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An Intelligent Computational Algorithm for Optimal Self Scheduling of GENCOs to Improve The Profit in a Day-ahead Energy and Reserve Market

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Abstract— This paper presents an effective methodology for self scheduling of thermal generators to improve the profit of generation companies (GENCOs) in a day-ahead joint energy and reserve market. A recently projected Exchange Market Algorithm (EMA) is proposed to solve self scheduling problem. EMA is a powerful tool and having two dominant absorbing operators to pulling the solutions toward optimality and two smart searching operators for extract optimum point in optimization problem. Therefore, the proposed approach provides capability to determine global optimal solution for self scheduling problem.

The problem modelled in the form of bi-objective optimization framework to simultaneously maximize the profit of GENCOs and reduce emission quantity taking into account reserve power generation.. The thermal generators emit the greenhouse gases into the atmosphere, which is answerable for change of climate and global warming in our environment. Sufficient spinning reserve is one of the major factors for reliable operation and profit maximization of power suppliers. So the problem is carefully coined with a view to maximize the profit of GENCOs by considering reserve power generation and added in the objective function. Also generated reserve power is sold in the reserve market. Numerical example with IEEE 39 bus (10 units with 24 hour) test system is considered to evaluate the performance of the proposed EMA. From the simulation results, it is found that the EMA based approach is able to afford the better solutions in terms of fuel cost, revenue, profit and emission with lesser computational effort.

Keywords— Deregulation, Self scheduling of GENCOs, Energy and Reserve generation, Profit maximization, Reduction of Emission, Exchange market algorithm.

I. INTRODUCTION

The global deregulation of power system is introduced competition among the power producers. It improves the efficiency and reliability of power generation at cheaper cost [1]. Better opportunities of financial resources are created in the energy market and many power companies are growing by their proper objectives, roles and utilities [2]. It becomes possible for independent power producers to maximize generation company profit and to participate in the electricity market [3].The generation company adopts Unit Commitment for maximizing their own profit instead of minimizing the total generation cost of the centralized power system. This problem is referred as Profit Based Unit Commitment (PBUC) problem. Profit Based Unit Commitment is defined as a method which schedules their generators economically based on forecasted information such as spot price, reserve price, demand and unit data with an objective to maximize the GENCOs profit. So, the solution methodology of PBUC problem seems to be complex than traditional UC problem. The PBUC problem is divided into two sub problems [3-4]. The first sub-problem is the determination of status of the generating units and second sub-problem is the determination of output powers of committed units.

One of the main contributions to the emission of greenhouse gases into the atmosphere, which is thought to be responsible for climate change on our environment, is through the use of fossil-fuelled power plants.

The major part of the work pertaining to emission limitation have been concentrated on the Economic Dispatch problem [84-88] which decides the power contribution of each thermal unit, but not deciding on which unit required to be committed for generation at that particular time period. The need for better emission limitation by proper tuning of UC of generating units has been brought out.

The researches have been proposed various mathematical and soft computing techniques. The mathematical are Lagrangian relaxation [7], Mixed-integer programming [8], Muller method [9, 10] and Tabu search [11] etc, were widely used to solve the PBUC problem. The classical methods involve huge computational time and suffer from convergence and always get stuck into a local optimum to obtain the solution because of its complex dimensionality with large number of generating units.

In order to prevail over these problems, many soft computing techniques such as Genetic algorithm [12], Memetic algorithm [13] , PSO [14], PPSO [15], Nodal ACO [16], Bacterial Foraging [17], Parallel ABC [18], Binary fireworks [19], Binary fish swarm [20] and Hybrid methods [21-23] have also been implemented for the solution of the PBUC problem.

Genetic algorithm [12] based solution for PBUC problem is proposed by Georgilakis P. S et al. The method has been applied to 10, 100 and 120 units 24 hour test system and the results show that the GA constantly best performs the LR based PBUC method for system with more than 60 units. D. K. dimitroulas et al. [13] Developed Memetic algorithm for PBUC. Here, ramp up and ramp down constraints are considered and two-level tournament selection mechanism are employed to minimize the computational time. Jacob Raglend , C et al. [14] solving the same problem using various PSO algorithms such as Chaotic PSO (CPSO), New PSO (NPSO) and Dispersed PSO (DPSO) and spinning reserve, non-spinning reserve, and system constraints are considered. This approach has been tested on 6 units 12 hour (EEE-30 bus system) test system.

Parallel PSO, Nodal ACO and parallel ABC was developed by Christopher Colombus et al. [15-17] for solving the PBUC problem in workstation cluster. The proposed approach uses a cluster of computers performing parallel operations in a distributed environment for obtaining the best solution. The time complexity and the solution quality with respect to the number of processors in the cluster are thoroughly tested. Binary coded fireworks [19] algorithm was proposed by Srikanth Reddy. K et al. The GENCO and IPP has the freedom to schedule its generators in one or more market through mimicking spectacular display of glorious fireworks explosion in sky. This approach tested on thermal unit system for different market scenarios namely with and without reserve market. Solutions display the pre-eminence of the fireworks algorithm for solving PBUC and compared to some other benchmark techniques in terms of fuel cost , profit and number of iterations.

