A REFINED SOLUTION TO CLASSICAL UNIT COMMITMENT PROBLEM USING IWO ALGORITHM

C. Christober Asir Rajan[1], K. Surendra[2], B. Rama Anvesh Reddy[3], R. Shobana[4], Y. Sreekanth Reddy[5]

[1]Associate Professor, Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India
[2]Student, Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India
[3]Student, Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India
[4]Student, Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India
[5]Student, Electrical and Electronics Engineering, Pondicherry Engineering College, Pondicherry, India

Abstract
This paper proposes a solution to effectively determine Unit Commitment and generation cost using the technique of Invasive Weed Optimization (IWO).The objective of this paper is to find the generation scheduling such that the total operating cost can be minimized, when subjected to variety of constraints. This also means that finding the optimal generating unit commitment in the power system for the next H hours is desirable. The different constraints considered in this technique are the time constraint and spinning reserve constraint. The result obtained from this is to be compared with the already existing result of Particle Swarm Optimization (PSO) for an 8 hour 4 unit IEEE system and 24 hour 10 unit IEEE system.

Keywords: constraints, fuel cost, Iwo, optimization.

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1. INTRODUCTION

The power systems operation decision functions has three stages. The first stage consists of the long-term where variables like capacity, type and number of power generators are determined. The second stage is to decide how to meet the excepted load during each hour and based on the generators operating costs and constraints. This decision is termed as Unit Commitment, takes place between one day and a few days ahead of the actual operations. The third stage is to efficiently determine the amount of power each committed unit will produce to meet the real-time electricity demand. This decision is called Economic load dispatch.

Unit Commitment is an Optimization problem used to determine the operation schedule of the generating units at every hour interval with varying loads under different constraints. The importance of UC is increasing with the constantly varying demands so there is an urgent need in the power sector to keep track of the latest methodologies to optimize the cost function. The optimal generation of power is necessary to meet the load demand and also to avoid wastage of power (Allen.J. Wood and B.F. Wollenberg(1984)). The different methods to effectively bring down the cost of generation are called evolutionary algorithms, meta-heuristic algorithms which are based on generic population. Some of them being Bacterial Foraging Technique, Particle Swam method, Cuckoo search method and Firefly algorithms. All these techniques are mapped from real life events such as growth of bacteria, foraging behavior of honeybees, nesting of

birds. All these methods are known to give out the optimum cost of power generation over a scheduled period of time depending on the load requirements, assuming that all the generator units are ON.

2. UC METHODOLOGY

UCP formulation for a large generating system results in a large scale non-linear mixed integer program with typically thousands of binary and continuous variables. A variety of techniques such as Lagrangian relaxation, dynamic programming, branch and bound, network programming and Benders decomposition along with meta-heuristics has been used to solve the UCP. Out of all different solution methods employed for this Lagrangian relaxation (LR) is the most widely used method because of its success in solving large scale problems. The LR method is used to find out the unit commitment results for a particular duration. The objective function of LR is to find out the units that are the most economical for operation. The economics of operation depend upon the fuel cost, uptime, downtime, cold time, maximum and minimum generation limits. The fuel cost of a generation unit is given in the form of a second order polynomial function which depends on the power output of that particular unit.

$$F\,(i)\ =\ a_iP_i^2 + b_iP_i + c_i$$

Where,
$F\,(i)$ - fuel cost of the unit i
P_i - Power output of the unit i

a_i, b_i, c_i - coefficients of the fuel cost polynomial

LR method finds out the derivative of the polynomial function $F(i)$ and obtains the incremental cost of the unit λ, lambda. This λ gives us the idea of the units with the least operational cost. The units are arranged in the order of increasing incremental cost starting with the one that has the least λ. The different conditions considered for determining the unit commitment are

1. Uptime
2. Downtime
3. Cold time
4. Initial status
5. Maximum generation limit
6. Minimum generation limit
7. Spinning reserve

3. INVASIVE WEED OPTIMIZATION

The technique of IWO was inspired from the biological growth of weed plants. It was first used by Mehrabian and Lucas in solving control system designing. This technique is based on the colonizing behavior of weed plants. Weed plants are called invasive because of the growth of weed plants is extensively invading in the growth area. IWO is known to be highly converging in nature since it is a derivative free algorithm. It also converges to the optimal solution thereby eliminating the possibilities of sub optimal solutions. This integer coded algorithm also involves simple coding. IWO has been so far implemented for several applications like DNA computing, antenna system design.

