit. A 2-state dynamic programming code is implemented to find an optimal UC schedule for each unit given a set of Lagrange multipliers. The second step involves updating of the possible solutions (particles) using the EPSO algorithm.

The subsequent subsections outline: (A) formation of the Lagrangian function; (B) initialization of possible solutions; (C) solution of the relaxed problem and (D) updating of Lagrange multipliers using EPSO.

A. Formation of Lagrangian Function

Constraint (9) – the power balance for bilateral contracts – is a unit coupling constraint meaning that a decision taken on one generator will affect decisions taken for the other generators. This makes it a difficult constraint to handle and it is therefore chosen to be relaxed using a set of Lagrange multipliers. Constraints (10) to (14) are not coupling constraints as they affect individual units independently.

A Lagrangian function $\mathcal{L}$ is formed as:

$$\mathcal{L} = RV - TC - \sum_{h=1}^{H} \lambda^h \left(P_b^h - \sum_{i=1}^{N} P_i^h \right) \tag{15}$$

The relaxed PBUC problem is then the maximization of $\mathcal{L}$ subject to constraints (10) to (14). For a given set of Lagrange multipliers: $\Lambda = \left\{\lambda^1, \lambda^2, \ldots, \lambda^H\right\}$, it is possible to determine a UC schedule that maximizes the Lagrangian function. The Lagrange multiplier set – and its corresponding UC schedule – that maximizes the Lagrangian function while meeting all operational constraints is then the optimal solution to the PBUC problem.

To maximize $\mathcal{L}$ with respect to P_i^h in (15):

$$\left.\frac{\partial \mathcal{L}}{\partial P_i^h}\right|_{P_i^{h*}} = \left(\alpha_s^h - \alpha_r^h\right) - \left(b_i + 2c_i P_i^{h*}\right) + \lambda^h = 0 \tag{16}$$

or

$$\lambda^h = \left(b_i + 2c_i P_i^{h*}\right) - \left(\alpha_s^h - \alpha_r^h\right) \tag{17}$$

The term $b_i + 2c_i P_i^{h*}$ in (17) is the unit marginal cost when generating P_i^{h*} MW. Hence, (17) states that, at the optimal generation level, the value of the Lagrange multiplier equals the difference between the marginal cost and the difference between the energy price and reserve price. This conclusion is used in section IV-B to determine a suitable initial values of the Lagrange multipliers.

Making P_i^{h*} the subject of the formula in (17):

$$P_i^{h*} = \frac{\alpha_s^h - \alpha_r^h + \lambda^h - b_i}{2c_i} \tag{18}$$

P_i^{h*} is the optimal output of unit i at hour h corresponding to Lagrange multiplier λ^h before considering the unit generation limits, minimum up time, minimum down time and ramp rate constraints. This conclusion is used in section IV-C in the procedure for solving the relaxed PBUC problem.

B. Initialization of Lagrange Multipliers

The solution space of the PBUC problem is large. For example, if the scheduling period is 24 hours, the solution will have 24 Lagrange multipliers hence the solution is defined in a 24-dimensional space. For such a large solution space, the chances of finding a good solution is reduced if the initial solution is not carefully chosen.

An initial "rough" solution is determined by solving the relaxed PBUC problem while disregarding the unit minimum up time, minimum down time and ramp rate constraints using the GENCO marginal cost curve as follows:

- For each hour, determine the marginal cost corresponding to the bilateral power commitment $MC(P_b^h)$ from the marginal cost curve.
- From (17), the initial value of the Lagrangian multiplier at hour h: $\lambda^{h,0}$ is given by:

$$\lambda^{h,0} = MC(P_b^h) - \left(\alpha_s^h - \alpha_r^h\right) \tag{19}$$

The Lagrange multipliers set: $\Lambda^0 = \left\{\lambda^{1,0}, \lambda^{2,0}, \ldots, \lambda^{H,0}\right\}$ is used as an initial solution to the PBUC problem.

The EPSO algorithm is initialized using random possible solutions (particles). Since the optimal solution when all constraints are considered will be close to $\Lambda^{h,0}$, the initial value of a Lagrange multiplier corresponding to particle k for hour h is given by:

$$\lambda_k^h = \max\left\{0, \lambda^{h,0} + \tau_\lambda N(0,1)\right\} \tag{20}$$

where $N(0,1)$ is a normally distributed random number with a mean of zero and variance of 1.

C. Solution of Relaxed Problem

The following procedure is used to solve the relaxed PBUC problem for a set of Lagrange multipliers: $\Lambda = \{\lambda^1, \lambda^2, \ldots, \lambda^H\}$.

