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A New Progressive Method for Solving Unit Commitment

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Abstract **-As the electric sector modernizes every time many of the modern algorithms for controlling the generating units need modification. The modern unit commitment problems mainly focus to reduce the operation costs. The Generation companies operate their generators with an aim to maximize their own profit to match the competition in the market. In such scenario price plays a major role in decision process. Here we introduce new technique called imperialistic competition algorithm (ICA) to solve the unit commitment (UC) problem. The method presented in this paper helps the electrical companies to make decision in how to schedule generators to gain more profit. Applying this new algorithm to systems of 10 generating unit will depicts the performance of the algorithm.**

I. INTRODUCTION

Electricity sector is the most vital sector that experiences significant changes in its structure. Because of some technological aspects, many countries generate their basic load by means of thermal power plants. The main problem in power industry is unit commitment (UC). UC is used to determine start-up and shut-down scheduling of generating units at minimum operating cost. Many solutions were proposed for this problem that can be divided into two classes.

Lagrangian Relaxation (LR) [3], Branch and Bound (B&B) [2], Mixed Integer Programing (MIP) [1] and Priority List (PL) [5] as classical methods. These methods are simple and fast and many of these suffer from numerical convergence. The second class is Simulated Annealing (SA) [4], Partial Swarm Optimization (PSO) [13], Genetic Algorithm (GA) [6] and Imperialist competitive algorithm (ICA) [19] as heuristic methods. These methods can solve complex nonlinear constraints and can give good solutions, but all of them have a problem of dimensionality. Atashpaz-Gargari first introduced Imperialistic competition algorithm (ICA) in 2007 [20]. This method is inspired by the imperialistic competition. All the countries are divided into two categories known as imperialists and colonies. The colonies are divided among imperialists. The imperialists and colonies combinely form some empires. Then the imperialistic competition among the empires begins. This hopefully causes the colonies to converge to the global optimum of the objective function. At the end of imperialistic competition, only one empire remains. The colonies of this empire are in the same position as the imperialist of this empire and have the same cost. Recently ICA has been successfully applied for solving some optimization problems [16], [22].

Generation Companies uses the UC not only to minimize the total operation cost but also for maximizing their own profit by using profit based UC problem (PBUC). PBUC is a method used to schedule generators based on economic aspects which utilizes the information, such as prices and demand/reserve with an objective to maximize the profit of Generation Company which is much more challenging problem to solve the traditional UC. During recent years, many classical methods like LR [7], [12] and MIP [12] methods are used to solve PBUC problem. These methods suffer more from numerical convergence which depends on quality of solutions on the algorithm which updates the Lagrangian multipliers. With the formation of progressive computation techniques, progressive algorithms (e.g. GA [8], Ant Colony Optimization (ACO) [18], Artificial Bee Colony (ABC) [21], Tabu search (TS) [11] and Muller method [15]) and hybrid methods based on combination of the heuristic techniques like combining the dynamic programming and nonlinear programming are used to solve existing problems. Heuristic methods have ability to search global optimal solutions & capability to deal with the complex nonlinear constraints related to the electric power system. But by using above methods consume more amount of time will be taken in computational process for large systems, in addition to advantages, By using heuristic search algorithms there is a advantage to overcome more computation time raising from large systems unit commitment.

Regarding to literature review, many approaches with the different quality of answers are proposed in recent years. Here a new technique to solve the PBUC optimization problem using a new method known as ICA is implemented. System and units constraints like demand constraint, unit generation limits, unit minimum ON/OFF durations are considered. By carrying out the proposed method on two case studies, validation of presented approach is assessed. Then Simulation results are compared with the solutions which provided by the existing methods.

II. IMPERIALISTIC COMPETITIVE ALGORITHM

Imperialist competitive algorithm (ICA) is a new global search heuristic algorithm introduced by Atashpaz Gargari based on imperialism and imperialistic competition process [14].Now-a-days ICA has been successfully utilized to solve optimization problems [17], [16]. ICA starts with an initial population that is called countries. Some of the best countries that have the best objective functions are selected to be imperialists. The rest of the countries will form the colonies of these imperialists. The colonies are divided among the imperialists based on the imperialists' power. Below Figure represents the initial population of each empire. The bigger empires have more number of colonies while weaker ones have less. In figure (1)

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imperialist 1 Formed the most powerful empire and has the more number of colonies.