In this algorithm, the number of decision variables are taken in the form of seeds and then randomly distributed in a definite search space. These seeds are then allowed to grow into plants and the fitness of each individual plant is determined. Depending upon the fitness values, new seeds are generated by each plant in accordance with a normalized standard deviation $\Box$. The importance of this $\Box$ is that it helps in converging to the optimal solution faster as it determines exactly where to distribute the new seeds so that the seeds always approach the optimal solution. In the next step the combined fitness values of seeds and plants is calculated until the fitness value converges to an optimal solution. The objective function of this technique is similar to any method, Min FC total = $\sum FCi$

Subjected to the constraints,

• Equality Constraint

$$\Box P_i = P_d$$

• Inequality Constraint

$$Pi \text{ min} \Box Pi \Box Pi \text{ max}$$

• Time Based Constraints

$$(T_{on}(i,t-1)-T_{up}(i))(U(i,t-1)-U(i,t))\Box 0$$

$$(Tdown(i)-T_{off}(i,t-1))(U(i,t-1)-U(i,t))\Box \ \Box$$

• Ramp Based Constraints

$$P(i,t) - P(i,t-1)\Box UR(i)$$

$$P(i,t-1) -P(i,t)\Box DR(i)$$

• Spinning Reserve

$$\sum_{I=1}^{n} \Box I(i,t)r_s(i,t)\Box R_s(i,t)$$

Step 1:
Read the input from the Unit commitment matrix and assign a matric of size depending upon the units that are ON.

Step 2:
Randomize the values obtained for generation for each unit subjected to the constraints time, ramp and spinning reserve. These units, otherwise called as seeds assume random values in the search space. The search space is reduced in this method as compared to the traditional IWO which assumes that all units are ON.

Step 3:
Determine the fuel cost for the obtained combination of generation values and repeat this procedure for a total of 100 iterations. The fuel cost, otherwise called as fitness values are assigned to the respective seeds.

Step 4:
Arrange these values of fuel cost in the increasing order. The minimum amount serves as the best fitness value.

Now depending upon these fitness values the next generation of seeds is produced using zero mean and variable standard deviation spread over the entire field.

Step 5:
The procedure is repeated until the maximum number of iterations is not met. The values with the best fitness values are taken and are put forwards as the generation values provided they are within the individual generation limits and meet the demand requirements.
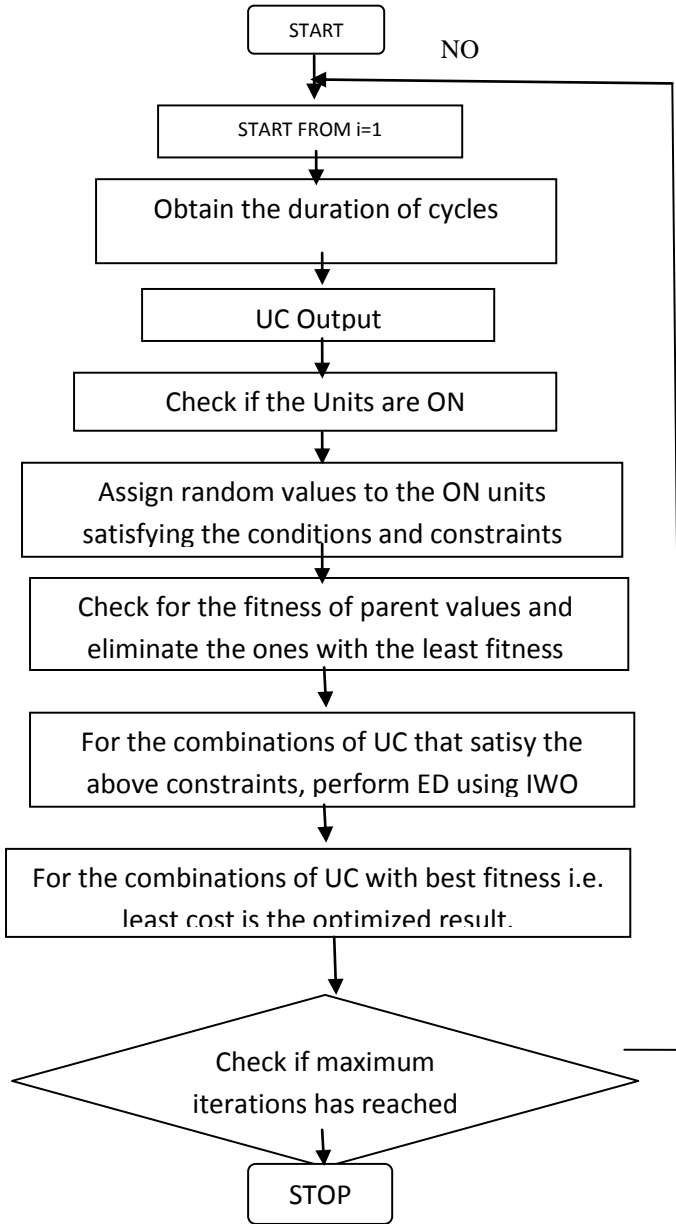
Fig.1 Flowchart for UC using IWO algorithm