A binary fish swarm algorithm (BFSA) and dynamic economic dispatch (DED) method was used to solve PBUC problem [20] taking into account power and reserve generations simultaneously in a day-ahead competitive electricity markets. BFSA is used to decide the unit commitment schedule and optimum economic dispatch is computed by DED method subjected to unit generation limits because of ramp rate constraints over the complete scheduled time horizon. The results obtained for PBUC problem with BFSA method have been compared with existing methods. Hybrid LR-EP based algorithm was suggested by Pathom Attaviriyanupap et al. [22]. The PBUC explored for scheduling both power and reserve generation at the same time horizon. However the allocation of reserve power is based on reserve value of probability. An EP algorithm is developed for the proper updating of LR multiplier. This problem also analyzed by Asokan and Ashok Kumar [23] using LR combined with ABC algorithm. The proposed methodology provides better solutions compared with existing methods. Here the multiplier is updated by proper tuning of ABC algorithm.

Emissions controlled PBUC are analysed by various intelligent approaches are listed in the references [25-30]. A swarm intelligence algorithm is proposed in reference [25] and obtains the compromised solutions. The binary PSO is applied to get the committed units schedule and real-valued PSO is adopted to decipher the sub problem of ED in the PBUC. J. P. S. Catalão et al [26, 27] solve the problem considering not only the economic viewpoint, but also the environmental viewpoint. It consider as a bi-objective optimization technique to touch the problem with conflicting profit and emission functions. The quality of the proposed MO approach tested on standard IEEE 30-bus test system.

The CO_2 emission reduction policy is developed for the thermal units scheduling problem in the competitive energy market by Lixin Tang and Ping Che [28]. Here, variable penalty factor is conceded and to apply a different penalty mode according to the range of the emissions amount. T. Venkatesan *et al* [29] solve emission controlled PBUC using shuffled Frog Leaping (SFLA) algorithm. The problem consider as a bi-objective optimization function to maximize GENCOs profit and minimizing the emission quantity. The SFLA tested on IEEE 39 bus test system and results are displayed. The results includes profit and emission for Traditional UC and PBUC. The same problem analysed by Asokan and Ashokkumar [30] using Modified Pre –Prepared power Demand (MPPD) Table with Artificial Bee Colony (ABC) algorithm. The proposed hybrid approach facilitated by emission minimization is believed to reduce the global warming and paves the way to enhance the profit of power producers.

In this article, an intelligent computational algorithm based optimal power generation scheduling of thermal plants is obtained to improve the profit of GENCOs in a day-ahead energy and reserve market. This problem considers as a bi-objective optimization function and solved by Exchange

Market algorithm. The EMA approach effectively optimizes the thermal variables and determines the best solutions of power generation, reserve allocation, fuel cost, revenue, profit and emission quantity of GENCOs. Finally, the simulation results are compared with other available methods.

II. PROB;EM FORMULATON

A. Objective function

The objective is to determine the optimal scheduling of thermal generators for maximizing the profit and minimize the total emission of Generation Companies (GENCOs) subject to the standard system constraints. The term profit is defined as the difference between revenue obtained from the sale of energy with market price and the total operating cost of the generating company.

The PBUC can be mathematically represented by equations (1 - 3).

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

$$RV = \sum_{i=1}^{N}\sum_{t=1}^{T}(P_{it}SP_t)X_{it} + r\sum_{i=1}^{N}\sum_{t=1}^{T}RP_tR_{it}X_{it} \tag{2}$$

$$TC = (1-r)\sum_{i=1}^{N}\sum_{i=1}^{T}F(P_{it}).X_{it} + r\sum_{i=1}^{N}\sum_{t=1}^{T}F(RP_tR_{it})X_{it} + ST_t.X_{it} + SD_t.X_{it} \tag{3}$$

The total operating cost, over the entire scheduling period is the sum of production cost and start-up/shutdown cost for all the units. The shutdown cost is assumed to be equal to zero for all the units. The production cost of the committed units is given by the quadratic equation (4).

$$Min.F_{it}(P_{it}) = a_i + b_iP_{it} + c_iP_{it}^2 \tag{4}$$

The Emission limitation is the most important optimization function in the electrical power system design, operation and scheduling of thermal power plants. A great deal of effort goes in the control of for emission over environmental pollution caused by the power plants. Thus the problem of emission of power plants and its influence on the environment is analyzed. Hence the emission function is incorporated in the objective function and it is formulated as in equation (5).

$$Emission(EM) = \min\sum_{t=1}^{T}\ \sum_{i=1}^{N}E(P_{it})X_{it} \tag{5}$$

Where

$$E(P_{it}) = \alpha_i + \beta_iP_{it} + \gamma_iP_{it}^2 \tag{6}$$

B. System and Unit Constraints

The power balance, spinning reserve, generator and reserve power limits, minimum ON/OFF time, and emission constraints are considered to solve the PBUC problem with emission limitations.

1. Power balance constraint

The system power balance constraint is the most important factor in the PBUC problem. The generated power from all the committed units envisages to be less than or equal to the system load demand. Hence, the equation 6 becomes

$$\sum_{i=1}^{N}P_{it}X_{it} \le P_{D\,t} \tag{7}$$

2. Spinning reserve constraint

The sum of the reserve power of committed thermal units during the planning period augurs to be less than or equal to total spinning reserve of the power plants and is mathematically defined as in equation (8).

$$\sum_{i=1}^{N}R_{it}\ X_{it} \le SR_t \tag{8}$$

The power balance and spinning reserve constraints are different from traditional UC problem because GENCO can now select to produce the demand and reserve less than the forecasted level if acquires a greater profit.

