International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 21 (2018) pp. 14997-15010
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Exchange Market algorithm based Profit Based Unit Commitment for GENCOs Considering Environmental Emissions

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Abstract

The deregulation of electric power industry across the world has created the market competition among the electricity suppliers. The competition provides the good organization and reliability of electricity at cheaper cost. Better opportunities of financial resources are created in the energy market and many power companies are growing by their proper objectives, roles and utilities. The optimal generation scheduling is one of main task in the power suppliers for improves their own profit so, this problem is known as Profit Based Unit Commitment (PBUC) problem. The thermal power units emit the greenhouse gases into the atmosphere, which is answerable for change of climate and global warming in our environment. This article emission constrained PBUC are formulated as a bi-objective optimization function. The two conflictive objectives of profit maximization and reduction of environmental emission are solved by Exchange Market (EM) algorithm. This approach has more ability and robustness for solving PBUC problem due to two smart searching operators. Effectiveness of EM algorithm examined on IEEE 39 bus (10 units with 24 hour) test system and the results are compared to those other methods in the literature. The proposed method has been tested on IEEE 39 bus (10 units with 24 hour) test system and the results are compared to those other methods in the literature. The comparisons of results validated that this approach is more effective for the solution of emission constrained PBUC in a competitive electricity market.

Keywords: Deregulation, Profit based unit commitment, Profit maximization, Emission limitations, Exchange market algorithm.

INTRODUCTION

The thermal power generation plays the vital role and comprises a major percentage of the electric power company around the world. Thermal generation comprises over 70% of the total power production in the world. In 2006, globally, thermoelectricity comprises 80% of the total quantity of electricity. The thermal power industry facing the major problem is the ecological emission caused by the extensive acceptance of thermal generation. The process of thermal generation is to convert the stored energy in fossil fuels into electricity by burning the fossil fuels [1]. The conversion includes three steps and is modelled in Fig. 1. In the first step, fossil fuels are burned in a boiler furnace to boil water into steam at high temperature and under high pressure. Simultaneously, Emissions such as NO_x, SO_x and CO_2 produced as a by-product. In the second step, the resulting high-pressure steam is piped into a stream turbine, and the expansion of the steam drives the stream turbine to rotate. In the last step, the rotation of the steam turbine provides mechanical energy, this energy drives the generator to produce electric energy [28].

In the process of thermal generation, a huge amount of fuel is consumed and a huge amount of emission is emitted. On average, approximately 335 g of coal are necessary to generate 1 kWh of electricity, which emits approximately 870 g of emission [28]. As a result this power industry is a major source for environmental pollutions.

The contributions of the power industry to environmental pollution raise questions concerning environmental protection and methods of dropping pollution from power plants either by design or by operational strategies. Emissions may be reduced through following methods [1, 2].

- Switching to fuels with small emission possible.
- Implement the post-combustion cleaning system, and
- Power dispatches of each unit with the objective of minimum emission send off.

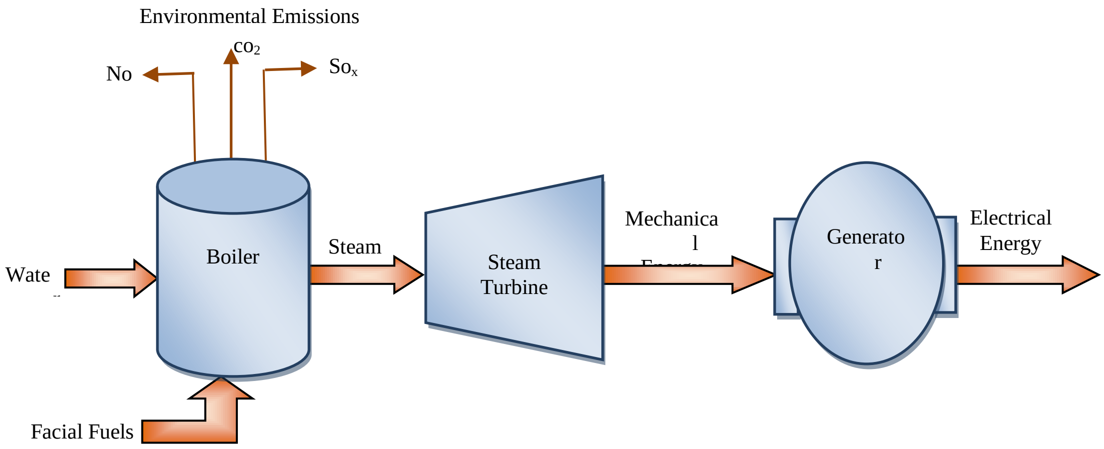

Figure 1. Conversion process of Electricity from Fossil fuels

The majority of the studies concerning emission limitations are on the Power dispatches of each unit through ED problem [2]. Here, only the optimally despatch the power of each thermal unit, but not considering the ON and OFF schedule of units for power despatch of short term and long term process.