4. RESULTS AND DISCUSSION

The developed algorithm was tested with 4 Unit 8 hour system and 10 Unit 24 Hour system. The detailed analysis are listed in the following tables.

IEEE CASE STUDY 1: FOUR UNITS EIGHT HOUR SYSTEM

In this four unit eight hour system, **Table-1** the system input data and load demand is given. The unit commitment scheduling of all the four generators for 8 hours is given in **Table-2.** In **Table-3** the generation dispatch using IWO is listed for each hour and the same is compared with PSO. The total cost of IWO is reasonably less when compared to PSO. The same is represented in the form of a graph in **Fig.2** where the generation cost of every hour using IWO and PSO has been shown. **Fig.3** shows the convergence graph for the IEEE system.

IEEE CASE STUDY 2: TEN UNITS TWENTY FOUR HOUR SYSTEM

Similar to the first case study, a second analysis was performed on a ten unit 24 hour system. In this case study, in **Table-4** the system input data and load data is given. The unit commitment scheduling of all 10 generators for 24 hours is given in **Table-5**. In **Table-6** the generation dispatch using IWO is listed for each hour. The total cost of IWO is reasonably less when compared to PSO. The same is represented in the form of a graph in **Fig.4** where the generation cost of every hour using IWO and PSO has been shown. **Fig.5** shows the convergence graph for the IEEE system.

Table-1 System Input Data

Unit	Pma x (MW)	Pmin (MW)	c ($/hr)	b ($/MW hr)	a ($/MW^{2}h)	tup (hr)	tdown (hr)	tcold (hr)	Shr ($)	Scr ($)	Init. Status
1	300	75	684.74	16.83	0.0021	5	4	5	500	1100	8
2	250	60	585.62	16.95	0.0042	5	3	5	170	400	8
3	80	25	213	20.74	0.0018	4	2	4	150	350	-5
4	60	20	252	23.6	0.0034	1	1	0	0	0.02	-6

LOAD DEMAND

Time (hr)	1	2	3	4	5	6	7	8
Load (MW)	450	530	600	540	400	280	290	500

Table-2 Units on/off status

Unit/Time(hr)	1	2	3	4
1	1	1	0	0
2	1	1	0	0
3	1	1	1	0
4	1	1	1	0
5	1	1	0	0
6	1	1	0	0
7	1	1	0	0
8	1	1	0	0