3. Generator and Reserve power limits constraint

The generation limits represent the minimum loading limit below which it is not economical to load the unit, and the maximum loading limit above which the unit is devoid of being loaded. Similarly, the sum of power and reserve power generation of each unit requires to be less than or equal to the maximum generation of that plant, which is represented as in equations (9 – 11).

$$P_{i\min} \le P_i \le P_{i\max} \tag{9}$$

$$0 \le R_i \le P_{i\max} - P_{i\min} \qquad 1 \le i \le N \tag{10}$$

$$P_i + R_i \le P_{i\max} \qquad 1 \le i \le N \tag{11}$$

4. Minimum up/down time constraints

Once the unit is running, it is not to be turned off immediately. Once the unit is de-committed, there is a minimum time before it can be recommitted. These constraints can be represented as in equations (12) and (6.13)

$$Ton_i \ge Tup_i \tag{12}$$

$$Toff_i \ge Tdown_i \tag{13}$$

5. Emission constraint

The sum of emission of all committed thermal units during the planning period echoes to be less than or equal to the total emission level, which is given by equation (14)

$$\sum_{t=1}^{T} \sum_{i=1}^{N} E(P_{it}) X_{it} \leq EM_t \tag{14}$$

III. SOLUTION METHODOLOGY

A. Exchange market algorithm

The inspiration toward the enlargement of EMA is from the behaviour of stock market, where in the shareholders trade variety of shares in the virtual stock market This algorithm is developed by Ghorbani and Babaei in the year 2014 and explain their work in [32]. It is a meta-heuristic approach for solving optimization problems. Also has two searcher operators as well as two absorbent operators. So, this algorithm simultaneously searches around the optimum point and in a vast range.

In EMA, each member is one of the answers. In the proposed algorithm there exists specific number of shares (in solving the PBUC problem the number of shares is the number of GENCOs), each member intelligently tries to buy a number of them (in the PBUC problem are the power output of each generating units), and intelligently performs to gain the maximum possible profit (in the PBUC problem, profits can be achieved by maximization GENCOs profit) at the end of each period by calculating the validity of his own total shares.

It is assumed that there exist two major market modes. In the first mode, the market condition is normal and faces with no considerable oscillation and the shareholders try to gain the maximum profit using the experiments of the successful members without performing any non-market risks (searching around the optimum point). In the second mode, the market experiences different oscillations and the shareholders try to perform some intelligent risks identifying the conditions to use the situation maximally to increase their assets (finding out the unknown points). In other words, each iteration of the EMA, the fitness of the function is evaluated twice. In this algorithm, the shareholders are classified into three groups under any market condition. Here, group means the primary, middle, and the end members of the shareholder population [32-36].

B. The exchange market in balanced condition

In this section, the market is balanced and there exist no oscillation. The stockholders are trying to search for the optimum points as follows: without taking non-market risks, using experiences of elite stockholders, and close consideration of the existing situations. In this section, each individual is ranked based on the numbers of each type of shares s/he holds and the fitness function.

Shareholders with high ranks

This group's members lead the stock market and preserve their ranking, they do not change their shares and do not undergo the trade risk. The individual of the group are the elite stockholders, or the best solutions for the problems which are necessary to say intact and unchanged.

Shareholders with mean ranks

This group of shareholders comprises of 20-50 percent of the stock market. The members of this group use the successful experiences of elite stockholders. They tend to take the least possible risk in changing their shares. They cleverly and consciously utilize the different of the values of the G1's share. In this section, a comparison is done between the shares of two shareholders. As mentioned earlier, the members of the group change the number of their shares based on the equ. (14) to achieve further profits.

$$pop_j^{group(2)} = r \times pop_{1,i}^{group(1)} + (1 - r) \times pop_{2,i}^{group(1)} \tag{15}$$

$i=1,2,3,\ldots..n_i$ and $j=1,2,3,\ldots.,n_j$

where n_i is the nth individual of the first group, n_j is the nth individual of the second group and r is a random number in interval [0,1]. $pop_{1,i}^{group(1)}$ and $pop_{2,i}^{group(1)}$ are the members of the first group and $pop_j^{group(2)}$ is the jth individual of the second group.

Shareholders with low ranks

This group of individual are the end- placed ranking shareholders. The behavioral characteristics of this group are as follows: their risk is high compared to the G2; they make use of small changes and differences of G1's shares; unlike second group individual, they utilize the differences of hare values of the first group as well as their share values differences compared to the first group individuals and change their shares. In order to earn more profits, the members of this group would change the number of their shares based on equ.(16);

$$Sk = 2 \times r_1 \times \left(pop_{i,1}^{group(1)} - pop_k^{group(3)}\right) + 2 \times r2 \times \left(pop_{i,2}^{group(1)} - pop_k^{group(3)}\right) \tag{16}$$

$$pop_k^{group(3)},new = pop_k^{group(3)} + 0.8 \times Sk$$

$$k = 1,2,3, \ldots., nk \tag{17}$$

Where r_1 and r_2 are random numbers in interval [0,1] and n_k is the nth member of the third group. $pop_k^{group(3)}$ is the kth member and S_k is the share variations of the kth member of the third group.

c. The exchange market in oscillated condition

In this section, having assessed the shareholders and ranked them based on their fitness values, the shareholders would start trading their shares [1}. With regard to their fitness, shareholders are categorized into 3 separate groups:

Shareholders with high ranks

This part of the population includes the elite stockholders or the individuals who are the best solution to the problem. This group leads the stock market and preserves their rank; they do not modify their shares and do not take any trading risks. This group consists of 10-30 percent of the population.

