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Wind Integrated Thermal Generation Unit Commitment using Tunicate Swarm Algorithm

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ABSTRACT
This paper presents Tunicate Swarm Algorithm to solve the problem of Unit Commitment (UC).Tunicate swarm algorithm(TSA) is a new bio-inspired meta-heuristic optimization. This algorithm mimics the behavior of jet propulsion and swarm behavior of tunicates. The main objective of this unit commitment problem is to reduce the total operating cost. The proposed technique is carried out on 4-unit system, 10-unit system and also on wind power system. When compared with other existing methods, the results of this proposed algorithm is better in terms of operating cost and efficiency.

Keywords - Unit commitment problem (UCP), Tunicate swarm algorithm (TSA), Transmission loss

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I. INTRODUCTION

Electrical energy is beneficial to every country, their industries, and overall prosperity. As the demand for electricity rises, power plants with rising capacities also increases, as a result the number of power transmission lines connecting the generating stations to load centre subsequently intensifies. Electricity demand in India has risen dramatically in recent years, because of rise in consumption of electricity for agricultural and other purposes. India's generating capacity is insufficient to meet the increasing demand .In comparison to other advanced countries, India's electricity generating and transmission are unsatisfactory[3]. We have few power station like coal, steam run, oceanic tides, irradiated substances and source of light oriented force, however we pick one over the other based economical, mechanical, and geographic contemplation. The Unit Commitment Problem (UCP) for an interconnected system is to decide scheduling switch-on and switch-off the generating units to meet the load demand and reduce the overall operating cost [4].

The Unit commitment problem is most typically solved by using Dynamic Programming and Lagrangian approaches. In comparison to other approaches, they have a significant advantages in terms of amount of time they require to exercise. Various innovative optimization approaches like Genetic Algorithm (GA) [1], Tabu search, Particle swarm optimization (PSO) [3], Lagrange relaxation, Gravitational search algorithm(GSA), Binary particle swarm optimization (BPSO)[12], Simulated Annealing (SA), Hybrid PSO-SQP[7], Ant colony optimization are these days powerful in addressing the problem of unit commitment. In this paper, a new bio-inspired meta-heuristic method known as Tunicate Swarm algorithm to solve the unit commitment problem. Tunicate swarm algorithm has been proposed by Kaur et al [15].

II. PROBLEM FORMULATION

The main function of Unit commitment problem is to reduce the overall operating cost and to fulfill the requirements. Unit commitment problem minimizes the incremental cost function are follows as :

$$F_T = \sum_{i=1}^{n} F(P_i) = \sum_{i=1}^{n} (a_i P_i^2 + b_i P_i + c_i) \qquad \text{(i)}$$

The total cost needs to be minimized in following ways :

1) Power balance equation : The total power generated is equal to total load demand plus power transmission loss.

$$\sum_{i-1}^{n} Pi = P_d + P_l \qquad \text{(ii)}$$

Transmission loss are represented as B-coefficient is a component of power generator. Transmission loss is injected in real power are found to be quadratic nature under normal operating condition. The ideal form of loss formula representing B-coefficient as:

$$P_l = \sum_{i=1}^{n} \sum_{j-1}^{n} P_i B_{ij} P_j \quad \text{... (iii)}$$

2) Generator limits : The power generation of individual generator needs to be restricted in between its minimum and maximum limits.

$$P_i^{min} \leq P_i \leq P_i^{max} \text{....i=1,2,....n} \quad \text{...(iv)}$$

Where

F_T : total fuel cost of generator

P_i : total power generated

a_i, b_i, c_i : fuel cost coefficient of i^{th} generator, Rs/MW^{2}h, Rs/MW h ,Rs/h

n : generator bus

P_d : total load demand MW

P_l : total transmission loss MW

B_{ij} : coefficient loss

P_i , P_j : real power injection in i^{th} and j^{th} bus

P_i^{min} ,P_i^{max} : minimum and maximum value of i^{th} generator MW

III. TUNICATE SWARM ALGORITHM

Tunicates have the potential to locate the source of food sight in the sea. They have no concept about the source of food at a particular search space. There are two such behaviors due to which tunicates are able to locate their food. These includes : jet propulsion and swarm behavior. The following three condition need to be fulfilled by tunicates[15] .To mathematically model the behavior of jet propulsion :