In the vertically integrated electric industry, UC problem is the tactical preparation of scheduling process of generating units over a given time period and to minimize the total cost with meets the system demand also pleasing the operating constraints [1, 2].

Deregulated power industry creates a competitive open market situation to get better performance and optimal operation of existing electric industry [3, 4]. In the electricity markets, GENCOs are operated to exploit their profit simultaneously minimize the environmental emissions. Here, it's not essential to meet the demand. So, GENCOs has a different objective than that of conventional UC and is referred as Profit Based UC (PBUC).

Many optimization techniques have been developed by the researches to solve the PBUC problem. The classical methods such as 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 inVolumeve 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 unit, 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 [21-24] have also been used for the solution of the PBUC problem.

Emissions controlled PBUC are analysed by various intelligent approaches are listed in the references [25-31]. 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 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 same problem analysed by Asokan and Ashokkumar [30] using mathematical approach of MPPD Table with ABC algorithm. The hybrid method facilitated by emission limitation is believed to reduce the global warming and paves the way to enhance the profit of power producers.

In this research work, explain the problem of bi-objective optimization frame work using an innovative computational intelligent approach of Exchange Market algorithm (EMA) based solution to Emission constrained PBUC in a deregulated environment.

The organization of this article is summarized as follows.

- Section 2 presents the mathematical model of PBUC problem. It formulated as a bi-objective optimization function subjected to standard operating constraints.

- Section 3 proposes the solution methodology and it includes overview of Exchange Market algorithm and Implementation of EMA for PBUC by using flow diagram under deregulated environment.
- Section 4 presents the numerical example, simulation results and discussion

Finally section 5 outlines the conclusions and list out the references

PROBLEM FORMULATION

A. Problem Formulation

A conceptual frame work is developed to solve the emission constrained PBUC by Exchange Market algorithm under competitive environment. The problem considered as a Bi-objective optimization functions which not only maximize the profit but also minimize the emission quantity.

Profit maximization function for GENCOs

The profit function of GENCOs are mathematically defined as follows

$$\mathrm{Pr}ofit(i,t) = \mathrm{Re}venue(i,t) - Total\cos t(i,t)$$

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

$$RV = \sum_{t=1}^{T}\sum_{i=1}^{N} P_{it}.SMP_t.U_{it} \tag{2}$$

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} F(P_{it}).U_{it} + ST.U_{it} + SD.U_{it} \tag{3}$$

Here $PF(i,t)$ is the total profit obtained from difference between Revenue and total operating cost. $RV(i,t)$ is the total revenue which is obtained from sale of power. $TC(i,t)$ is the total cost of the planning period. It includes fuel cost and start-up/shutdown cost of thermal units. The fuel cost of the thermal plants is represented by the quadratic equation as

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

Emission limitation function for GENCOs

The emission function of GENCOs incorporated in the objective function and it is formulated as in equation

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

The Emission reduction is one of the important task in the electrical power system. The emission curve of the thermal plants is represented by the quadratic form as.

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

System and Unit Constraints

The proposed PBUC problem subjected to standard operating constraints such as power balance, spinning reserve, generator power limits, minimum ON/OFF time, and emission constraints.

i. Power balance constraint

$$\sum_{i=1}^{N} P_{it} U_{it} \le P_{D\,t} \quad 1 \le i \le N \text{ and } 1 \le t \le T \tag{7}$$

ii. Generator limit constraint

$$P_i^{\min} U_{it} \le P_i \le P_i^{\max} U_{it} \quad 1 \le i \le N \text{ and } 1 \le t \le T \tag{8}$$

iii. Spinning reserve constraint

$$\sum_{i=1}^{N} R_{it}\ U_{it} \le SR_t \quad 1 \le i \le N \text{ and } 1 \le t \le T \tag{9}$$

iv. Minimum up/down time constraints

$$Ton_i \ge Tup_i \qquad 1 \le i \le N \tag{10}$$

$$Toff_i \ge Tdown_i \quad 1 \le i \le N \tag{11}$$

v. Emission constraints

$$\sum_{t=1}^{T}\sum_{i=1}^{N} E(P_{it}).U_{it} \le EM_t \quad 1 \le i \le N \textbf{ and } 1 \le t \le T \tag{12}$$

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].