Table-3: Generation Dispatch

| Time (hrs)	UNIT I (MW)		UNIT II (MW)		UNIT III (MW)		UNIT IV (MW)		LOAD (MW)	COST/hr ($/hr)	
	PSO	IWO	PSO	IWO	PSO	IWO	PSO	IWO		PSO	IWO
1	292.86	300	132.14	150	25	0	0	0	450	9575	9145.36
2	300	300	205	230	25	0	0	0	530	10892	10629.04
3	300	300	250	250	30	50	20	0	600	12571	12262.86
4	300	300	215	215	25	25	0	0	540	11079	11079.38
5	276.19	276	123.81	124	0	0	0	0	400	8241.8	8241.8
6	196.19	196	83.81	84	0	0	0	0	280	6103.1	6103.1
7	202.86	203	87.143	87	0	0	0	0	290	6279.8	6279.8
8	300	300	200	200	0	0	0	0	500	10066	10066
										74658	73807.34
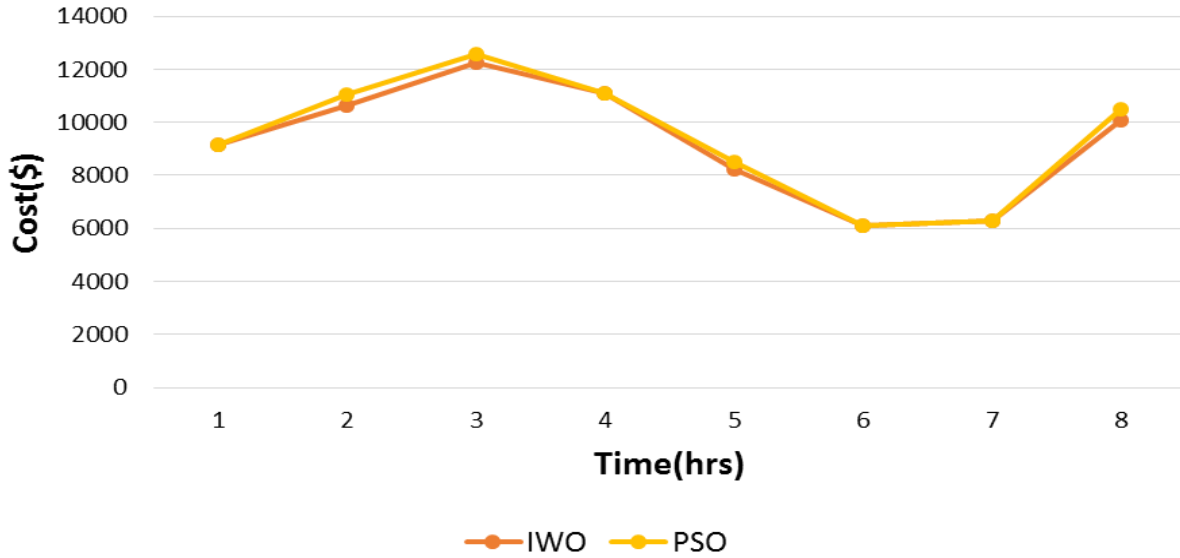
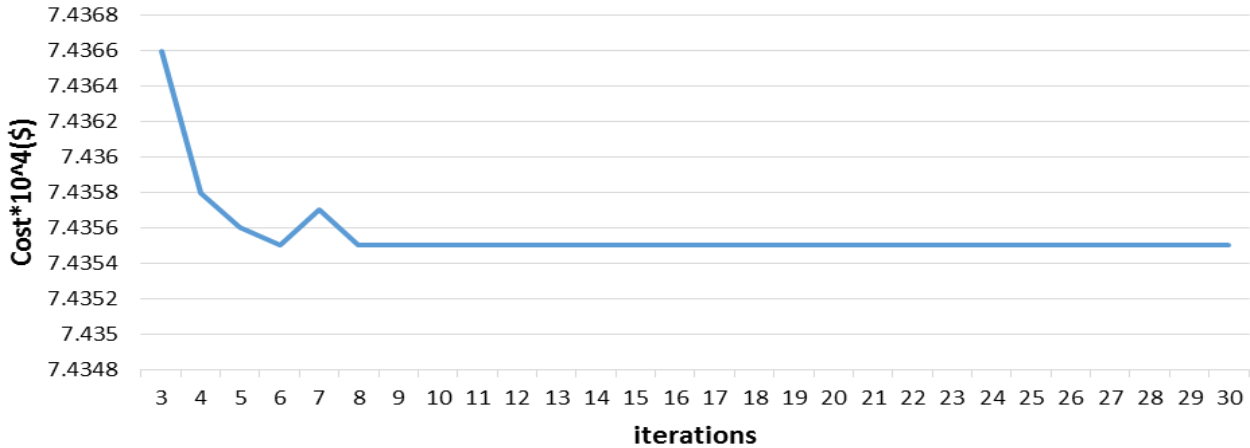**Fig.2** comparison of IWO and PSO for 4 units 8 hour system