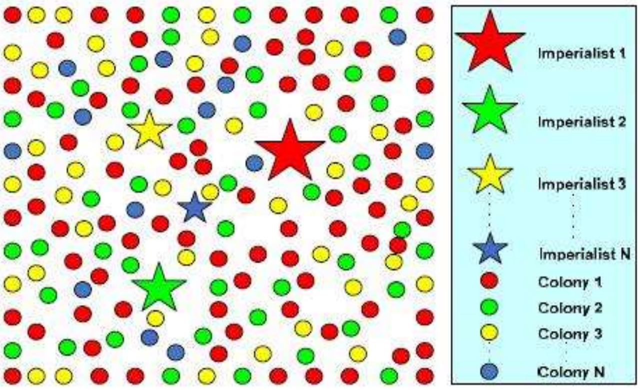

Fig. 1: Generating the initial empires: The more colonies an imperialist possess, the bigger is its relevant ★ mark.

ICA is divided into two separate categories based on the cost of countries that are results of evaluation of the objective function for given initial countries (1).

$$\text{Cost}_n = f(\text{conuntry}_n) \quad (1)$$

Where

$Cost_n$ = Cost of country n

f = Objective function

$Country_n$ = Country n

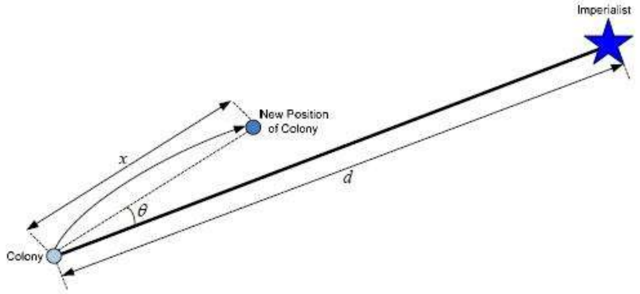

Fig 2: Moving colonies toward their related imperialist

In this classification, N_{imp} elite countries are selected as imperialists and N_{col} the rest of countries that are called colonies should accept citizenship of one of the imperialists based on power of them. Here we consider an inverse relation between the cost and the power of imperialists in which most powerful imperialist that enjoys least cost value, possess maximum number of colonies. Mathematical expression of this relation is given in (2).

$$\hat{N}_i = round\left\{\hat{P}_i . \text{Ncol}\right\} \quad i = 1,\ldots, \text{N}_{\text{imp}} \quad (2)$$

Where

$\hat{N}_i$ = Number of initial colonies of imperialist i

$\hat{P}_i$ = Normalized power of imperialist i

$Ncol$ = Number of colonies

$Nimp$ = Number of imperialists

To form initial empires, $\hat{N}_i$ number of initial colonies is accrued to the *i*th imperialist. Then, the normalized power of each imperialist is calculated as follows:

$$\hat{P}_i = \frac{\hat{C}_i - max\left\{\hat{C}_1,\ldots,\hat{C}_{\text{Nimp}}\right\}}{\sum_{i=1}^{N_{imp}} \hat{C}_i} \quad i = 1,\ldots, \text{N}_{\text{imp}} \quad (3)$$

Here

$\hat{P}_i$ = Normalized power of imperialist i

$\hat{C}i$ = Cost of imperialist i

$Nimp$ = Number of imperialists

i = Index of generator unit

After randomly allocating all colonies to the imperialists, these colonies along with their imperialist establish the empires. In the further step, the colonies move towards their relevant imperialist with the aim of searching solution surface. Fig. 2 shows assimilation procedure of a colony toward its imperialist. New position of the assimilated colony can be calculated by (4).

$$Pos_C^{d+1} = Pos_C^d + \beta\left(Pos_I^d - Pos_C^d\right).rand(0,1) \quad (4)$$

Where

Pos_C^{d+1} = Positions of a colony at the next decade, in a specific empire

Pos_C^d = Positions of a colony at the current decade, in a specific empire

β = Assimilation weight factor

Pos_I^d = Positions of an imperialist at the current decade, in a specific empire

Pos_C^d = Positions of a colony at the current decade, in a specific empire

To improve the searching process of proposed algorithm, it is considered that movement of colony toward their imperialist is associated with some amount of deviation from the original direction. In addition to that a revolution operator is applied to the algorithm after exerting assimilation operator that helps algorithm not to involve in local optima. As same as mutation operator in GA, this operator executes a sudden surge in the infrastructure of colonies. After implementation of two stated operators, the colony will reach to a position with lower cost than that of the imperialist .The country cost will conquer position of their imperialists & other colonies should assimilate toward position of new more powerful imperialist. In this procedure of imperialistic competition, more powerful empires start to import colonies that are under possession of weaker empires. It is noteworthy to mention that, as it is given in (5), the total power of an empire depends on both the powers of imperialist and colonies. But it is mainly effected by the power of the imperialist.