A.1. 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.

$$\mathrm{pop}_j^{\mathrm{group(2)}} = r \times \mathrm{pop}_{1,i}^{\mathrm{group(1)}} + (1-r) \times \mathrm{pop}_{2,i}^{\mathrm{group(1)}} \tag{13}$$

$i=1,2,3,\ldots..n_i$ 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]. $\mathrm{pop}_{1,i}^{\mathrm{group(1)}}$ and $\mathrm{pop}_{2,i}^{\mathrm{group(1)}}$ are the members of the first group and $\mathrm{pop}_j^{\mathrm{group(2)}}$ 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);

$$\mathrm{Sk} = 2 \times r_1 \times \left(\mathrm{pop}_{i,1}^{\mathrm{group(1)}} - \mathrm{pop}_k^{\mathrm{group(3)}}\right) + 2 \times r2 \times \left(\mathrm{pop}_{i,2}^{\mathrm{group(1)}} - \mathrm{pop}_k^{\mathrm{group(3)}}\right) \tag{14}$$

$$\mathrm{pop}_k^{\mathrm{group(3)}}, \mathrm{new} = \mathrm{pop}_k^{\mathrm{group(3)}} + 0.8 \times \mathrm{Sk} \qquad k = 1,2,3,\ldots.,\mathrm{nk} \tag{15}$$

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

A.2. 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 itno 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:

$$\Delta n_{t1} = n_{t1} - \delta + (2 \times r \times \mu \times \eta_1) \quad (16)$$

$$\mu = \left(\frac{tpop}{npop}\right) \quad (17)$$

$$n_{t1} = \sum_{y=1}^{n} |Sty| \qquad y = 1,2,3,\dots,n \quad (18)$$

$$\eta_1 = n_{c1} \ x \ g_1 \quad (19)$$

$$g_1^k = g_1, max - \frac{g_{1,max} - g_{1,max}}{iter_{max}} \times k \quad (20)$$

Where Δn_{t1} is the amount of shares should be added randomly to some shares, n_{t1} is total shares of tth 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 tth 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;

$$\Delta n_{t2} = n_{t2} - \delta \quad (21)$$

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 rth 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:

$$\Delta n_{t3} = (4 \times r_s \times \mu \ x \ \eta_2) \quad (22)$$

$$R_s = (0.52 - rand) \quad (23)$$

$$\eta_2 = n_{t1} \times g_2 \quad (24)$$

$$g_1^k = g_2, max - \frac{g_{2,max} - g_{2,max}}{iter_{max}} \times k \quad (25)$$

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.

IMPLEMENTATION OF EMA FOR EMISSION CONSTRAINED PBUC

The PBUC problem optimization is accomplished using the EMA by taking the following steps:

1. Read GENCOs unit and system data like 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 or market price for each shareholder
5. Calculate the objective function (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 2nd and 3rd groups using equations (13) and (15) respectively