Fig.3 Convergence graph for an 4 unit 8 hour system by using IWO algorithm

Table-4 system input data for 10 unit 24 hour IEEE system

UNIT	Pmax (MW)	Pmin (MW)	C ($/hr)	b ($/MWhr)	A ($/MW²h)	Tup (hr)	Tdown (hr)	Tcold (hr)	Shr ($)	Scr ($)	Init. Status
1	455	150	1000	16.19	0.00048	8	8	5	4500	9000	8
2	455	150	970	17.26	0.00031	8	8	5	5000	10000	8
3	130	20	700	16.6	0.002	5	5	4	550	1100	-5
4	130	20	680	16.5	0.00211	5	5	4	560	1120	-5
5	162	25	450	19.7	0.00398	6	6	4	900	1800	-6
6	80	20	370	22.26	0.00712	3	3	2	170	340	-3
7	85	25	480	27.74	0.00079	3	3	2	260	520	-3
8	55	10	660	25.92	0.00413	1	1	0	30	60	-1
9	55	10	665	27.27	0.00222	1	1	0	30	60	-1
10	55	10	670	22.79	0.00173	1	1	0	30	60	-1

LOAD DEMAND

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

Table-6 Units on/off status

Unit/Time(hr)	1	2	3	4	5	6	7	8	9	10
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	1	0	0	0	0	0	0
5	1	1	0	1	1	0	0	0	0	0
6	1	1	0	1	1	0	0	0	0	0
7	1	1	0	1	1	0	0	0	0	0
8	1	1	1	1	1	0	0	0	0	0
9	1	1	1	1	1	1	0	0	0	0
10	1	1	1	1	1	1	1	0	0	0
11	1	1	1	1	1	1	1	1	0	0
12	1	1	1	1	1	1	1	1	1	0
13	1	1	1	1	1	1	1	0	0	0
14	1	1	1	1	1	1	0	0	0	0
15	1	1	1	1	1	0	0	0	0	0
16	1	1	1	1	1	0	0	0	0	0
17	1	1	1	1	1	0	0	0	0	0
18	1	1	1	1	1	0	0	0	0	0
19	1	1	1	1	1	1	0	0	0	0
20	1	1	1	1	1	1	0	1	1	0
21	1	1	1	1	1	1	0	0	0	0
22	1	1		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

Table-7: Generation Dispatch

Time	load	1	2	3	4	5	6	7	8	9	10	Cost($/hr)
1	700	455	245	0	0	0	0	0	0	0	0	13683.129
2	750	455	295	0	0	0	0	0	0	0	0	14554.499
3	850	455	395	0	0	0	0	0	0	0	0	16301.889
4	950	455	365	0	130	0	0	0	0	0	0	18658.511
5	1000	455	424	0	96	25	0	0	0	0	0	20022.81
6	1100	455	455	0	130	60	0	0	0	0	0	21863.109
7	1150	455	455	0	130	110	0	0	0	0	0	22881.947
8	1200	455	455	130	130	30	0	0	0	0	0	24153.171
9	1300	455	455	130	130	110	20	0	0	0	0	26591.787
10	1400	455	455	130	130	162	43	0	0	0	0	29368.73
11	1450	455	455	130	130	162	80	0	0	0	0	31227.683
12	1500	455	455	130	130	162	80	0	0	0	0	33204.01
13	1400	455	455	130	130	162	43	25	0	0	0	29368.73