Shareholders with mean ranks

In this section the sum of the shares held by individuals tends to be constant and only some each type of shares increase and some decrease such that the sum remains constant. At first, the number of shares held by each individual increases based on the following equation:

$$\Delta n_{t1} = n_{t1} - \delta + (2 \times r \times \mu \times \eta_1) \tag{18}$$

$$\mu = \left(\frac{tpop}{npop}\right) \tag{19}$$

$$n_{t1} = \sum_{y=1}^{n} |Sty| \qquad y = 1,2,3,\dots,n \tag{20}$$

$$\eta_1 = n_{c1} \, x \, g_1 \tag{21}$$

$$g_1^k = g_1, \max - \frac{g_{1,max} - g_{1,max}}{iter_{max}} \times k \tag{22}$$

Where Δn_{t1} is the amount of shares should be added randomly to some shares, n_{t1} is total shares of *t*th member before applying share changes. S_{ty} is the shares of the rth member, δ is the information of exchange market. R is a random number in interval [0,1]. η_1 is risk level related to each member of the second group, t_{pop} is the number of the *t*th member in exchange market, μ is a constant coefficient for each member and g_1 is the common market risk amount that decreases with the increase in iteration number .$iter_{max}$ is the last iteration number and k is the number of program iteration. $G_{1,max}$ and $g_{1,min}$ indicate the maximum and minimum values of risk in market, respectively.

In the second part of this section, it is required that each individual sells some of his/her shares randomly being equal to the number s/he has purchased in a way that the sum of each individual's shares remain constant. tn this section, It is essential that each individual reduces the number of his/her shares in Δn_{t2} of each individual equals by;

$$\Delta n_{t2} = n_{t2} - \delta \tag{23}$$

Where Δn_{t2} is the amount of shares are to be decreased randomly from some shares and n_{t2} is the sum share amount of *r*th member after applying the share variations.

Shareholders with low ranks

The risk percentage of individuals in this group is variable. With reduction of their fitness, this risk increases. In this section, unlike G2, the sum of the individual's number of shares would change after each trade. In other words, in each section, the shareholders of this group change some of their shares based on the following equation:

$$\Delta n_{t3} = (4 \times r_s \times \mu \, x \, \eta_2) \tag{24}$$

$$R_s = (0.52 - rand) \tag{25}$$

$$\eta_2 = n_{t1} \times g_2 \tag{26}$$

$$g_1^k = g_2, \max - \frac{g_{2,max} - g_{2,max}}{iter_{max}} \times k \tag{27}$$

Where Δn_{t3} is the share amount are to be randomly added to the shares of each member, r_s is a random number in [-0.5 0.5] and η_2 is the risk coefficient related to each member of the third group. G_2 is the variable risk of the market in the third group and μ is the risk increase coefficient which forces lower ranked shareholders from fitness function viewpoint to perform more risk in comparison with successes competitors to increase their finance. G_2 is the variable risk coefficient of the market and determines what percentage of shares should be changed by shareholders.