The total power of an empire is defined as

$$T\hat{P} = \hat{C} + \xi.\{mean\ (SCcol)\} \qquad (5)$$

Where

$T\hat{P}_i$ = Total power of imperialist i

ξ = Colonies' corporation factor in imperialist' power (i.e. a positive number which is considered to be less than 1)

SC_{col} = Summation of costs of the colonies, existing in the territory of an empire

The imperialistic competition assists powerful empires to gain more power and leads weaker empires to collapse. In such a manner, most optimal solution (most powerful empire) gains more chance to attract other solution toward a globally optimal solution of the problem. Probability of each empire to possess the weakest colony of the weakest empire is given in (6).

$$\hat{\sigma}_i = \frac{T\hat{P}_i - max\{T\hat{P}_i, \ldots, T\hat{P}_{i\,Nimp}\}}{\sum_{i=1}^{N_{imp}} T\hat{P}_i} \qquad i = 1,\ldots, N_{imp} \qquad (6)$$

Where

σ_i = Probability of imperialist i

$T\hat{P}_i$ = Total power of imperialist i

$Nimp$ = Number of imperialists

Highest chance to increase its power by the possessing weakest empire's colony is belonged to the empire that enjoys highest value of prosperity, which is given in (7).

$$\mu\, r_i = \hat{\sigma}_i - r_i \qquad i = 1,\ldots, N_{imp} \qquad (7)$$

$$= [\hat{\sigma}_1 - r_1,\ \hat{\sigma}_2 - r_2, \ldots, \hat{\sigma}_{Nimp} - r_{Nimp}]$$

Where

μr_i = Prosperity value of ith empire

σ_i = Probability of imperialist i

$Nimp$ = Number of imperialists

These competitions among the empires leads the algorithm to collapse weaker empires and finally the most powerful imperialist that represents the global optimal solution of problem will stay & remaining all the other countries are colonies of this empire. Fig. 3 shows outline of Imperialistic competitive algorithm

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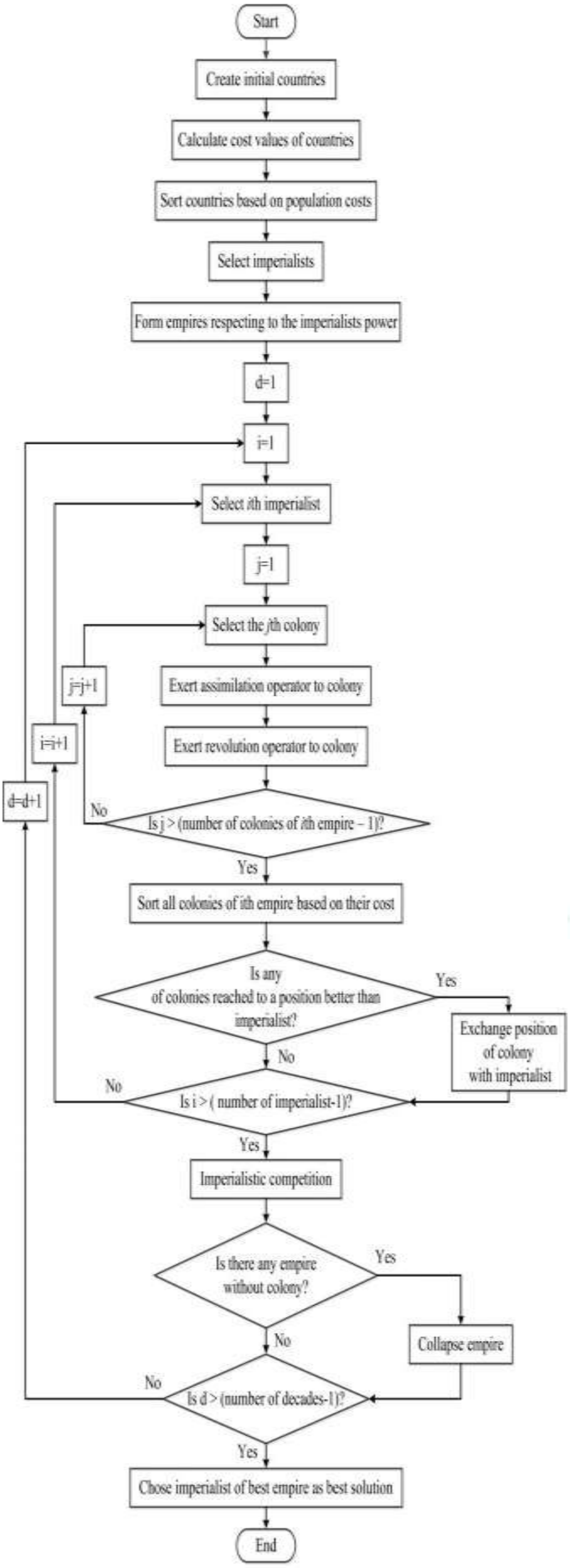