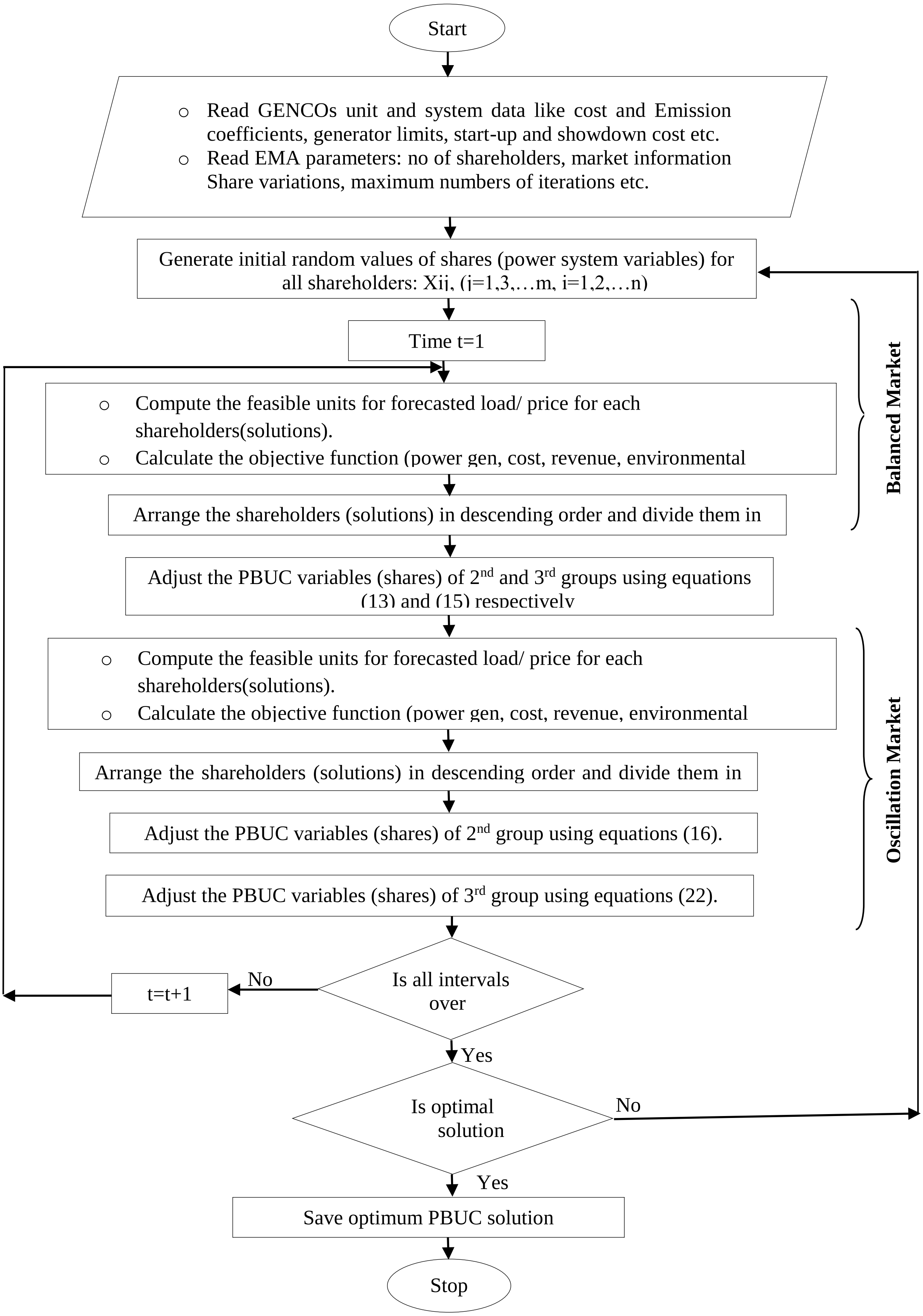

Fig. 2. Flow diagram of PBUC with Emission limitations by proposed method

Oscillation market

1. Compute the feasible units for forecasted load/ price for each shareholders.
2. Calculate the objective function (power gen, cost, revenue, environmental emission etc).
3. Calculate the profit (fitness) of each shareholders (solutions)
4. Arrange the shareholders (solutions) in descending order and divide them in three
5. Adjust the PBUC variables (shares) of 2nd group using equations (16).
6. Adjust the PBUC variables (shares) of 3rd group using equations (22).
7. Check the time interval for 24 hours. If satisfied go to next step otherwise go to step 4.
8. Evaluate fitness values of objective functions (maximum profit and minimum emission level) of the PBUC problem.
9. Verify whether optimal solution is reached. If all constraints are satisfied go to next step otherwise go to step 3.
10. 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.2. the control parameters of EMA approach has been displayed in Table 1 by using trial and error method.

Table 1. Control parameters of EMA

Parameters	Value
Population size (Balanced Market)	50 (25%, 25%, and 50%)
Population size (Oscilation Market)	50 (20%, 60%, and 20%)
Risk factor g1 (Max, Min)	(0.005, 0.001)
Risk factor g2 (Max, Min)	(0.01, 0.002)
Maximum number of iterations	500

NUMERICAL RESULTS

Applicability and superiority of the proposed EMA methodology tested on IEEE 39 bus test system. It consists of ten thermal generating units (GENCOs) with 24 hour test system. The thermal generator data, Forecasted system demand and market price are taken from reference [29] and given in Table 2 and 3. Emission co-efficient of generating units are shown in Table 4 and one line diagram of IEEE, 39 bus test system displayed in fig 3.