Step 1: Get the price data for both the energy and reserve markets and values of Lagrange multipliers for each scheduling hour.
Step 2: set $i = 1$.
Step 3: Get the input data for unit i: P_i^{max}, P_i^{min} etc.
Step 4: Set $h = 1$.
Step 5: Calculate P_i^{h*} from (18).
Step 6: Check and correct for generator limit constraints:
if $P_i^{h*} > P_i^{max}$, set $P_i^{h*} = P_i^{max}$
if $P_i^{h*} < P_i^{min}$, set $P_i^{h*} = P_i^{min}$
Step 7: Check and correct for unit ramp up and ramp down constraints:
if $P_i^{h*} > P_i^{h-1} + RU_i$, set $P_i^{h*} = P_i^{h-1} + RU_i$
if $P_i^{h*} < P_i^{h-1} - RD_i$, set $P_i^{h*} = P_i^{h-1} - RD_i$
Step 8: Compute the unit profits corresponding to various state transitions considering the minimum up time and minimum down time constraints and pick the optimal (more profitable) options.
Step 9: set $h = h + 1$. If all hours have been covered, go to *Step 10* else, go back to *Step 5*.
Step 10: Pick the option that results in higher profits and return the corresponding UC schedule as optimal solution.
Step 11: set $i = i + 1$. If all generators have been covered, go to *Step 12* else, go back to *Step 3*.
Step 12: Return the optimal UC schedule.

D. Lagrange Multipliers Update Using Evolutionary Particle Swarm Optimization

The EPSO algorithm is used to update the Lagrange Multipliers to determine the set that provides the best results. In the solution of the PBUC problem, a particle represents a candidate solution to the problem i.e. a set of Lagrange Multipliers with one Lagrange multiplier for each hour of the scheduling horizon. Given a scheduling period of H hours, the j^{th} particle after k iterations $\Lambda_{j,k} = \{\lambda_{j,k}^1, \lambda_{j,k}^2, \lambda_{j,k}^3, \ldots, \lambda_{j,k}^H\}$ represents a position in the H-dimension solution space. The particle also has an associated velocity $V_{j,k} = \{v_{j,k}^1, v_{j,k}^2, v_{j,k}^3, \ldots, v_{j,k}^H\}$ which represents a direction in which the particle is moving in the solution space. The particle also has an associated set of weights $W_{j,k} = \{w_{j,k}^0, w_{j,k}^1, w_{j,k}^2\}$ which govern the direction of particle movement. $w_{j,k}^0$ governs the particle's inertia habit, $w_{j,k}^1$ governs its memory habit, while $w_{j,k}^2$ governs its cooperation habit [10].

The following procedure is used to solve the PBUC problem while updating particles (candidate solutions) using the EPSO algorithm:

Step 1: *Initialization*:
Initialize J particles $\Lambda_{j,0}\quad j = 1, 2, \ldots, J$. Each particle is a set of H Lagrange multipliers whereby the Lagrange multiplier corresponding to the j^{th} particle and hour h is obtained from (20). Store each initialized particle as $pBest_j$; the fitness of each initialized particle as the best fitness value for the corresponding particle; and the fittest particle of all initialized particles as initial $gBest$.
Step 2: set $k = 1$.
Step 3: *Replication*
Each particle is replicated R times i.e. R new particles are created as:

$$\Lambda_{j,k}^r = \Lambda_{j,k} \qquad r = 1, 2, \ldots R \tag{21}$$

Step 4: *Mutation*
Each particle has its weights mutated as:

$$w_{j,k+1}^{l,r} = w_{j,k}^{l,0} + \tau_{w,l} N(0,1) \quad l = 0,1,2; \quad r = 1, 2, \ldots R \tag{22}$$

Step 5: *Reproduction*
Each particle and its replicas generate an offspring according to the *particle movement rule*[1].

$$\Lambda_{j,k+1}^r = \Lambda_{j,k}^r + V_{j,k+1}^r \qquad r = 0, 1, 2, \ldots R \tag{23}$$

where

$$V_{j,k+1}^r = w_{j,k}^{0,r} \cdot V_{j,k+1}^r + w_{j,k}^{1,r} \cdot \left(pBest_{j,k} - \Lambda_{j,k}^r\right) + w_{j,k}^{2,r} \cdot \left(gBest_k^* - \Lambda_{j,k}^r\right) \tag{24}$$

[1] $\Lambda_{j,k}^0$ refers to the original particle while $\Lambda_{j,k}^1, \Lambda_{j,k}^2, \ldots$ refer to the replica particles