Fig. 3: Outline of the Imperialistic competitive algorithm

III. UC PROBLEM FOR COMPETITIVE ENVIRONMENT

The cost-based unit commitment in a power industry aims to satisfy load demand by minimizing the operational costs. PBUC problem plays a major role in optimization tasks with the aim of maximizing the total profit of generation companies over the scheduling horizon. In a new power market, every generation company run its own unit commitment by ignoring the load demand restriction to provide results with more profit for its own company. As the profit not only depends on cost but on revenue as well, the signal that would enforce a unit to be ON or OFF status would be the energy price, including the fuel purchase price and energy sale [7]. This problem can be done mathematically as follows:

A. *Objective Function*

The objective function of PBUC problem is given as (8):

$$Maximize\ PF = RV - TC \qquad (8)$$

or

$$Minimize\ TC - RV \qquad (9)$$

Where
PF = Total profit ($)
RV = Total revenue ($)
TC = Total cost ($)

Here,

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N}\left[C_i\left(P_{(i,t)}.I_{(i,t)}\right) + ST_{(i,t)}.I_{(i,t)}.[1 - I_{(i,t-1)}]\right] \qquad (10)$$

Where
TC = Total cost ($)
Ci = Cost function of unit i ($), $Ci\left(P(i,t)\right) = ai + bi * P(i,t) + ci * P(i,t)^2$
$I(i,t)$ = Commitment state of unit i at time t
i = Index of generator unit
$ST_{(i,t)}$ = Start-up cost of unit i at time t ($)

$$RV = \sum_{t=1}^{T}\sum_{i=1}^{N}\left[\rho_{gm}(t).P_{(i,t)}.I_{(i,t)}\right] \qquad (11)$$

Where
RV = Total revenue ($)
$\rho_{gm}(t)$ = Forecasted market price for energy at time t ($/MW h)
$P_{(i,t)}$ = Generation of unit i at time t (MW)
$I(i,t)$ = Commitment state of unit i at time t

Where, start-up cost is defined as follows:

$$ST_{(i,t)}\begin{cases}CSC_{(i)}, & if\ X_{(i,t)}^{off} < CST_{(i)} + T_{(i)}^{off} \\ HSC_{(i)}, & if\ X_{(i,t)}^{off} < CST_{(i)} + T_{(i)}^{off}\end{cases} \quad (12)$$

Where

$ST_{(i,t)}$ = Start-up cost of unit i at time t ($)

$CSC(i)$ = Cold start – up Cost of unit i ($\$/h$)

HSC_i = Hot start – up Cost of unit i ($\$/h$)

$X_{(i,t)}^{on}$ = Time duration for which unit i has been ON at time t (h)

$X_{(i,t)}^{off}$ = Time duration for which unit i has been OFF at time t (h)

$CST(i)$ = Cooling constant of unit i (h)

B. Constraints

The PBUC problem is formulated subject to following system & unit constraints

System Constraints

1. Demand constraints

B

$$\sum_{i=1}^{N} P_{(i,t)}.I_{(i,t)} \geq PD_{(t)} \qquad t=1,\ldots,T \quad (13)$$