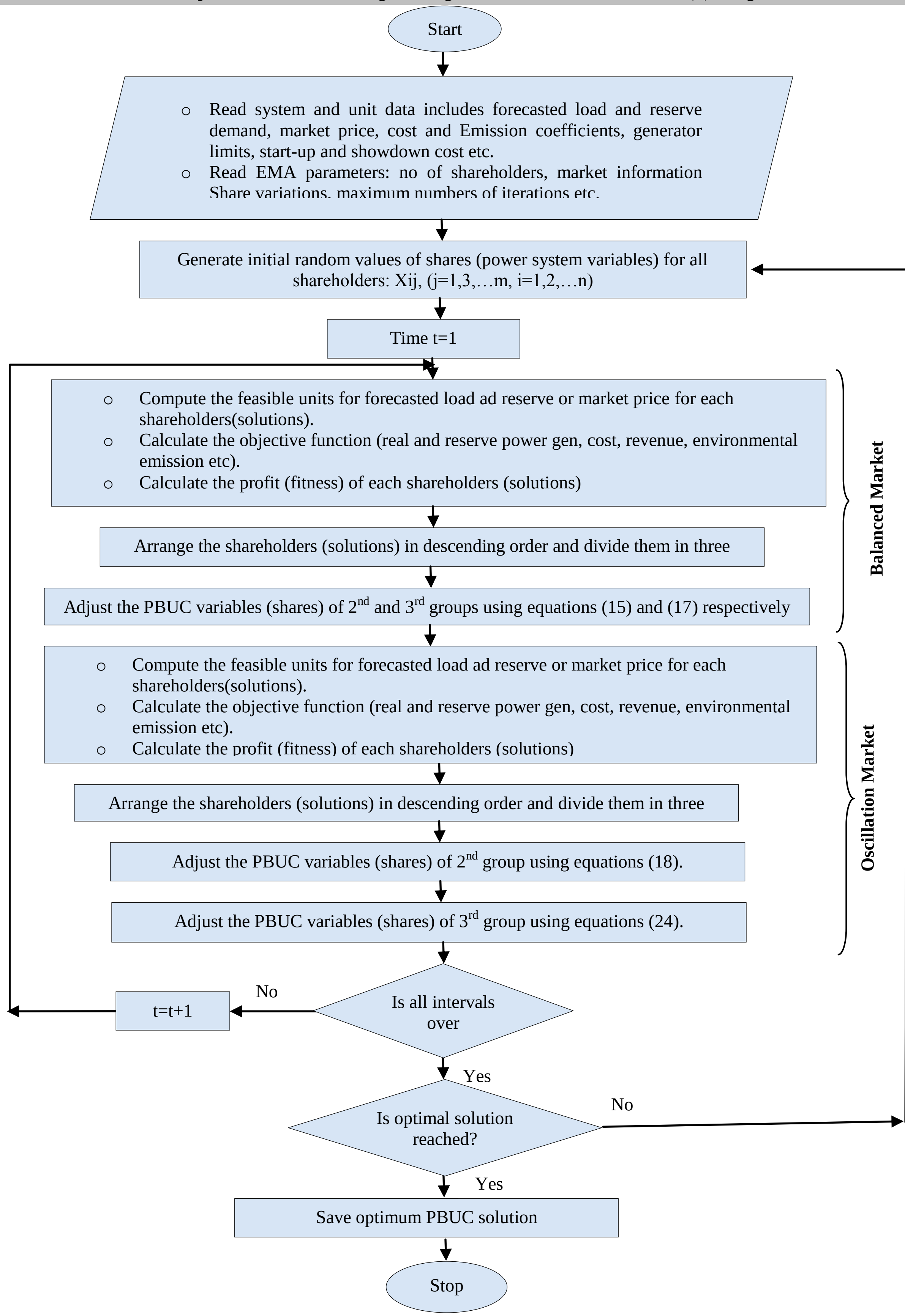

Figure 1. Flow diagram of PBUC considering spinning reserve and emission limitations by proposed method

D. Implementation of EMA for Emission constrained PBUC

The spinning reserve and emission constrained PBUC problem optimization is accomplished using the EMA by taking the following steps:

1. Read system and unit data includes forecasted load and reserve demand, market price, cost and Emission coefficients, generator limits, start-up and showdown cost etc.
2. Read EMA parameters: such as no of shareholders, market information Share variations, maximum numbers of iterations etc.
3. Generate initial random values of shares (power system variables) for all shareholders: Xij, (j=1,3,…m, i=1,2,…n).

Balanced Market

4. Compute the feasible units for forecasted load ad reserve or market price for each shareholders.
5. Calculate the objective function (real and reserve power gen, cost, revenue, environmental emission etc).
6. Calculate the profit (fitness) of each shareholders (solutions).
7. Arrange the shareholders (solutions) in descending order and divide them in three.
8. Adjust the PBUC variables (shares) of 2^{nd} and 3^{rd} groups using equations (15) and (17) respectively.

Oscillation market

9. Compute the feasible units for forecasted load ad reserve or market price for each shareholders.
10. Calculate the objective function (real and reserve power gen, cost, revenue, environmental emission etc).
11. Calculate the profit (fitness) of each shareholders (solutions)
12. Arrange the shareholders (solutions) in descending order and divide them in three
13. Adjust the PBUC variables (shares) of 2^{nd} group using equations (18).
14. Adjust the PBUC variables (shares) of 3^{rd} group using equations (24).
15. Check the time interval for 24 hours. If satisfied go to next step otherwise go to step 4.
16. Evaluate fitness values of objective functions (maximum profit and minimum emission level) of the PBUC problem.
17. Verify whether optimal solution is reached. If all constraints are satisfied go to next step otherwise go to step 3.
18. Save the best simulation results and stop.

In these steps, the market oscillation condition is finished and the program starts to operate in order to evaluate the shareholders from step 2 if end up conditions are not satisfied. That is the number4 of program iteration; the programming operation is ended up.

Flow diagram of EMA's implementation for solving the emission constrained PBUC problem is shown in Fig.1.

IV. SIMULATION AND RESULTS

Spinning reserve and emission constrained optimal self scheduling problem is solved using exchange market algorithm. The validity and performance of the proposed EMA illustrated on IEEE 39 Bus test system. The test system consists of 39 Buses and 54 Lines, 10 thermal generating units. The one line diagram of IEEE 39 bus test system as shown in fig 2. The generator data includes maximum/minimum generating limits, cost and emission coefficients, hot and cold startup cost, minimum up/down time and initial status of generators are given in table.1 and table.2. The system data of forecasted load demand, forecasted reserve demand and market price are given in table 3. In IEEE 39 bus test system, reserve demand is the 10% of actual load demand. The generator and system data are adopted from reference **[29]**.

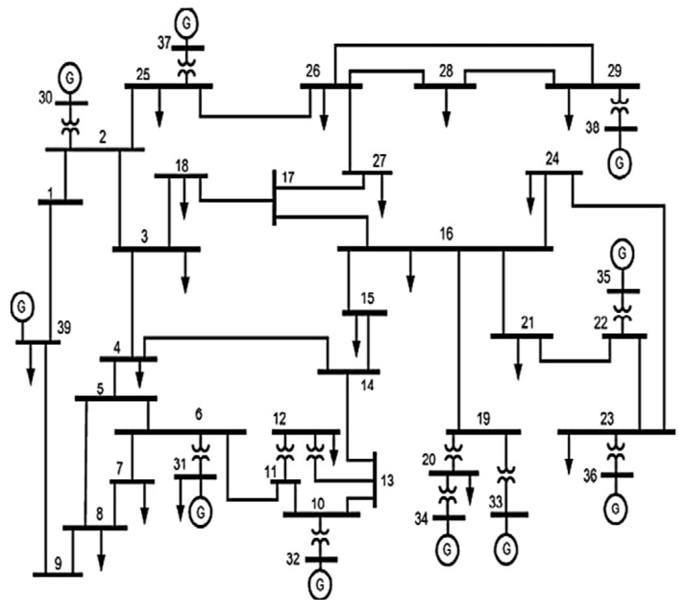

Figure 2. Single line diagram of IEEE-39 Bus System

The proposed EMA approach effectively determines the feasible unit commitment schedule based on the forecasted load demand, reserve demand and market price. This approach optimizes the thermal power based on maximum profit as well as minimum emission and dispatch the real power generation and reserve allocation. The feasible unit commitment schedule, real power generation and reserve allocation are reported in table 4 and table 5.