1) Avoid dispute among search agents For determining the location of new search agent Vector $\vec{A}$ is deployed.

$$\vec{A} = \vec{G} / \vec{M} \quad \text{(v)}$$

$$\vec{G} = r_2 + r_3 - \vec{F} \quad \text{(vi)}$$

$$\vec{F} = 2.\, r_1 \quad \text{(vii)}$$

where $\vec{G}$ represents gravitational force, $\vec{F}$ represents water steam advection in deep sea, r_1, r_2 ,r_3 represents random variables range lies from [0,1]. Equation of $\vec{M}$

$$\vec{M} = [\, P_{min} + r_1.\, P_{max} - P_{min} \,] \quad \text{(viii)}$$

where $\vec{M}$ represents social forces between search agents, P_{min} and P_{max} address the initial and secondary rates to make social interactions.

2) Step more toward the best acquaintance

By escaping the tension between neighbors, the search agent moves towards the finest neighbors.

$$P\vec{D} = |\, F\vec{S} - r_{and} \,.\, P_p(\vec{x}) \,| \quad \text{(ix)}$$

where $\vec{P}_p$ represents tunicate location, $F\vec{S}$ represents food source's location, $P\vec{D}$ represents separation between food source and search agent, x shows current iteration, P_{min} and P_{max} address the initial and secondary rates to make social connection, r_{and} shows random values from 0 to 1 .

3) Join towards the search agent having maximum fitness value

Tunicate tries to sustain their food source around the search agent.

$$P_p(\vec{x}) = \{F\vec{S} + \vec{A}\,.P\vec{D}, \text{ if } r_{and} \geq 0.5$$

$$\{F\vec{S} + \vec{A}.\, P\vec{D}, \text{ if } r_{and} < 0.5 \quad \text{(x)}$$

where $P_p(\vec{x})$ represents new position of tunicate with respect to position of food source $F\vec{S}$.

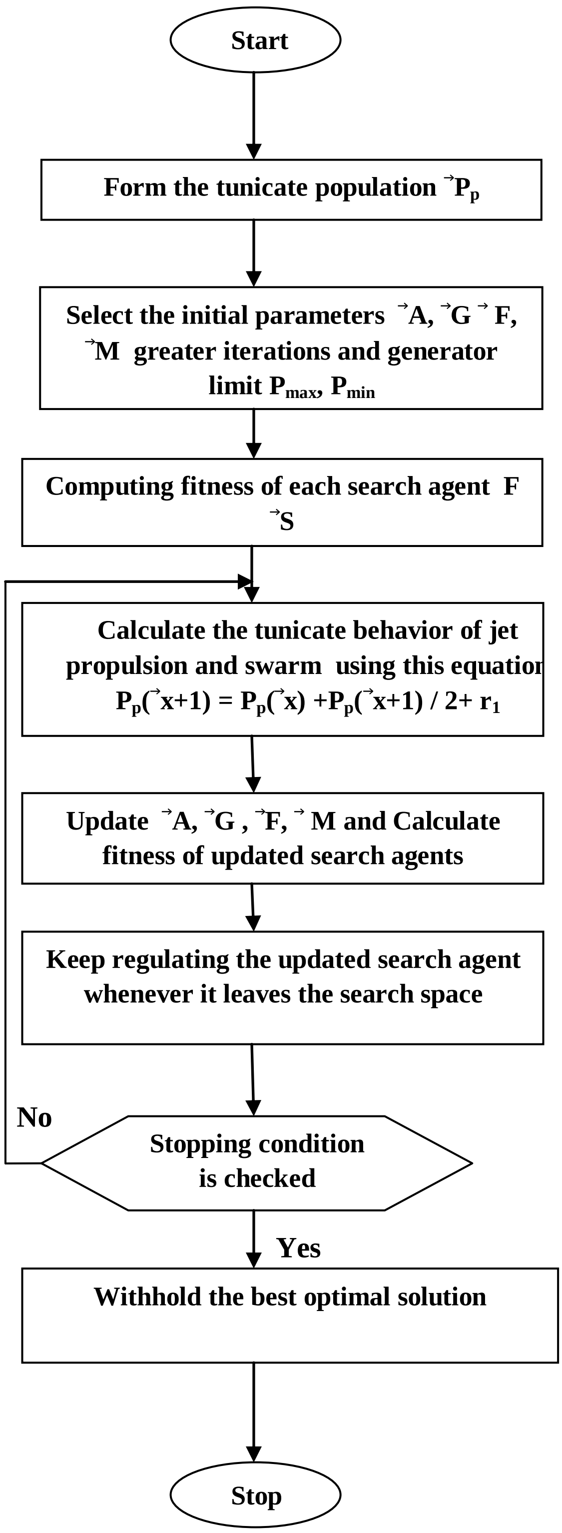
4) Swarm Behavior

All tunicates keep on revising their position with respect to first second tunicates. This is represented as :