Where

$P_{(i,t)}$ = Generation of unit i at time t (MW)

$I(i,t)$ = Commitment state of unit i at time t

$PD_{(t)}$ = Total system demand at time t (MW)

Unit Constraints

1. Unit Generation Limits

$$P_{(i)}^{gmin} \leq P_{(i,t)}.I_{(i,t)} \leq P_{(i)}^{gmax} \quad (14)$$

Where

$P_{(i)}^{gmin}$ = Minimum generation of unit i (MW)

$P_{(i)}^{gmax}$ = Maximum generation of unit i (MW)

$P_{(i,t)}$ = Generation of unit i at time t (MW)

$I(i,t)$ = Commitment state of unit i at time t

2. Unit Minimum ON/OFF Durations

$$\left[X_{(i,t-1)}^{on} - T_{(i)}^{on}\right] * \left[I_{(i,t-1)} - I_{(i,t)}\right] \geq 0 \quad (15)$$

$$\left[X_{(i,t-1)}^{off} - T_{(i)}^{off}\right] * \left[I_{(i,t-1)} - I_{(i,t)}\right] \geq 0 \quad (16)$$

Where

$T_{(i)}^{on}$ = Minimum ON time of unit i (h)

$T_{(i)}^{off}$ = Minimum OFF time of unit i (h)

$I(i,t)$ = Commitment state of unit i at time t

IV. CASE STUDY AND RESULTS

The proposed method for solving PBUC problem is Implemented on a 10 generating units- 24 hours test system.

TABLE I. DATA FOR THE TEN-UNIT SYSTEM

Hour [h]	Load [MW]	Price [$/MW]	Hour [h]	Load [MW]	Price [$/MW]
1	700	22.15	13	1400	24.60
2	750	22.00	14	1300	24.50
3	850	23.10	15	1200	22.50
4	950	22.65	16	1050	22.30
5	1000	23.25	17	1000	22.25
6	1100	22.95	18	1100	22.05
7	1150	22.50	19	1200	22.20
8	1200	22.15	20	1400	22.65
9	1300	22.80	21	1300	23.10
10	1400	29.35	22	1100	22.95
11	1450	30.15	23	900	22.75
12	1500	31.65	24	800	22.55

TABLE III OPTIMAL SOLUTION TO ICA PROBLEM

TABLE II LOAD DEMAND AND FORECASTED PRICE FOR 24 h

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Pi gmax	455	455	130	130	162
Pi gmin	150	150	20	20	25
ai	1000	970	700	680	450
bi	16.19	17.26	16.60	16.50	19.70
ci	0.00048	0.00031	0.002	0.00211	0.00398
Ti off	8	8	5	5	6
Ti on	8	8	5	5	6
HSCi	4500	5000	550	560	900
CSCi	9000	10000	1100	1120	1800
CSTi	5	5	4	4	4
Ini.Si	8	8	-5	-5	-6

	Unit 6	Unit 7	Unit 8	Unit 9	Unit 10
Pi gmax	80	85	55	55	55
Pi gmin	20	25	10	10	10
ai	370	480	660	665	670
bi	22.26	27.74	25.92	27.27	27.79
ci	0.00712	0.00079	0.00413	0.00222	0.00173
Ti off	3	3	1	1	1
Ti on	3	3	1	1	1
HSCi	170	260	30	30	30
CSCi	340	520	60	60	60
CSTi	2	2	0	0	0
Ini.Si	-3	-3	-2	-1	-1