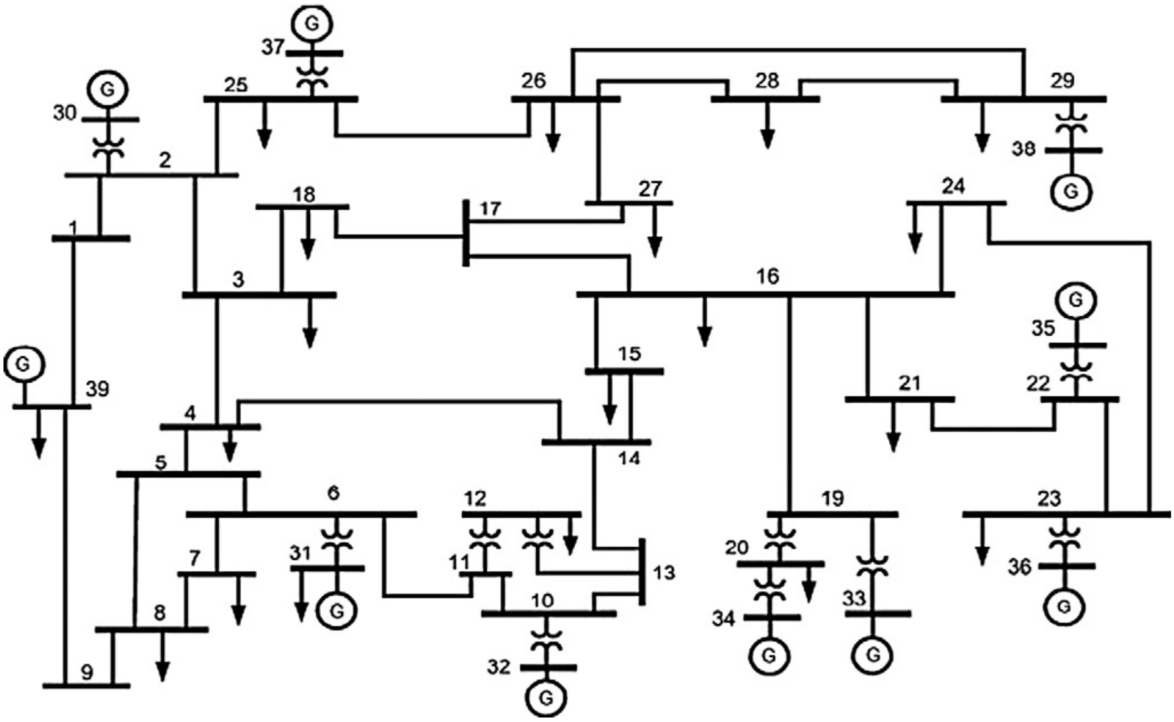

Figure 3. Single line diagram of IEEE-39 Bus System

Table 2 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
Initl Stu (h)	8	8	-5	-5	-6	-3	-3	-1	-1	-1

Table 3 Forecasted load demand and Market price for IEEE 39 bus test system

Hour (h)	Forecasted Demand (MW)	Forecasted Market Price (Rs/MWh)
1	700	996.75
2	750	990.00
3	850	1039.50
4	950	1019.25
5	1000	1046.25
6	1100	1032.75
7	1150	1012.50
8	1200	996.75
9	1300	1026.00
10	1400	1320.75
11	1450	1356.75
12	1500	1424.25
13	1400	1107.00
14	1300	1102.50
15	1200	1012.50
16	1050	1003.50
17	1000	1001.25
18	1100	992.25
19	1200	999.00
20	1400	1019.25
21	1300	1039.50
22	1100	1032.75
23	900	1023.75
24	800	1014.75