14	1300	455	455	130	130	110	20	25	13	0	0	26581.787
15	1200	455	455	130	130	30	0	42	36	10	0	24153.171
16	1050	455	322	126	122	25	0	25	0	0	0	21547.438
17	1000	455	384	74	62	25	0	0	0	0	0	20657.692
18	1100	455	376	114	130	25	0	0	0	0	0	22393.052
19	1200	455	455	130	115	25	20	0	0	0	0	24615.266
20	1400	455	455	130	130	159	51	0	10	10	0	30166.773
21	1300	455	455	130	130	110	20	0	0	0	0	26591.787
22	1100	455	385	130	130	0	0	0	0	0	0	21882.161
23	900	455	445	0	0	0	0	0	0	0	0	17180.909
24	800	455	345	0	0	0	0	0	0	0	0	15430.419
											Total	553081.46
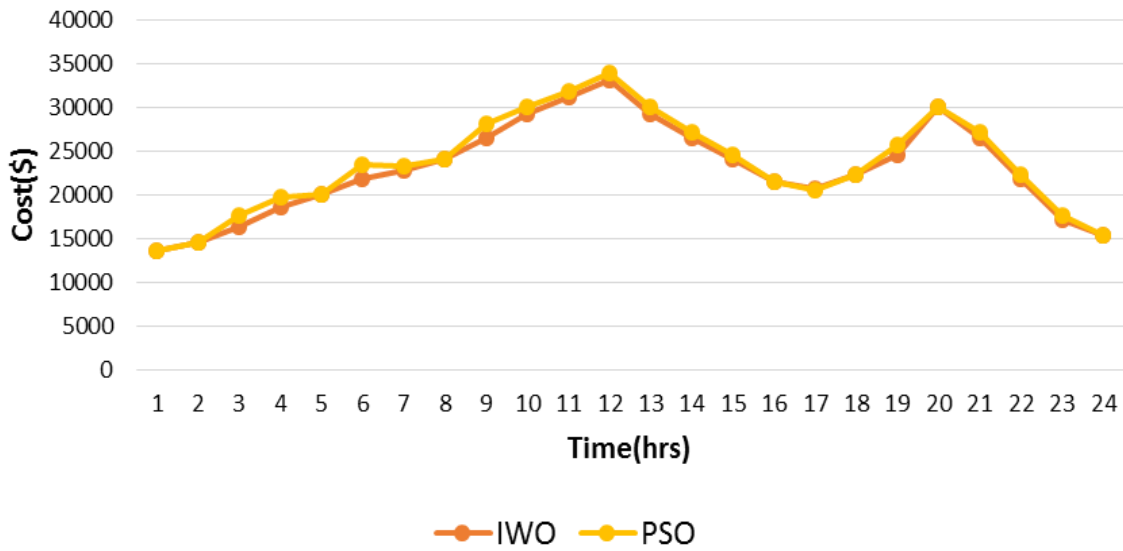
Fig.4 comparison of IWO and PSO for 10 unit 24 hour system
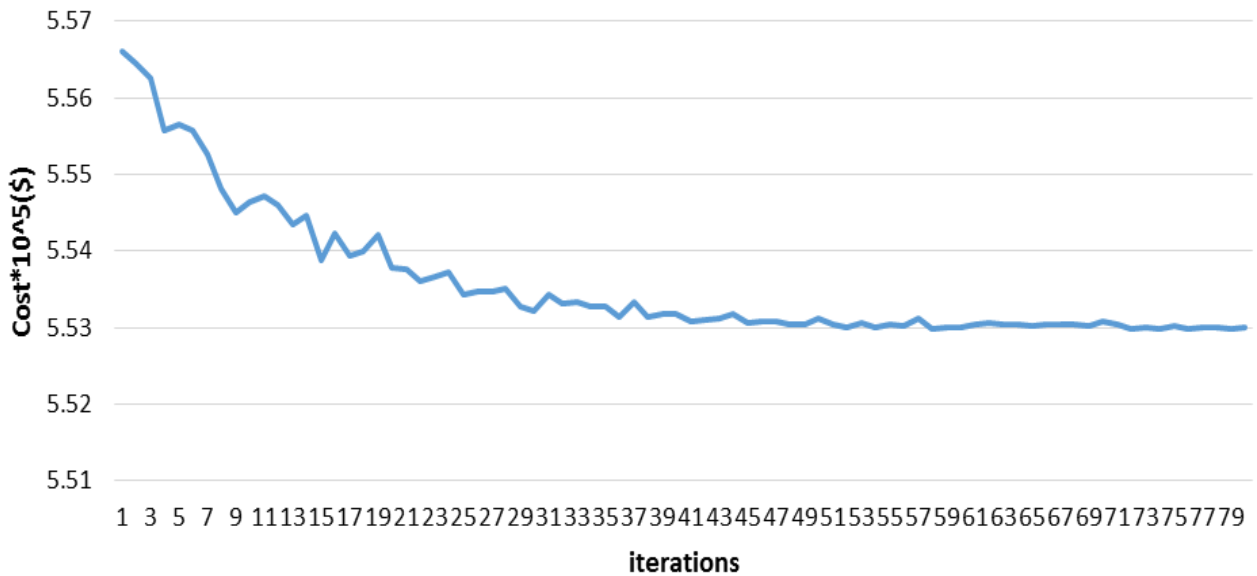