$$P_p(\vec{x}+1) = P_p(\vec{x}) + P_p(\vec{x}+1) / 2 + r_1 \quad \text{(xi)}$$

where $P_p(\vec{x}+1)$ shows updated position of search agent .

3.1 Flow chart of TSA



V. RESULTS & DISCUSSIONS

The problem of Unit Commitment is solved by Tunicate Swarm Algorithm (TSA) in three different test cases to see how well it can optimize the objective function, it was constrained by producing system of power ranges of generating units and initial parameters were also considered. The number of times each test scenario was iterated 1000. In all three cases, the tunicate population ranges from 50 to 100.

1) Test System 1 : We have considered 4 generating units which contain initial parameters such as cost coefficient, maximum and minimum values, minimum up and down time, Hot and Cold start-up costs, Initial status along with 8-hour load pattern represented in table no 4.1and 4.2. Unit commitment for four generator is resolved with TSA and their results shown in table no 4.3 are analyze along with LR and PSO-LR shown in table no 4.4 and reference no [8].

Table 4.1: Four-Generating unit data

Parameter	Unit1	Unit2	Unit3	Unit4
P_{max}(MW)	300	250	80	60
P_{min}(MW)	75	60	25	20
a($/MW^{2}hr)	684.74	585.62	213.00	252.00
b($/MWhr)	16.83	16.95	20.74	23.60
c($/hr)	0.0021	0.0042	0.0018	0.0034
Min up time(hr)	5	5	4	1
Min down time(hr)	4	3	2	1
Hot start-up cost($)	500	170	150	0
Cold start-up cost ($)	1100	400	350	0.02
Cold star-up hrs(hr)	5	5	4	0
Initial status(hr)	8	8	-5	-6

Table 4.2: Load Pattern for Four-unit system

Hour (h)	Load (MW)
1	450
2	530
3	600
4	540
5	400
6	280

7	290
8	500

Table 4.3 : TSA results for 4-unit system

Load	G1	G2	G3	G4	Fuel cost(Rs/hr)
450	300	150	0	0	9146.725
530	300	205	25	0	10892.24
600	300	250	30	20	12571.614
540	300	215	25	0	11079.38
400	300	0	80	20	8525.5386
280	255	0	25	0	6395.2986
290	265	0	25	0	6571.2786
500	300	200	0	0	10066.36
Start-up Cost=150.02			**Total Operating Cost= 74476.08**		

Table 4.4: Comparison result of TSA for 4-unit system

Technique	**LR** [8]	**PSO-LR** [8]	**TSA**
Cost(Rs/hr)	75231.9	74808	74476.08

2) Test System 2: We have considered 10generating units which contain initial parameters such as cost coefficient, maximum and minimum values, minimum up and down time, Hot and cold start-up costs, initial status along with 24-hour load pattern represented in table no 4.5and 4.6. The problem of unit commitment resolved with TSA and their results represent in table no 4.7 are analyze with other methods shown in table 4.8.