Table 4 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

The proposed approach effectively determine optimum unit commitment schedule and it compared with conventional UC schedule which is tabulated in Table 5. In this table maximum six units only committed to generate the power due to conflictive objective function of maximum profit and minimum emission.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 21 (2018) pp. 14997-15010
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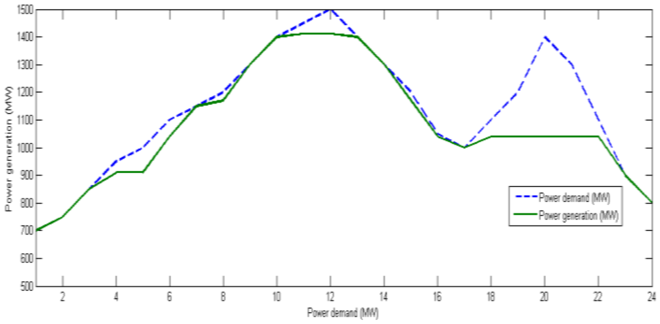

Figure 4 Power Demand and power Generation of IEEE 39 bus test system

The cumulative system demand is 27100 MW but the proposed approaches optimally generate 25814 MW only. The system demand and power generation of each unit and total power generation are reported in Table 6 and graphically displayed in fig 4. The start-up cost of conventional UC and profit based UC (proposed method) are compared and displayed in the bar chat in fig 5. Here the conventional UC have higher start-up cost due to more generators are committed to meet the system demand but PBUC have inequality demand constraint so no obligation to meet the system demand.

Table 5 Unit Commitment Schedule of Conventional and Profit Based UC (Proposed) for IEEE39 bus test system

H (h)	Conventional UC										Profit Based UC (Proposed Method)									
	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U1	U2	U3	U4	U5	U6	U7	U8	U9	U10
1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
2	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
3	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
4	1	1	0	1	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
5	1	1	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
6	1	1	1	1	0	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0
7	1	1	1	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0
8	1	1	1	1	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0
9	1	1	1	1	0	1	0	0	0	1	1	1	1	1	1	0	0	0	0	0
10	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0
11	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0
12	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0
13	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	0	0	0
14	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	0	0
15	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	0	0	0	0	0
16	1	1	1	1	1	1	0	1	0	0	1	1	1	1	0	0	0	0	0	0
17	1	1	1	1	1	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0
18	1	1	1	1	1	1	0	1	0	0	1	1	0	1	0	0	0	0	0	0
19	1	1	1	1	1	1	0	0	0	0	1	1	0	1	0	0	0	0	0	0
20	1	1	1	1	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0
21	1	1	1	1	1	0	1	0	0	0	1	1	0	1	0	0	0	0	0	0
22	1	1	0	1	1	0	1	1	0	0	1	1	0	1	0	0	0	0	0	0
23	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
24	1	1	0	0	0	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0

Table 6 Power generation of IEEE39 bus test system by proposed method

H (h)	PD (MW)	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	Power Gen (MW)
1	700	454.8439	245.1561	0	0	0	0	0	0	0	0	700.0000
2	750	296.2006	453.7994	0	0	0	0	0	0	0	0	750.0000
3	850	405.3151	444.6848	0	0	0	0	0	0	0	0	850.0000
4	950	455.0000	455.0000	0	0	0	0	0	0	0	0	910.0000
5	1000	455.0000	455.0000	0	0	0	0	0	0	0	0	910.0000
6	1100	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
7	1150	454.9835	435.1098	129.9722	129.9339	0	0	0	0	0	0	1150.0000
8	1200	455.0000	455.0000	130.0000	130.0000	0	0	0	0	0	0	1170.0000
9	1300	454.9981	454.9894	129.9932	129.9998	130.0194	0	0	0	0	0	1300.0000
10	1400	454.7905	454.6826	129.9882	129.4702	157.7756	73.2928	0	0	0	0	1400.0000
11	1450	455.0000	455.0000	130.0000	130.0000	162.0000	80.0000	0	0	0	0	1412.0000
12	1500	455.0000	455.0000	130.0000	130.0000	162.0000	80.0000	0	0	0	0	1412.0000
13	1400	454.7509	454.6423	129.9789	129.4486	157.9314	73.2479	0	0	0	0	1400.0000
14	1300	454.9984	454.9912	129.9944	129.9998	130.0162	0	0	0	0	0	1300.0000
15	1200	455.0000	455.0000	130.0000	130.0000	0	0	0	0	0	0	1170.0000
16	1050	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
17	1000	454.9957	416.1059	0	128.8983	0	0	0	0	0	0	1000.0000
18	1100	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
19	1200	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
20	1400	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
21	1300	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
22	1100	455.0000	455.0000	0	130.0000	0	0	0	0	0	0	1040.0000
23	900	454.9985	445.0015	0	0	0	0	0	0	0	0	900.0000
24	800	454.9602	345.0395	0	0	0	0	0	0	0	0	800.0000