Time [h]	Load [MW]	U1 [MW]	U2 [MW]	U3 [MW]	U4 [MW]	U5 [MW]	U6 [MW]	U7 [MW]	U8 [MW]	U9 [MW]	U10 [MW]	REVENUE	FUEL COST	START UP COST	PROFIT
1	700	455	295	0	0	0	0	0	0	0	0	15505	13683	0	1822
2	750	455	395	0	0	0	0	0	0	0	0	16500	14554	0	1946
3	850	455	455	0	0	40	0	0	0	0	0	19635	16302	0	3333
4	950	455	455	0	0	90	0	0	0	0	0	21518	18598	900	2020
5	1000	455	455	0	28	162	0	0	0	0	0	23250	19609	0	3641
6	1100	455	455	0	78	162	0	0	0	0	0	25245	22243	560	2442
7	1150	455	455	0	128	162	0	0	0	0	0	25875	23079	0	2796
8	1200	455	455	98	130	162	0	0	0	0	0	26580	23926	0	2654
9	1300	455	455	130	130	162	68	0	0	0	0	29640	26306	0	3334
10	1400	455	455	130	130	162	80	38	0	0	0	41090	28768	1100	11222
11	1450	455	455	130	130	162	80	85	0	0	0	43718	30583	340	12794
12	1500	455	455	130	130	162	68	0	0	0	0	47475	31892	520	15063
13	1400	455	455	98	130	162	0	0	0	0	0	34440	28768	0	5672
14	1300	455	455	0	128	162	0	0	0	0	0	31850	26306	0	5544
15	1200	455	455	0	0	140	0	0	0	0	0	27000	23926	0	3074
16	1050	455	455	0	0	90	0	0	0	0	0	23415	20639	0	2776
17	1000	455	455	0	28	162	0	0	0	0	0	22250	19609	0	2641
18	1100	455	455	0	128	162	0	0	0	0	0	24255	22243	560	1452
19	1200	455	455	130	130	162	68	0	0	0	0	26640	23926	0	2714
20	1400	455	455	98	130	162	0	0	0	0	0	31710	28768	550	2392
21	1300	455	455	0	28	162	0	0	0	0	0	30030	26306	0	3724
22	1100	455	455	0	0	0	0	0	0	0	0	25245	22243	0	3002
23	900	455	445	0	0	0	0	0	0	0	0	20475	17178	0	3297
24	800	455	345	0	0	0	0	0	0	0	0	18040	15427	0	2613
TOTAL												651380	540350	4530	106500
TOTAL PROFIT = 1,06,500															

The system data and generation units' data corresponding to this test system given in Table I and II, respectively. The simulation result obtained using ICA is shown in Table III. Optimal parameters of ICA for this problem are considered as N_{imp}=5, N_{col}=200, β=5, δ=0.02 .The result is compared with that of other approaches in Table IV.

TABLE IV. COMPARISON OF SOLUTIONS

METHOD	PROFIT[$]
MULLER METHOD [15]	1,03,296
NODAL ACO [19]	1,05,549
PARALLEL ACO [21]	1,05,878
ICA	1,06,500

V. CONCLUSION

An efficient new method called imperialistic competitive algorithm (ICA) is proposed in this paper to solve PBUC problem in a Power industry. Based on generating company's point of view, a UC problem with the aim of maximizing their profits is formulated. The presented algorithm is applied to the 10 generating units, 24 hours test system. An economical scheduling of thermal power plants is prepared by the proposed method. A glimpse at the performance of the ICA based PBUC in comparison with that of existing heuristic Methods, demonstrates applicability and high efficiency of the proposed algorithm rather than other algorithms. Moreover, simplicity of the implementation and low time consuming feature of the newly found algorithm remarkably assists generation units' operators to reach an optimal unit commitment in case of larger systems with larger number of generating units.

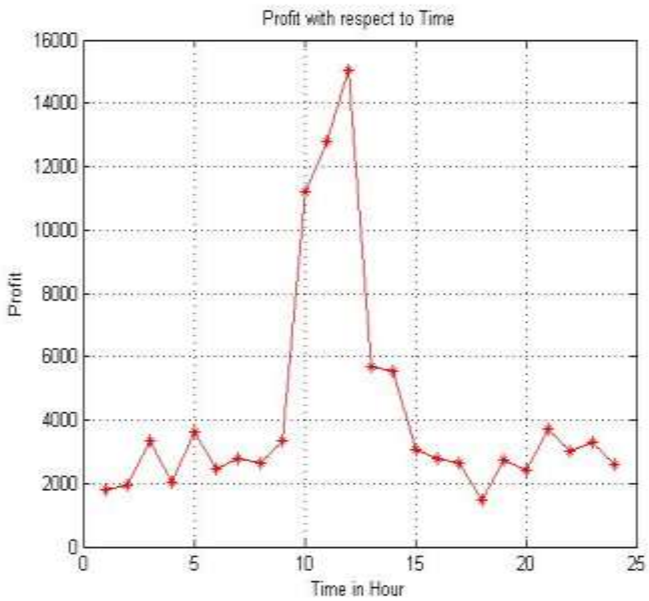

Fig 4: Characteristics of algorithm showing Profit with respect to Time

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