In (24), the $gBest_k$ value is disturbed to give $gBest_k^*$ using:

$$gBest_k^* = gBest_k + \tau_g N(0, 1) \quad (25)$$

Step 6: *Evaluation*
For each offspring, an optimal UC schedule is obtained by solving the relaxed PBUC problem as described by the procedure in section IV-C. The obtained UC schedule is used to calculate the offspring's fitness.
Step 7: *Updating pBest and gBest*
The fitness value of each offspring is used to update the $pBest_{j,k}$ and $gBest_k$ values.
Step 8: *Selection*
For each set of offspring, one is chosen to survive to the next generation through a stochastic tournament. The stochastic tournament is carried out as follows:

- The best particle between the offspring of each particle is determined.
- This particle survives to the next generation with a probability p_{luck} while the other particles survive with a probability $(1 - p_{luck})/r$.
- If p_{luck} is set to 100% then the best particle will always be chosen (pure *elitism* selection) while if p_{luck} is set to 0%, there will pure random selection.

Step 9: *Convergence test*
$k = k + 1$. If $k = K$ go to *Step 10*. Else go to *Step 3*.
Step 10: Store $gBest_K$ and its corresponding UC schedule as the optimal solution and STOP.

V. Simulation Results

A. Test System

The proposed methodology is implemented in MATLAB and tested for a GENCO with 10 thermal units whose data is shown in Table II. The data is adapted from the IEEE 118-bus test system which has 54 thermal units. Other unit data such as ramp rate limits and minimum up and down times can be found from http://motor.ece.iit.edu/data/ PBUCData.pdf. The total installed capacity for the GENCO is 830 MW, about 10% of the system installed capacity of 8270 MW. In this case, because of the size of the GENCO it can be assumed to be a price taker (negligible market power) and hence it can be assumed that there is no relationship between its power output and the electricity market price.

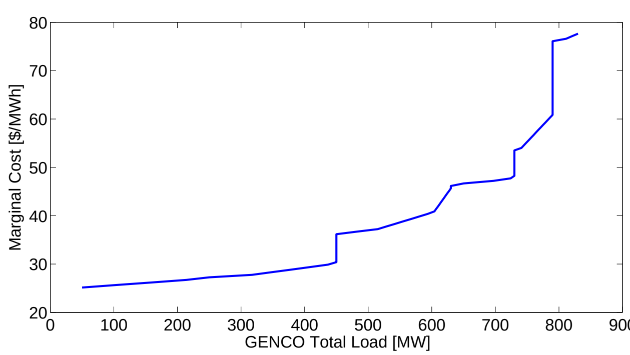

Fig. 1. GENCO Marginal cost curve

TABLE II
GENERATING UNITS DATA

Unit No.	P_i^{min} [MW]	P_i^{max} [MW]	P_i^0 [MW]	a [$]	b [$/MW]	c [$/MW^2]
1	8	20	0	35.90	75.39	0.05660
2	8	20	0	35.90	75.39	0.05660
3	5	30	0	63.34	52.49	0.13932
4	5	30	0	63.34	52.49	0.13932
5	20	50	0	117.62	45.88	0.01954
6	25	50	0	117.62	45.88	0.01954
7	30	80	40	148.66	30.94	0.09184
8	25	100	100	20.30	35.64	0.02560
9	50	200	100	78.00	26.58	0.00880
10	50	250	250	56.00	24.66	0.00480

TABLE III
ENERGY AND RESERVE PRICE DATA

Hour	Energy Price [$/MWh]	Reserve Price [$/MWh]	Hour	Energy Price [$/MWh]	Reserve Price [$/MWh]
1	29.23	2.00	13	57.01	2.77
2	26.40	1.70	14	54.42	2.87
3	22.47	1.27	15	63.12	2.92
4	21.07	1.12	16	65.59	3.32
5	23.16	1.35	17	67.24	3.23
6	30.86	2.18	18	63.87	2.97
7	31.56	2.17	19	55.61	2.96
8	47.39	2.34	20	52.55	2.73
9	49.70	2.51	21	47.55	2.35
10	52.10	2.69	22	39.69	1.76
11	55.35	2.94	23	37.00	1.57
12	55.50	2.95	24	30.51	1.16

TABLE IV
BILATERAL MARKET DATA

Hour	Bilateral Load [MW]	Bilateral Price [$/MWh]	Hour	Bilateral Load [MW]	Bilateral Price [$/MWh]
1	397	32.09	13	422	32.57
2	387	31.89	14	412	32.37
3	371	31.58	15	417	32.47
4	360	31.37	16	422	32.57
5	347	31.12	17	435	32.82
6	380	31.75	18	445	33.21
7	397	32.08	19	457	39.91
8	417	32.47	20	467	40.10
9	427	32.66	21	472	40.19
10	442	33.08	22	447	33.30
11	445	33.21	23	440	33.00
12	432	32.76	24	427	32.66