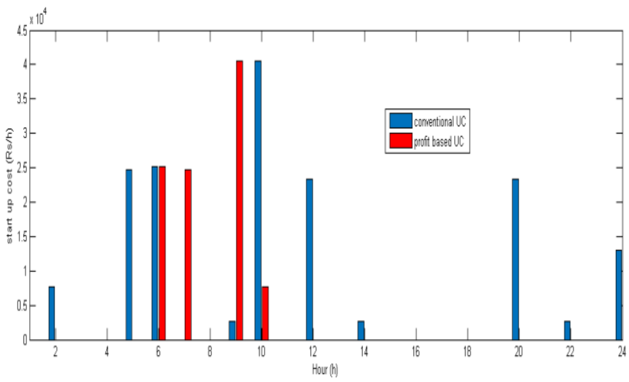

Figure 5 Comparison of start up cost of Conventional and Profit Based UC

The simulation results of IEEE 39 bus test system are given in table 7. It includes fuel cost, start-up cost, revenue, profit and emission level of GENCO's. The proposed EMA approach optimally evaluates the maximum profit and minimum emission level and graphically represented in fig 6. The total profit Rs 4806363 and emission is 26214.67 tons. The profit and environmental emission are compared with conventional UC method and represented in fig 6 and 7.

Table 7 Simulation Results for Profit Based UC with Emission limitations

H (h)	Power Demand (MW)	Power Generation (MW)	Fuel cost (Rs)	Start up cost (Rs)	Revenue (Rs)	Profit (Rs)	Emission (tons)
1	700	700	615746.3	0	697675.30	81929	682.59
2	750	750	661681.2	0	742447.20	80766	753.625
3	850	850	735636.2	0	883512.17	147876	942.456
4	950	910	780898.5	0	927451.54	146553	1090.11
5	1000	910	780898.8	0	952019.80	171121	1090.11
6	1100	1040	909628.60	25200	1073983.62	139155	1153.27
7	1150	1150	1068931	24750	1164291.71	70610.7	1165.92
8	1200	1170	1087521	0	1166114.57	78593.6	1216.42
9	1300	1300	1178284	40500	1333705.15	114921	1256.96
10	1400	1400	1295302	7650	1848918.51	545967	1294.56
11	1450	1412	1307159	0	1915594.77	608436	1300.44
12	1500	1412	1307159	0	2010897.99	703739	1300.44
13	1400	1400	1295316	0	1549689.79	254374	1294.43
14	1300	1300	1178283	0	1433148.08	254865	1256.96
15	1200	1170	1039759	0	1184540.76	144782	1216.42
16	1050	1040	909627.8	0	1043565.79	133938	1153.27
17	1000	1000	878097.8	0	1001178.80	123081	1056.05
18	1100	1040	909628.60	0	1073983.62	164355	1153.27
19	1200	1040	909628.60	0	1073983.62	164355	1153.27
20	1400	1040	909628.60	0	1073983.62	164355	1153.27
21	1300	1040	909628.60	0	1073983.62	164355	1153.27
22	1100	1040	909628.60	0	1073983.62	164355	1153.27
23	900	900	773006.5	0	921309.47	148303	1064.47
24	800	800	694235.1	0	811742.05	117507	842.406
Total (Rs)			**23043008**	**98100**	**27947471**	**4806363**	**26214.67**

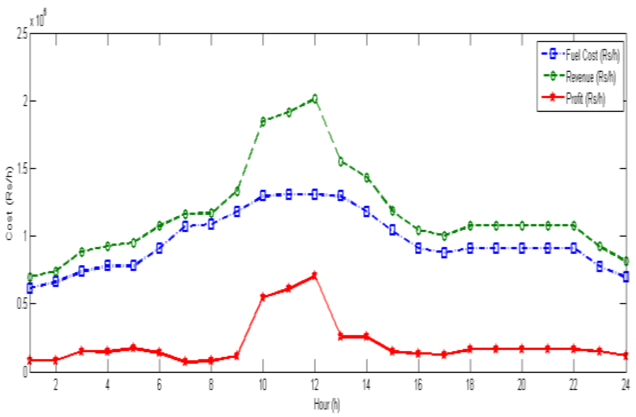

Figure 6 Revenue, Fuel cost and Profit of IEEE 39 bus test system

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 [27]	3661454.32	28244.15
SFLA [27]	4744910.10	26617.56
MPPD – ABC [30]	4745099.00	26646.85
EMA (Proposed)	4806363.00	26214.67