Table 1. Unit data for IEEE 39 bus test system

Quantities	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
P_{max} (MW)	455	455	130	130	162	80	85	55	55	55
P_{min} (MW)	150	150	20	20	25	20	25	10	10	10
a ($/h)	1000	970	700	680	450	370	480	660	665	670
b ($/MWh)	16.19	17.26	16.60	16.50	19.70	22.26	27.74	25.92	27.27	27.79
c ($/MW^{2}h)	0.00048	0.00031	0.00200	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MUT (h)	8	8	5	5	6	3	3	1	1	1
MDT (h)	8	8	5	5	6	3	3	1	1	1
H_{cost} ($)	4500	5000	550	560	900	170	260	30	30	30
C_{cost} ($)	9000	10,000	1100	1120	1800	340	520	60	60	60
Initial stu (h)	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Table 2. Emission Coefficients for Ten unit (IEEE 39 bus) test system

Units	α_i(ton/h)	β_i(ton/MW h)	γ_i(ton/MW^2 h)
Unit 1	10.33908	-0.24444	0.00312
Unit 2	10.33908	-0.24444	0.00312
Unit 3	30.03910	-0.40695	0.00509
Unit 4	30.03910	-0.40695	0.00509
Unit 5	32.00006	-0.38132	0.00344
Unit 6	32.00006	-0.38132	0.00344
Unit 7	33.00056	-0.39023	0.00465
Unit 8	33.00056	-0.39023	0.00465
Unit 9	33.00056	-0.39524	0.00465
Unit 10	36.00012	-0.39864	0.00470

Table 3. Forecasted load demand, Reserve Demand and Market price for IEEE 39 bus test system

Hour (h)	Forecasted Demand (MW)	Forecasted Reserve Demand (MW)	Forecasted Market Price (Rs/MWh)	Hour (h)	Forecasted Demand (MW)	Forecasted Reserve Demand (MW)	Forecasted Market Price (Rs/MWh)
1	700	70	996.75	13	1400	140	1107.00
2	750	75	990.00	14	1300	130	1102.50
3	850	85	1039.50	15	1200	120	1012.50
4	950	95	1019.25	16	1050	105	1003.50
5	1000	100	1046.25	17	1000	100	1001.25
6	1100	110	1032.75	18	1100	110	992.25
7	1150	115	1012.50	19	1200	120	999.00
8	1200	120	996.75	20	1400	140	1019.25
9	1300	130	1026.00	21	1300	130	1039.50

10	1400	140	1320.75	22	1100	110	1032.75
11	1450	145	1356.75	23	900	90	1023.75
12	1500	150	1424.25	24	800	800	1014.75

Table 4 Unit Commitment Schedule of Profit Based UC for IEEE39 bus test system

H (h)	Unit commitment schedule									
	U1	**U2**	**U3**	**U4**	**U5**	**U6**	**U7**	**U8**	**U9**	**U10**
1	1	1	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	0	0
3	1	1	0	0	0	0	0	0	0	0
4	1	1	0	0	0	0	0	0	0	0
5	1	1	0	0	0	0	0	0	0	0
6	1	1	0	1	0	0	0	0	0	0
7	1	1	1	1	0	0	0	0	0	0
8	1	1	1	1	0	0	0	0	0	0
9	1	1	1	1	1	0	0	0	0	0
10	1	1	1	1	1	1	0	0	0	0
11	1	1	1	1	1	1	0	0	0	0
12	1	1	1	1	1	1	0	0	0	0
13	1	1	1	1	1	1	0	0	0	0
14	1	1	1	1	1	0	0	0	0	0
15	1	1	1	1	0	0	0	0	0	0
16	1	1	1	1	0	0	0	0	0	0
17	1	1	0	1	0	0	0	0	0	0
18	1	1	0	1	0	0	0	0	0	0
19	1	1	0	1	0	0	0	0	0	0
20	1	1	0	1	0	0	0	0	0	0
21	1	1	0	1	0	0	0	0	0	0
22	1	1	0	1	0	0	0	0	0	0
23	1	1	0	0	0	0	0	0	0	0
24	1	1	0	0	0	0	0	0	0	0

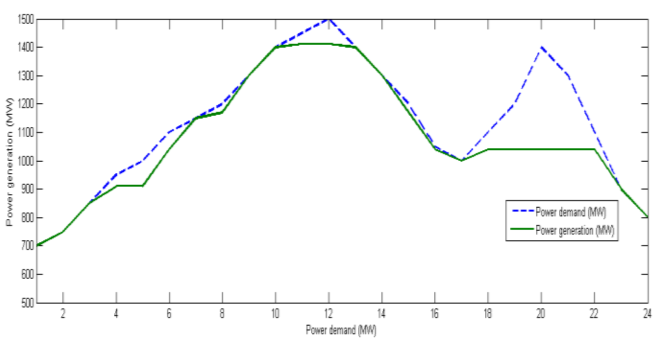

Figure 3. Power Demand and power Generation of IEEE 39 bus test system

Under deregulated environment, the power and reserve generation is not necessary to meet the system load and reserve demand. So the power and reserve generation is less than or equal to the forecasted values. The total power generation and reserve allocation of 10 units are reported in 24 hours and given in table 6 also graphically represented in fig. 3 and fig 4.