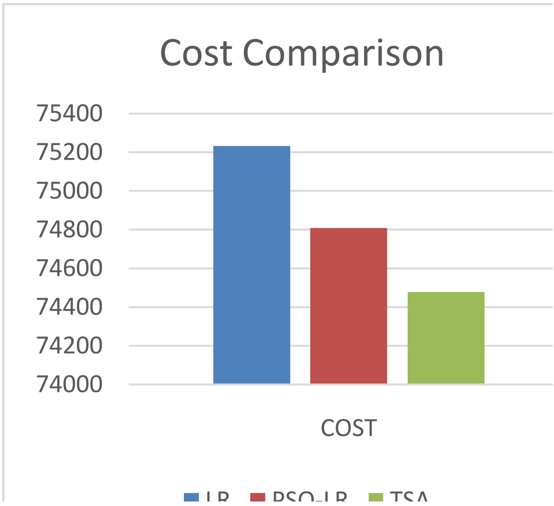


Fig 4.1: TSA Cost Comparison

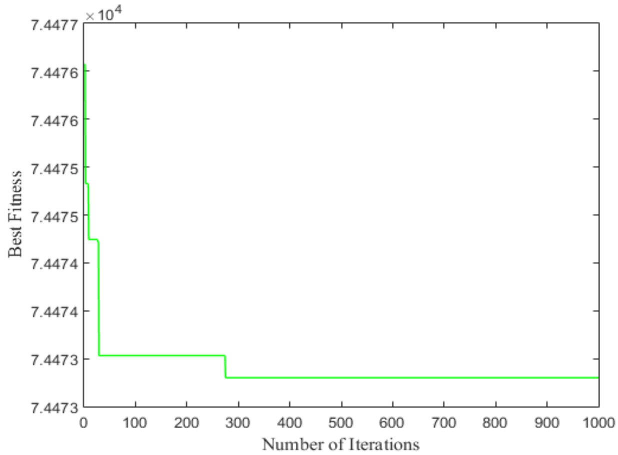


Fig 4.2: Convergence Characteristics using TSA (4-unit system)

Table 4.5 : 10- Generating unit data

Parameters	**Unit1**	**Unit2**	**Unit3**	**Unit4**	**Unit5**
P_{max}(MW)	455	455	130	130	162
P_{min}(MW)	150	150	20	20	25
a($/MW^{2}hr)	1000	970	700	680	450
b($/MWhr)	16.19	17.26	16.60	16.50	19.70
c($/hr)	0.00048	0.00031	0.002	0.00211	0.00398
Min up time(MW)	8	8	5	5	6
Min down time(MW)	8	8	5	5	6
Hot start-up cost($)	4500	5000	550	560	900

Cold start-up cost($)	9000	10000	1100	1120	1800
Cold start-up hrs(hr)	5	5	4	4	4
Initial status(h)	8	8	-5	-5	-5

Parameters	**Unit6**	**Unit7**	**Unit8**	**Unit9**	**Unit10**
P_{max}(MW)	80	85	55	55	55
P_{min}(MW)	20	25	10	10	10
a($/MW^{2}hr)	370	480	660	665	670
b($/MW hr)	22.26	27.74	25.92	27.27	27.79
c($/hr)	0.00712	0.00079	0.00413	0.00222	0.00173
Min up time($)	3	3	1	1	1
Min down time($)	3	3	1	1	1
Hot start-up cost($)	170	260	30	30	30
Cold start-up cost($)	340	520	60	60	60
Cold start-up hrs(hr)	2	2	0	0	0
Initial status(hr)	-3	-3	-1	-1	-1

Table 4.6 : Load Pattern for Ten-generating units

Hour(h)	**Load(MW)**	**Hour(h)**	**Load(MW)**	**Hour(h)**	**Load(MW)**
1	700	9	1300	17	1000
2	750	10	1400	18	1100
3	850	11	1450	19	1200
4	950	12	1500	20	1400
5	1000	13	1400	21	1300
6	1100	14	1300	22	1100
7	1150	15	1200	23	900
8	1200	16	1050	24	800

Table 4.7 : TSA results for 10-unit system

Load	**G1**	**G2**	**G3**	**G4**	**G5**	**G6**	**G7**	**G8**	**G9**	**G10**
700	455	245	0	0	0	0	0	0	0	0
750	455	295	0	0	0	0	0	0	0	0
850	455	370	0	0	25	0	0	0	0	0
950	455	455	0	0	40	0	0	0	0	0
1000	455	390	130	0	25	0	0	0	0	0
1100	455	360	130	130	25	0	0	0	0	0
1150	455	410	130	130	25	0	0	0	0	0
1200	455	455	130	130	30	0	0	0	0	0
1300	455	455	130	130	100	20	0	10	0	0
1400	455	455	130	130	162	33	25	10	0	0
1450	455	55	130	130	162	73	25	0	10	10
1500	455	455	130	130	162	80	25	43	10	10
1400	455	455	130	130	162	33	25	10	0	0
1300	455	455	130	130	85	20	25	0	0	0
1200	455	455	130	130	30	0	0	0	0	0
1050	455	310	130	130	25	0	0	0	0	0
1000	455	260	130	130	25	0	0	0	0	0
1100	455	360	130	130	25	0	0	0	0	0