Fig. 1 shows the GENCO's marginal cost curve obtained from the unit characteristics of Table II. The marginal cost curve is used to determine the initial values of the Lagrange multipliers as explained in Section IV-B. The hourly price of energy and reserve is shown in Table III. It is assumed that reserve price is the same for both standing and spinning reserve. The hourly bilateral market commitment and price is shown

TABLE V
COMPARISON OF SOLUTION QUALITY OBTAINED BY PSO AND EPSO

Algorithm	Best Solution	Average Solution	Worst Solution
PSO	$178,069	$177,591	$172,685
EPSO	$178,911	$178,317	$177,408

in Table IV. The hourly bilateral market price is assumed to be 10% higher than the marginal cost corresponding to the bilaterally committed load as can be read from Fig.1.

B. Comparison of Solution Quality

The PBUC problem was solved using EPSO for the GENCO described in Section V-A. For the purpose of solution quality and convergence characteristics comparison, an equivalent methodology based on the classic PSO algorithm [12] was also tested. Both algorithms were run thirty times. In each case, the initial weights were randomly generated from uniform distributions. w_j^0 was drawn from the range [0 1], while both w_j^1 and w_j^2 were drawn from the range [0 2]. In each trial the same values of the weights were used for both the EPSO and PSO algorithms. The other EPSO parameters are set as: $J = 20$, $K = 500$, $R = 1$, $p_{luck} = 0.8$, $\tau_\lambda = 1$, $\tau_w = 0.5$, and $\tau_g = 0.05$. For both algorithms, the best solution, average solution, and worst solutions were determined and are reported in Table V. It is clearly seen that the proposed EPSO algorithm produces better solutions than the classic PSO algorithm in terms of the final value of the GENCO profit.

The GENCO's total committed generation from the best run of the EPSO and PSO algorithms are shown in Fig. 2. The slight differences in the two curves result in the differences in the values of profit shown in Table V.

C. Comparison of Convergence Characteristics

The convergence characteristics of the average value of the objective function at each iteration is shown in Fig. 3 It is seen that the proposed EPSO algorithm converges faster and generally to a higher value of profit than the PSO algorithm. On average, it takes about less than 6 iterations for the EPSO algorithm to reach the average final objective function value reached by the PSO algorithm. The better performance of the EPSO algorithm confirmed by Table V and Fig. 3 is due to the inherent parameter tuning characteristic due to the mutation step of the algorithm.

VI. CONCLUSION

A solution methodology based on the Evolutionary particle swarm optimization technique is proposed to solve the profit based unit commitment problem for GENCOs in deregulated markets. The problem has been formulated including a constraint setting the minimum GENCO output at a given hour as the bilaterally committed generation for the hour. An implementation for a GENCO with 10 thermal units shows that the proposed methodology has a better performance than the classic PSO algorithm both in terms of solution quality and convergence characteristics.

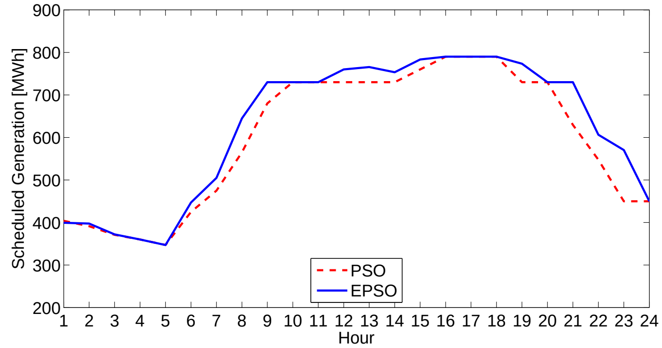

Fig. 2. Comparison of best generation schedule produced by the EPSO and PSO algorithms

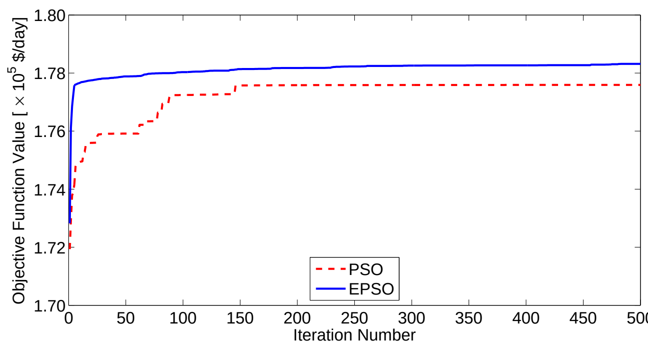

Fig. 3. Comparison of PSO and EPSO convergence characteristics

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