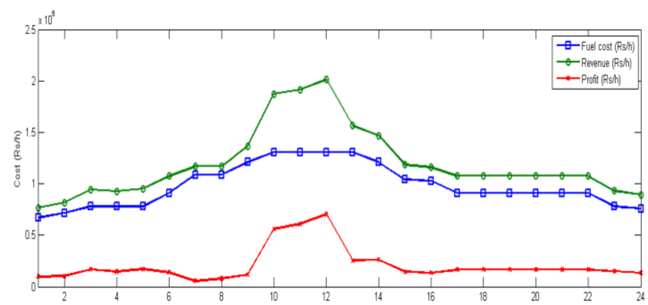

Figure 4. Reserve Demand and reserve Generation of IEEE 39 bus test system

Table 7 explains the simulation results of IEEE 39 bus system. It includes fuel cost, revenue, profit and emission. It is graphically represented in fig 5. This results getting from optimized values of real and reserve power. The pie chart representation of fuel cost and profit are displayed in fig 6.

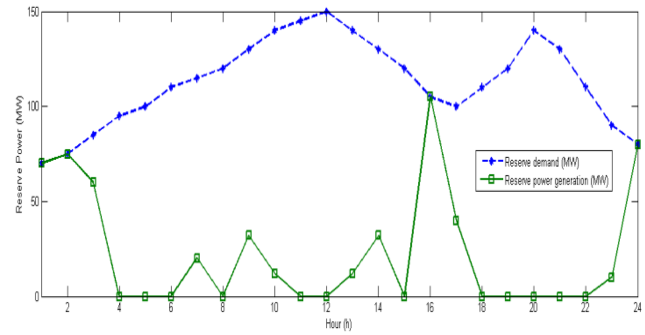

Figure 5. Revenue, Fuel cost and Profit of IEEE 39 bus test system considering reserve power generation and emisssion limitations

Table 5. Power generation and Reserve allocation of IEEE 39 bus test system

	Power Generations (MW)										Reserve Allocation (MW)									
H (h)	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
1	455	245	0	0	0	0	0	0	0	0	0	70	0	0	0	0	0	0	0	0
2	455	295	0	0	0	0	0	0	0	0	0	75	0	0	0	0	0	0	0	0
3	455	395	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0	0	0
4	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	455	455	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	455	455	130	110	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0
8	455	455	130	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	455	455	130	130	130	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0
10	455	455	130	130	150	80	0	0	0	0	0	0	0	0	12	0	0	0	0	0
11	455	455	130	130	162	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	455	455	130	130	162	80	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	455	455	130	130	150	80	0	0	0	0	0	0	0	0	12	0	0	0	0	0
14	455	455	130	130	132	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0
15	455	455	130	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	455	435	130	40	0	0	0	0	0	0	0	15	0	90	0	0	0	0	0	0
17	455	455	0	90	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0
18	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	455	455	0	130	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	455	445	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
24	397	403	0	0	0	0	0	0	0	0	29	51	0	0	0	0	0	0	0	0

Table 6. Total power generation and total reserve allocation of IEEE 39 bus test system

(h)	Power Demand (MW)	Power Gen (MW)	Reserve Demand (MW)	Reserve Gen (MW)
1	700	700	70	70
2	750	750	75	75
3	850	850	85	60
4	950	910	95	0
5	1000	910	100	0
6	1100	1040	110	0
7	1150	1150	115	20
8	1200	1170	120	0
9	1300	1300	130	32
10	1400	1400	140	12
11	1450	1412	145	0
12	1500	1412	150	0
13	1400	1400	140	12
14	1300	1300	130	32
15	1200	1170	120	0
16	1050	1060	105	105
17	1000	1000	100	40
18	1100	1040	110	0
19	1200	1040	120	0
20	1400	1040	140	0
21	1300	1040	130	0
22	1100	1040	110	0
23	900	900	90	10
24	800	800	80	80

Table 7. Simulation Results for IEEE 39 bus test system

H (h)	Demand (MW)	Fuel cost (Rs)	Start up cost (Rs)	Revenue (Rs)	Profit (Rs)	Emission (tons)
1	700	670657.3	0	767442.8	96785.5	787.973
2	750	713900.9	0	816691.9	102791	892.089
3	850	780898.7	0	945877.7	164979	1090.11
4	950	780898.5	0	927451.5	146553	1090.11
5	1000	780898.8	0	952019.8	171121	1090.11
6	1100	909628.6	25200	1073984	139155	1153.27
7	1150	1087521	24750	1166114.57	53843.6	1216.42
8	1200	1087521	0	1166114.57	78593.6	1216.42
9	1300	1208323	40500	1366535	117712	1276.93
10	1400	1307159	7650	1872416	557607	1300.44
11	1450	1307159	0	1915595	608436	1300.44
12	1500	1307159	0	2010898	703739	1300.44
13	1400	1307159	0	1562973	255814	1300.44
14	1300	1208323	0	1468426	260103	1276.93
15	1200	1039758	0	1184540	144782	1216.42
16	1050	1027966	0	1158960	130994	1178.47
17	1000	909628.60	0	1073983.62	164355	1153.27
18	1100	909628.60	0	1073983.62	164355	1153.27