Fig.5 convergence graph for an 10 unit 24 hour system by using IWO algorithm

5. CONCLUSIONS

This paper proposes an improved variant of a recently developed ecologically inspired algorithm called Invasive Weed Optimization, for finding the solution to classical unit commitment problem. This paper evidently proves that the IWO technique is much more effective than PSO in case of cost optimization for generating power. The inputs are taken in the form of Unit Commitment data obtained by LR method which effectively reduces time of execution along with giving more optimized results. This technique could be extended for any number of generating units and for any duration of load scheduling. Future works could rely on the possibilities of obtaining Unit Commitment output using the

Invasive Weed Optimization technique itself instead of obtaining the outputs of Unit Commitment from some other technique which will effectively reduce the speed of execution using the invasive weed optimization technique. The area of applications of IWO is vast. This technique could also be employed in distribution of power in the transmission system. Obtaining data for optimized transmission of power flow using IWO could lead to a completely optimized power grid, right from generation of power to distribution to the consumers.

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NOMENCLATURE

$F(i)$ Fuel cost- objective function.

$P(i)$ Power output of the generation unit.

$J*$ Objective function value of the optimal solution to the primal problem

P_d Load requirements

P_{max} Maximum amount of power unit can produce once it is turned on

P_{min} Minimum amount of power unit can produce once it is turned on

P_{kt} Power produced by unit k at time period t

S_c Cold state startup cost.

S_h Hot state startup cost.

S_{kt} Cost of starting up unit k at time t.

$t_{coldstar}$ Time a generator is in hot state after it is turned off

t_{up} Minimum number of hours required for a generator to stay up once it is on

t_{down} Minimum number of hours required for a generator to stay down once it is off.

λ Incremental cost.

σ Standard deviation of the load at hour t.

BIOGRAPHIES

C.Christober Asir Rajan born on 1970 and received his B.E. (Distn.) degree (Electrical and Electronics) and M.E. (Distn.) degree (Power System) from the Madurai Kamaraj University, And he received his postgraduate degree in DI.S. (Distn.) from the Annamalai University, He is currently working as Associate Professor in the Electrical Engineering Department at Pondicherry Engineering College, Pondicherry, India

Shobana R born on 1993 and currently pursuing B.Tech final year in Electrical and Electronics Engineering department in Pondicherry Engineering College, Pondicherry, India

Sreekanth Reddy Y born on 1992 and currently pursuing B.Tech final year in Electrical and Electronics Engineering department in Pondicherry Engineering College, Pondicherry, India

Surendra K born on 1991 and currently pursuing B.Tech final year in Electrical and Electronics Engineering department in Pondicherry Engineering College, Pondicherry, India

Rama Anvesh Reddy B born on 1991 and currently pursuing B.Tech final year in Electrical and Electronics Engineering department in Pondicherry Engineering College, Pondicherry, India