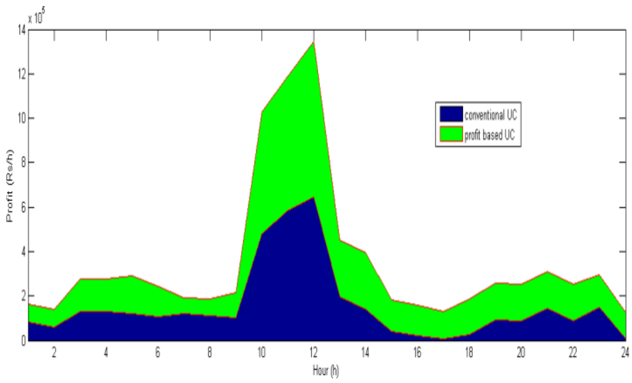

Figure 8. Comparison of Emission level; of Conventional and Profit Based UC

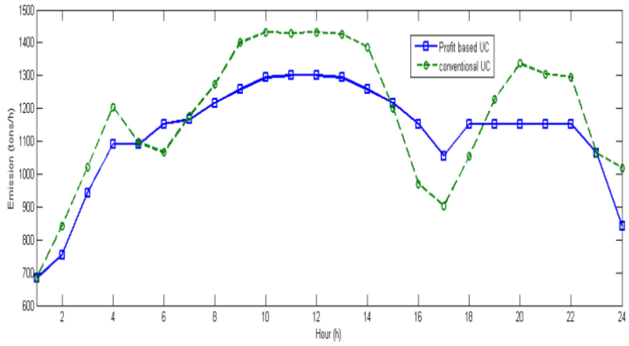

Figure 9. Comparison of Emission level; of Conventional and Profit Based UC

The best solution of profit and emission are compared with conventional methods, SFLA and MPPD with ABC approaches are given in table 8 table 9. From the comparison, the proposed method effectively optimizes the power, profit and emission quantity of GENCO's in electricity market.

CONCLUSION

In this research work, a simple and effective methodology of Exchange Market Algorithm (EMA) is prescribed to determine the solution of PBUC considering environmental emission in a competitive electricity market. The PBUC is considered as a bi=objective optimization problem. The objective is to maximize the profit and simultaneously minimize the environmental emission of the GENCO's. The proposed EMA optimally allocate the generators to evaluate the fitness value of objective function (profit and emission) in a balanced and oscillated market. The numerical examples with IEEE 39 bus test system (10 unit 24 hour) are considered to illustrate the superior performance of proposed method. The simulation results are carried out on a proposed test system it includes optimum UC schedule, power generation, fuel cost, start-up cost, revenue, profit and emission. The comparative study also made with other benchmark approaches such as conventional UC SFLA and MPPD with ABC. From the solution it is evident that the proposed EMA have more ability, accuracy, robustness with less computational time for the solution of power system optimization problems in competitive market.

NOMENCLATURE

PF	Total profit of GENCOs
RV	Total revenue of GENCOs
TC	Total generation cost of GENCOs
EM	Total emission of GENCOs
SPM	Sport Market Price
ST	Start up cost
Ton_i	Time duration for which unit i has been ON
U_{it}	Unit status
SR *(t)*	Spinning reserve during hour of t
R_i *(t)*	Reserve of i^{th} generating unit during hour of t
DISCO	Distribution Company
TRANSCO	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
PBUC	Profit based unit commitment
ED	Economic dispatch
UC	Unit commitment
N	Number of generating units
T	Number of time Periods considered
N	Number of generating units considered
$Tdown_i$	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
FMP_t	Forecasted market price at hour of t
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
EMA	Exchane market algorithm

ACKNOWLEDGEMENT

The authors gratefully acknowledge the authorities of Annamalai University for the facilities offered to carry out this work.

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