19	1200	909628.60	0	1073983.62	164355	1153.27
20	1400	909628.60	0	1073983.62	164355	1153.27
21	1300	909628.60	0	1073983.62	164355	1153.27
22	1100	909628.60	0	1073983.62	164355	1153.27
23	900	780898.3	0	931546.3	150648	1090.11
24	800	758437.5	0	892916.5	134479	1014.93
Total		**23522038**	**98100**	**28624404**	**5004266**	**27711.67**

Table 8. Comparison of Total profit and Emission level of Proposed method with the Existing methods

Method	Profit (Rs/24h)	Emission (tons/24h)
Traditional UC [97]	3661454.32	28244.15
SFLA [97]	4744910.10	26617.56
MPPD – ABC	4745099.00	26646.85
EMA (Proposed)	5004266	27711.67

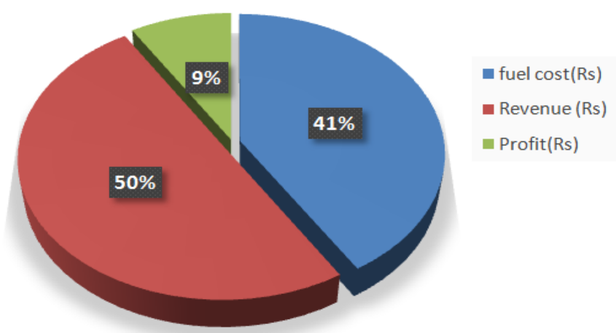

Figure 6. Pie chart representation of fuel cost, revenue and profit of IEEE 30 bus test system

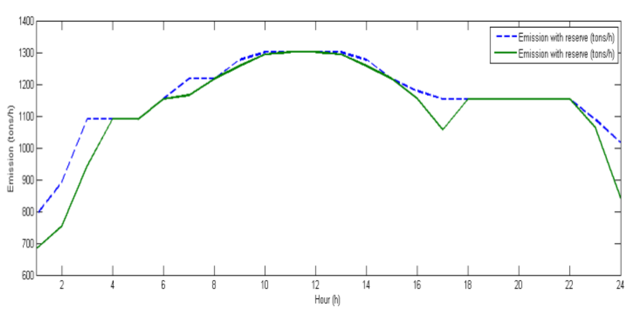

Figure 7. Comparison profits of with and without reserve power generation

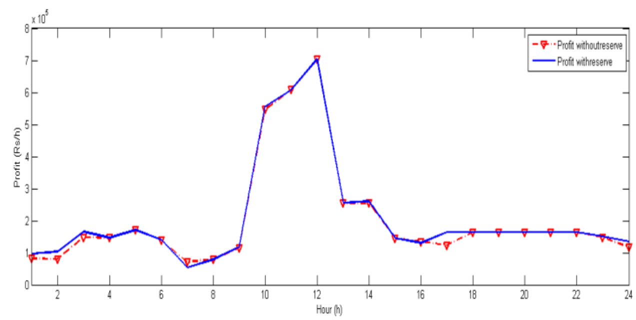

Figure 8. Comparison emission level of with and without reserve power generation

The comparative study also done to evaluate effectiveness of proposed EMA. The simulation results (profit and emission) are compared with other optimization method such as conventional approach, SFLA and MPPD-ABC and also given in table 8. The profit and emission of proposed method is compared with conventional method are graphically reported in fig. 7 and fig. 8. From the study, the proposed approach provides best solution compared with existing literature.

V. CONCLUSION

This article presents the optimal self scheduling of GENCO's to improve the profit and reduce environmental pollutions in deregulated power system. The proposed self scheduling problem solved by EMA approach. This algorithm obtains two effective operators so it can easily optimize power system variables. This method determines optimal unit commitment scheduled, real power generation, reserve allocation, fuel cost, revenue, profit and emission level of GENCO's. Numerical example with IEEE 39 bus test system is considered to validate the effectiveness of proposed method. The EMA offers best solution and provide less computational time. The results also compared with other available methods. From the results, it can be concluded that the proposed EMA paves the best way for solving complex power system optimization problem under deregulated environment.

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APPENDIX.A

Nomenclature	
PF	Total profit of GENCOs
RV	Total revenue of GENCOs
TC	Total cost ofGENCOs
EM	Total emission of GENCOs
SP_t	Forecasted Market Price
ST	Start up cost
SD	Shut down cost
Ton_i	Time duration for which unit i has been ON
X_{it}	Unit status
SR *(t)*	Spinning reserve during hour of t
RP_i *(t)*	Reserve of i^{th} generating unit during hour of t
DISCO	Distribution Company
TRANSO	Transmission Company
GENCO	Generation Company
$\alpha_i, \beta_i, \gamma_i$	Emission co-efficient of i^{th} generator
a_i, b_i, c_i	Cost co-efficient of i^{th} generator
r	Reserve Probability
PBUC	Profit based unit commitment
ED	Economic dispatch
UC	Unit commitment
EMA	Exchange Market Algorithm
GA	Genetic Algorithm
PSO	Particle Swam Optimization
N	Number of generating units
T	Number of time Periods
$Tdown_i$	Minimum down time of unit i
Tup_i	Minimum up time of unit i
$Toff_i$	Time duration for which unit i has been OFF
P_{it}^{min}	Minimum limit of i^{th} unit during hour of t
P_{it}^{max}	Maximum limit of i^{th} unit during hour of t
P_{Dt}	Forecasted system demand during hour t
P_{it}	Real power output of i^{th} Generator