1200	455	455	130	130	30	0	0	0	0	0
1400	455	455	130	130	162	33	25	10	0	0
1300	455	455	130	130	85	20	25	0	0	0
1100	455	455	0	0	145	20	25	0	0	0
900	455	420	0	0	25	0	0	0	0	0
800	455	345	0	0	0	0	0	0	0	0
Start-up cost = 4070					**Total operating Cost = 564018.015**					

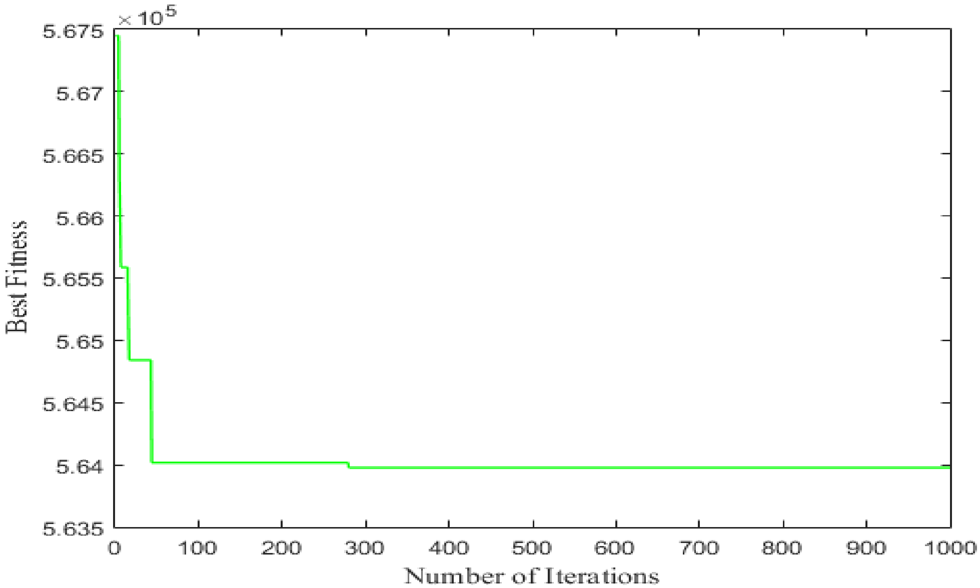


Fig 4.3 : Convergence characteristics for TSA

Table 4.8 : Comparison result of TSA for 10-unit system

Techniques	**Cost**
Lagrangian search Genetic Algorithm(LSGA) [2]	609,023.69
Improved binary particle swarm Optimization(IBPSO) [12]	599,782
New genetic algorithm [5]	591,715
PSO [1]	581,450
Binary Particle swarm Optimization with bit change mutation(MPSO) [10]	574,905
HPSO [3]	574,153
LCA-PSO [13]	570,006
Two-stage genetic based technique [11]	568,315

Hybrid PSO-SQP [7]	568,032.3
BCGA [6]	567,367
SM [9]	566,686
LR [9]	566,107
GA [9]	565,866
Genetic algorithm (GA) [1]	565,852
Enhanced simulated annealing(ESA) [9]	565,828
Lagrangain relaxation (LR) [1]	565,825
Dynamic Programming (DP) [1]	565,825
Improved Lagrangain relaxation(ILR) [8]	565,823.23
LRPSO [8]	565,275.2
NPSO [14]	565,213.00
Hybrid PSO-GWO [14]	565,210.2564
Tunicate Swarm Algorithm[proposed]	**564018**

3) Test system 3: The Tunicate swarm algorithm method's performance is evaluated using a conventional test system including producing units and one wind farm over a horizon of 24 hours. Reference no.16 is used for producing unit data and load demand. The wind farm is made up of 20 generators wind turbine as identical version which are working in parallel.

Table 4.9 : Data for Wind Power Generation

Interval(h)	**Wind power(MW)**	**Interval(h)**	**Wind power(MW)**	**Interval(h)**	**Wind power(MW)**
1	42.602	9	21.784	17	72.194
2	35.409	10	15.01	18	49.655
3	60	11	24.383	19	36.44
4	17.193	12	27.058	20	57.185
5	20	13	41.233	21	64.243
6	31.309	14	50.478	22	85.541

7	40	15	80	23	70.677
8	32.802	16	98.559	24	61.298

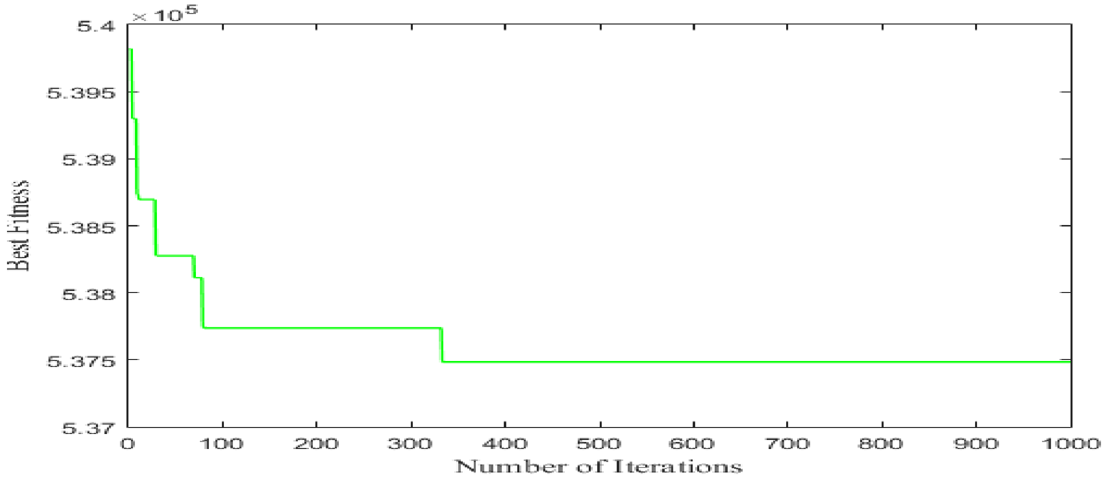


Fig 4.4 Convergence Characteristics for TSA

Table 4.10 : TSA results for Wind Data System

Load (MW)	P_{wind}	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
700	42.602	455	202.398	0	0	0	0	0	0	0	0
750	35.049	455	259.591	0	0	0	0	0	0	0	0
850	60	455	335	0	0	0	0	0	0	0	0
950	17.193	455	452.807	0	0	25	0	0	0	0	0
1000	20	455	370	0	130	25	0	0	0	0	0
1100	31.309	455	455	0	130	28.691	0	0	0	0	0
1150	40	455	370	130	130	25	0	0	0	0	0
1200	32.802	455	427.198	130	130	25	0	0	0	0	0
1300	21.784	455	455	130	130	88.216	20	0	0	0	0
1400	15.01	455	455	130	130	159.99	20	25	10	0	0
1450	24.383	455	455	130	130	162	48.617	25	10	0	10
1500	27.058	455	455	130	130	162	80	25	15.942	10	10
1400	41.233	455	455	130	130	143.767	20	25	0	0	0
1300	50.478	455	455	130	130	59.522	20	0	0	0	0
1200	80	455	455	130	130	60	20	0	0	0	0
1050	98.559	455	341.441	130	130	25	0	0	0	0	0
1000	72.194	455	317.806	130	130	25	0	0	0	0	0
1100	49.655	455	440.345	130	130	25	0	0	0	0	0
1200	36.44	455	455	130	0	98.56	0	25	0	0	0
1400	57.185	455	455	130	130	127.815	20	25	0	0	0
1300	64.243	455	455	0	130	150.757	20	25	0	0	0
1100	85.541	455	409.459	0	130	0	20	0	0	0	0
900	70.677	455	244.323	0	130	0	0	0	0	0	0
800	61.298	455	153.702	0	130	0	0	0	0	0	0

Start-up Cost = 4780	**Total operating Cost =537483.3**

V. CONCULSION

In this research paper, Tunicate Swarm Algorithm optimization method is used to solve the problem of Unit commitment. This algorithm is written in MATLAB(R2015a) programming language. The result represents capability of TSA technique for solving the unit commitment problem. The simplicity, reliability and effectiveness of the TSA algorithm make it ideal for practical applications.

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